

CONTINUITY OF NASA EARTH OBSERVATIONS FROM SPACE: A VALUE FRAMEWORK

Briefing to the National Academies Space Studies Board

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Background

- ESD faces difficult choices among competing priorities, including new responsibilities for investing in the continuation of existing measurements and developing new measurement capability to address new research priorities
 - A problem compounded by highly-constrained budgets and increased responsibility—to date without commensurate budget increases—starting after the JPSS-1 era for vertical profiles of stratospheric and upper tropospheric ozone (OMPS-L), solar irradiance (TSIS), Earth radiation budget measurements (RBI), and altimetry follow-ons beyond Jason-3 (AFO).
- In 2013, at the request of the ESD, an ad hoc committee of the Academies was convened with the task of providing a framework to assist in the determination of when an ESD measurement or dataset should be collected for extended periods

COMMITTEE ON A FRAMEWORK FOR ANALYZING THE NEEDS FOR CONTINUITY OF NASA-SUSTAINED REMOTE SENSING OBSERVATIONS OF THE EARTH FROM SPACE

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Assumptions for Study

- ESD is currently in a capped budget environment
 - Increasing demands for implementation of new measurements
 - Growing demand for continuing important measurements from current mission suite
 - Executive and Congressional Branch priorities
 - ESD Program Plans
 - Survey from NRC Decadal Survey
 - International Collaboration opportunities
- Response in charge is constrained to Climate Change focus
 - Most demanding requirements and likely largest set of actionable options
 - Include issues of instrument performance, stability, cross calibration and the data issues associated with algorithm change in processing and reprocessing
- Recommendation focus is on the measurements required to determine geophysical variables, not on instruments or missions
 - NRC Decadal Survey will provide prioritized QESO's and associated Geophysical variables
 - ESD will provide the instrument and mission response to the set of QESO's
- Emphasis placed on quantitative decision approaches
 - Framework is recommended, but implementation data base still needs development

What's In this Report

- In attempting to meet its Statement of Task the Committee presents a framework that
 - Focuses on science objectives, where space-based continuity measurements make substantial contributions
 - Relies on a small, but sufficient set of key continuity characteristics to effectively discriminate between competing climate change science-driven continuity measurements
 - Emphasizes quantitative evaluation methods to achieve process objectivity and transparency
 - Complements the existing NASA proposal evaluation processes for Research Announcements (NRA) and Earth Venture Announcements of Opportunity (AO)
 - Is extensible to decision-making between competing measurements for purposes other than climate change driven science and between sets of measurements focused on one science objective or single measurements capable of addressing multiple objectives

What's Not in this Report

- In considering the full breadth of ESD interests and the inherent difficulties in evaluating measurements for purposes other than climate change, science-driven continuity, the presented framework does not
 - Prescribe a single, fully defined method for evaluation of climate change, science-driven continuity measurements
 - Work through the details of, or examples for, new Science or Applications driven measurements
 - Summarize the total value of a single measurement relative to all science objectives of interest.

Definition of Continuity

Finding: Continuity of an Earth measurement exists when the quality of the measurement for a specific QESO is maintained over the required temporal and spatial domain set by the objective.

- Assessing the Quality characteristic of a particular measurement requires knowledge of the measurement's combined standard uncertainty, the instrument's calibration accuracy, the stability of that calibration over time, and the consequences of data gaps on the relevant QESO. After applying this framework to measurements collected by current missions, it became clear that the relative Value of a measurement is closely linked to its Quality.

The Basic Framework Building Blocks – Quantified Earth Science Objectives (QESOs)

- The notion of a quantified Earth science objective (QESO) is the starting point for the recommended decision framework.
- A well-formulated QESO would be directly relevant to achieving an overarching science goal of the ESD and allow for an analytical assessment of how the quantified objective would help meet that science goal.
- Proposed space-based continuity measurements should be evaluated in the context of the QESO they address. The resolution, uncertainty, and repeatability of candidate measurements should all be taken into account when deciding whether a QESO is achievable.
 - An example of a QESO could be: “Determine the rate of global mean sea level rise to $\pm 1 \text{ mm yr}^{-1} \text{ decade}^{-1}(1\sigma)$ ”.
- To establish a small set of QESOs, ESD could turn to the same sources that inform the development of its program plan, notably the scientific community consensus priorities expressed in decadal surveys along with guidance from the Executive and Congressional branches. The decadal survey process, which also confronts the same problem of allocating finite resources, might also benefit from expressing priorities through QESOs.

