Space Policy 28 (2012) 259–269

Contents lists available at SciVerse ScienceDirect

Space Policy

journal homepage: www.elsevier.com/locate/spacepol

Program goals for the NASA/NOAA Earth Observation Program derived from a stakeholder value network analysis

Timothy A. Sutherland [a,*], Bruce G. Cameron [b], Edward F. Crawley [b]

[a] 205 Richdale Ave. Unit A27, Cambridge, MA 02140, USA
[b] Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139, USA

ARTICLE INFO

Article history:
Received 5 February 2012
Received in revised form
27 March 2012
Accepted 6 April 2012
Available online 12 October 2012

ABSTRACT

The 2007 US National Research Council Decadal Survey for Earth Science and Applications from Space was the first consensus perspective produced by the US Earth Science community of the relative priorities among a sequence of 17 satellite missions over the course of the next decade. However, the Decadal Survey only captured the perspective of the science community, leading to questions about the inclusion of broader priorities from constituent communities and stakeholders. We present a stakeholder value network analysis for the NASA/NOAA Earth Observation Program. The analysis includes a rigorous articulation of the needs and objectives of 13 major stakeholders and a complete stakeholder value network with 190 individual "value flows" that capture the interactions between all the stakeholders. It produces a novel stakeholder map, graphically indicating the outputs most likely to create a lasting Earth Science program. The most important value loops and program outputs are used to derive a set of high-level program goals that suggest *what* NASA and NOAA should do, as well as *how* they should conduct business. The analysis concludes that international partnerships represent a strong potential partner for certain science missions with greater potential value delivery than currently-prioritized efforts with defense stakeholders and concludes that weather and land-use missions, in addition to climate missions, should be given highest priority; water, human health, and solid Earth missions should be given lower priority based on each science category's potential for delivering value to the entire stakeholder network.

1. Introduction

In 2007, the US National Research Council Space Studies Board released a Decadal Survey for the Earth Science and applications communities [1]. This report was the first of its kind for the US Earth science community, in that it produced a consensus perspective of the relative priorities among a sequence of 17 satellite missions over the course of the next decade. It presented a vision for a decadal-scale program of space-based Earth science research and applications that advances the fundamental understanding of the Earth as a system and increases the application of this understanding to serve the nation and the world.

However, the Decadal Survey only captured the perspective of the science community, leading to questions about the inclusion of broader priorities from constituent communities and stakeholders. The vision established by the Decadal Survey requires a paradigm shift for Earth system science: societal needs must help guide the scientific priorities, and emerging scientific knowledge must be actively applied to obtain societal benefits. The USA agencies responsible for designing and operating civilian Earth-observing satellites (NASA and NOAA), with additional contributions from the US Geological Survey (USGS), are routinely charged with questions of stakeholder engagement, but do not have clear internal policies for the creation of this analysis. In this paper we re-imagine the priorities of the Decadal Survey, using a method of stakeholder analysis that provides traceability to constituent needs and priorities.

The general objective of the paper is to maximize the value of the US space-based Earth observation system by capturing the complete set of needs and objectives using a stakeholder value network analysis methodology. To these ends, we define stakeholders as those who 1) have a direct or indirect effect on NASA/NOAA's Earth observation activities; 2) receive direct or indirect benefits from Earth observation activities; or 3) possess a significant, legitimate interest in Earth observation activities. The following section provides a review of stakeholder definition and analysis.

* Corresponding author. Tel.: +1 617 947 0171; fax: +1 617 324 6901.
E-mail addresses: tasuther@alum.mit.edu (T.A. Sutherland), bcameron@alum.mit.edu (B.G. Cameron), crawley@mit.edu (E.F. Crawley).

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http://dx.doi.org/10.1016/j.spacepol.2012.09.007

2. Background and literature review

The Decadal Survey is the product of the collaborative effort of over 70 leading scientists and roughly 30 representatives from NASA, NOAA, international space agencies, commercial industry, and other government agencies. To emphasize the interdisciplinary nature of the interactions of the Earth system, the participants were organized into seven thematic panels:

1. Earth science applications and societal benefits;
2. Human health and security;
3. Land-use, ecosystems, and biodiversity;
4. Solid Earth hazards, natural resources, and dynamics;
5. Climate variability and change;
6. Weather science and applications;
7. Water resources and global hydrological cycle.

The Decadal Survey committee worked with the individual panels to recommend 17 satellite missions. Each mission represented a compromise of instruments or spacecraft operational characteristics that satisfied the needs of multiple panels.

The publishing of the Decadal Survey was an achievement for the Earth Science community, but some aspects of the process and final report could benefit from a more rigorous stakeholder analysis. The needs and objectives articulated throughout the report are described mostly from the perspective of scientists. Although one of the panels focused on applications and societal benefits, the needs and objectives of non-scientist stakeholders received much less thorough treatment. This creates a lack of traceability between the Decadal Survey's program recommendations and the total delivery of value to the nation, creating an opportunity to inform the broader prioritization of goals by understanding the non-scientist stakeholders.

