

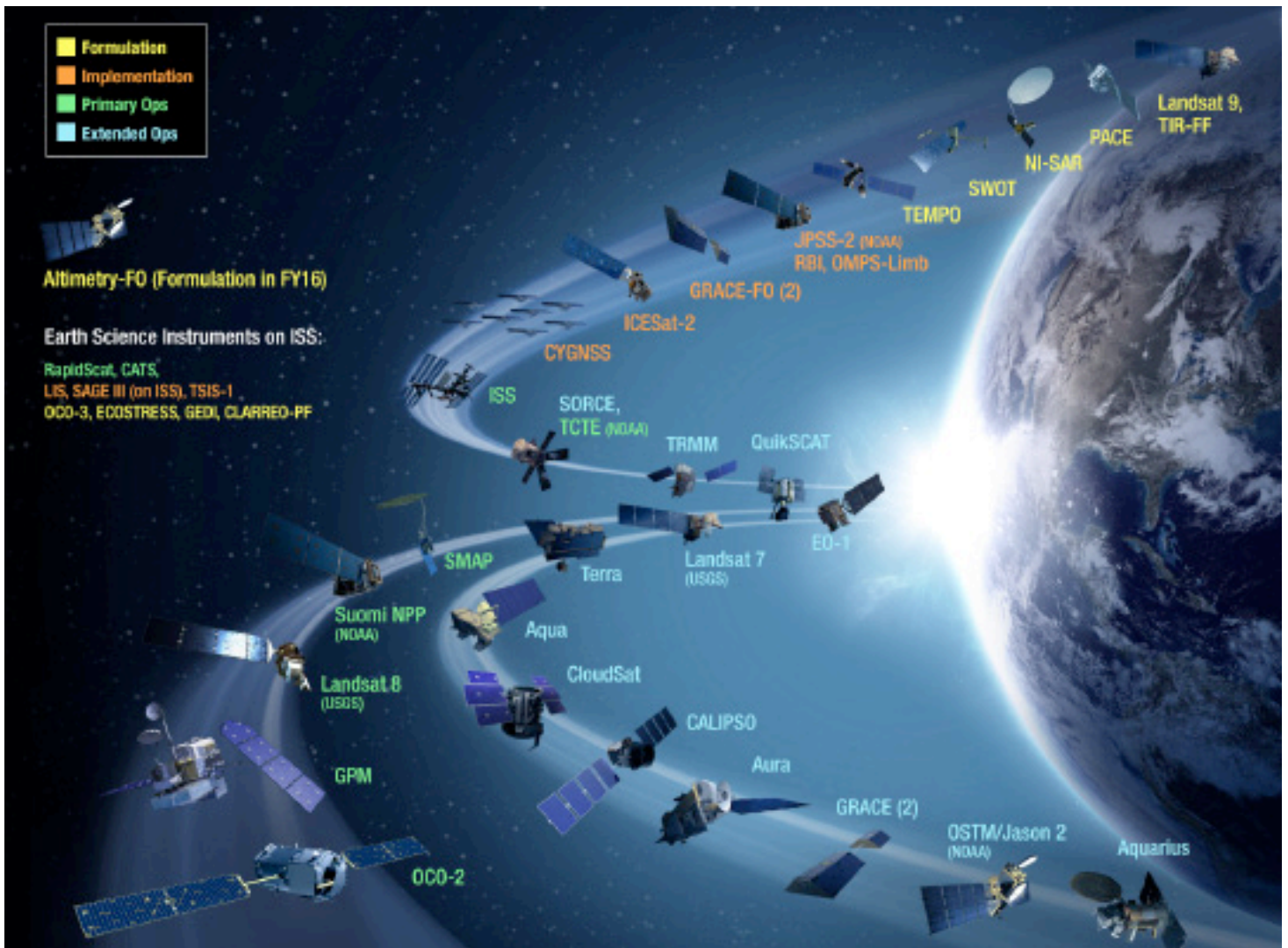
## Continuity of NASA Earth Observations from Space: A Value Framework

