CONTINUITY OF NASA EARTH OBSERVATIONS FROM SPACE: A VALUE FRAMEWORK

Presentation to the National Academies' Committee on Solar and Space Physics

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Chair of National Academies' Ad Hoc Study Committee

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A Framework for Analyzing the Needs for NASA-Sustained Remote Sensing Observations of the Earth: Background in 2013

NASA's Earth Science Division (ESD) faces difficult choices among competing priorities, including new responsibilities*, without commensurate budget increases*, for the *continuation of existing measurements* and *developing new measurement* capability to address new research priorities

The problem is compounded by responsibility for existing missions from:

- *Foundational Continuity Measurements*: Stratospheric and Upper Tropospheric Ozone (OMPS-L), Solar Irradiance (TSIS), Earth Radiation Budget (CERES), and Ocean Altimetry (Jason-3 FO)
- *2010 Climate Architecture*: Global Temporal Mass Change(GRACE –FO, Polar Ice Mass Change(ICESat-2), Ocean Color and Clouds/Aerosols (PACE), Ozone and Aerosols(SAGE III) and Atmospheric CO_2(OCO-2)
- *Federal Concerns:* Landsat Data Continuity (Landsat-8 FO)
- *Suite of EOS Instrument Measurements*: TERRA, AQUI, AURA, ICESat

Response and Committee Charge

In 2013, at the request of ESD, an ad hoc committee of the National Research Council (NRC) was charged with the task of providing a framework to assist in the determination of when a measurement(s) or data set(s), initiated by ESD, should be collected for extended periods.

In considering the expected constrained budgets for the NASA Earth Science program, the committee was asked to:

1. Provide working *definitions of*, and describe the *roles for*, "*continuity*" of the measurements and data sets ESD initiates and uses to accomplish Earth system science objectives; and

2. *Establish methodologies and/or metrics* that NASA can use *to inform strategic programmatic decisions* regarding the scope and design of its observation and processing systems.

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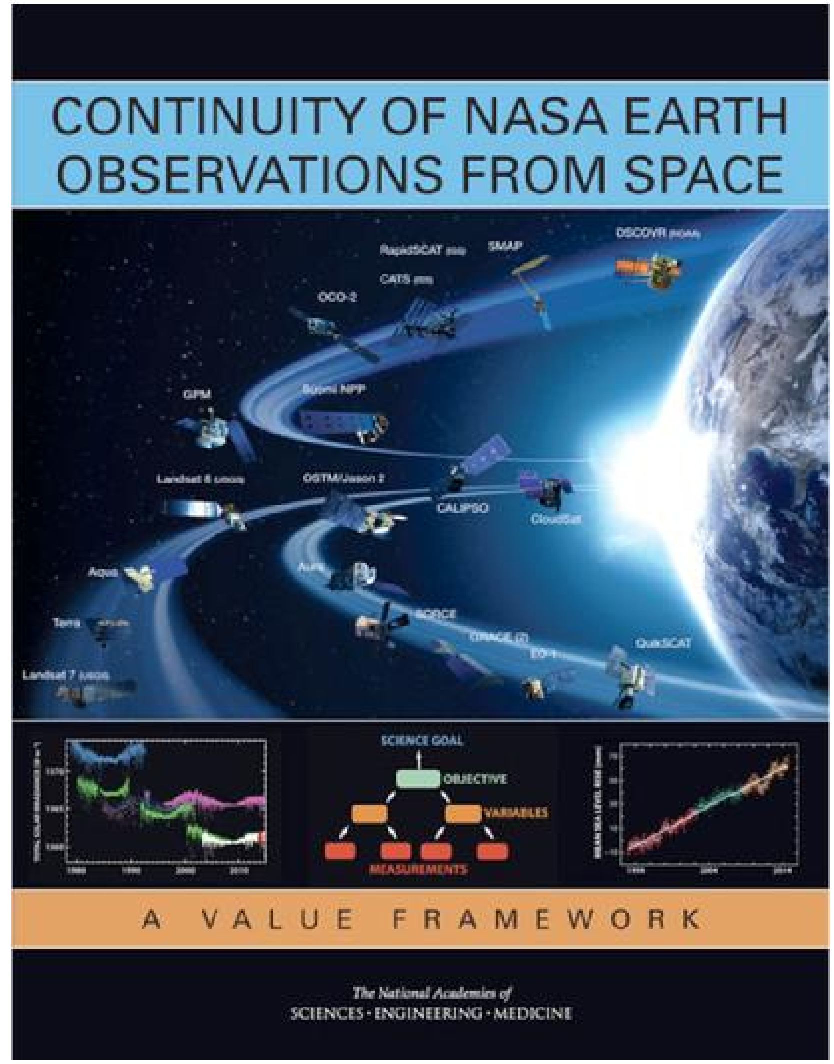