Harris and Miller highlight the current immaturity of 'value delivery to the public' analysis in current Earth Observation Programs, using a categorization of Earth Observation data to structure a 'public good' analysis [2]. This analysis provides a detailed view of data uses, but does not holistically capture the net benefit to stakeholders, who may receive more than one type of data.

Traditional stakeholder analysis techniques typically consider a central organization and the stakeholders with which the organization interacts directly [3]. Mitchell provides a history of varying definitions of what constitutes a stakeholder [4], noting that a limited definition of stockholders is not necessarily appropriate in a public policy context, given its reliance on ownership concepts (e.g. the ownership of or legal right to the company's assets).

A partial solution to ownership concepts is to differentiate between market and non-market contexts [5], where the "non-market" environment includes interactions between the public, government, media, public institutions, and other stakeholders. While deferring to Porter's characterization of market forces, Baron divides the non-market environment into the "four i's": issues, institutions, interests, and information. Institutions and interests, as defined, represent two categories of stakeholders, while issues and information represent sources of influence and power [5].

Another approach is to compare the type of influence stakeholders wield. Handy proposes five types of stakeholder power: physical, positional, resource, expert, and personal power [6]. Stakeholders can then be classified using a power/interest matrix, resulting in four stable configurations:

- those who require *minimal effort*, such as a client's customers;
- those who must be *kept informed*, such as the local community;
- those who much be *kept satisfied*, such as regulatory bodies;
- the *key players*, including the enterprise and other crucial stakeholders.

Stakeholder maps have emerged as an important component in the visualization, completeness checks, and influence comparison necessary for stakeholder analysis. Freeman proposed stakeholder mapping as a necessary step in identifying stakeholders with a claim on the project [3], and also in assessing each stakeholder's ability to press that claim.

Based on the concept of stakeholder maps, the idea of using network analysis to understand the context and policy options available has become a fruitful research direction [7,8]. The literature is split between investigations of the overall network structure with a view to explaining group behavior (such as free riding [9,10] and intertribal marriage [11]), and investigations which use network dynamics to understand the opportunities for an individual actor [12].

Although a large literature already exists on the prioritization of needs by a single actor [13], the available techniques for weighing needs among multiple stakeholders is less rich, relying instead on market sizing or panel judgment to weight stakeholders against each other. Cameron proposed stakeholder network analysis for overcoming this challenge [14], using network metrics linked to the satisfaction of individual needs. In essence, this method assigns stakeholders greater importance if they provide inputs that are important to the central organization, here NASA and NOAA. Stakeholder network analysis has since been expanded to define goals for an organization [15], based on a prioritized listing of stakeholder needs, incorporating information about how the propagation of value in the network should be written into the organization's goals.

We now present the results of a comprehensive stakeholder value network analysis of the Earth Observation Program. The results are based on a model that uses a qualitative and quantitative stakeholder network approach [15,16,17] to understand both the direct and indirect relationships between the stakeholders of the Earth Observation Program. We expand on existing work in stakeholder maps and needs prioritization by introducing a new stakeholder map, where link thickness corresponds to need salience, providing a clear visual indication of important policy considerations. In light of increasing calls for renewed international collaboration in Earth observations [18,19], this method offers a potential future contribution to resolving differences between contributing members.

The specific objectives of the paper are as follows:

(1) to develop a more complete understanding of all stakeholders of NASA/NOAA's Earth Observation Program by articulating the goals, objectives, and needs of every stakeholder;
(2) to understand the important interactions among all stakeholders by constructing a detailed stakeholder map showing the inputs and outputs of each stakeholder;
(3) to identify the most important stakeholders, the highest value-producing interactions among stakeholders, and most important NASA/NOAA outputs;
(4) to complement the recommendations of the Decadal Survey by providing more specific, targeted insights and recommendations.

The results from the stakeholder value network analysis provide insights regarding the total value produced by the Earth Observation Program. The most important value loops and program outputs are used to derive a set of high-level program goals, including goals that suggest *what* NASA and NOAA should do, as well as *how* they should conduct business. The insights and results from the analysis provide the foundation for a set of recommendations for the Earth Observation Program, which complement the recommendations put forth in the Decadal Survey.

The third section of this paper presents a qualitative stakeholder model, including identification of stakeholders, articulation of their needs and objectives, and the mapping of value-producing inputs and output among all stakeholders.

The fourth section presents a quantitative stakeholder model, including techniques used to quantify the value flows between each stakeholder, methods for validating the value flow scores, and a method for calculating the "value loops" within the stakeholder network.

The fifth section presents the analytical results of the quantitative stakeholder analysis, including the identification of the most important stakeholders, value flows, value loops, and NASA/NOAA inputs and outputs. These important flows and loops are graphically illustrated using a novel technique of weighting the thickness of lines by their computed importance.

The final section describes the major insights yielded from the stakeholder value network analysis and presents a list of recommendations for the Earth Observation Program.

