Essential Geodetic Variables

presented by

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Implementation of the GGRF in Latin America
International Workshop

September 16–20, 2019
Buenos Aires, Argentina

Jet Propulsion Laboratory
California Institute of Technology

Essential (Climate / Ocean / Geodetic) Variables

THE CONCEPT OF ESSENTIAL CLIMATE VARIABLES IN SUPPORT OF CLIMATE RESEARCH, APPLICATIONS, AND POLICY

BY STEPHAN BOJINSKI, MICHEL VERSTRAETE, THOMAS C. PETERSON, CAROLIN RICHTER, ADRIAN SIMMONS, AND MICHAEL ZEMP

Described is the concept of Essential Climate Variables developed under the Global Climate Observing System for a range of applications, as well as to provide an empirical basis for understanding past, current, and possible future climate variability and change.

Observations are fundamental to advancing scientific understanding of climate (Doherty et al. 2009; Shapiro et al. 2010) and delivering the vetted, timely, and purposeful climate information needed to support decision making in many sectors. Observations and monitoring are key elements of the emerging Global Framework for Climate Services (WMO 2011a) and more generally support climate research, the assessment of climate change, and the development of policy responses (Fig. 1). For these purposes, observational datasets in general need to be traceable to quality standards, be readily interpretable and freely available, and cover sufficiently long periods: for example, the 30 years traditionally used for calculating climate normals (WMO 2011b). Transparency in the generation of climate datasets is

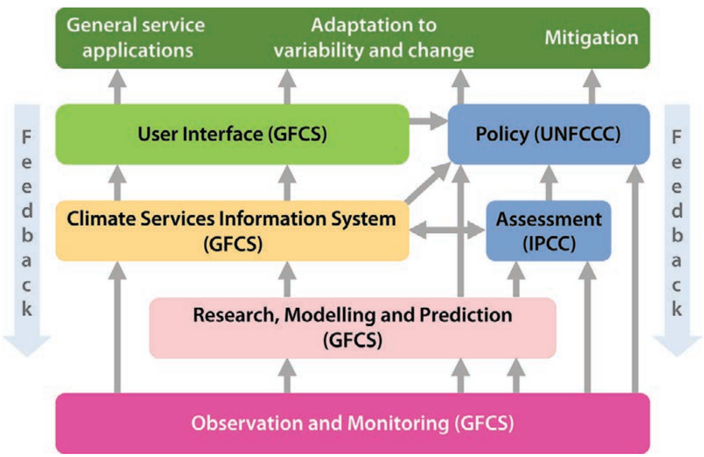


FIG. 1. The role of observation within the Global Framework for Climate Services (GFCS) and in support of research; the assessment of climate change, in particular as undertaken by the IPCC; and the development and implementation of policy responses, in particular under the UNFCCC. Gray arrows denote the main directions of flow of climate data and derived information. Feedback for system improvement flows mainly in the opposite direction. The GFCS includes a substantial capacity-development component that underlies all illustrated components. Adapted from WMO (2009, 2011a).

Bojinski et al., *BAMS*, 2014

essential for ensuring the credibility of the climate record (UN 2012).

In the 1990s, gaps in knowledge of climate and declining core observational networks in many countries (Houghton et al. 2012) led to calls for systematic observation of a limited set of critical variables. To provide guidance, the Global Climate Observing System (GCOS) program developed the concept of "essential climate variables" (ECVs), which has since been broadly adopted in science and policy circles.

In this article, we define the ECV concept and describe its provenance, scientific rationale and uptake. We also discuss challenges and opportunities concerning the ECV concept and its possible evolution, in particular with regard to the GCOS-led process of assessment, adequacy, and implementation of global observing systems for climate.

WHAT ARE THE ECVS? 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 climatic events to underlying causes, and to underpin climate services. The current list of ECVs is specified in GCOS (2010a) (all GCOS reports are available at www.wmo.int/pages/prog/gcos/index.php?name=Publications) and reproduced in Table 1.