http://www.nap.edu/catalog/21789/continuity-of-nasa-earth-observations-from-space-a-value-framework

* Represents members of CESAS, the oversight committee for the decadal survey

What's In the 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

Study Assumptions

ESD will remain 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

Study response is constrained to *Climate Change focus*

- Involves 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 science objectives and associated Geophysical variables
- ESD will provide the instrument and mission response to the set of Geophysical Variables

Emphasis placed on *quantitative decision approaches*

- Framework is recommended, but implementation data base still needs development

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.

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

The committee found that *a value-centered framework is capable of 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.)*

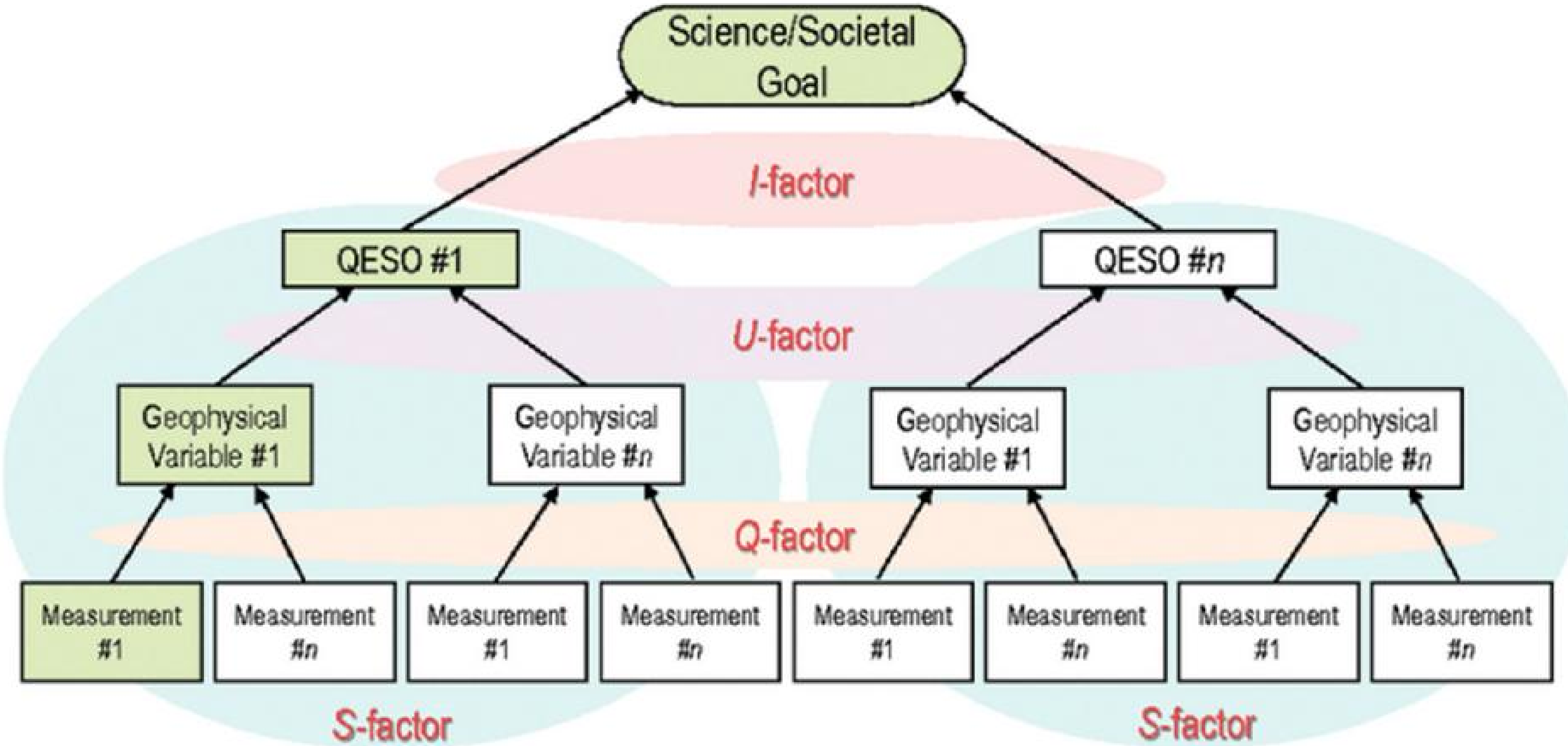
Evaluation Factor	Value Range	Description
Importance (I)	1 – 5	Importance indicates the documented community priorities for science goals and QESOs. It represents the maximum potential benefit of a given measurement.
Utility (U)	0 – 1	Utility includes consideration of all of the key geophysical variables, 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.