3. Qualitative model

The qualitative stakeholder model is a tool that can help provide an in-depth understanding of the stakeholders within the system. It is useful for articulating each stakeholder's needs and objectives and understanding the complex interactions between them. By incorporating the most important inputs and outputs of each stakeholder, the model allows one to visualize and understand, in a qualitative sense, how value is created and delivered throughout the system. The model includes both monetary and non-monetary forms of value. It also provides an indication of the connectedness of each stakeholder to the entire stakeholder network.

Within the model, recall that stakeholders are those who have a direct or indirect effect on NASA/NOAA's Earth observation activities, receive direct or indirect benefits from them, or possess a significant interest in Earth observation activities. Stakeholders were identified as those mentioned in the Decadal Survey, the Space Act of 1958 [20], NASA policy documents [21,22], and participants in the US Climate Change Science Program (CCSP) [23].

An initial list of over 30 stakeholders was refined and aggregated into a smaller list of 13, shown in Table 1. Reducing the number of stakeholders helps keep the model conceptually and computationally manageable, since the number of possible links in the system scales combinatorially with the number of nodes.

Stakeholder aggregation involved combining multiple stakeholders based on their roles or functions within the stakeholder network. For example, Congress, the Executive Branch, and the Judiciary were aggregated into one stakeholder called the Government. This eliminates the complex interactions between the three branches of government from the model and instead treats the Government as a single stakeholder with the combined inputs and outputs of its three component branches.

Similarly, the interactions between the divisions within NASA and NOAA are too complicated to include in this model. Their inputs and outputs would be almost identical if they were modeled separately, although the type of science data they produce differs. Also, the operational boundaries between NASA and NOAA can be fuzzy at times. They are therefore treated as a single stakeholder in the model.

Next, we arranged the stakeholders on a visual map, shown in Fig. 1. A coherent stakeholder map allows one to visualize the connections between the stakeholders and to better understand how value is delivered throughout the stakeholder network. The stakeholders are situated on the four quadrants of the map according to their primary roles within the value chain. Some of the stakeholders span multiple quadrants because they serve multiple roles within the system. For example, the Department of Defense provides some funding to NASA and is both a generator and user of weather-related data.

Table 1
List of stakeholders included in the model.

Stakeholder group	Definition and role
Commercial data users	Companies that rely on space-acquired Earth observation data and derived knowledge, products, and services.
Commercial industry	Companies that interact directly or indirectly with NASA/NOAA and rely on funding, launch and space services, and space technology from NASA/NOAA.
Department of defense	The U.S. military as it interacts with NASA/NOAA on collaborative Earth-observing missions such as NPOESS.
Educators	Individuals and institutions that comprise the U.S. educational system, from the primary level to universities (does *not* include university scientists).
Federal agencies	U.S. federal agencies involved in public health, safety, environmental protection, scientific research, land-use, transportation, energy, and agriculture.
Government	The legislative, executive, and judicial branches of the U.S. government.
International partners	Non-U.S. national space agencies that collaborate with NASA/NOAA and fulfill the same role as NASA/NOAA in their respective nations.
Media	Organizations responsible for the acquisition, composition, and distribution of news and information.
NASA/NOAA	U.S. federal entities that provide the means with which to expand human knowledge of the Earth and space.
Non-governmental organizations (NGOs)	Advocacy and industry trade groups that promote the importance of Earth Science and observations on behalf of scientists, industry, and the public.
Public/society	The general U.S. population and society as a whole.
Science & technology advisory bodies	The science and technical advisory organizations for the U.S. federal government.
Scientists	Scientists employed by academia, NASA, NOAA, federal agencies, and the commercial sector that use Earth observation data to generate knowledge.

The arrows on the map indicate a high-level abstraction of the process by which the Earth Observation Program delivers value to its stakeholders. Beginning in the upper left quadrant of the figure, policy makers provide funding and policy direction to data providers in the upper right quadrant. Data providers acquire Earth measurements and transmit the data to data users in the lower right quadrant. Data users analyze the data to produce knowledge, which they pass along to the public and beneficiaries in the lower left quadrant. The public and beneficiaries interpret the knowledge and use it to make decisions and provide support to the policy makers in the upper left quadrant; thus completing the cycle.

Performing a rigorous stakeholder analysis involves developing an appreciation for the interests and objectives of each stakeholder as well as an in-depth understanding of how each stakeholder contributes to and derives value from the system. This requires a methodology for capturing this information and presenting it in a format that provides traceability between the interactions among stakeholders and the satisfaction of each stakeholder's needs and objectives.

We developed a stakeholder characterization template, shown below in Fig. 2, that can be used to succinctly articulate the role, objectives, and specific needs of each stakeholder. The template also indicates the inputs that the stakeholder receives from other stakeholders. The template in the figure has been populated with information for the Public stakeholder group.