More than variables: The ECV concept. The ECVs must not be understood as a select group of stand-alone variables; they are part of a wider concept (Fig. 2). ECVs are identified based on the following criteria:

- Relevance: The variable is critical for characterizing the climate system and its changes.
- 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.

To make practical use of the ECVs, guidance and best practices are needed to enable and support the generation of high-quality, traceable ECV data records (see details in Fig. 2). The ECV concept accommodates mixed or changing observing system technologies and is therefore conducive to meeting user needs for information over the long term. It helps distil a complex field into a manageable list of priorities and related actions (GCOS 2010a).

PROVENANCE. Some 20 years ago, the international community began exploring a more coordinated approach to observing climate on a global scale. The GCOS program, founded in 1992 by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organisation (IOC/UNESCO), the United Nations Environment Programme (UNEP), and

Table 1. The essential climate variables (for qualifying details, see GCOS 2010a).		
Atmospheric	Surface:[a]	Air temperature, wind speed and direction, water vapor, pressure, precipitation, surface radiation budget
	Upper air:[b]	Temperature, wind speed and direction, water vapor, cloud properties, Earth radiation budget (including solar irradiance)
	Composition:	Carbon dioxide, methane, other long-lived greenhouse gases,[c] ozone and aerosol supported by their precursors[d]
Oceanic	Surface:[e]	Sea surface temperature, sea surface salinity, sea level, sea state, sea ice, surface current, ocean color, carbon dioxide partial pressure, ocean acidity, phytoplankton
	Subsurface:	Temperature, salinity, current, nutrients, carbon dioxide partial pressure, ocean acidity, oxygen, tracers
Terrestrial		River discharge, water use, groundwater, lakes, snow cover, glaciers and ice caps, ice sheets, permafrost, albedo, land cover (including vegetation type), fraction of absorbed photosynthetically active radiation, leaf area index, above-ground biomass, soil carbon, fire disturbance, soil moisture

[a] Including measurements at standardized but globally varying heights in close proximity to the surface.

[b] Up to the stratopause.

[c] Including N_2O, chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), SF_6, and perfluorocarbons (PFCs).

[d] In particular NO_2, SO_2, HCHO, and CO.

[e] Including measurements within the surface mixed layer, usually within the upper 15 m.