EXAMPLE QUANTIFIED EARTH SCIENCE OBJECTIVES

Example Quantified Science Objectives for ESS continuity measurements:

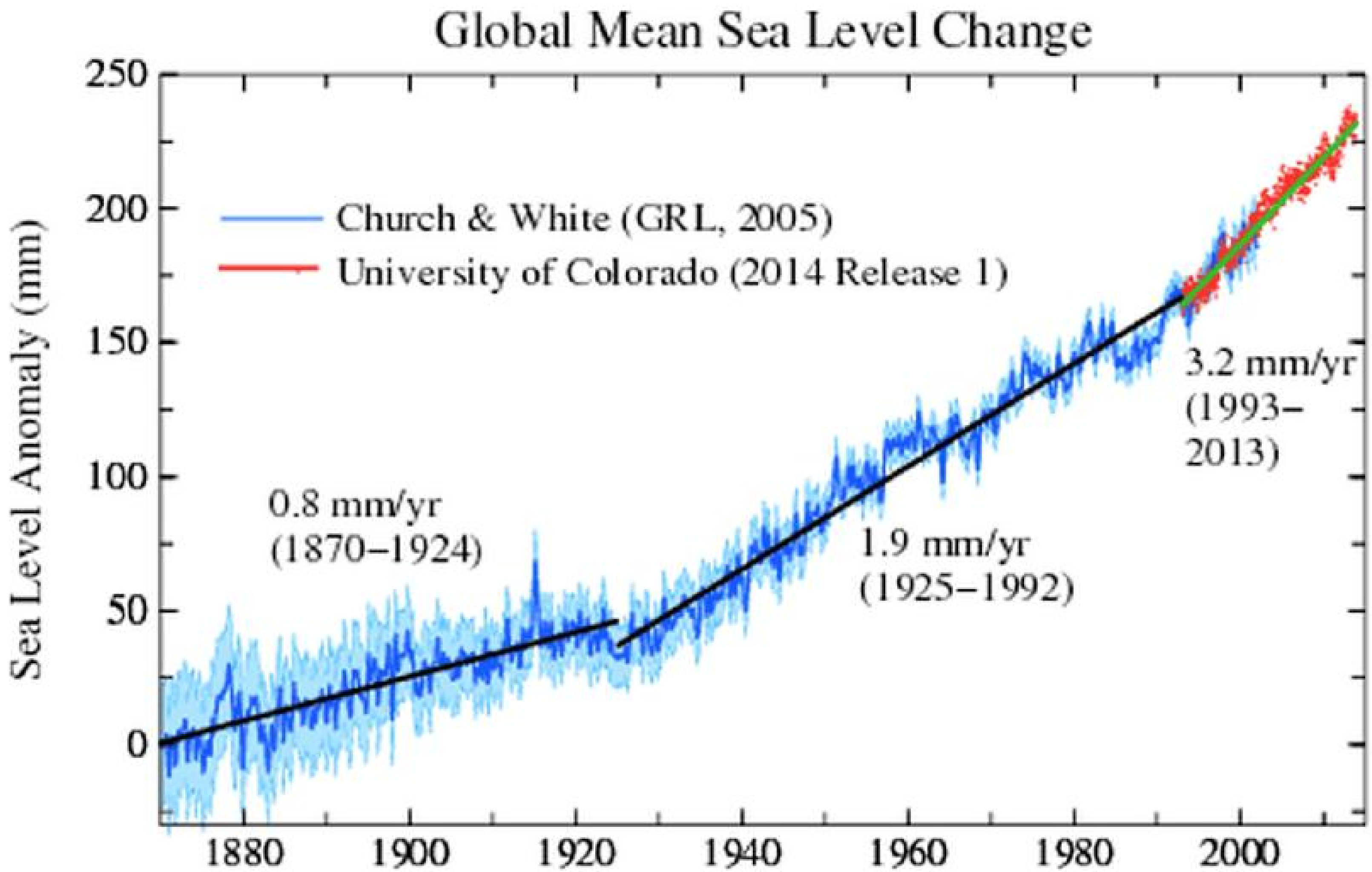
- *Narrow the Intergovernmental Panel on Climate Change Fifth Assessment (IPCC AR5) uncertainty in equilibrium climate sensitivity (ECS) (1.5 to 6°C at 90% confidence) by a factor of 2.*
- *Detect decadal change in the effective climate radiative forcing (ERF) to better than 0.05 W m-2 (1σ).*
- *Determine the rate of global mean sea level rise to ±1 mm per year per decade(1σ).*
- *Identify the land carbon sink and quantify this globally to ±1.0 Pg C per year aggregating from the 1° × 1° scale.*
- *Determine the change in ocean heat storage within 0.1 W m-2 per decade (1σ).*
- *Determine changes in ice sheet mass balance within 15 Gt/yr per decade or 1.5 Gt/yr2 (1σ).*