The upper box in the template describes the role of each stakeholder within the context of the Earth Observation Program. The center box in the template shows the stakeholder's objectives,

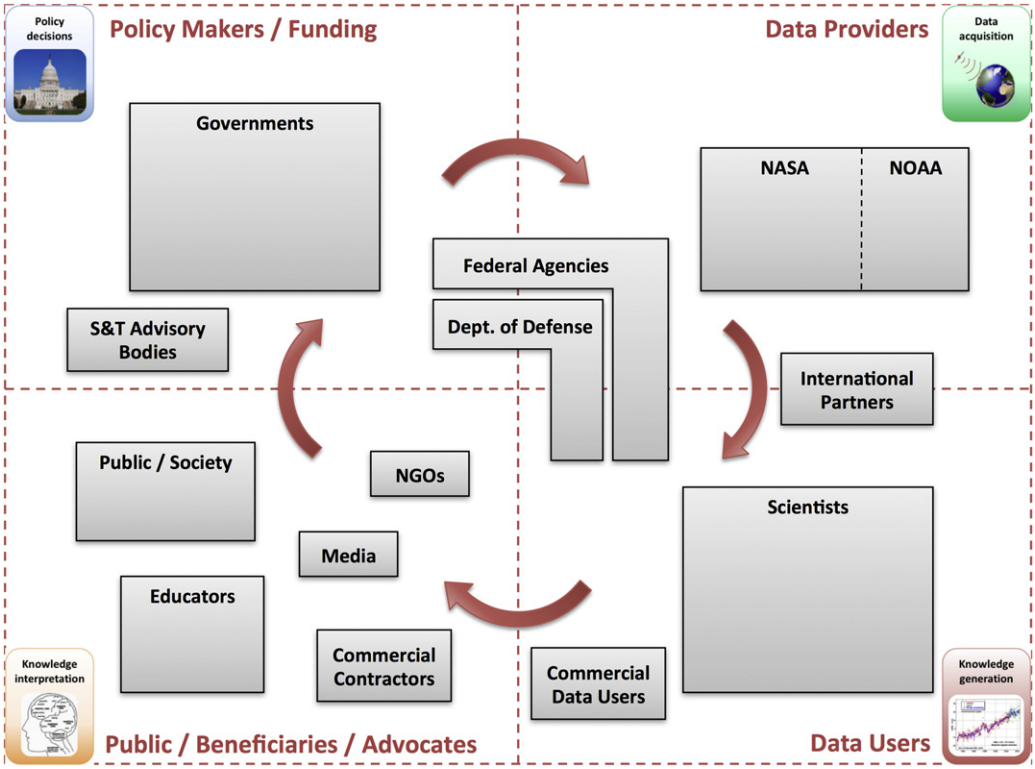

Fig. 1. Stakeholder map.

which are goal statements often published on a stakeholder's website or found in policy and strategy documents, mission statements, or other official documents. The lower box in the template contains the stakeholder's specific needs required to satisfy its stated objectives. We determined many of the stakeholder objectives and specific needs from information contained in the Decadal Survey, CCSP reports [23], the Space Act [20], stakeholder websites, and stakeholder policy and strategy documents [21,22,24–26].

The left side of the template lists the inputs that the stakeholder receives from other stakeholders. Each input fulfills, either partially or wholly, a specific need of the stakeholder. To create the list of inputs to a stakeholder, we examined each specific need and determined which of the other stakeholders in the model produce outputs that satisfy that need. We also used this method to check the stakeholder list for completeness, by assessing whether any of the specific needs could be satisfied by stakeholders not included in the model. Using this method to determine the inputs to each stakeholder ensures that the stakeholder model will capture all the relevant actors. Each of the inputs to a stakeholder becomes a "value flow" in the value network model.

After articulating the objectives, specific needs, and inputs of each stakeholder, we next created the stakeholder value network

Fig. 2. Stakeholder characterization template, shown for the public.

model by connecting each stakeholder using the inputs identified in the stakeholder characterization templates. Each identified input to a stakeholder became an output of the originating stakeholder. Since the sum of all the inputs articulated in the stakeholder characterization templates provides a complete set of the value-delivering interactions within the stakeholder network, it is unnecessary to complete a separate exercise determining each stakeholder's outputs to other stakeholders. Also, it is generally easier to identify a stakeholder's required inputs than it is to identify which of its outputs provide value to other stakeholders.

In the value network model we use the term *value flow* to indicate the output of one stakeholder as the input to another – it represents the delivery of value from one stakeholder to another. Fig. 3 below shows the value flows into and out of the Public. The four colors used for the stakeholders correspond to the colors used in the four quadrants of the stakeholder map.

Some of the science-related value flows in the model, such as Earth observation-derived products and services from NASA/NOAA and Commercial Data Users to the Public, were modeled as six separate value flows corresponding to the categories of the six science-themed Decadal Survey panels. These particular value flows are designated as double-thickness arrows in Fig. 3. We chose to separate the science-related flows in this way because certain stakeholders place widely different value on inputs related to the six different science categories. For example, the Department of Defense may value weather data much more highly than data regarding ecosystems and biodiversity. Separating these science-related value flows within the model produced results that are more architecturally distinguishing and can be used to make more specific policy recommendations.