Bojinski et al., *BAMS*, 2014

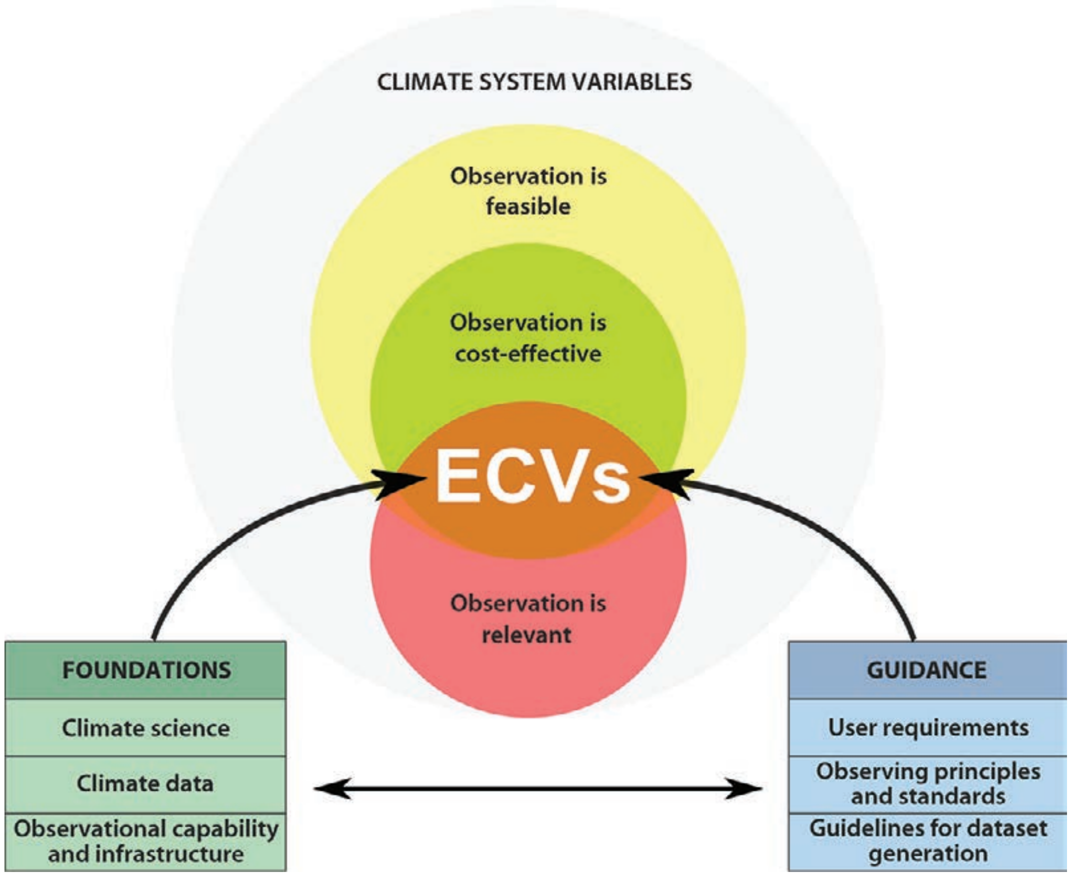


Fig. 2. Schematic of the ECV concept: knowing existing climate-relevant observing capabilities, climate datasets, and the level of scientific understanding of the climate system are the foundations (lower-left box) necessary for selecting the ECVs from a pool of climate system variables. In addition, guidance is needed to make practical use of the ECVs (lower-right box): user requirements capture the data quality needs of science, services, and policy; climate-specific principles guide the operation of observing systems and infrastructure; and guidelines facilitate the transparent generation of ECV data records. The latter address the availability of metadata, provisions for data curation and distribution, and the need for quality assessment and peer review.

Bojinski et al., *BAMS*, 2014

In summary, identifying ECVs and associated guidance has encouraged scientists and observing system operators to put more focus on these variables. It has stimulated the engagement of national and international organizations and funding agencies to support work on the variables. It has also helped many nations to make commitments to support systematic, sustained climate records.

The variable-based approach has been adopted more broadly as a basis for prioritized requirements setting and focused, coordinated action. In particular, the ocean and biodiversity communities have identified essential ocean variables (UNESCO 2012) and essential biodiversity variables (Pereira et al. 2013). Furthermore, many ECVs may also be useful for addressing applications that are not directly climate related: for instance, in support of other societal benefit areas of the Global Earth Observation System of Systems (GEOSS; e.g., Hollingsworth et al. 2005).

Bojinski et al., *BAMS*, 2014

ECV Requirements: Ocean

ECV	Product	Frequency	Resolution	Required Measurement uncertainty	Stability (per decade unless otherwise specified
Physical					
Ocean Surface Heat Flux	Latent Heat Flux	hourly to monthly	1-25km	10-15Wm-2	1-2Wm-2
	Sensible Heat Flux	hourly to monthly	1-25km	10-15Wm-2	1-2Wm-2
Sea Ice	Sea Ice Concentration	Weekly	10 km to 15 km	5% ice area fraction	5%
	Sea Ice Extent/Edge	Weekly	1 km to 5 km	5 km	unspecified
	Sea Ice Thickness	Monthly	25km	0.1 m	unspecified
	Sea Ice Drift	Weekly	5 km	1 km/day	unspecified
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)
	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)
Sea State	Wave Height	3 hourly	25 km	10 cm	5 cm
Sea Surface Salinity	Sea Surface Salinity	Hourly to monthly	1-100 km	0.01 psu	0.001 psu
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
Subsurface Curents	Interior Currents	Hourly to weekly	1-10km	0.02m/s	Not specified
Subsurface Salinity	Interior Salinity	Hourly to monthly	1-10km	0.01psu	Not specified
Subsurface Temperature	Interior Temperature	Hourly to monthly	1-10km	0.01K	not specified
Surface Currents	Surface Geostrophic Current	Hourly to weekly	30 km	5 cm/s	Not specified
Surface Stress	Surface Stress	hourly-monthly	10-100km	0.001-4Nm2	Not specified