The Basic Framework Building Blocks – Measurement Characteristics and Value

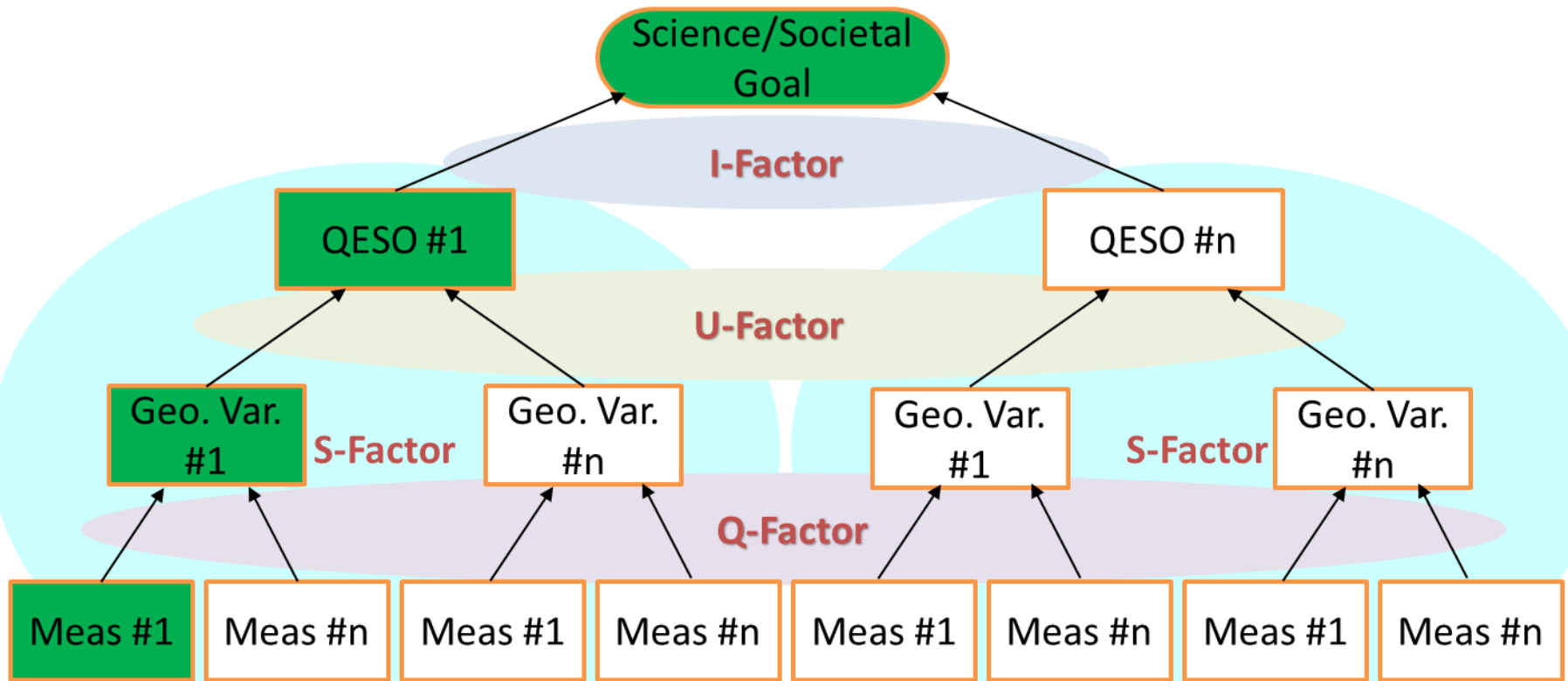
- Just as economic cost benefit analysis attempts to summarize the value of funding for a particular project or endeavor, the committee found that a value-centered framework is capable of effectively distinguishing among competing Earth measurements relevant to a QESO(s). We identify five key characteristics that define the value of a measurement proposed in pursuit of a QESO: Importance (I), Utility (U), Quality (Q), Success Probability (S), and Affordability (A)
- The committee takes Value (V) to be the product of Benefit (B) and Affordability (A); it found a useful expression of B to be an unweighted product of the factors I, U, Q, and S. Thus:

$$V^* = B \times A = (I \times U \times Q \times S) \times A$$

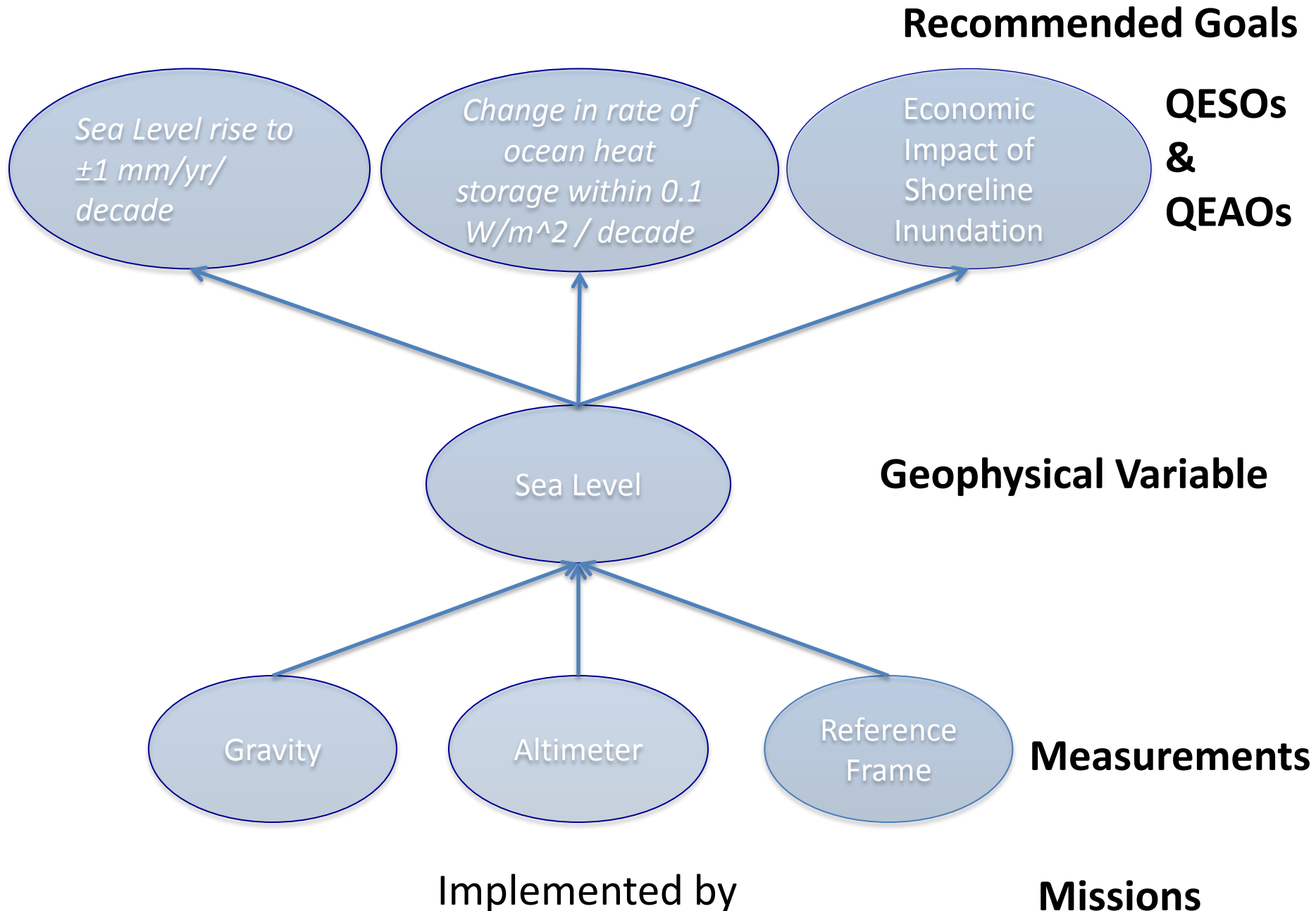
- Successful implementation of this approach requires determining the relative weights of the Benefit and Affordability terms and defining the ratings scales of the individual benefit terms in a way that maintains the relative B and A weights. A self-consistent method is to first assign ratings scales (e.g. 1 to 5) to the Importance and Affordability terms that reflect the desired relative weights for B and A, and, second, to define the Utility, Quality, and Success Probability rating scales in terms of percentages.

** These factors are not statistically independent (e.g., changes in A can affect S). Additional cross-cutting factors impact both benefit and affordability; methods to treat them appropriately within the framework are discussed in the report. (Examples of cross-cutting factors include the ability to leverage other measurement opportunities in pursuit of the science objective, and the resilience of a geophysical variable record to unexpected degradation (or gaps) in the measurement quality.)*

Relating Measurement Characteristics to Value



An Example of the Process



Evaluation Factor	Value Range	Description
Importance (I)	1 – 5	Importance indicates the documented community priorities for science goals and QESOs. It represents the maximum potential benefit of a given measurement.
Utility (U)	0 – 1	Utility includes consideration of all of the key geophysical variables, and their relative contributions for addressing a QESO. It represents the percentage of a QESO that would be achieved by obtaining the targeted geophysical variable record.
Quality (Q)	0 – 1	Quality includes consideration of its uncertainty, repeatability, time and space sampling, and data algorithm characteristics relative to that required for achieving a QESO. It represents the percentage of the required geophysical variable record that would be obtained by the proposed measurement.
Success Probability (S)	0 – 1	Success Probability includes consideration of the heritage and maturity of the proposed instrument and its associated data algorithms, the likelihood of leveraging similar or complementary measurements, and the likelihood of data gaps that would adversely affect the quality of the measurement. It represents the probability that the proposed measurement would be successfully achieved.
Affordability (A)	1 – 5	Affordability of a proposed continuity measurement includes consideration of the total cost of developing, producing, and maintaining the sought-after data record.