The complete value flow model contains 190 value flows among all 13 stakeholders in the model. This illustrates the complexity of the model and reinforces the justification for simplifying the total number of stakeholders. In the complete model, policy and opinion value flows generally flow from the Public quadrant to the Government quadrant shown previously in Fig. 1, and from the Government to the NASA/NOAA quadrant. Monetary flows tend to be fairly evenly distributed throughout the stakeholder network. Knowledge and information flows are most highly concentrated within the lower two quadrants, representing the flow of knowledge from the Scientists to the Public and other beneficiaries. Goods and services are most highly concentrated within the two right quadrants, which represent strong links between NASA/NOAA and Scientists as well as NASA/NOAA and the Commercial sectors. Finally, jobs and public benefit flows are concentrated around the Public stakeholders in the lower left quadrant.

The value flow map also includes value flows that are non-monetizable or difficult to quantify, such as knowledge and information, policy and opinions, and certain public benefits such as "security". Typically, these types of value flows would be excluded by other techniques such as cost–benefit analysis or system dynamics models. Including them in this analysis provides a more complete understanding of the ultimate value delivered by the Earth Observation Program.

The complete stakeholder value flow map provides a much more comprehensive understanding of each stakeholder's role and interactions within the network than other stakeholder analysis techniques would provide. NASA's Systems Engineering Processes and Requirements Handbook [27] requires the definition of stakeholder interests and expectations of the system, but this predominantly yields only the direct transactions between NASA and each other stakeholder. The transactions between non-NASA stakeholders can be just as important, however. Articulating every stakeholder's value flows reveals that certain stakeholders, such as the Government and Scientists, have numerous direct interactions with NASA/NOAA. Other stakeholders, such as the Public, have few direct interactions with NASA/NOAA but are highly connected to other stakeholders and play a crucial role in the delivery of value throughout the network.

4. Determining quantitative model inputs

Developing a quantitative stakeholder model requires quantifying the benefit to the recipients of the qualitative value flows in the model. The method used to assign numerical scores to each value flow draws inspiration from Kano's methods for

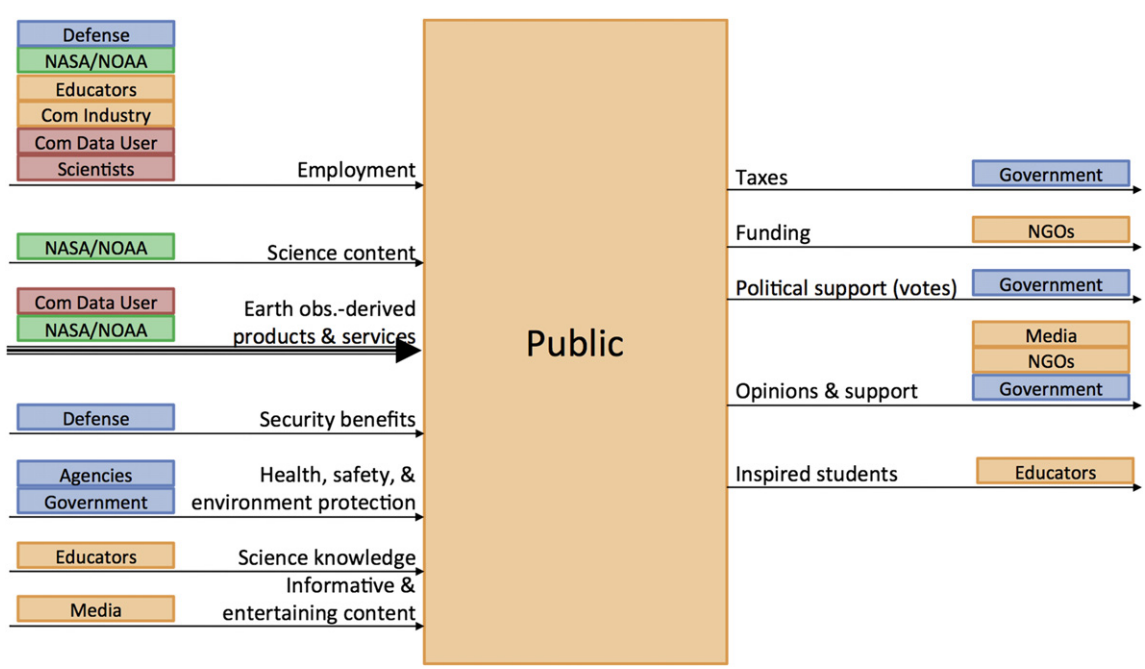

Fig. 3. Value flows into and out of the public.

understanding how consumers define quality in the goods and services they purchase [14,28]. The strength of this methodology is that it only requires definition of the need importance *from the perspective of the stakeholder* – it does not require system-level judgments. The technique used to assign numerical scores to the value flows requires evaluating two attributes of each value flow, described in detail in [14] and combines:

1. the intensity of the specific need, on the part of the recipient, that the value flow satisfies;
2. the importance of a particular source in fulfilling the specific need.

A three-stage process was used to determine the primary model inputs, the numerical scores assigned to each stakeholder need. First, questionnaires were completed from the perspective of each stakeholder by five individuals with a keen familiarity with the Decadal Survey and broad knowledge of the Earth Observation Program. Second, a Defense stakeholder reviewed the relative prioritization of their needs, as previously demonstrated in [15]. Third, policy documents were coded for relative need priority, and compared against the ranking produced by the questionnaires and stakeholder interviews. These three steps are described in detail below.

