Assimila

ESA EO Science Strategy Foundation Study

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7 May 2024, ESRIN

NERSC

Steeple

Symbios

www.assimila.earth

1| Study Context and Objectives

1 High level Objectives

- Deploy an international inter-disciplinary science team to **identify**, justify, document and rank a limited number of **Candidate EO Science Questions** (CSQs) as the **potential science drivers** for the next EO Science Strategy
- **Identify** through a systematic, rigorous and well documented traceability exercise **geophysical information gaps** associated with the candidate EO Science Questions
- **Demonstrate** through a systematic, rigorous and well documented **traceability** exercise how addressing the candidate EO Science Question within ESA EO programmes is linked **to societal benefits and** contributes to **international policies** and agendas
- Support **community consultation** and discussions with ACEO, and take on board feedback in the evolution of the study

1 | The Team

Ana Bastos

Maria Fabrizia Buongiorno

David Crisp

Han Dolman

Christine Gommenginger

Alain Hauchecorne

Martin Herold

Assimila

Jon Styles, Andy Shaw, Gerardo Lopez Saldana, Josie Mahony

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Stephen Ward, George Dyke

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Anna Hogg

Jose Moreno

Isabelle Panet

Karina von Schuckmann

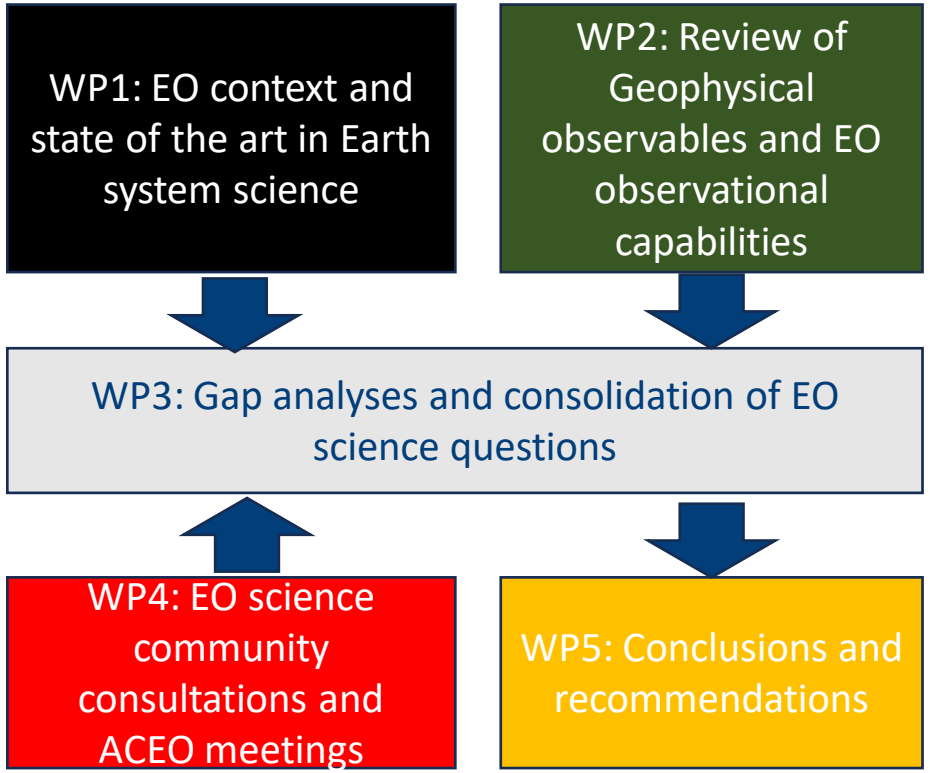
Bob Su

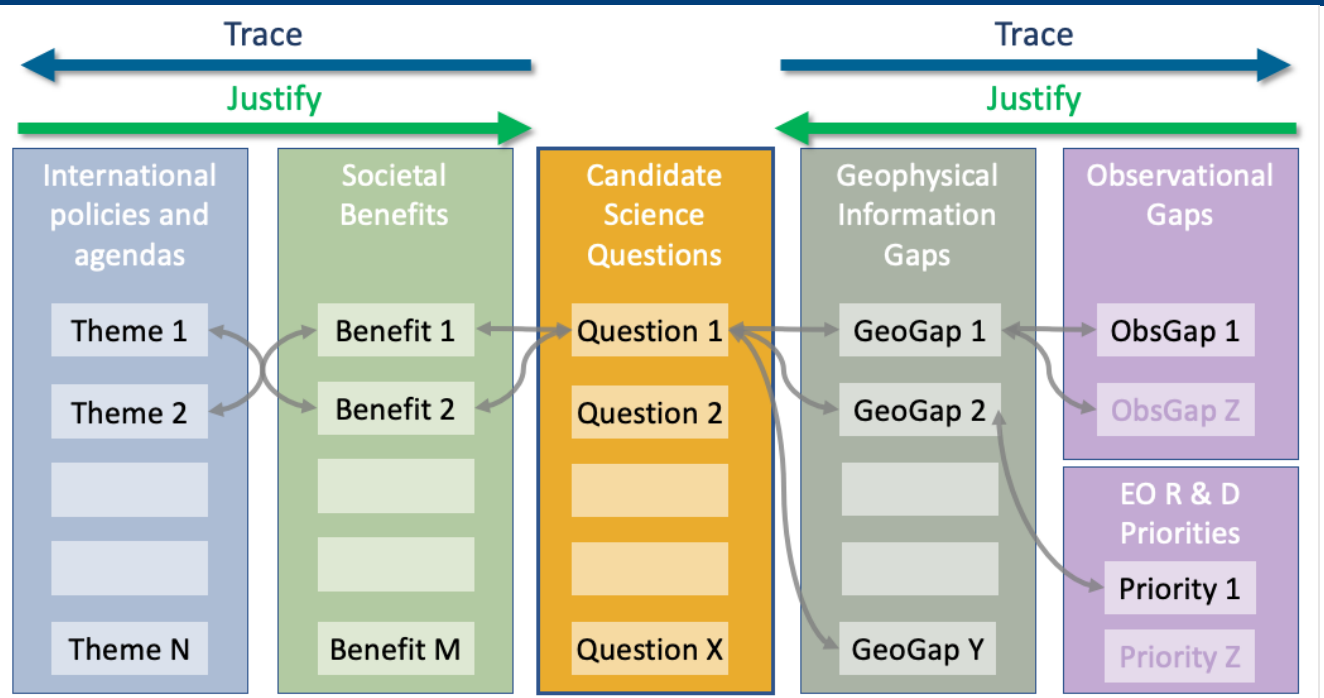
Johanna Tamminen

Peter Thorne

2 | Study Concept

1. Review context and State of the Art
2. Identify initial science questions
3. Summarize current and planned observation capabilities



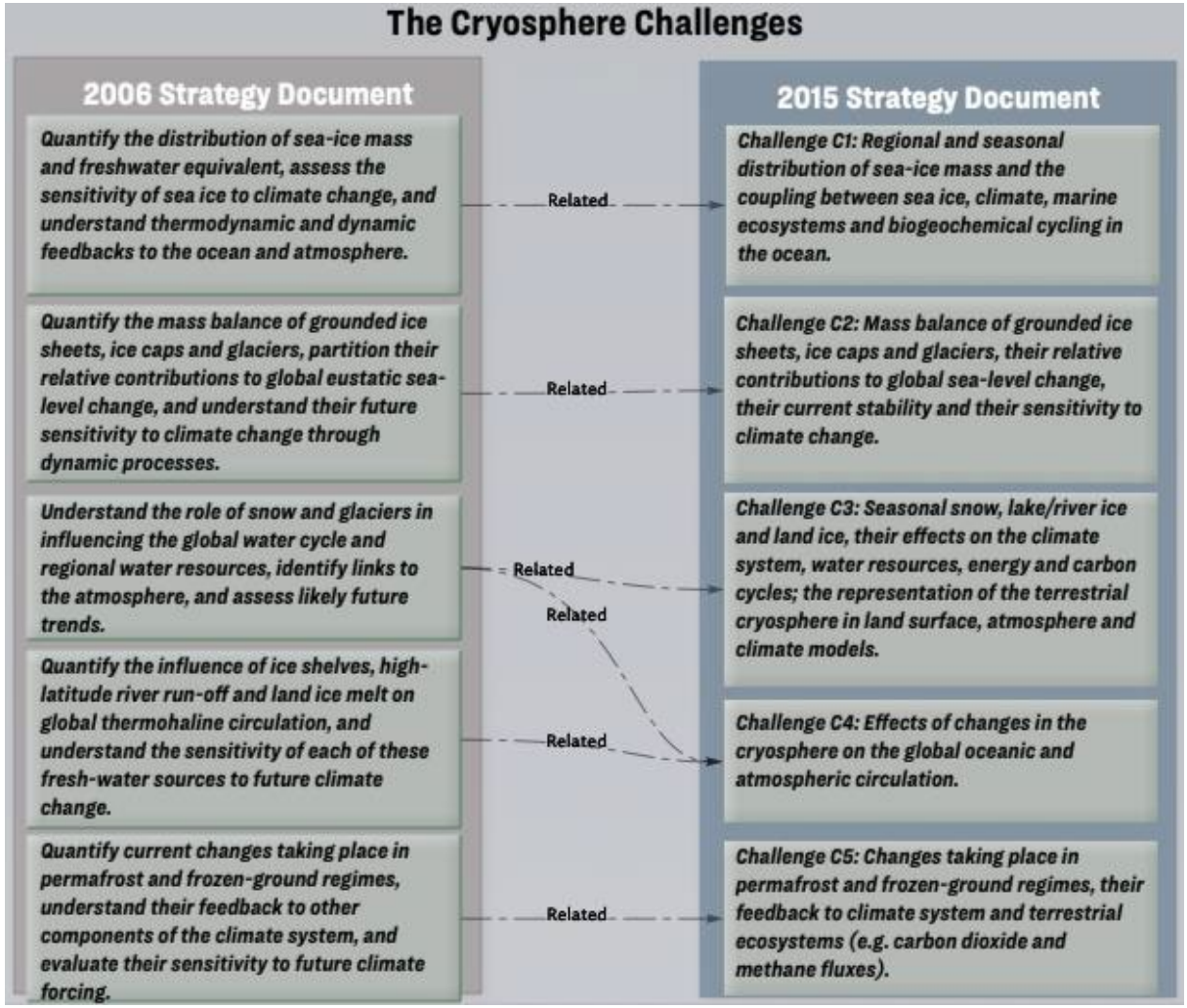


4. Identify gaps (observations, R&D…)
5. Consolidate and prioritize CSQs
6. Finalize CSQs, traced to societal needs and justified by science priorities