Implementing the Framework: Suggested Steps

1. Decide on the approach to, and cadence for, collecting input to apply the continuity framework
2. Finalize and document detailed evaluation criteria definitions and scoring approach
3. Develop appropriate tools for quantitative (or semi-quantitative) evaluation of measurement utility (OSSEs), quality (analytics for measurement uncertainty), success probability (satellite and mission lifetime probability analysis) and affordability (CATEs)
4. Begin development of approach to QEAOs, and QESOs for new exploratory measurements

Back-Up

Guidelines for Continuity Measurement Framework Input-I

1. **Identify the QESO(s) the measurement under consideration addresses**
2. **Describe the *Importance* of the QESO to a high priority, societally-relevant science goal**
 - Description should be short, referenced, but understandable to a broader audience.
 - Provide a perspective on how the QESO fits within the broader scientific issues of understanding global change.
 - Provide a perspective on how the QESO benefits society, beyond the science.
3. **Explain the *Utility* of the measured geophysical variable(s) to achieving the QESO**
 - Explanation of the geophysical variables to be provided by the mission / measurement(s).
 - Description of the utility of these variables in terms of the relative fraction* they contribute to answering the QESO.
 - A list of auxiliary data required to deliver the proposed measurement(s), but not part of the proposed mission, delineated by program and instrument.

* The committee notes that its evaluation methods for the Importance and Utility characteristics are subjective; however, it recommends (see chapter 3) that the sum of the utility of all observations needed by the QESO be equal to 1.0. This allows the framework to account for some observations being more important than others, while avoiding a “check the box” process that just counts the number of observation sources without consideration of relative importance. It also normalizes the utility of all QESOs to the same numerical scale, thereby allowing an “apples-to-apples” comparison. The report also shows a path toward future more rigorous and objective analysis of Utility using a Bayesian framework.

Guidelines for Continuity Measurement Framework Input – II

4. **Detail the *Quality* of the measurement relative to that needed for the QESO**
 - Assess the quality of the proposed measurement against the requirements of the QESO.
 - Includes, *inter alia*, calibration uncertainty, repeatability, time and space sampling, algorithms, reprocessing of the complete data stream, availability of all data products.
 - Assess the ability to satisfy QESO both with and without proposed observation(s).
5. **Discuss the *Success Probability* of achieving the measurement**
 - Provide an assessment of the heritage and maturity of proposed instruments and data algorithms
 - Assess the likelihood of leveraging similar or complementary non-NASA measurements
 - Provide a quantitative analysis of the risk of a gap in the measurement, and the effect of that gap on quality of the long-term record and the ability to remain useful in meeting the QESO.
6. **Provide an estimate of the Affordability of the measurement**
 - Estimate the total cost of the proposed observation(s)
 - Include the expected years of record on orbit at reasonable levels (e.g. 85%) of reliability
 - Include additional costs to mitigate unacceptable risks of measurement gaps

Measurement Evaluation – Ice Sheet Mass Balance Example

QESO	Relevant Geophysical Variables	Example Instrument Data Types
<p>Ice Sheet Mass Balance Change</p> <p><i>(Determine changes in ice sheet mass balance within 15 Gt/yr per decade or 1.5 Gt/yr²)</i></p>	<ul style="list-style-type: none"> • Ice Sheet Mass • Ice Sheet Elevation • Ice Sheet Velocity • Ice Sheet Base Topography • Ocean Temperature Profile near Ice Sheet Edge 	<ul style="list-style-type: none"> • Surface Interferometry • Radar and laser altimetry, supplemented by SAR, Broadband radiances • Gravity Change Measurements • Spectrally-resolved solar irradiances VIS/IR radiances, VIS/IR imager radiances

Measurements/Missions to Compare

- 1) ICESAT-2, OIB
- 2) GRACE-FO
- 3) NISAR

Example Measurement Value Comparison

Measurement	I	U*	Q	S	B	Scoring Rationale
ICESat-2, OIB (Altimetry series)	5	1	0.6	0.8	2.4	Established performance less than 1.5 cm/yr objective. Laser longevity uncertain
GRACE-FO (Gravity series)	5	1	0.9	1.0	4.5	Established performance meets objective for most regions. Long-term instrument performance well established.
NISAR (SAR series)	5	1	0.9	0.8	3.6	Established performance from previous SAR missions for most regions of interest. Interferometric instrument performance uncertain.

*Given the complementarity of the three geophysical variables for achieving the quantified objective, each variable is given the same utility score in this example.