Questionnaires were completed by five individuals with a keen familiarity with the Decadal Survey and broad knowledge of the Earth Observation Program. These individuals had direct knowledge of the needs of the NASA/NOAA, Scientists, and Educators stakeholder groups, and past experience at a senior policy level with the remaining stakeholders.

- Deputy Director for the Sciences and Exploration Directorate (NASA);
- Chief Engineer of Earth Sciences Division (NASA);
- Associate Director for Flight Programs in Earth Science Division (NASA);
- Professor of Aeronautics & Astronautics and Engineering Systems (MIT);
- Graduate students in the System Architecture group involved with the project (MIT).

As described in detail in [14], these questionnaires asked two questions for each value flow:

1. How would you characterize the presence or absence of fulfillment of this needs?
2. If this need were to be fulfilled, how important would this source be in fulfilling the need?

Each question had five possible answers spanning an anchored scale, such as (for Question #1) "A. I would be satisfied by its presence, but I would not regret its absence". After the completed questionnaires from each individual were tallied, we used a modified Delphi method with one round of revision to reconcile major differences among scores for particular value flows [29]. To resolve small discrepancies between the five scores for each value flow after the round of revisions, the final value flow score was determined by taking the average of the five individual scores. Table 2 below shows the combined value flow scores for the Public, which include any revisions made after the one round of discussion.

The second process step, validation with the Defense stakeholder, was particularly important in capturing input not directly represented in the first step. A former Secretary of the Air Force was used as the Defense stakeholder. During the stakeholder interview, the individual was provided with an overview of the qualitative stakeholder model, including the stakeholder maps and value flow maps. We also created a diagram showing the *inputs* to that stakeholder in rank order based on the combined value flow scores assigned by the questionnaire scorers. The Defense stakeholder representative was asked to evaluate the *relative* rankings of the value flows to provide an anecdotal validation of the value flow scores. This relative comparison enabled the stakeholder to engage with the model without the added complexity of the questionnaire, reflecting more closely prioritization schemes they use in an active policy context.

The third process step for validating the value flow scores involved comparing the relative rankings of value flow inputs to a given stakeholder to evidence presented in various literature and data sources. Value flow rankings for inputs to NASA/NOAA, Defense, Commercial Data Users, Media, Public, S&T Advisory Bodies, and the Government were validated using this method. Table 3 shows the sources used to validate the value flow scores for these stakeholders.

The following example shows how the value flow score rankings were validated for the Public. We validated the scores by tabulating results from major national polls conducted periodically during the period 2002–2008, which were aggregated at a single website [25]. The polls ask respondents to name their single top issue of importance. The results are presented in Table 4.

Table 5 compares the value flow score rankings to the rankings derived from the public surveys. The table is ranked according to the survey rankings. The comparison shows that the relative value flow score rankings in the stakeholder model largely reproduce the rankings from the public surveys.

In general, the value flow scores in the stakeholder model showed strong agreement with the proxy data sources, providing

Table 2
Combined value flow scores for public.

To: Stakeholder	Value flow	From: Stakeholder	Final scores from scorers					Combined value flow score
			#1	#2	#3	#4	#5	
Public	Earth observation-derived products & services	Commercial data users	0.44	0.44	0.10	0.44	0.15	0.32
Public	Earth observation-derived products & services	NASA/NOAA	0.44	0.56	0.11	0.56	0.44	0.42
Public	Employment	Commercial data users	0.32	0.44	0.26	0.44	0.26	0.32
Public	Employment	Commercial industry	0.76	0.44	0.26	0.44	0.18	0.49
Public	Employment	Defense	0.54	0.31	0.18	0.44	0.18	0.44
Public	Employment	NASA/NOAA	0.54	0.31	0.04	0.44	0.11	0.37
Public	Employment	Scientists	0.54	0.18	0.11	0.44	0.44	0.33
Public	Health, safety, & environmental protection	Federal agencies	0.26	0.26	0.18	0.44	0.56	0.29
Public	Health, safety, & environmental protection	Government	0.26	0.56	0.15	0.10	0.26	0.34
Public	Informative & entertaining content	Media	0.56	0.26	0.10	0.26	0.44	0.33
Public	Science content	NASA/NOAA	0.26	0.18	0.06	0.26	0.15	0.31
Public	Science knowledge	Educators	0.56	0.56	0.44	0.26	0.19	0.24
Public	Security benefits	Defense	0.44	0.44	0.26	0.44	0.26	0.44

Table 3
Sources for validating value flow scores.