2| Development of the CSQs

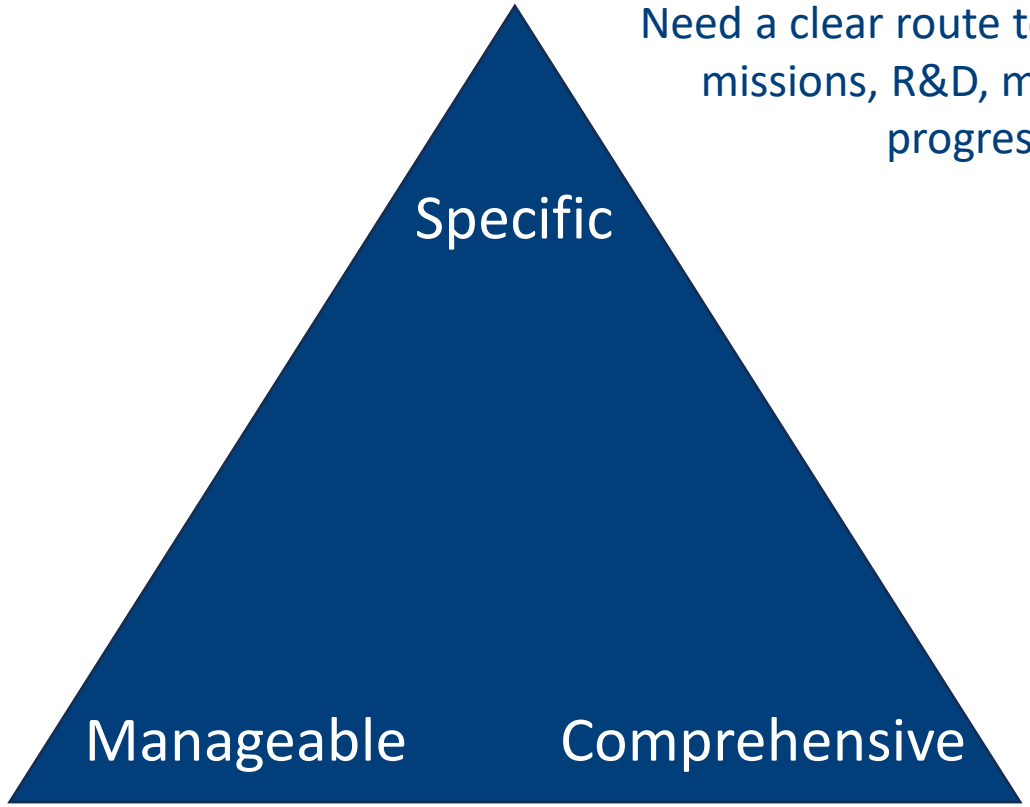
2 | Requirements for the CSQs

- Develop a stronger link between outcomes of the ESA programme and delivery of **societal benefits**
- Use an inter-disciplinary approach to identify science questions and knowledge gaps which cut across Earth system science domains rather than domain specific challenges.
- Focus on the **different timescales** over which actions resulting from the strategy would be undertaken (and deliver results) and desire for more frequent updating of the strategy
- Produce a **smaller number** of challenges than in previous strategies to allow for more targeted actions



2| Constraints on CSQs

There is a tension between the desire for highly detailed questions, manageable in number, yet cover the domain of ESA EO community interest, and pressing science priorities



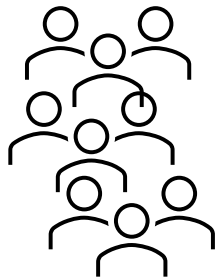
Need a clear route to actions (new missions, R&D, measureable progress)

Too many CSQs will dilute the attention of the programme and could lead to unfocussed strategy

Need to cover the breadth of ESS and engage the whole ESA community

2| CSQs Evolution

Science team



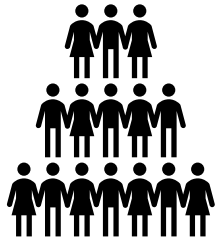
12 cross-cutting perspectives

V1
97 CSQs

Narrative in style
Based around 12 cross cutting themes

V1.5
57 CSQs

Structured format
Initial identification of observables



ESA Workshop / ACEO

Selection of CSQs for Geophysical observable analysis

Detailed specification of geophysical observables with Links to CEOS/OSCAR DB

V2.1
22 CSQs

57CSQs

Identification of cross-cutting themes for all 57 CSQs

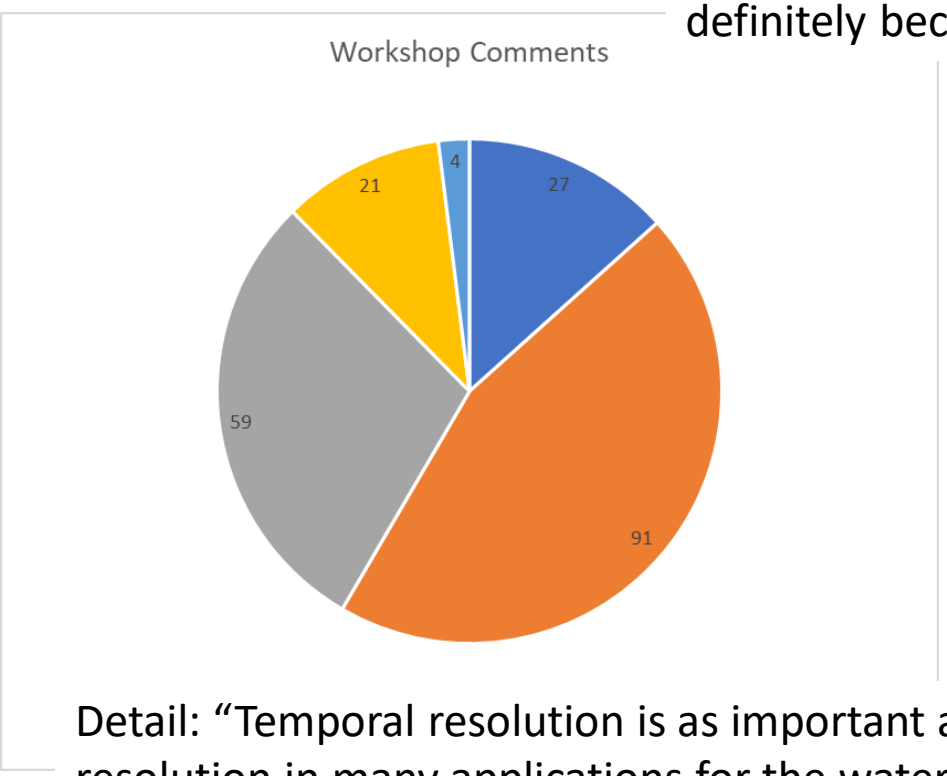
2| Source of the CSQs

- Analysis of the state of the art, and other international policies provided the baseline
- Initial CSQ formulation through Science Team(ST) discussion sub-groups
- ST members led discussions from a range of cross cutting perspectives
- Multiple topics discussed together to aid cross fertilization of ideas
- Each CSQ reviewed and agreed by two independent groups

Team member	Perspective
Han Dolman (Chair)	
Christine Gommenginger	Coastal
Ana Bastos	Planetary boundaries
David Crisp	Carbon cycle
Martin Herold	Biodiversity/ecosystems
Alain Hauchecorne	Cross cutting/technical issues
Jose Moreno	Climate tipping points
Peter Thorne (Chair)	
Karina von Schuckmann	Energy cycle
Bob Su	Water cycle
Anna Hogg	Polar
Isabelle Panet	Solid Earth/mass changes/geomagnetism
Johnny Johannessen (Chair)	
Maria Fabrizia Buongiorno	Earthquakes/vulcanism and minerals
Johanna Tamminen	Extreme events

Community Feedback

- 202 Substantive Comments.



Positive: “This CSQ addresses a very topical issue (tsunamis) which can potentially have dramatic impacts (Fukushima, etc.) and contributions to advance this question should definitely become a priority….”

Comment: “We continue to lack good early warning systems to predict extreme rainfall and properly characterize droughts”

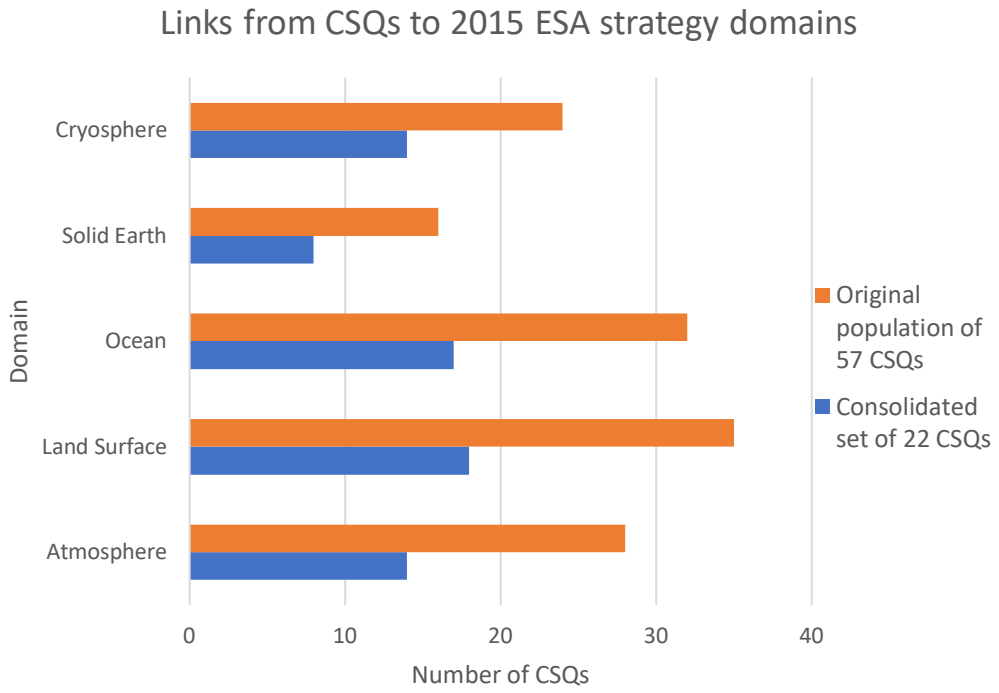
Addition: “Please add:
1. Measurements of river runoff in estuaries
2. Measurements of along-shore coastal currents (to understand how fresh water from rivers in estuaries is transported along the coast)”

Detail: “Temporal resolution is as important as spatial resolution in many applications for the water cycle (floods, landslides, precipitation, irrigation, ...) “

		Comment_Count	Theme
	ystem of systems while ites under different orbit ing capacities?	31	NT
	g of extreme events and climate	24	EE
	eeded: polar / tropical regions, ong-term series of observation, large-scale field experiments?		NT
CSQ-14	What are the main issues with calibra calibration, long-term monitoring?		NT
CSQ-9	What are the characteristics of the pr extremes and the hazards related to t		EE
CSQ-1	What anthropogenic and natural proc carbon cycle?	16	CC
CSQ-2	How has the land biosphere responded to human activity and climate change?	15	CC
CSQ-10	How can we improve the characterization and preparedness for risks related to com		
CSQ-43	What are the main water and carbon c forcings and feedba Earth system?		
	ant are ow accu n the w		
	improve estimates of the internal flow of energy limate system with respect to major uncertainties for equilibrium climate sensitivity evaluations?	12	EC

Workshop Feedback & Consolidation

- Analysis of the post-workshop feedback
  - The “positive” (27 comments) and “comments” (91 comments) categories required noting but not action
  - Of the remaining “detail” (21 comments) and “addition” (59 comments), 30 comments related to the CSQs under detail assessment, with 27 updates made to the CSQs as a result
  - Workshop attendees were invited to produce additional CSQs. Only two were received, both related to very high atmosphere phenomena and connections between the ionosphere, thermosphere and terrestrial magnetic fields.



Basis for selecting CSQs for further identification of observables

- Discussion at the last workshop
  - Overall feedback from the workshop discussion that cross cutting issues related to methods, EO sampling, cal/val etc were important and worthy of consideration in the policy, but not necessarily the basis for the CSQ which should be more science process oriented
- Direction from ACEO that the focus for the CSQs should be based on:
  - Where are benefits to society inhibited by lack of scientific understanding of Earth system processes?
  - Where is understanding/discovery of Earth system processes inhibited by lack of appropriate Earth observation data and related innovation?
- Practicality
  - The next step was to detail geophysical observables required by the CSQs, and subsequently observation gaps
  - Need CSQs where specific observables could be identified

Examples

Geophysical Observable Analysis

CSQ-1: What anthropogenic and natural processes are driving the global carbon cycle?

CSQ-5: What processes drive changes sea level in the coastal ocean?

CSQ-33: How does the solid Earth deform under present and past ice loads and what does it tell us about its rheology ?