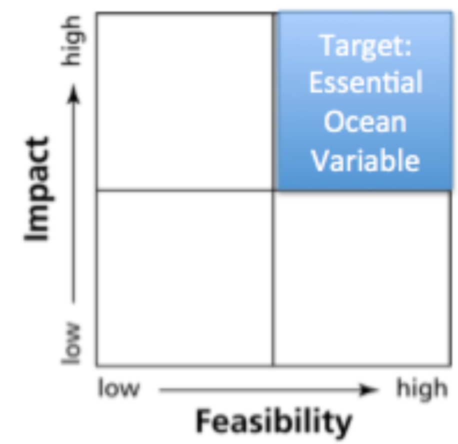
https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables

Essential Variables

- Global Climate Observing System (GCOS)
  - Developed concept of Essential Climate Variables in 1990s
    - To provide guidance for observing critical climate variables in face of declining core observational networks
  - Essential Climate Variables (EGVs)
    - Variable (physical, chemical, biological) critical to characterizing Earth's climate
    - Provide empirical evidence needed to understand and predict evolution of climate, guide mitigation and adaptation measures, assess risks and enable attribution of climatic events to underlying causes, and underpin climate services
    - Identified based on relevance, feasibility, and cost effectiveness
    - Broadly adopted in science and policy circles as basis for prioritized requirements setting and focused, coordinated action
- Global Ocean Observing System (GOOS)
  - Identified Essential Ocean Variables

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.

http://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114

Essential Ocean Variables

[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	Hard coral cover and composition
Subsurface temperature	Nitrous oxide	Seagrass cover
Surface currents	Stable carbon isotopes	Macroalgal canopy cover
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		

http://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114

The Global Ocean Observing System

Essential Ocean Variables

[Click on each EOV for their repsective spec sheets]

PHYSICS	BIOGEOCHEMISTRY	BIOLOGY AND ECOSYSTEMS
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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?	?		