Relating Measurement Characteristics to Value

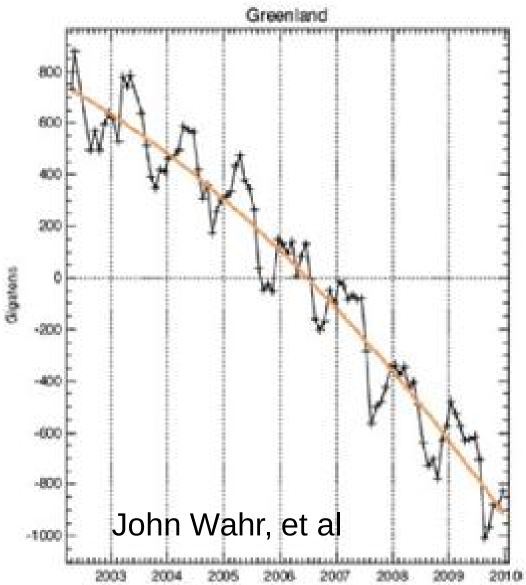


$$V^* = B \times A = (I \times U \times Q \times S) \times A$$

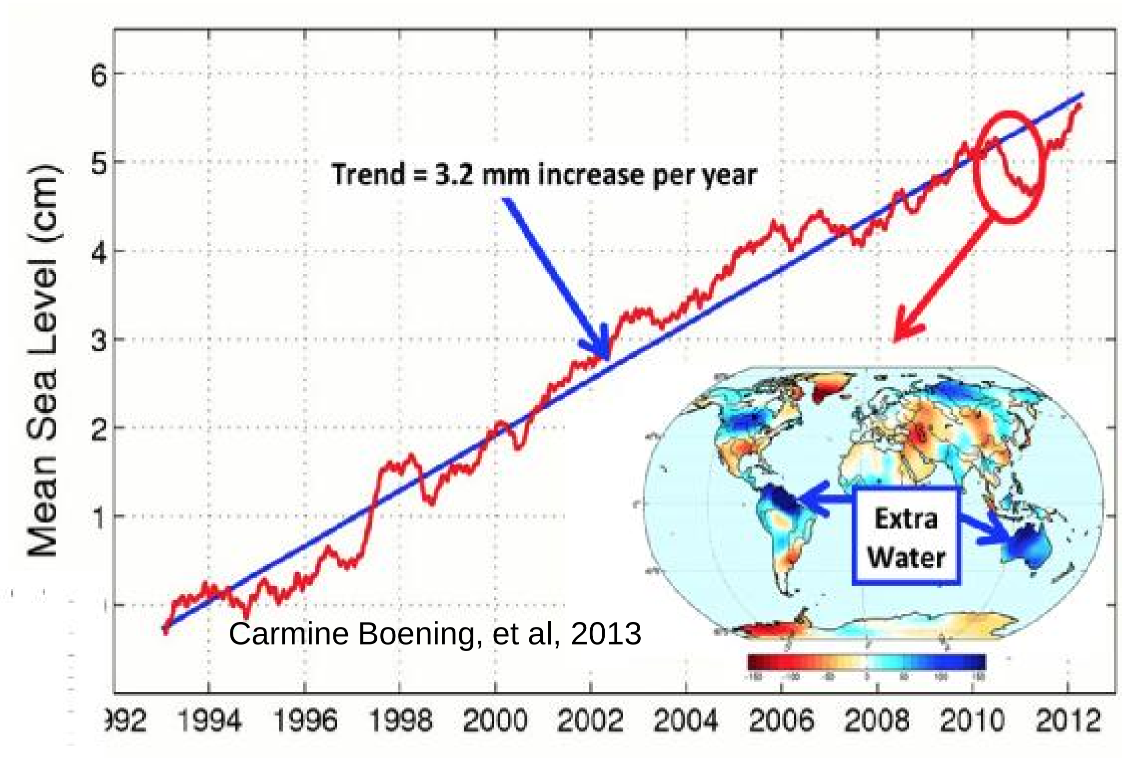
NOAA JASON-3 Satellite


Global Mean Sea Level Change
Sea Level Anomaly (mm)
250
200
150
100
50
0
1880
1900
1920
1940
1960
1980
2000
Church & White (GRL, 2005)
University of Colorado (2014 Release 1)
0.8 mm/yr
(1870–1924)
1.9 mm/yr
(1925–1992)
3.2 mm/yr
(1993–
2013)