Cross Cutting issues

CSQ-14: What are the main issues with calibration-validation, absolute calibration, long-term monitoring?

Methodology issue

CSQ-53: Can we map topography, surface mineralogic composition and distribution, thermal properties, soil properties/water content?

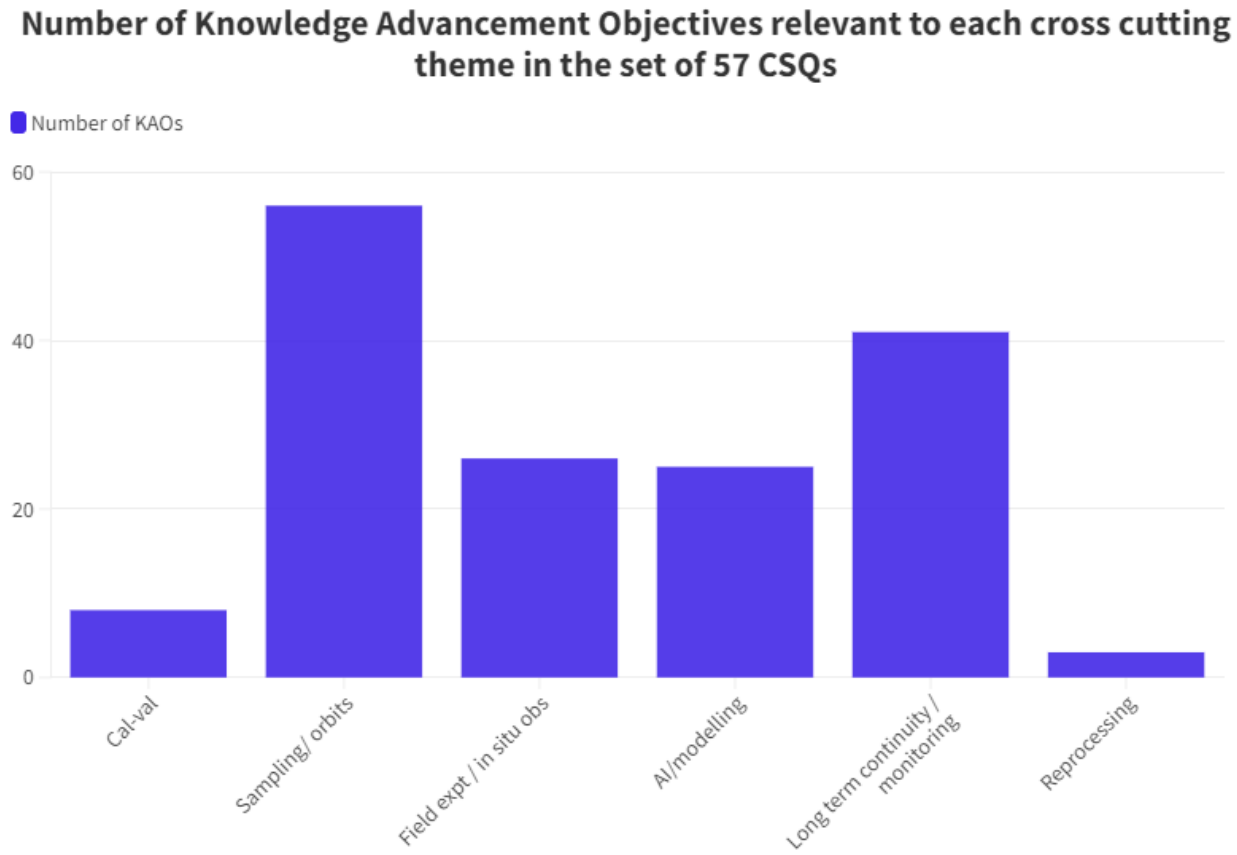
Focus on mapping / monitoring as opposed to processes

CSQ-28: Are there tipping points/elements in the climate system not yet identified?

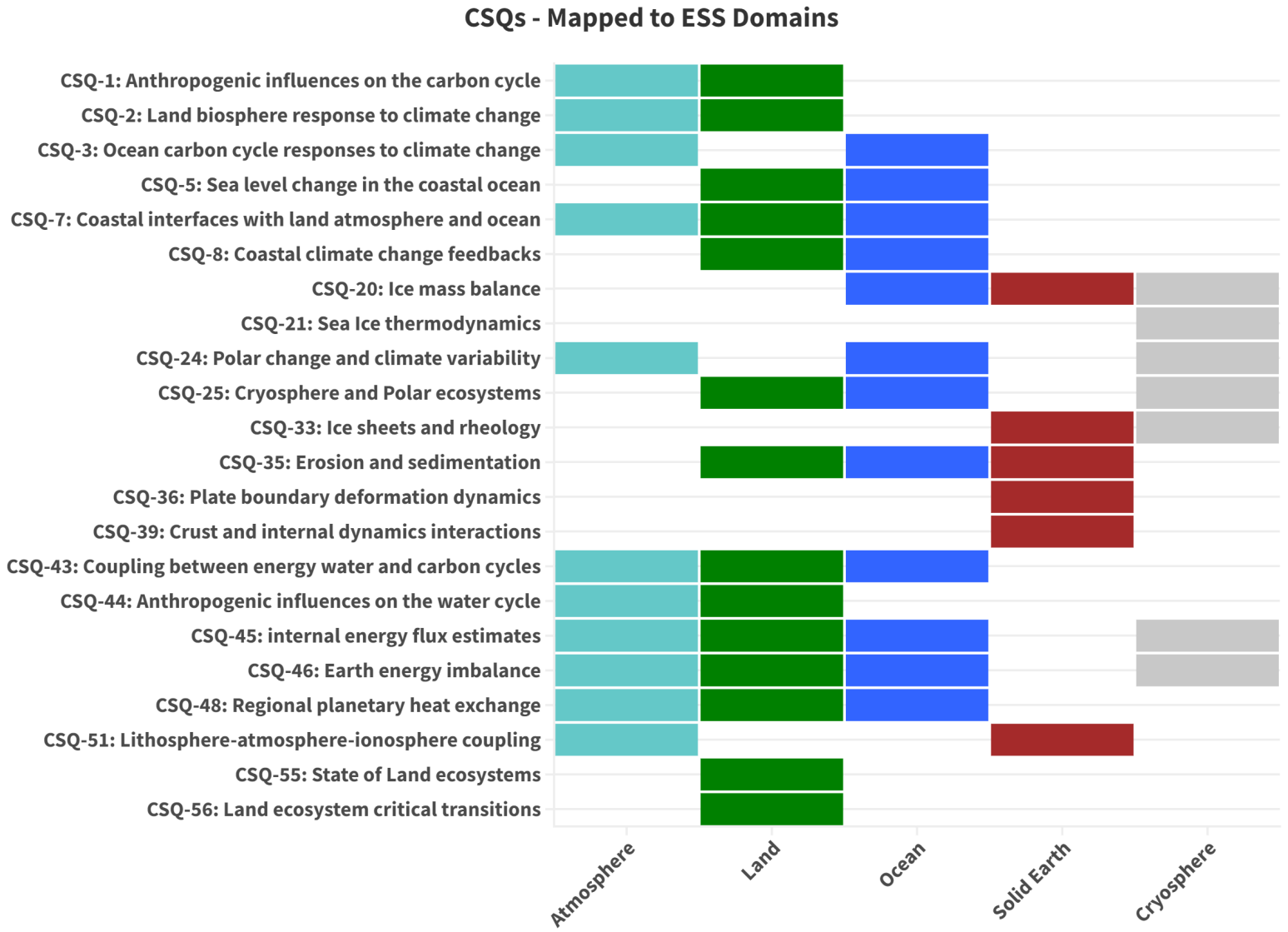
Challenge to identify specific observables

Cross cutting implementation issues identified in the full set of 57 CSQs

- All of the CSQs were assessed for relevance to a set of cross cutting EO technology themes
  - Cal/val
  - Sampling/orbits
  - Field experiments / in situ obs
  - AI/modelling
  - Long term monitoring
  - Reprocessing
- This was done for each of the full set of 57 CSQs



CSQs for analysis of observables



CSQ structure

Question	Knowledge Advancement Objectives	Geophysical Observables [Links to MIM databases]	MIM Number	Measurement Specifications	Data sets, Methods, Tools & Models	Policies / Benefits
How has the ocean carbon cycle responded to anthropogenic CO_2 and climate change?	**A) Track changes in ocean uptake and removal of CO_2 associated with changes in atmospheric CO_2 concentration, sea surface temperature, ocean transport and biological productivity at 1°x1° or higher resolution over the globe?**	**1. Critical Parameters** *Precise/accurate estimates of near-surface atmospheric CO_2 and its spatial and temporal gradients*			Atmospheric GHG retrieval algorithms Atmospheric flux inverse models Global ocean biogeochemical models (GOBMs) Enhanced Cal/val	CC mitigation and adaptation policy
		Atmospheric CO_2 dry air mole fraction	CEOS-44	Precise/accurate (0.1 ppm) XCO_2 and XO_2 at a resolution of 1°x1° or higher at monthly intervals		
		Sea surface temperature (SST) and salinity				
		Sea Surface salinity	CEOS-152	SST, salinity at a spatial resolution of 1°x1° or higher at daily intervals		
		Sea surface temperature	CEOS-144			
		Surface vector winds				
		Wind speed over sea surface (horizontal)	CEOS-141	Ocean wind speed at a spatial resolution of 1°x1° or higher at daily intervals		
		Wind vector over sea surface (horizontal)	CEOS-143			
		Ocean colour				
		Ocean chlorophyll concentration	CEOS-149	Ocean colour at a spatial resolution of 1°x1° or higher at daily intervals		
		Ocean suspended sediment concentration	CEOS-150			
		Colour dissolved organic matter (CDOM)	CEOS-151			
		2. Supporting Parameters				
		Precipitation	CEOS-116	precipitation at a spatial resolution of 1°x1° or higher daily		