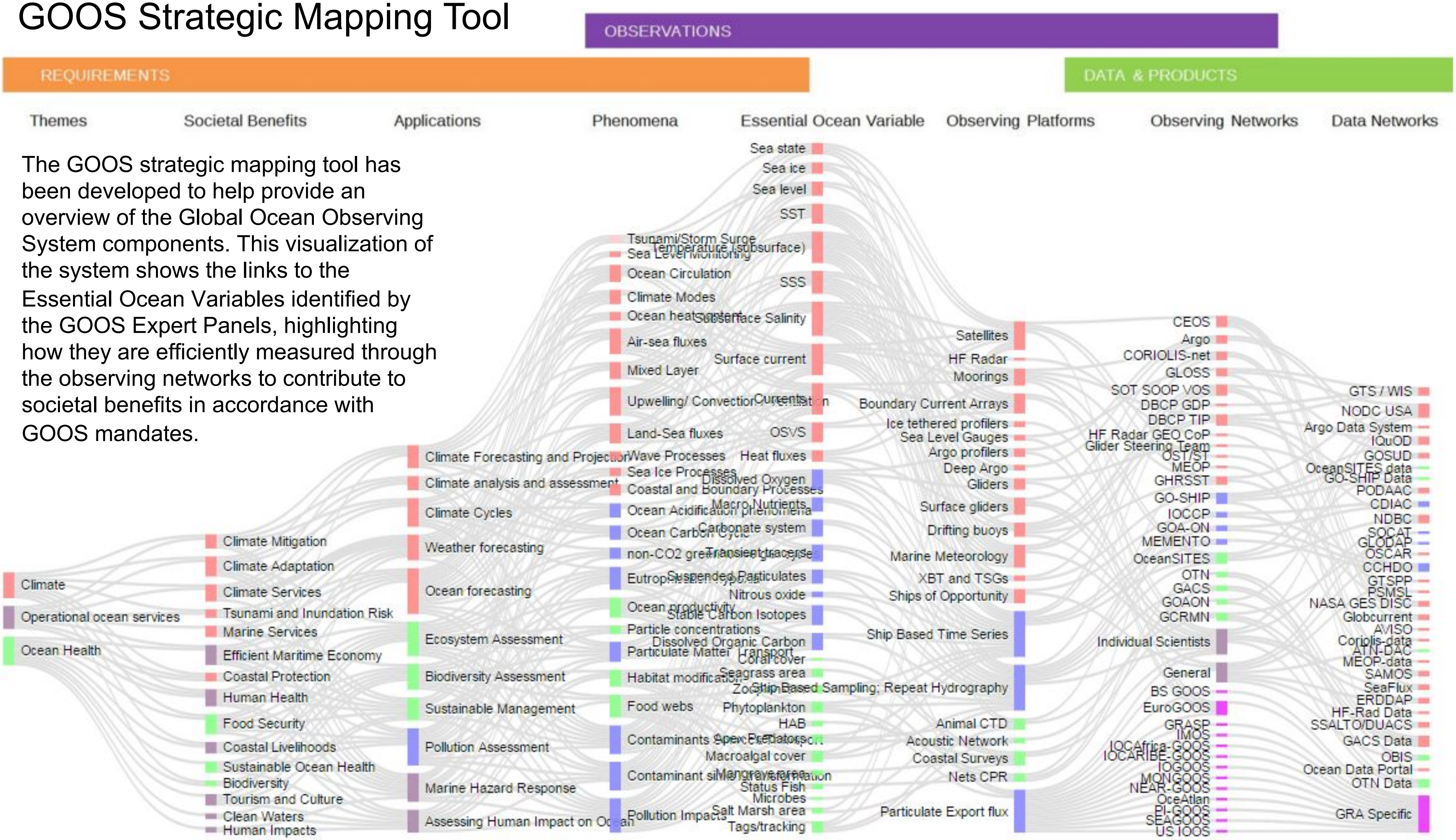
EOV: Sea Surface Height

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.



http://www.goosocean.org/index.php?option=com_content&view=article&id=120&Itemid=277

Essential Geodetic Variables

- Observed variables
  - Crucial to characterizing geodetic properties of Earth
  - Key to sustainable geodetic observations
    - Positions of reference objects (ground stations, radio sources), EOPs
    - Gravity measurements (ground-based, space-based)
- Assign requirements to each EGV
  - Accuracy, spatial and temporal resolution, latency, stability, …
- Derive requirements
  - On EGV-dependent products (TRF, CRF, …)
  - On infrastructure (observing systems)
- Can be used to update GGOS2020 book
  - Bottoms-up approach to deriving requirements
    - Complements top-down approach used in GGOS2020 book (user needs)
- Established Committee within GGOS BPS
  - To create list of EGVs, assign requirements to them, etc.
  - Committee includes representatives of
    - IAG Services, Commissions, Intercommission Committees, GGOS Focus Areas

Committee on EGVs

GGOS
- Detlef Angermann (Germany)
- Richard Gross, Chair (USA)
- Harald Schuh (Germany)

GGOS Focus Area 1
(Unified Height System)
- Bernhard Heck (Germany)

GGOS Focus Area 2
(Geohazards Monitoring)
- Diego Melgar (USA)