Stakeholder	Validation sources
NASA/NOAA	Relative ranking of science priorities contained in NASA's Science Plan for 2007–2016 [21]
Defense	Relative ranking of science priorities contained in: • Climate Change Science Program [23] • 2005 Strategic Plan for the U.S. Integrated Earth Observation System [22] • National Security and the Threat of Climate Change [24]
Commercial data users	Relative ranking of science priorities based on: • Mission statements of commercial geospatial users belonging to the Management Association for Private Photogrammatic Surveyors • NOAA report detailing usage of Solid Earth satellite data for commercial natural resource exploration [30] • Article describing usage of satellite data by insurance companies [31]
Media	Research paper examining ranking of online news-viewing topics [32]
Public	Relative ranking of employment value flows based on number of Americans employed by each stakeholder group; National polls showing relative importance of key issues [25]
S&T advisory bodies	Representation of each major stakeholder group to NRC Decadal Survey [1]
Government	Survey of Congressmen on the importance of various actors in determining voting decisions [26]; Ranking of science priorities based on frequency and nature of Congressional testimony by Earth scientists

a high-level of confidence in the model and the technique used to assign the value flow scores.

5. Results

The basis for the model is the computation of reinforcing feedback loops, known as a value loop [16]. Stakeholder value network analysis computes the product of all value flow scores contained within a loop, and can be heuristically understood as 'strong links produce a strong chain'. The details of the generalized exchange computation, together with the underlying representation of utility is provided in [14]. Value loops also provide the means for developing an in-depth understanding of how value is created and delivered throughout the stakeholder network, which may not be immediately obvious or intuitive to Earth Observation Program planners.

The stakeholder model contained 1880 unique value loops. We used a computer software program called Object Process Network to compute the value loop scores [33].

The value loop scores were analyzed to determine the following:

- most important stakeholders;
- most important value loops;
- most important value flows;
- highest value NASA/NOAA outputs;
- highest value NASA/NOAA inputs;
- value potential for each of the six science categories.

Table 4
Survey results for public issues [25].

Issue	% respondents declaring as most important issue	Rank
Security/defense/war	39%	1
Economy/budget/taxes	27%	2
Health care	12%	3
Energy/environment	6%	4
Domestic issues	4%	5
Knowledge/education	2%	6
Other	10%	–

To calculate the importance of each stakeholder, we used the weighted sum of the stakeholder's occurrence in all value loops, known as the Stakeholder Loop Occurrence [15]. Each time a stakeholder appears in a value loop, the score for that loop is added to the stakeholder's total. The final values were normalized by the sum of all value loop scores included in the set. By definition, NASA/NOAA has a score of 1.0 because it appears in every value loop. Fig. 4 shows the relative importance of each stakeholder in the model. The top four stakeholders are NASA/NOAA, Government, Scientists, and Public.

The complete stakeholder value flow map with all 13 stakeholders and 190 value flows is enormously complex. A diagram showing only the most important stakeholders and value flows would provide a more comprehensible view of the stakeholder network and would serve as a much more useful reference tool.

To produce the simplified stakeholder diagram, shown in Fig. 5, we combined the information yielded from the three analyses of the most important stakeholders, value flows, and value loops. Stakeholders and value flows that appeared consistently across the three analyses were included in the simplified diagram. We added additional stakeholders and value flows if they played a significant role in at least one of the three analyses. Certain stakeholders and value flows were deleted if their presence was minor or inconsistent across the three analyses. Most importantly, we varied the thickness of each value flow varies according to its relative importance in the model, thus creating a new dimension of stakeholder maps.

The first tier of stakeholders, indicated with solid black borders in Fig. 5, includes NASA/NOAA, Scientists, the Public, and the Government. These four stakeholders and the value flows among them appeared consistently across the three analyses.

The second tier of stakeholders, indicated with dashed line borders, includes S&T Advisory Bodies, International Partners, Commercial Data Users, Educators, and Commercial Industry. Of these five stakeholders, S&T Advisory Bodies are the most important based on the analyses conducted in the previous sections. This is reflective of the deference with which NASA, NOAA, the Executive and Congress treat the Decadal Survey, and of the importance of the advisory process performed by the National Academies and other science- and technology-focused advisory bodies. The other four Tier 2 stakeholders are not absolutely critical to the success of the Earth Observation Program, but they each contribute to important value chains that provide high-value resources that can greatly enhance the program's success. International Partners have the capacity to provide program cooperation and cost-sharing to NASA/NOAA and space-acquired data to Scientists. As the Decadal Survey mentions, this could alleviate the need for certain missions or significantly reduce the cost to NASA and NOAA of obtaining space-acquired data. Commercial Data Users use the space-acquired data from NASA/NOAA and the knowledge from Scientists to provide Earth observation-related products and services to the Public. These include services such as weather forecasts and land-imaging products such as Google Earth and Microsoft Virtual Earth, but are separate from products provided directly to the public by NASA/NOAA, such as weather images. Educators provide a skilled and motivated workforce, which is a key asset for NASA/NOAA to maintain its leadership position in Earth observations. Commercial Industry is the weakest of the Tier 2 stakeholders, having appeared inconsistently in the stakeholder, value flow, and value loop analyses. However, in addition to providing science systems, Commercial Industry has the capacity to provide launch services to NASA/NOAA, another key asset for the Earth Observation Program.

Finally, the third tier of stakeholders includes the Media, Defense, Federal Agencies, and NGOs. While these four stakeholders do contribute some value to the program, their overall

Table 5
Comparison of public value flow rankings to survey results.