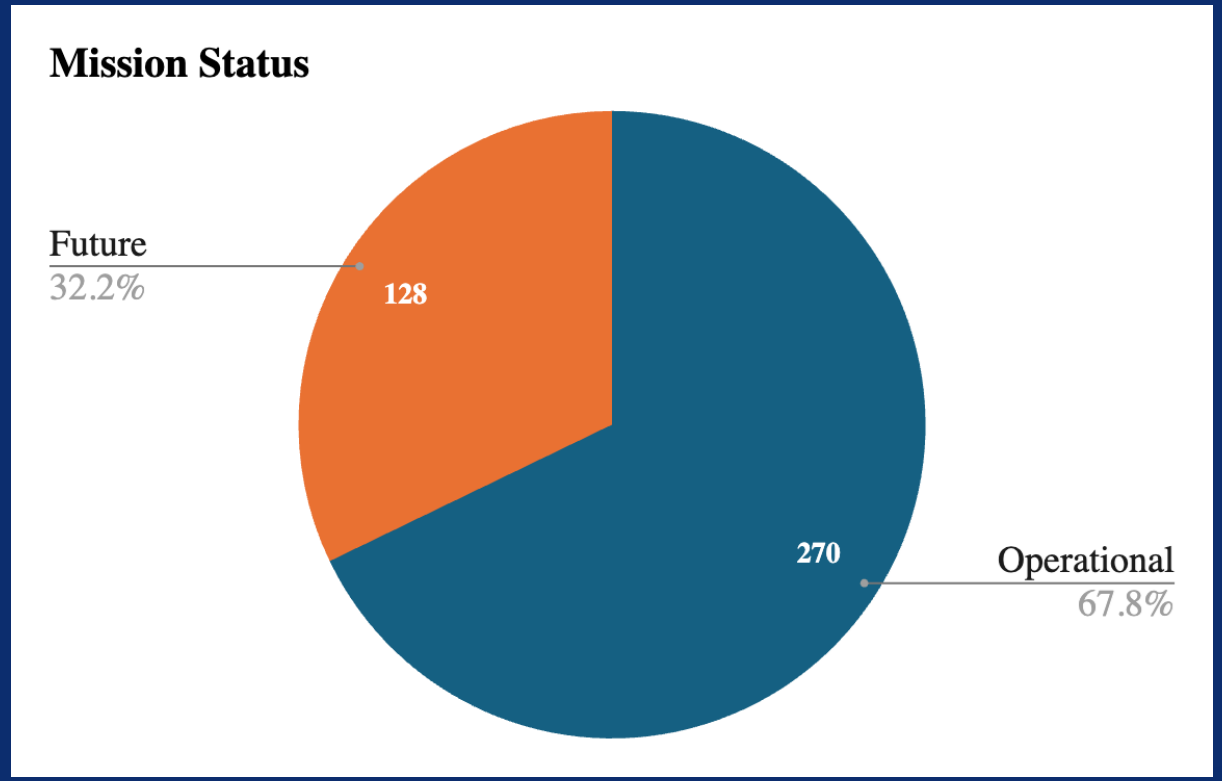
Identification of observables

- Geophysical Observables required to support progress on the CSQ and individual Knowledge Advancement Objectives (KAO) identified by the original CSQ author, supported by core team (Assimila/Symbios/NERSC)
- To ensure comparability, choices were constrained, where possible, to entries in the CEOS DB – failing that the OSCAR DB, and failing that identifying a new observable
- Observables divided into:
  - Critical: "an observation that is uniquely enabling to address the CSQ above and beyond current capabilities"
  - Supporting "an observation that makes significant a contribution to understanding, or other observations which are ancillary to those above which are assumed to be routinely available"
- Where possible, specifications of the observable requirements (from the science perspectives were added

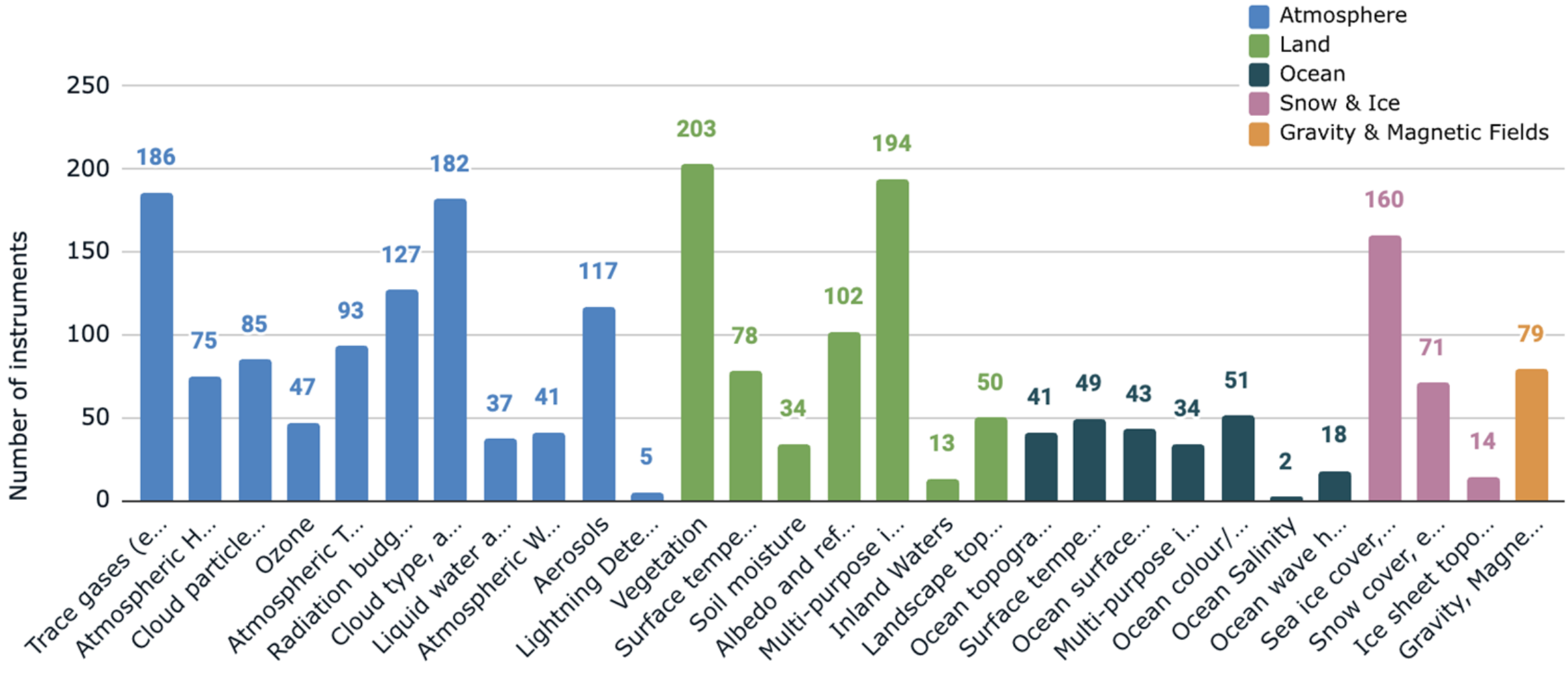
Summary of Satellites and Missions DB

Symbios

- Derived from: CEOS Database, OSCAR/Space, plus other sources such as UCS Database, NORAD
- Unique missions: **398**
- Unique instruments: **505**
  - Instrument-on-mission pairs: **966**
- Unique geophysical observables: **156**
  - Mission-instrument-observable mappings: **4026**



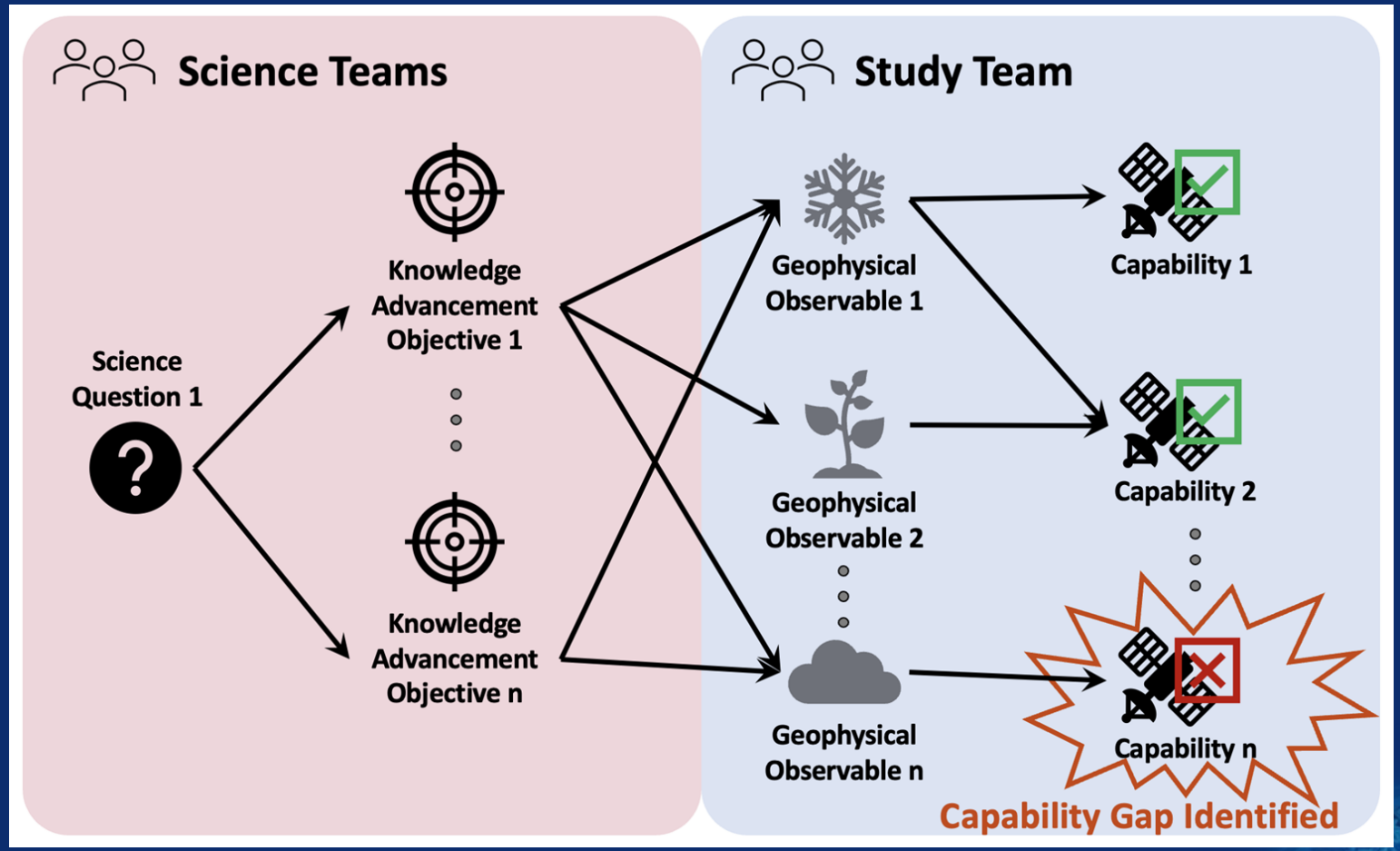
Database Characterisation



Summary of high-level gap analysis

Title: Geophysical Observables and their Descriptive Parameters

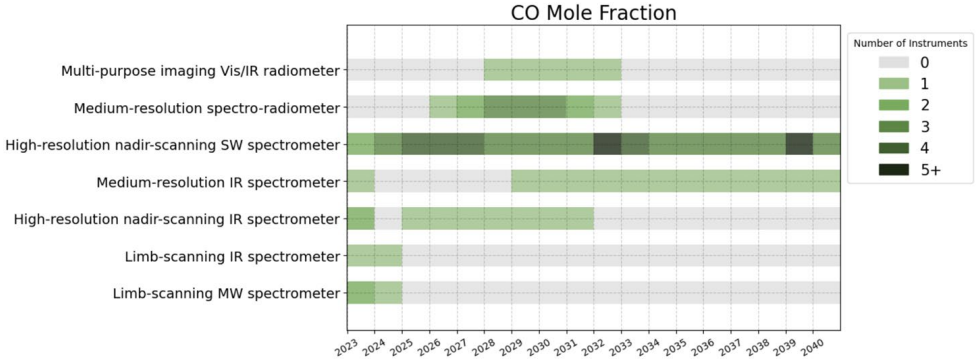
- *D5: Table with a comprehensive list of Geophysical Observables and their descriptive parameters in format to be defined by the study team*