GGOS Focus Area 3
(Sea Level Change)
- Don Chambers (USA)

GGOS Focus Area 4
(Space Weather)
- Ehsan Forootan (UK)

IAG Commission 1
- Markus Rothacher (Switzerland)
- Geoffrey Blewitt (USA)

IAG Commission 2
- Kosuke Heki (Japan)
- Thomas Gruber (Germany)

IAG Commission 3
- Jianli Chen (USA)
- Jose Ferrandiz (Spain)

IAG Commission 4
- Jens Wickert (Germany)
- Pawel Wielgosz (Poland)

IAG ICC Theory
- Yoshiyuki Tanaka (Japan)
- Mattia Crespi (Italy)

IAG ICC Climate
- Annette Eicker (Germany)

IERS
- Tom Herring (USA)

IGS
- Tom Herring (USA)
- Michael Moore (Australia)

ILRS
- Erricos Pavlis (USA)
- Jürgen Müller (Germany)

IVS
- John Gipson (USA)
- Johannes Böhm (Austria)

IDS
- Laurent Soudarin (France)
- Jean-Michel Lemoine (France)

IGFS
- Urs Marti (Switzerland)
- Georgios Vergos (Greece)

BGI
- Sylvain Bonvalot (France)

ICGEM
- E. Sinem Ince (Germany)

ISG
- Jianliang Huang (Canada)

IGETS
- Hartmut Wziontek (Germany)
- Jean-Paul Boy (France)

IDEMS
- Christian Hirt (Germany)
- Michael Kuhn (Australia)

PSMSL
- Svetlana Jevrejeva (UK)

BIPM
- TBD

Total: 36

Essential Polar Motion Variables

Variable Information

- Name of variable
  - Polar motion (PMX, PMY)
- Sub-variables
  - Polar motion rate (PMX-rate, PMY-rate)
- Derived variables or products
  - Excitation functions (chi-x, chi-y)
- Contact/lead expert(s)
  - IERS

Requirements Settings

- Responsible organization
  - Committee on Essential Geodetic Variables
- Readiness level
  - Maturity level 8
- Phenomena to capture
  - Polar Motion
- Temporal scales of the phenomena
  - Real-time (seconds)
  - Ultra-rapid (hours)
  - Rapid (days)
  - Final (weeks)
- Spatial scales of the phenomena
  - Global

Current Observing Elements

Responsible Service	IVS	ILRS	ILRS	IGS	IDS
Relevant Parameters	Polar motion	Polar motion	Variation of latitude	Polar motion	Polar motion
Sensors/Technique	VLBI	SLR	LLR	GNSS	DORIS
Readiness Level	Maturity level 8	Maturity level 8	Maturity level 8	Maturity level 8	Maturity level 8
Temporal resolution	1-day	1-day		1-day (UR, R, F)	1-day
Latency				3-9 hours (UR) 17-41 hours (R) 11-17 days (F)	
Uncertainty (Current Capability)				50 μas (UR) 40 μas (R) 30 μas (F)	
Uncertainty (Future Requirement)					

GGOS Requirement: 1 mm accuracy (3 mm in near real-time)
1 hour temporal resolution, 1 week latency

Future Observing Elements

Observing Element	GNSS	Ring Laser Gyroscope	Superfluid Helium Gyroscope
Relevant Parameters	Polar motion	Rotation vector	
Sensors/Technique			
Readiness Level	Maturity level 6	Maturity level 4	Maturity level 2
Temporal Resoluiton			
Latency	Near real-time		
Uncertainty (Current Capability)			


شكراً جزيلاً
рахмат
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ngiyabonga
teşekkür ederim
Баярлалаа
спасибо
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mersi
kia ora
barka
welalin
tack
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blagodaram
misaotra
matondo
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mahalo
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dhanyavad
maururu
thank you
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хвала
asante
manana
obrigada
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mercé
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