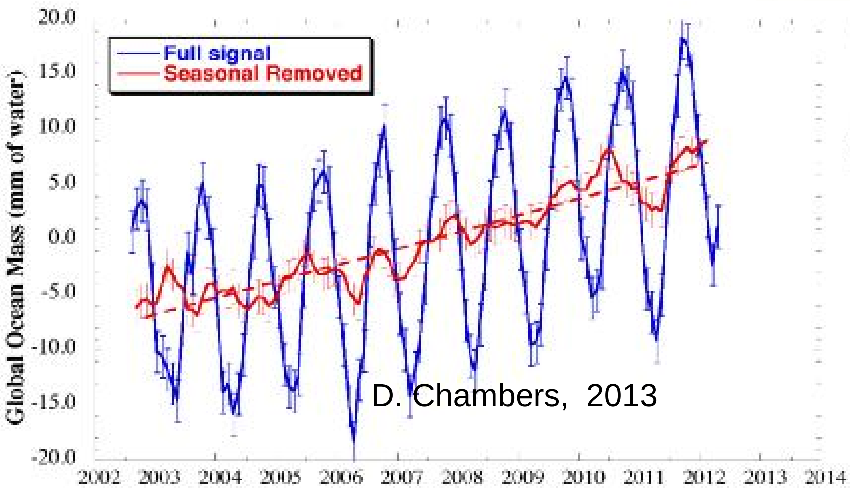
Global Sea Level Change



John Wahr, et al



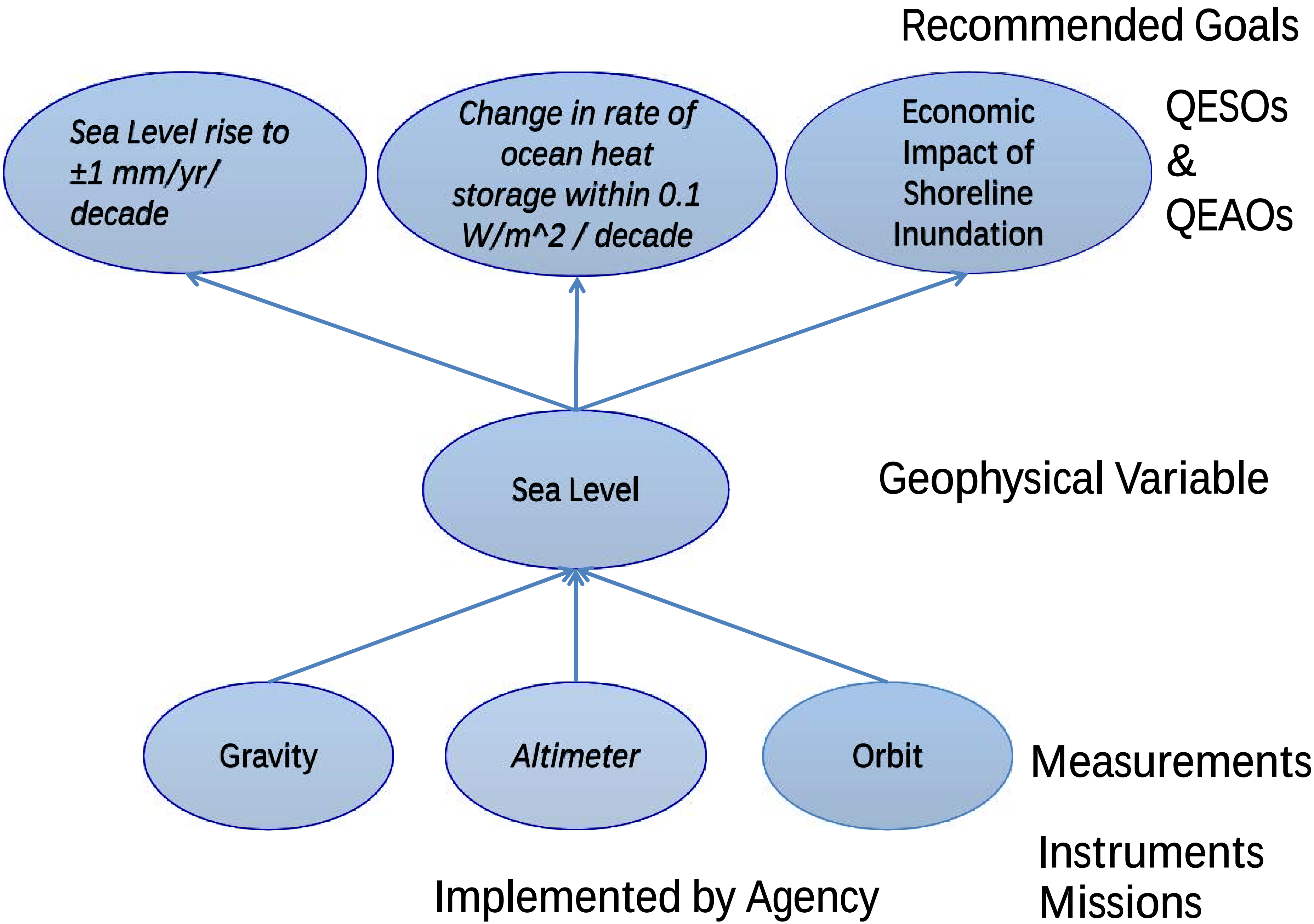
Carmine Boening, et al, 2013



D. Chambers, 2013

Error bars are 1 standard error.

An Example of the Process



Recommendations and Findings-I

There are many inherent challenges in moving from subjective to quantitative evaluations, which is why the report uses a hybrid approach that combines subjective ratings for Importance, semi-analytical ratings for Utility and Success Probability, and analytical ratings for Quality and Affordability.

These metrics establish a transparent way to rate different measurement characteristics; as noted in previous slide, they are not statistically independent.

Should NASA use this framework, it would be essential to develop a consistent procedure for assigning a numerical value to each factor and for combining these factors to calculate the overall Value (V).

Recommendation: NASA should establish a value-based decision approach that includes clear evaluation methods for the recommended framework characteristics and well-defined summary methods leading to value assessment.

Recommendations and Findings-II

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.

Recommendations and Findings-III

Evaluation of a measurement's affordability and benefit characteristics for decision-making purposes can likely be accomplished through a number of equally valid methods. Regardless of the evaluation methods that NASA and the community adopt, the application of those methods should make consistent use of well-documented and understood tools and studies, as highlighted in the following recommendations.