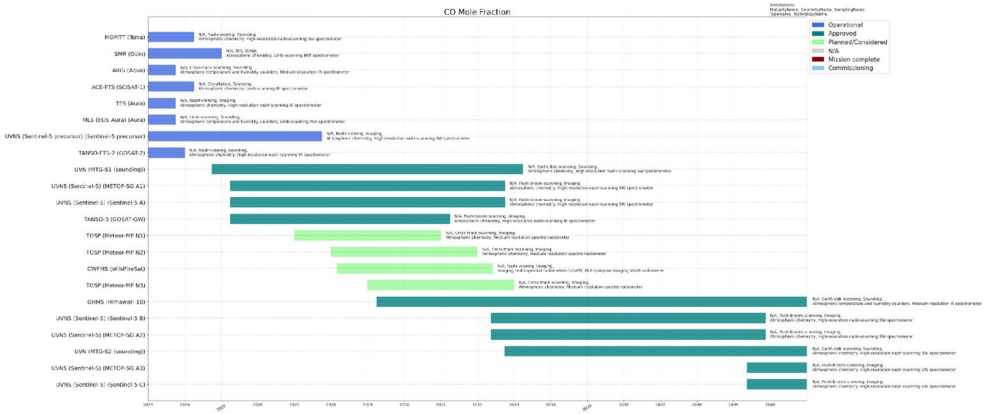
Example of high-level gap analysis

Symbios

Graphical Timelines



Detailed Timeline



Instrument Lists

Instruments

Instruments recorded in ESSFS D4 as measuring Cloud type

Instrument	Utility (as assessed by agency)	Missions	CEOS DB Entry
SEVIRI	High Utility	Meteosat-9, Meteosat-10, Meteosat-11	https://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=302
AMSU-A	High Utility	NOAA-18, Metop-C, NOAA-19, Metop-B	https://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=312
OLS	High Utility	DMSP F-17, DMSP F-18, DMSP F-16	https://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=450
VISSR-2	High Utility	FY-2G, FY-2H	https://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=665
MWRI	High Utility	FY-3F, FY-3RM-2, FY-3RM-1, FY-3D, FY-3C	https://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=672
VIRR	High Utility	FY-3C	https://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=684
MSU-GS	High Utility	Elektro-L N2, Elektro-L N3, Elektro-L N4, Elektro-L N5	https://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=784

3| CSQ Characterisation

4a | CSQ Categorisation and assessment

- So far, the process resulted with a list of 22 candidate science questions based on science priorities
  - Defined with involvement and input from wider science community and ACEO
- The next step was providing a flexible, multidimensional framework for categorizing the CSQs according to different criteria
- Four criteria were agreed:
  1. **Frontier science & discovery:** reflecting the potential for scientific impact
  2. **From science to benefits**: addressing potential for societal impact
  3. **Reducing critical knowledge gaps**: focusing on potential for short term impact
  4. **Filling critical observation gaps**: relative role of new satellite/sensing technology
- Applying these criteria supports identification of what **ESA** EO **Science** should do
  - Criteria can be weighted to reflect importance/value

4a| Assessment categories and criteria

Category	Justification	Assessment Criteria
1. Frontier science and discovery	Innovative/blue-skies science that is groundbreaking/technologically challenging, and can best be addressed via multilateral cooperation through ESA.	High Score: Answering the question would deliver fundamentally new knowledge or help to quantify processes, fluxes or stores that are unmeasured, or have large or poorly understood uncertainties. Low Score: The science is derivative – delivers incremental gains in already well understood processes.
2. From science to benefits	Clear benefits to society are an increasingly important driver to the ESA strategy. Need to support greater confidence in actions by governments the private sector and individuals	High Score: Makes a unique or leading contribution to an area of societal benefit that is significant in scope, economic impact, or risk. EO data plays a unique or very significant role in delivering Low Score: The societal or policy relevance of the CSQ is minimal or marginal. EO data makes a minor contribution alongside several other actions by other parties.
3. Reducing critical knowledge gaps	The updated EO science strategy will have a horizon of 5-10 years, with the associated need to demonstrate significant progress within the first 5-6 years.	High Score: Demonstrable progress can be made on specific and scientifically / societally important objectives through R&D and technology development (including with AI/ML) that exploits existing or planned data, particularly from the ESA science programme. Low Score: Progress can only be achieved in the long term, possibly because entirely new missions would be needed that are not currently planned
4. Filling critical observation gaps	Filling critical observation gaps through technology development is fundamental to the ESA EO programme.	High Score: Represents a critical knowledge gap and advancement is critically / uniquely dependent on new EO technologies. Technology development needed for CSQ progress could result in new operational observations in the long term. Low Score: Criticality of knowledge gap is low and / or existing data and instrument types are adequate to make progress. Or, conversely, required measurements cannot feasibly be made from space.

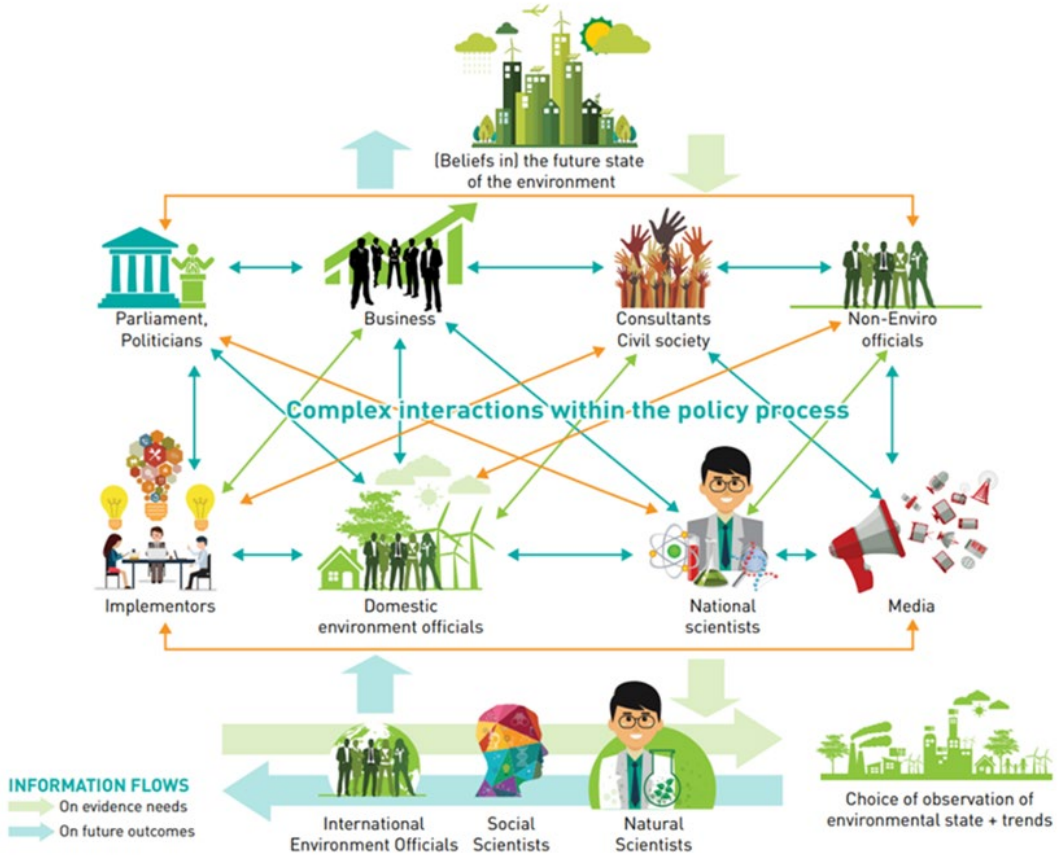
4a| Overall Process

- Establishment and agreement of the categories and assessment criteria
- Categories 1,3 & 4
  - Assessment of the CSQs against the criteria by the Science Team Chairs and Science Leader
  - Standardisation, collation and moderation by the core team
- Category 2 (policies/benefits)
  - Bottom-up assessment based on policy and treaty components (details following)

4b|Category 2 - Policies and Benefits I

Key areas for the study, to demonstrate traceability to benefits to society and respond to international/national policy objectives

- Detailed study of policy/benefits from undertaken at the beginning of the study in WP1
- Benefits / policy domain is complex and diffuse – a wide range of themes are involved, and organizations differ from country to country, and to international organizations



4b| Steps to linking CSQs with policy/benefit areas

1. Define policy domains

2. Establish links to CSQs

3. Scoring and justification

4. Visualisation and analysis

4b| International treaties/agreements

Treaty/Agreement	Component/goal/target
UNFCCC / Paris Agreement	Art.4 Mitigation goal; Art.5 Maintain sinks and reservoirs; Art.7 Adaptation goal; Art.8 Minimize loss and damage; Art.12 Public engagement; Art.13 Enhanced transparency framework; Art.14 Global stocktake
UN Convention on Biodiversity	Article 6. General Measures for Conservation and Sustainable Use; Article 7. Identification and Monitoring; Article 8. In-situ Conservation; Article 9. Ex-situ Conservation; Article 11. Incentive Measures; Article 13. Public Education and Awareness
UN Sustainable Development Goals	SDG6 Clean water, sanitation; SDG11 Sustainable cities; SDG12 Climate action; SDG13 Life below water; SDG14 Life on land
UNDRR / Sendai Framework Disaster Risk Reduction	Priority 1: Understanding disaster risk; Priority 2: Strengthening disaster risk governance to manage disaster risk; Priority 3: Investing in disaster risk reduction for resilience; Priority 4: Enhancing disaster preparedness for effective response
EU Green Deal	Net Zero by 2050; Clean, affordable, secure energy; Circular economy; Energy efficiency; Zero pollution; Ecosystems and biodiversity; Farm to fork' sustainable food system; Sustainable mobility

4b| National policy domains

Policy / benefit domain	Components	Major international treaties/ agreements	Relevant international bodies/agencies	UN SDGs	EU DGs and EAs
Energy	- Energy policy - Climate mitigation	UNFCCC Paris Agreement REDD	IPCC IEA TCFD WB/IADB/ADB/IMF	7 Affordable and clean energy 13 Climate action 15 Life on land	ENER CLIMA CINEA
Environment	- Nature and biodiversity - Air quality and ozone - Water quality - Forestry - Coastal & marine environment	CBD Ramsar Convention Montreal Protocol	UNEP IPBES TNFD	6 Clean water and sanitation 13 Climate action 14 Life below water 15 Life on land	ENV
Agriculture, fisheries and food security	- Food production - Food supply chain - International commodities - Fisheries	Common Agriculture Policy	UN FAO UN WFP IFAD IMO	2 Zero hunger 13 Climate action	AGRI MARE (Fisheries)
Transport and infrastructure	- Air/maritime/land transport - Smart cities and urban - Regional development	SOLAS, MARPOL	IMO ICAO IBRD WB/IADB/ADB/IMF	13 Climate action 14 Life below water 11 Sustainable cities and communities	MOVE MARE (Maritime transport) REGIO
Civil protection and humanitarian aid	- Disaster risk reduction/resilience - Emergency response - Humanitarian response	Sendai Framework	UN HCR UN OCHA UN DP ICRC/IFRC	15 Life on land	ECHO
Public health	- Health - Social wellbeing - Disease risk - Accident and emergency		WHO UN DP	3 Good health and well being 15 Life on land	SANTE HERA

4b| Establishing relevant links between CSQs and policy domains

Policy role	Description	Example contribution
Inform	EO science to inform policy debate through provision of knowledge, understanding and evidence. Includes *identifying*, *monitoring* and *assessing* global environmental issues.	Further understanding regarding drivers and constraints affecting global terrestrial and ocean GHG sinks and reservoirs required for Art 4/5 of the Paris Agreement (SQ1); Increased understanding of processes driving climate sensitivity will be a direct contribution to Art.4 of the Paris Agreement (SQ45); Art.6/7 of the CBD concerning conservation options and means to monitor global biodiversity require improved knowledge of ecosystem function and responses to climate change (SQ2,5,25,55,56).
Assist	Supporting society address environmental issues, reduce loss of life, etc	Combination of improved understanding of hydrometeorological processes and understanding of coastal flood risk will assist reduction of loss to life and property (SQ5,44); Advancing understanding of geophysical processes will aid our ability to model and assess risk of loss from hazardous events (SQ33,35,38).
Comply	Enforcement of policy outcomes/ legislation	Improved ability to model and monitor sources and sinks of GHGs will support verification of commitments to meeting Net Zero (SQ1,2); Compliance with aims of CBD will be aided by better understanding of the extent, condition and dynamics of critical ecosystems (SQ2,25, 55,56).
Evaluate	Assessment of the outcomes of specific policy decisions	A variety of policy commitments at national and international scale will require global monitoring and interpretation; Example include Net Zero policies (SQ1,2,3,8,20,45,48,56), voluntary carbon markets (SQ1,2,55,56), zero deforestation (SQ55,56) and efforts to reduce risk exposure and loss (SQ5,33,35,38,44).