In a highly constrained budgetary environment, NASA, like all federal agencies, is faced with difficult choices among competing priorities for investment. Within the Earth Science Division (ESD), part of NASA's Science Mission Directorate, these choices include whether to invest in the continuation of one existing data stream over another, or to develop a new measurement capability sought by the research community. 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. *Continuity of NASA Earth Observations from Space: A Value Framework*, the resulting study by the National Academies of Sciences, Engineering, and Medicine, establishes methodologies and metrics that NASA can use to inform strategic programmatic decisions by prioritizing measurements based on their scientific value. The report identifies key evaluation factors and puts forward a decision-making framework that quantifies the need for measurement continuity and the consequences of measurement gaps for achieving long-term science goals.

### BACKGROUND

NASA's Earth Science Division (ESD) conducts a wide range of satellite and sub-orbital missions in order to better understand Earth as an integrated system. Earth observations provide the foundation for critical scientific advances and data products derived from these observations are used for an extraordinary range of societal applications including resource management, weather forecasts, climate projections, agricultural production, and natural disaster response. While applications such as numerical weather forecasting require almost real-time data availability, applications related to climate change science objectives typically require accurate, stable measurements that are sustained over long periods of time. ESD develops its observing strategy in response to Congressional and Executive Branch direction and through consultation with the scientific community. In particular, the consensus views of the scientific community as expressed in the 2007 Academies' "decadal survey" report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, are used to guide future investments. Start-

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NASA Earth Science Division Missions (as of February 2015). Source: NASA/Goddard Space Flight Center

ing in fiscal year 2014, the Administration and Congress directed NASA to assume responsibility for a suite of climate-relevant observations for the purpose of continuing a multi-decadal data record in ozone profiling, measurements of Earth’s radiation budget, and measurements of the Sun’s total irradiance. In the future, NASA will also be responsible for follow-ons in the Jason U.S.-European series of satellite missions that measure the height of the ocean surface. To date, this increase in responsibility for sustained, “continuity” measurements has not been accompanied by a commensurate increase in the ESD budget. Further, NASA, like all federal agencies is facing an austere budgetary environment for the foreseeable future.

Community guidance to the ESD from the 2007 decadal survey largely focused on new measurements, owing to assumptions made about the role of other agencies in supporting high priority climate, weather, and land surface continuity measurements. The survey also assumed out-year budget increases that did not materialize and it underestimated the cost of implementing its recommendations. These factors, along with an increased demand for Earth

observations to support societal applications, have put additional pressure on the ESD budget. The next decadal survey in Earth science and applications from space, which will begin in the fall of 2015, will confront this problem anew, exacerbated by the increasing number of measurements that are candidates for continuation and the large number of missions remaining in the queue of the previous decadal survey.

### FRAMEWORK SCOPE

The current NASA decision-making process is primarily intuitive and qualitative. The framework presented in this report provides a transparent and partially quantitative alternative that prioritizes the relative importance of different measurements based on their scientific value. However, while the proposed framework is fully developed, it is only an initial step towards a more comprehensive methodology. Because the framework is designed to balance scientific needs to make choices, it primarily applies to choices among extended missions focused on the climate change science goals where space-based continuity mea-

surements are expected to make substantial contributions. Extended missions directed mainly at exploratory science or societal applications were not readily compatible, but with appropriate modifications the initial framework could be expanded to include other types of measurements.

## IDENTIFYING QUANTIFIED OBJECTIVES FOR EARTH SCIENCE

The notion of a quantified objective is the starting point for the recommended decision framework. A well-formulated Earth science objective would be directly relevant to achieving an overarching science goal of the ESD and would 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 quantified objective they address. The resolution, uncertainty, and repeatability of candidate measurements should all be taken into account when deciding whether a quantified objective is achievable. An example of a quantified objective 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 quantified objectives, NASA’s 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 quantified objectives.

## QUANTITATIVE EVALUATION

Just as an economic cost-benefit analysis attempts to summarize the value of funding 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 quantified objective. The report identifies five key characteristics that define the value of a measurement proposed in pursuit of an objective: Importance (I), Utility (U), Quality (Q), Success Probability (S), and Affordability (A).