Recommendation: NASA should foster a consistent methodology to evaluate the utility of geophysical variables for achieving quantified Earth science objectives. The committee notes that such a methodology could also be utilized by the Earth Science Decadal Survey in its priority recommendations.

Recommendation: NASA should extend their current mission cost tools to address continuity measurement-related costs needed for the decision-framework.

Recommendations and Findings-IV

The ability of ESD officials to make informed decisions requires unbiased and consistent information on benefits and affordability that is re-evaluated regularly and presented on a time frame appropriate for NASA planning. The committee advises that inputs to these evaluations be derived from sources including submitted proposals as well as face-to-face interactions with measurement advocates.

Recommendation: NASA ESD should establish a regular process for critical evaluation and modification of QESOs and QEAOs and their associated measurements. The committee suggests creating an analog to the Senior Review of current satellite operations, which uses senior researchers from a range of communities and results in consistent recommendations to the ESD Director.

Recommendations and Findings-V

In addition to research, Earth observations and their derived information products support numerous user communities both inside and outside federal agencies. Extending this decision framework to measurements focused on societal-benefit applications is desirable but will require expertise outside of the Earth science community to formulate quantitative Earth application objectives (QEAOs) that are analogous to QESOs.

Recommendation: NASA should initiate studies to identify and assess quantified Earth application objectives (QEAOs) related to high-priority, societal-benefit areas.

Continuity Implementation Questions

- What are the quantifiable science objectives that are important and amenable to study with the synergy of the various existing measurements and models?
- What are the needs for, and definitions of, continuity with respect to each measurement and with respect to understanding global change?
- What are the temporal, spatial, and accuracy requirements for such measurements, whether they be current or proposed?
- Are there alternate approaches to meeting the measurement requirements with acceptable performance and/or reduced costs?

Backup Slides

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.

QESO for ICE Sheet Mass Change

- *Determine changes in ice sheet mass balance within 15 Gt/yr per decade or 1.5 Gt/yr2 (1σ)*.
  - Ice sheets are losing mass at an accelerating rate of 300 Gt/yr per decade, or 30 Gt/yr2. Detecting changes at the 5 percent level is essential for understanding the interactions of ice sheets and climate at the regional level and for improving projections from numerical models.

Measurement Evaluation – Ice Sheet Mass Balance Example

QESO	**Relevant Geophysical Variables**	**Example Instrument Data Types**
Ice Sheet Mass Balance Change *(Determine changes in ice sheet mass balance within 15 Gt/yr per decade or 1.5 Gt/yr^2)*	• Ice Sheet Mass • Ice Sheet Elevation • Ice Sheet Velocity • Ice Sheet Base Topography • Ocean Temperature Profile near Ice Sheet Edge	• 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

<u>Measurements/Missions to Compare</u>

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

Example ICE Sheet Mass Change

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.

A Note about Measurement Gap Risk

Early in its discussions, the committee included "Gap Risk" as an independent characteristic in the Value framework. It rapidly became clear, however, that Gap Risk affects many of the other characteristics in the Value framework, and thus should be addressed as part of those factors.

- *First*, the occurrence of a gap can increase the uncertainty and decrease the repeatability and therefore affects the *Quality* characteristic for that record. The primary effect on *Quality* arises from discontinuities in a long-term geophysical variable record without sufficient absolute calibration uncertainty of the measurement. Another *Quality* impact can occur if there are time-space gaps that do not capture abrupt changes (e.g., volcanic eruption) or sufficiently average over internal natural variability (such as ENSO).
- *Second*, the statistical likelihood of a data gap depends on instrument and spacecraft reliability design (e.g., 3 yr., 5 yr., 7 yr.), launch schedules, as well as existing instruments and their age in orbit. All of these factors in the observing system design will affect the *Success Probability* of achieving a geophysical variable record of desired *Quality*.
- *Third,* the strategy to avoid gaps will involve instrument and spacecraft reliability and launch schedules. These factors will then drive cost and the associated *Affordability* factor.

For these reasons, a careful gap risk analysis is required as part of the Value analysis, but gap risk must be considered in 3 of the characteristics (Quality, Success, and Affordability) and cannot be treated as a single factor.