Modified from *Onoda, M. and Young, Oran R.,* Satellite Earth Observations and Their Impact on Society and Policy, 2017, p14.

4b| Scoring and justification

Scoring

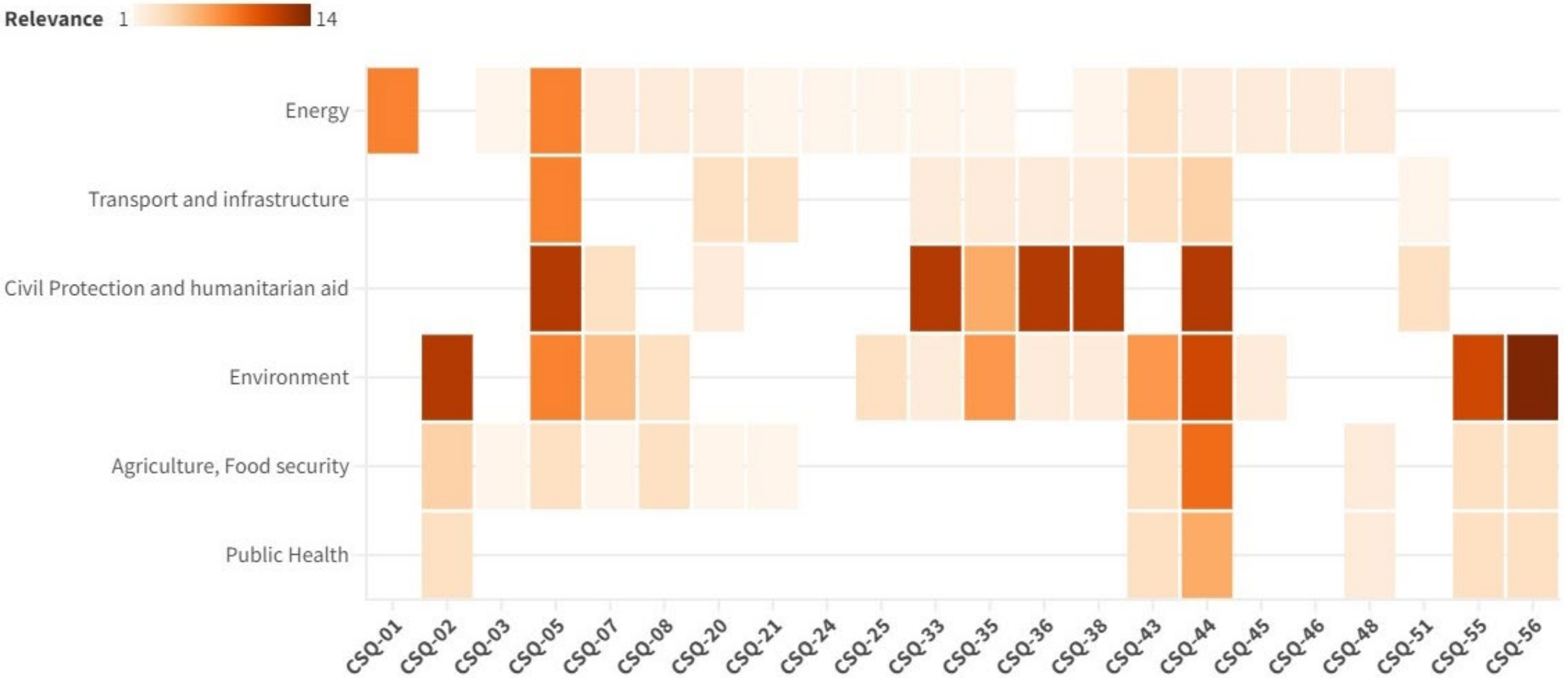
	Complementary	Unique
Direct	2	3
Indirect	1	2

Uniqueness

			Paris Agreement	Convention on Biodiversity	Sustainable Development Goals	Sendai Framework	EU Green Deal
CSQ-01	Global carbon cycle		Major contribution to informing Art. 4 Mitigation and evaluating policy responses; Major contribution to Art. 5 on maintaining sinks and reservoirs, both terrestrial and ocean; Other contribution to Enhanced Transparency Framework and Global Stocktake	Informs Arts 6/7/8/9 pm measures, monitoring, in-situ conservation and ex-situ conservation	Major contribution to SDG 12 Climate Action	N/A	Contributes to policy goals Net Zero by 2050 and Clean, Affordable Energy
CSQ-02	Land biosphere responses		Major contribution to informing Art 4 policy on climate state ; Major contribution to Art. 5 on maintaining land/biosphere sinks and reservoirs; Potential to assist adaptation policy and Global Stocktake	Major contribution to Art 9 Ex-situ conservation; Inform/evaluate contribution to Arts 6, 7, 8, 11 and 13; Needed to assess impact of financing measures	Major contribution to SDG154 Life on Land; Informs policy goal on SDG12 Climate action	N/A	Contributes to Net Zero by 2050 ; Strong contribution to Ecosystems and Biodiversity policy
CSQ-03	Ocean carbon cycle		Relevance to Art 4 Mitigation, reporting on climate state ; Informs Art 5 on ocean sink status and potential to assist policy delivery	Some relevance to Art 6 on measures for conservation; Some relevance to Art 7 on identification and monitoring ;	Relevance to SDG12 Climate action and SDG13 Life below water	N/A	Some relevance to Net Zero by 2050
CSQ-05	Coastal sea level		Some relevance to Art 4 on climate state and Art 5 ocean sinks; Strong contribution to Art 7 on adaptation and Art 8 Minimise loss and damage	Some relevance to Art 6/7/13 incl. impacts on conservation measures for coastal habitats	Strong relevance to SDG11 Sustainable cities and costal population/ development; Relevance to SDG12/13/14 pertaining to climate action, life on land and life under water;	Informing Priorities 1/2/3/4 for coastal risk assessment and adaptation policies; Informs financing of prevention measures	Informs urgency of Net Zero by 2050
CSQ-07	Coastal process mediation		Relevance to Arts 4/5/7/8	N/A	Some relevance to SDG13 Life below Water	N/A	N/A
CSQ-08	Coastal carbon cycle		Medium relevance to Art 4 mitigation; Some contribution to Art 5 maintaining ocean sink	Art 7/13 some relevance to Identification/ Monitoring and Public education	Some relevance to SDG13 Life below water	N/A	Indirect relevance to Net Zero policy
CSQ-20	Ice mass balance		Strong contribution to informing Art 4 Mitigation; Strong relevance to Art 7/8 on adaptation and minimising loss and damage; Strong public relevance	Art7 Identification and monitoring of Arctic habitat	Relevance to SDG12/13/15 Climate action and life on land/under the ocean	Indirect relevance to understanding disaster risk via to sea level	Informs Net Zero policy
CSQ-55	State of land ecosystems		Informs most Articles of the Paris Agreement	Strong relevance across all Articles of the CBD	Strong link to SDG14 Life on land; Relevance to SDG12 Climate action	N/A	Strong relevance to Ecosystems and Biodiversity policy
CSQ-56	Ecosystems transition		Informs most Articles of the Paris Agreement	Strong relevance across all Articles of the CBD	Strong link to SDG14 Life on land; Relevance to SDG12 Climate action	N/A	Strong relevance to Ecosystems and Biodiversity policy

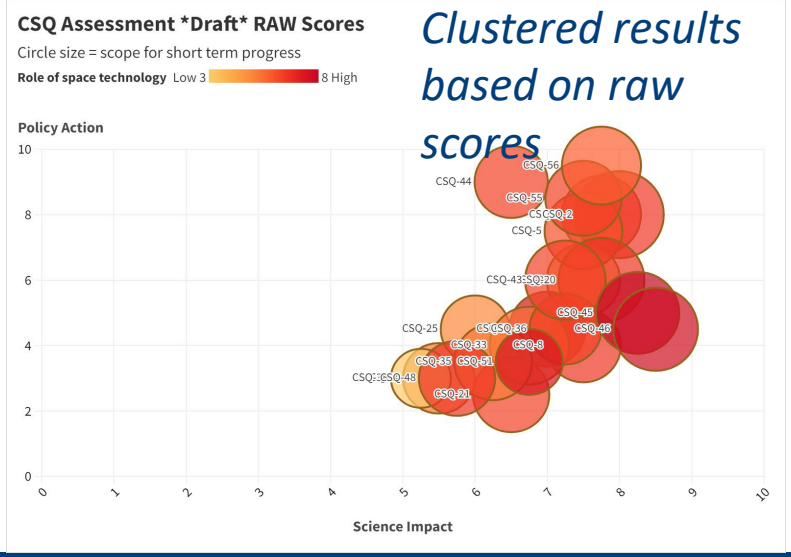
			International agreements and treaties					*National policy domains*									
			Paris Agreement	Convention on Biodiversity	Sustainable Development Goals	Sendai Framework	EU Green Deal	Energy	Environment	Agriculture, fisheries and food security	Transport and infrastructure	Civil protection and humanitarian assistance	Public health & wellbeing	Inform	Assist	Comply	Evaluate
CSQ1	Global carbon cycle	Inform	11	4	3		3	3						24			
		Assist	4		1		2	2							9		
		Comply	2		1			1								4	
		Evaluate	9		3		3	2									17
CSQ2	Land biosphere responses	Inform	5	7	3		3		5	2			3	28			
		Assist	6		2		2		3	2					15		
		Comply	2		2											4	
		Evaluate	6	7	3		2		4								22
CSQ3	Ocean carbon cycle	Inform	5	2	2		1	1		1				12			
		Assist	3		2		1								6		
		Comply														0	
		Evaluate	3	3	2		1										9
CSQ5	Coastal sea level	Inform	8	2	7	6	2	4	4	3	5	6		47			
		Assist	4	1	5	4	2	3	2		3	6			30		
		Comply														0	
		Evaluate	3		5		1	1	2								12
CSQ7	Coastal process mediation	Inform	5		1			1	2	1		3		13			
		Assist						1	1						2		
		Comply														0	
		Evaluate	4						2								6
CSQ8	Coastal carbon cycle	Inform	3	1	1		1	1	1	3				11			
		Assist		1				1	1						3		
		Comply														0	
		Evaluate	3						1								4
CSQ20	Ice mass balance	Inform	6	1	3	1	1	1		1	2	2		18			
		Assist	7	1	3			1			1				13		
		Comply														0	
		Evaluate	6	1	3												10
CSQ21	Sea ice themodynamics	Inform	5				1	1		1	2			10			
		Assist									1				1		
		Comply														0	
		Evaluate	2														2
CSQ24	Polar climate relationship	Inform	5		1		1	1						8			
		Assist													0		
		Comply														0	
		Evaluate	1		1		1										3
CSQ25	Polar ecosystem impacts	Inform	5	7	1		1	1	1					16			
		Assist		3	1		1		1						6		
		Comply														0	
		Evaluate	1	9	1		1		1								13