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. It should be noted that these metrics are put forward in order to establish a transparent way to rate different measurement characteristics and that 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.

This report presents a notional framework that could be used as a basis for refining the method NASA uses to inform strategic programmatic decisions. The recommended approach mimics a typical cost-benefit analysis, where the Benefit (B) is a function of Importance, Utility, Quality, and Success Probability, and is combined with Affordability to yield the Value, a number that can be used to directly compare different measurements:

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

MEASUREMENT EVALUATION FACTORS	
METRIC	DESCRIPTION
Importance (I)	Importance indicates the documented community priorities for science goals and quantified objectives. It represents the maximum potential benefit of a given measurement.
Utility (U)	Utility includes consideration of all of the key geophysical variables, and their relative contributions for addressing a quantified objective. It represents the percentage of the objective that would be achieved by obtaining the targeted geophysical variable record.
Quality (Q)	Quality includes consideration of its uncertainty, repeatability, time and space sampling, and data algorithm characteristics relative to that required for achieving a quantified objective. It represents the percentage of the required geophysical variable record that would be obtained by the proposed measurement.
Success Probability (S)	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)	Affordability of a proposed continuity measurement includes consideration of the total cost of developing, producing, and maintaining the sought-after data record.

Successful implementation of this approach requires determining the relative weights of the Benefit and Affordability terms and defining the rating scales of the individual benefit terms in a way that maintains that B to A ratio. A self-consistent method is to 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 then define the remaining variables in terms of percentages (e.g., 0 to 1).

## MEASUREMENT CONTINUITY AND QUALITY

Understanding global change requires long-term, reliable measurements of the key geophysical variables that define the variability, trends, and shifts in state of the Earth system. While the vantage point of space facilitates global and repeatable observations of Earth, the development of long-term measurement time-series having small combined standard uncertainties on multiple spatial scales is particularly challenging. Furthermore, ensuring continuity for a variable using data from a series of instruments or from copies of the same instrument requires a careful program of calibration, instrument characterization, and validation. For the purposes of this decision-making framework, the report defines measurement continuity as follows:

**FINDING:** Continuity of an Earth measurement exists when the quality of the measurement for a specific quan-

tified objective for Earth science 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 quantified objective. 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.

## FUTURE DIRECTIONS

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 quantified application objectives.

**RECOMMENDATION:** NASA should initiate studies to identify and assess quantified objectives in Earth applications related to high-priority, societal-benefit areas.

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**COMMITTEE ON A FRAMEWORK FOR ANALYZING THE NEEDS FOR CONTINUITY OF NASA-SUSTAINED REMOTE SENSING OBSERVATIONS OF THE EARTH FROM SPACE:** Byron D. Tapley, University of Texas at Austin, *Chair*; Michael D. King, University of Colorado, Boulder, *Vice Chair*; Mark R. Abbott, Woods Hole Oceanographic Institution; Steven A. Ackerman, University of Wisconsin, Madison; John J. Bates, NOAA/NESDIS National Climate Data Center; Rafael L. Bras, Georgia Institute of Technology; Robert E. Dickinson, University of Texas at Austin; Randall R. Friedl, Jet Propulsion Laboratory; Lee-Lueng Fu, Jet Propulsion Laboratory; Chelle L. Gentemann, Remote Sensing Systems; Kathryn A. Kelly, University of Washington; Judith L. Lean, Naval Research Laboratory; Joyce E. Penner, University of Michigan; Michael J. Prather, University of California, Irvine; Eric J. Rignot, University of California, Irvine; William L. Smith, Hampton University; Compton J. Tucker, NASA Goddard Space Flight Center; Bruce A. Wielicki, NASA Langley Research Center

**STAFF:** Arthur A. Charo, Senior Program Officer, *Study Director*; Lewis B. Groswald, Associate Program Officer; Anesia Wilks, Senior Project Assistant; Katie Daud, Research Associate; Michelle Thompson, 2014 Lloyd V. Berkner Space Policy Intern; Angela Dapremont, 2014 Fall Lloyd V. Berkner Space Policy Intern; Michael H. Moloney, Director, Space Studies Board

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