4b| CSQ - National Policies Heatmap



4c| Characterising Category 1, 3, 4 - Scoring Method

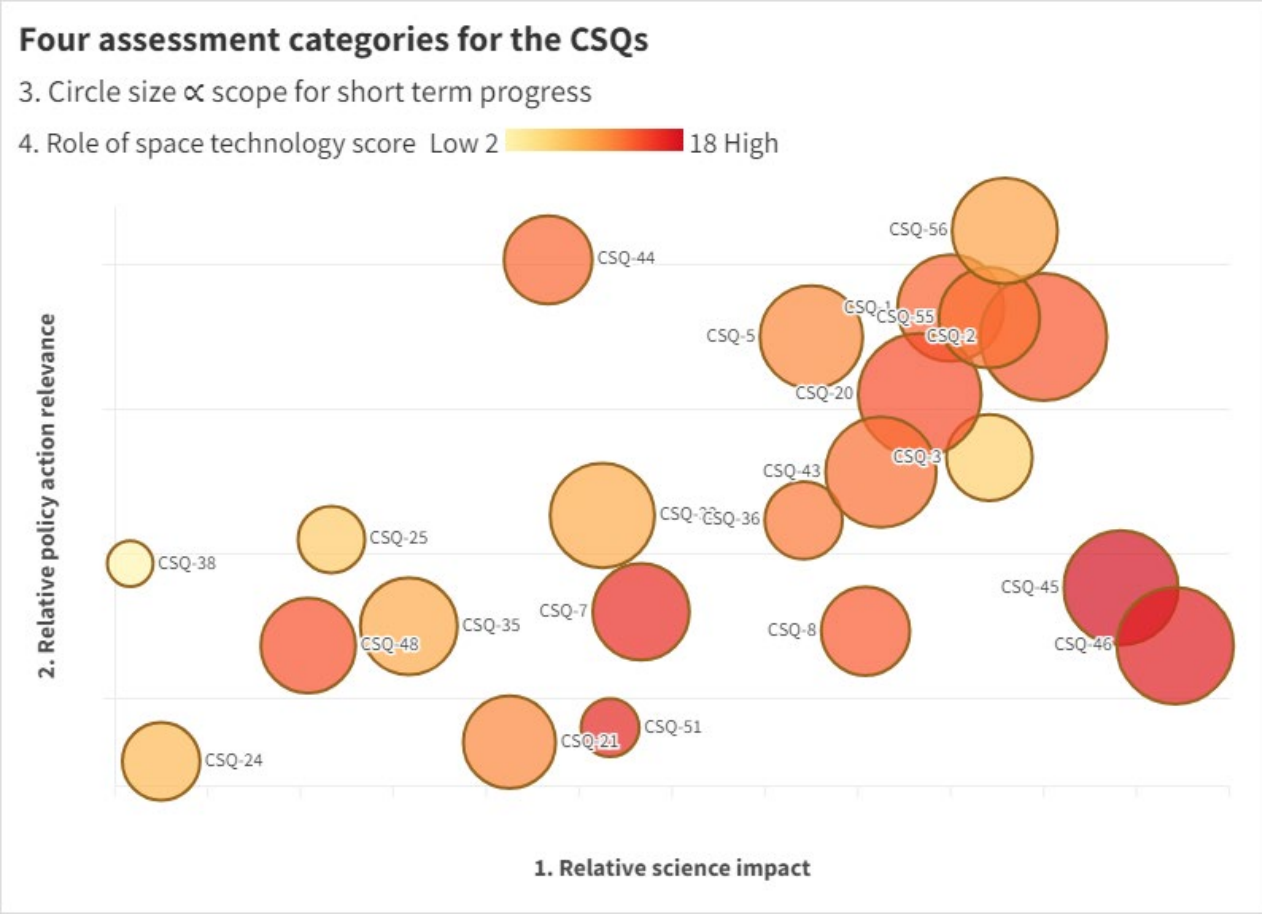
- Each CSQ was scored by the Science Team Leader and Chairs
- Scoring was rank-based in order to normalize between assessors, and to try and highlight differences between CSQs
- The initial scoring was universally high in several categories
- Therefore, for each assessor, the 22 CSQs were ranked in score order, then the top scored was given 22 points, the next 21 points etc..
- Then the ranks were averaged to give the final scores



Clustered results based on raw scores

4c| Overall Assessment

- The overall results of the assessment against the four categories are combined in the chart
- Recall that the scores are based on rankings, so are relative
- Reflects ranking of the study team



4c| Summary: Top 5 CSQs in each category

Frontier Science and discovery		**Reducing critical knowledge gaps**	
CSQ-02	Land biosphere response to CC	CSQ-02	Land biosphere response to CC
CSQ-03	Ocean carbon cycle responses to climate change	CSQ-20	Ice mass balance
CSQ-45	Internal energy flux estimates	CSQ-46	Earth energy imbalance
CSQ-46	Earth energy imbalance	CSQ-45	Internal energy flux estimates
CSQ-55	State of Land ecosystems	CSQ-43	Coupling between energy water and carbon cycles
From science to benefits		**Filling critical observation gaps**	
CSQ-01	Anthropogenic influences on the carbon cycle	CSQ-07	Coastal interfaces with land atmosphere and ocean
CSQ-56	Land ecosystem critical transitions	CSQ-20	Ice mass balance
CSQ-44	Anthropogenic influences on the water cycle	CSQ-45	Internal energy flux estimates
CSQ-55	State of Land ecosystems	CSQ-46	Earth energy imbalance
CSQ-05	Sea level change in the coastal ocean	CSQ-51	Lithosphere-atmosphere-ionosphere coupling

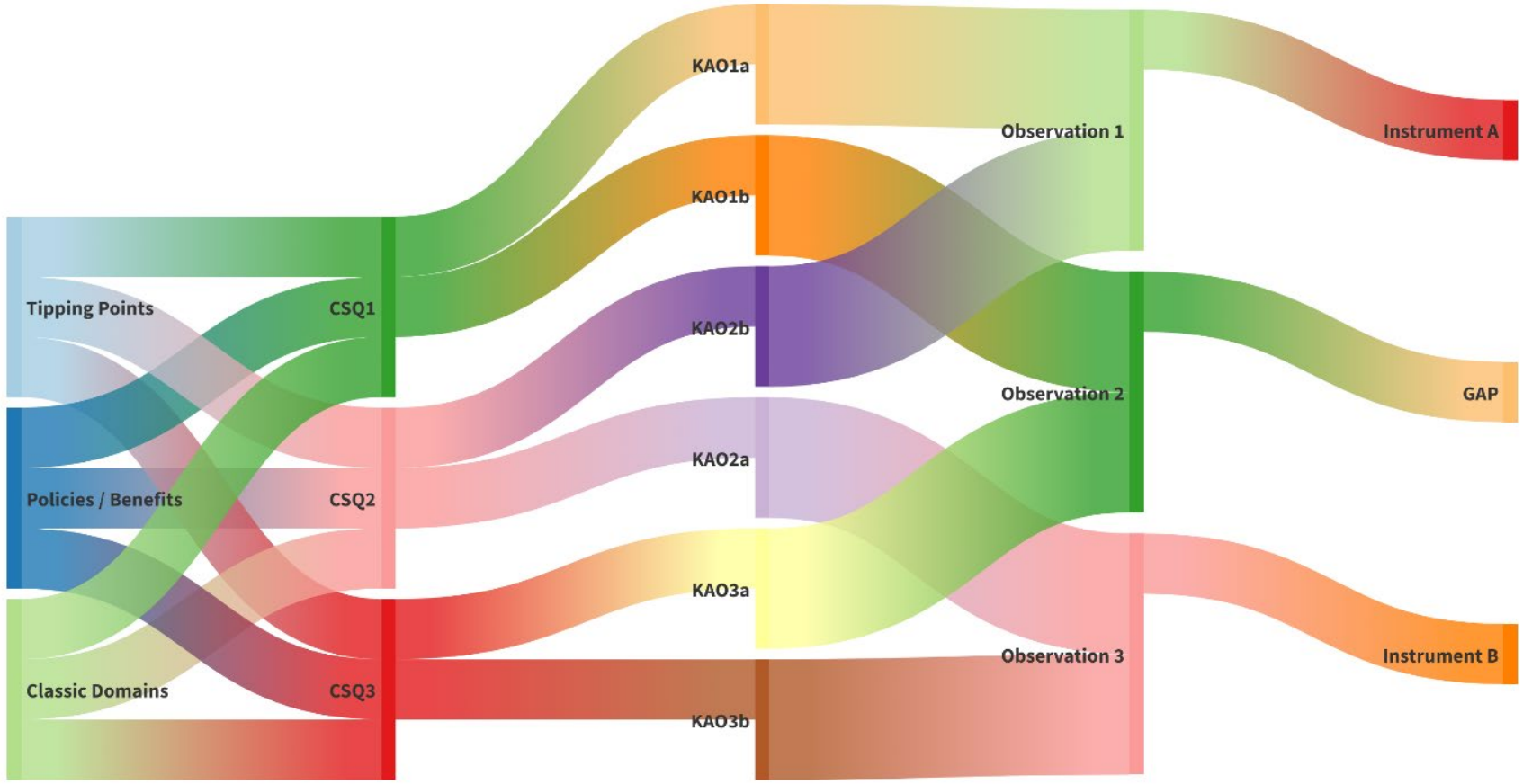
Atmosphere Land Ocean Solid earth Cryosphere

4 |Tracing CSQs to geophysical information needs and Earth Observation Missions

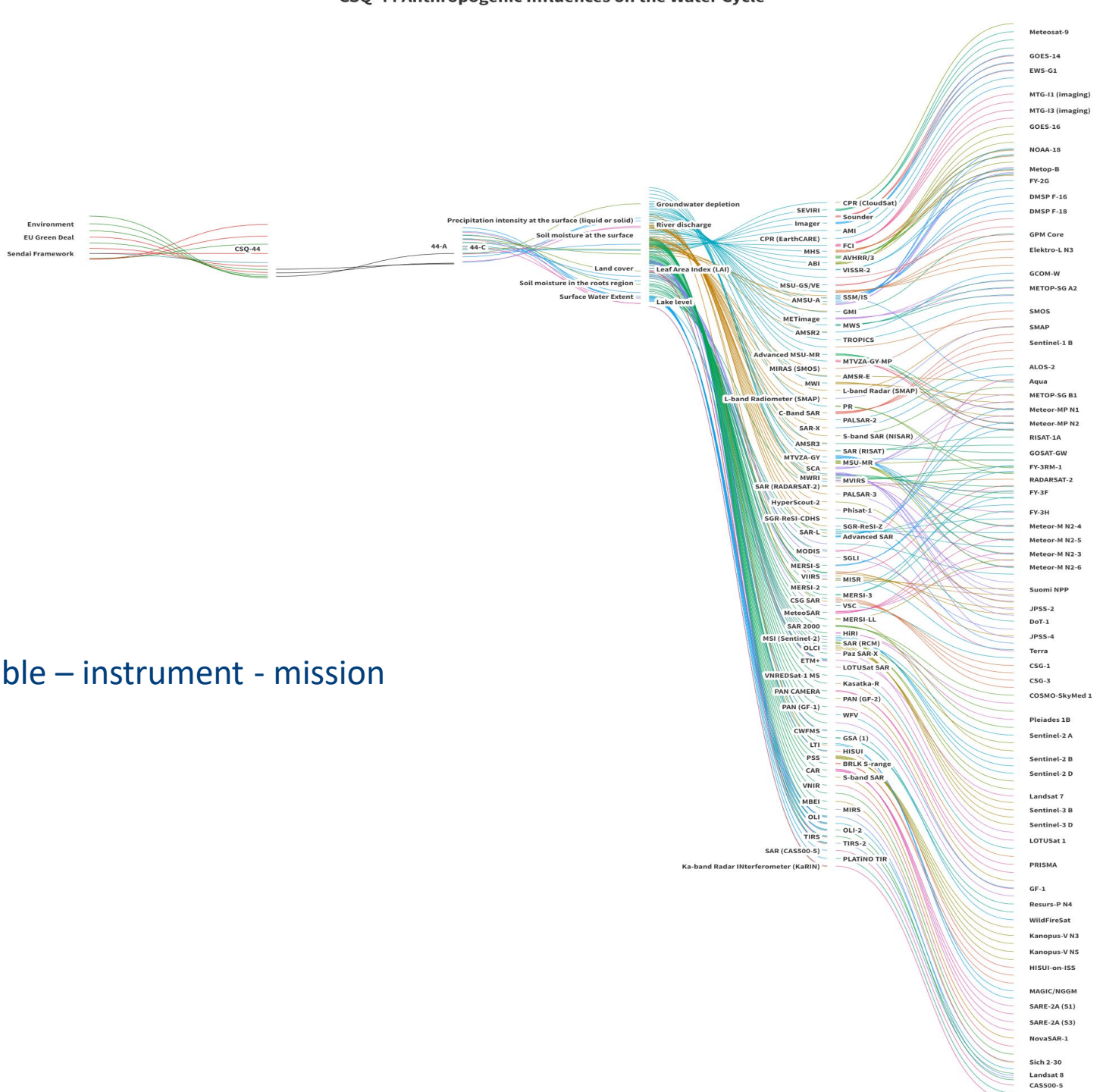
Database and visualization model

#	Element	Categories	Linked to
1	Benefits and Policies	7 grouped policy / benefit areas (see detail below)	CSQs
2	Domains	6 Classic Earth system domains from the previous ESA strategies: Atmosphere, Ocean, Land Surface, Cryosphere & Solid Earth	CSQs
3	Cross Cutting themes	Eg Tipping points, planetary boundaries etc.	CSQs
4	CSQs	Each of the 22 individual CSQs	Policies, Domains, Cross Cutting themes, KAOs
5	KAOs	Each of the 62 individual KAOs within a CSQ	CSQs, Observables
6	Geophysical Observables	Individual geophysical observable definitions, linked to CEOS or OSCAR database definitions. They are defined as “critical” or “supporting” and if no existing solution is available, may be mapped to “gaps”	KAOs, Instruments
7	Instruments	Specific satellite instruments	KAOs, Missions
8	Missions	Specific EO satellite missions	Instruments, Agencies
9	Agencies	Space agencies or commercial operators	Missions

Database and visualization model



Tracing examples CSQ-44



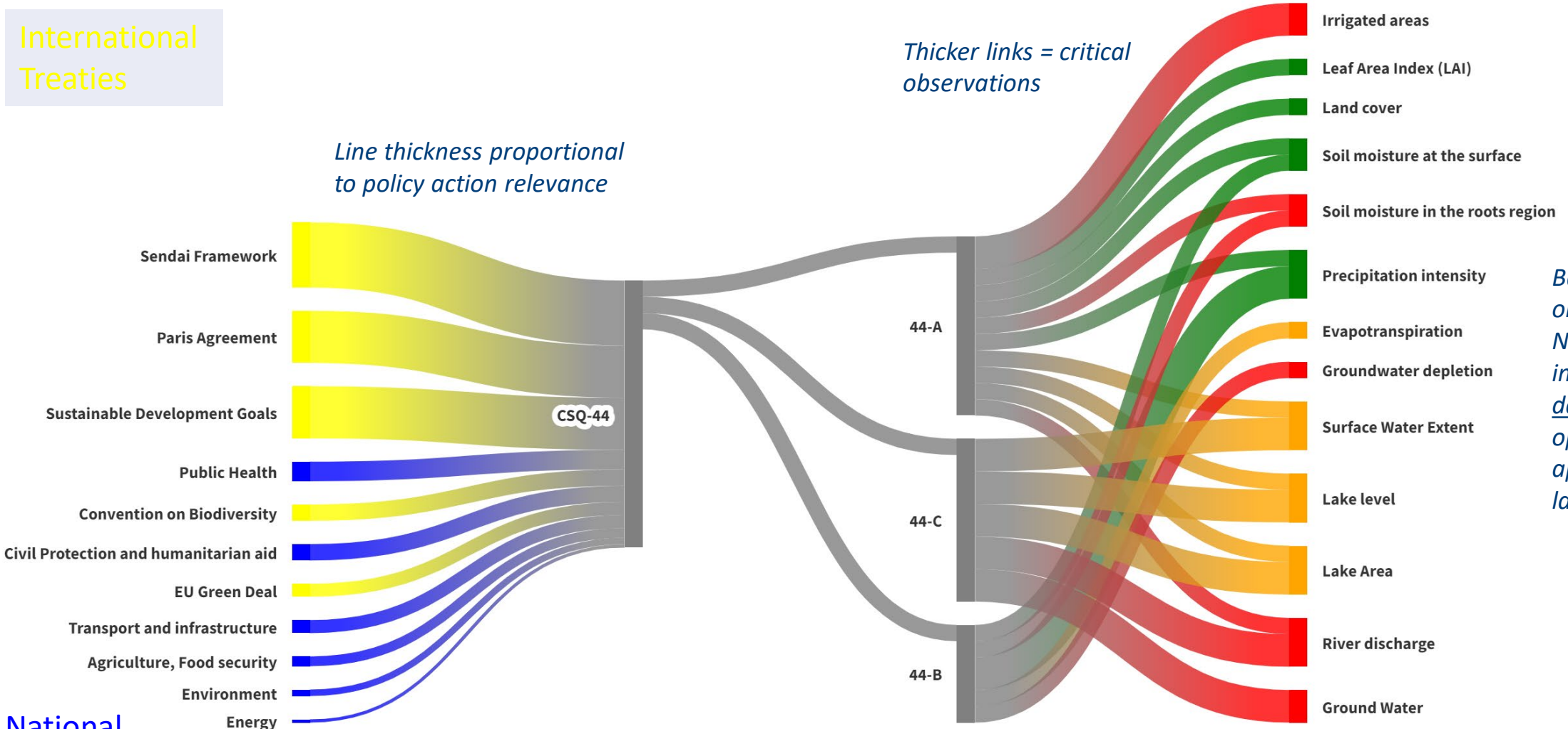
Policy/Treaty – CSQ – KAO – Observable – instrument - mission

Tracing examples – CSQ-44

International Treaties

Line thickness proportional to policy action relevance

Thicker links = critical observations



National Policies

Gap Status
Plentiful
Limited
Gaps

Based on availability, only, not quality. Number of instruments in the database that are operational or approved with EoL later than 2024

5 | Conclusions

5 |Conclusions

- 22 CSQs identify interesting science questions without reference to domain, technology etc and can be used to prioritise ESA programmatic actions
- Other CSQs (30+) identify programmatic and technical issues that could be addressed
  - Better sampling, possibly due to innovative orbits, repeat cycles, multiple platforms..
  - Better calibration and long-term stability of data
  - Better access to and security of long-term datasets

  These may not require major new scientific understanding, but can be used to identify further programmatic actions needed to support the community in addition to the invention of novel science/observations
- CSQs are based on geophysical science innovation that underpins wider utility and implementation in Earth Action. They provide the science basis on which services more closely relevant to society, for example in human health or food security, can be built.

5 |Conclusions

- Any selection of science priorities/questions will be difficult. We have attempted to adress this by the range of scientists involved, by the study methodology (mixed discipline groups) and by wider consultation.
- The 22 CSQs *slightly* smaller number than the previous 25 challenges. However, the use of additional features of the questions, i.e. policy relevance, timely action, relevance to satellite technology, further allow the prioritisation of a smaller number of topics according to priority programmatic considerations.

5| Summary

- The study has delivered 3 distinct outputs
  - The CSQs themselves, including the science justifications, linked to required observables and national and international policies
  - A database of current and planned satellite missions with linkages via observables to the science questions
  - A method, structure and process to formulate, refine characterize and assess Science Questions

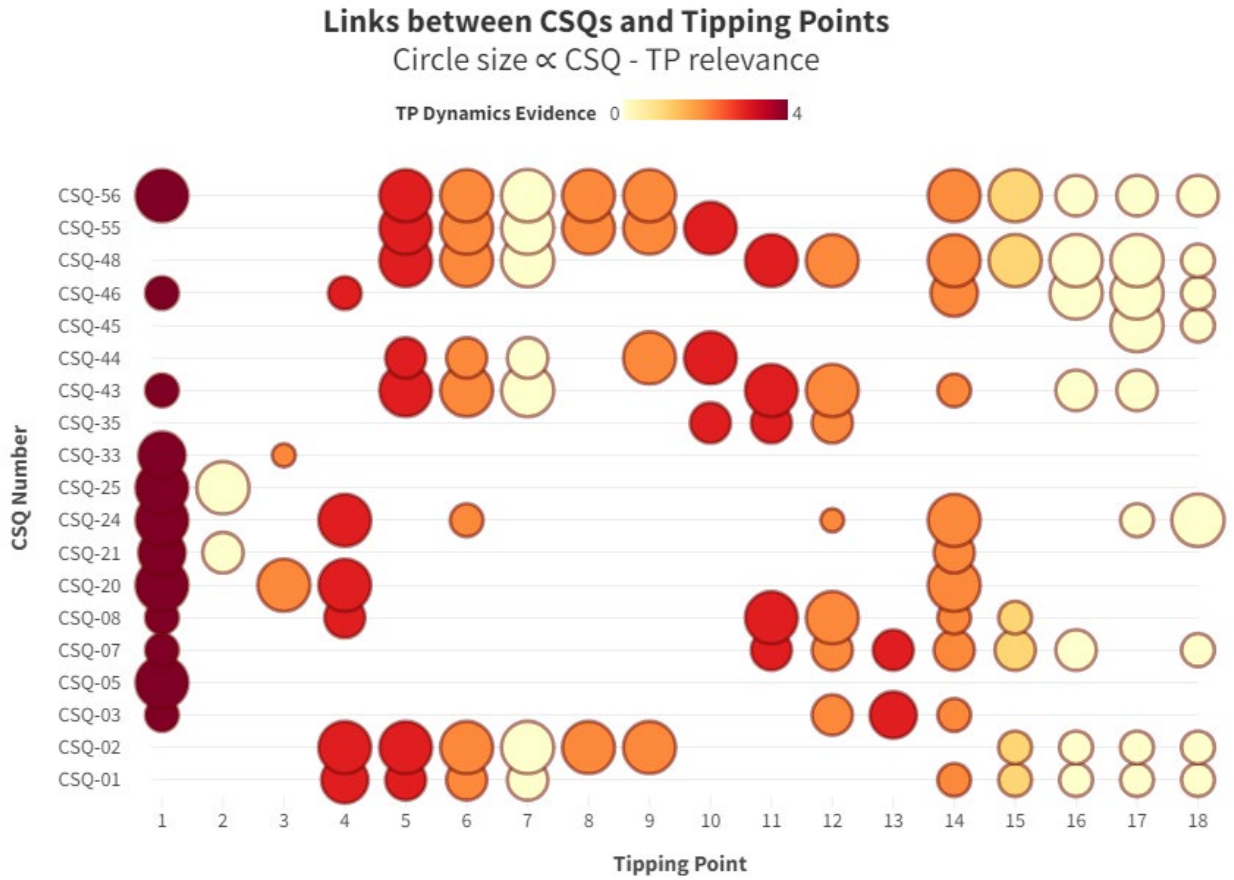
  - The method can be re-used to add further science questions in future, and adapted and re-used for future exercises, and to monitor the ongoing implementation of the strategy.

Additional Slides

Other cross-cutting themes

- With the data structure in place, we can display the relationship between the CSQs and a range of alternative concepts and themes
- Eg Tipping points based on the recent Global Tipping Points report (https://global-tipping-points.org/)
  - 18 Tipping points identified from the report
  - Can be linked to the CSQs where CSQ progress relates to refinement of information on tipping point nature or risk of occurring
- Technology cross cutting themes in the full set of 57 CSQs

CSQ-TP Assessment



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