Public survey issue category	Rank from surveys	Value flow	From: Stakeholder	Value flow scores	Average flow scores
Security/defense/war	1	Security benefits	Defense	0.43	0.43
Economy/budget/taxes	2	Employment	Com. data users	0.32	0.41
			Com. industry	0.54	
			Defense	0.44	
			NASA/NOAA	0.37	
			Scientists	0.46	
			Com. data users	0.32	
Health care and energy/environment	3/4	Health, safety, & environmental protection	Government	0.34	0.32
			Agencies	0.29	
Knowledge/education	6	Informative content	Media	0.33	0.31
		Science content	NASA/NOAA	0.31	
		Science knowledge	Educators	0.29	

importance to the Earth Observation Program is minimal and they should receive a lower priority than stakeholders in the first and second tiers. One of the notable differences between the NASA/NOAA Earth Observation Program and the NASA exploration programs is the importance of the Media. In Cameron's analysis of the exploration program [15], the Media was one of the more important stakeholders. This was because much of the value created by the exploration program is delivered by the Media to the Public, through photo and video imagery. In the Earth Observation Program, however, much of the value of the program is delivered through science knowledge to the Government and Earth observation-related products and services to the Public. Neither of these outputs involve value flows through the Media. While the Media does provide sensational news reports regarding weather and climate change, these are not among the high-scoring value flows within the stakeholder value network.

The stakeholder value network analysis indicated that satellite missions related to weather, climate, and solid Earth provide the most overall value to the stakeholder network. Visualizations of the value flow maps for these three science categories reveal differences in how each delivers value to the nation. For example, Fig. 6 shows the most significant value flows created by climate change missions. Fig. 7 shows the most significant value flows created by land-use missions. Although not shown, the value flow map for weather missions is most similar to that of land-use missions.

Fig. 6 shows that the most significant value flows (i.e. thicker value flow lines) created by climate change missions are science knowledge from Scientists to NASA/NOAA, the Government, and S&T Advisory Bodies, as well as science policy advice from S&T Advisory bodies to the Government. However, these value flows are not as strong in the land-use map. Fig. 7 shows that land-use missions deliver much more of their value through Commercial Data Users and the Public than climate missions. Weather and land-use missions create more Earth observation-derived products and services (i.e. thicker purple lines). This model indicates that because of the tremendous commercial value in weather and land-use data, missions from these two categories would produce roughly equivalent amounts of value to the stakeholder network as climate-related missions. Note that most of the value flows out of Commercial Data Users flow to the Public.

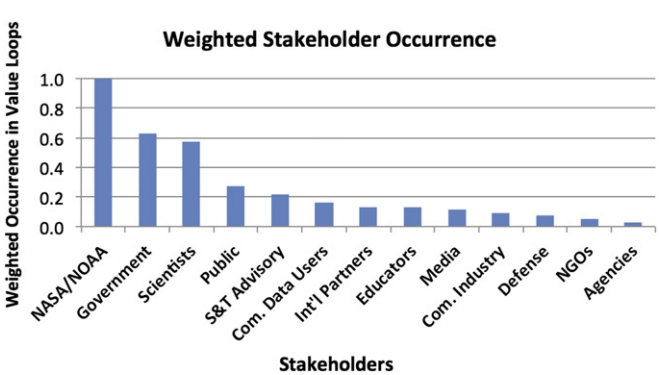

Fig. 4. Weighted stakeholder occurrence scores.

These value flow maps suggest that, although NASA/NOAA may place a higher value on climate change than the other science categories, weather and land-use missions produce more products and services for the Public, such that NASA/NOAA should prioritize them equally with climate missions. This differs from much of the current consensus that climate missions should receive higher priority than all other science categories, perhaps arising from the uncertainty in quantifying the benefits of climate missions.

The analysis also concludes that the human health and solid Earth science categories provide the smallest amount of value to the network. This provides a somewhat objective rationale for assigning low priority to missions from these two categories. While solid Earth information could be useful in helping to predict natural hazards such as earthquakes, there are other more important needs to be fulfilled for the Public and other beneficiaries. Given NASA/NOAA's current lack of sufficient resources for Earth science, it may be beneficial to assign responsibility for solid Earth missions to another federal agency such as the USGS. With regards to human health missions, this falls outside the traditional boundary of NASA's Earth science program. Human health is not specifically mentioned in the list of objectives for NASA's Earth science program [27].

6. Recommendations

The stakeholder value network analysis yielded the following major insights about the Earth Observation Program:

- *NASA/NOAA should prioritize its outputs in the following order:*
  1. data and resources to Scientists;
  2. future plans information and funding to S&T Advisory Bodies;
  3. program cooperation and cost-sharing with International Partners;
  4. future plans information and funding to Commercial Industry;
  5. data and future plans information to Commercial Data Users;
  6. Earth observation-derived products and services and employment to the Public.
- *It is inherently difficult for NASA/NOAA to achieve significant collaboration with Defense, International Partners, and other*

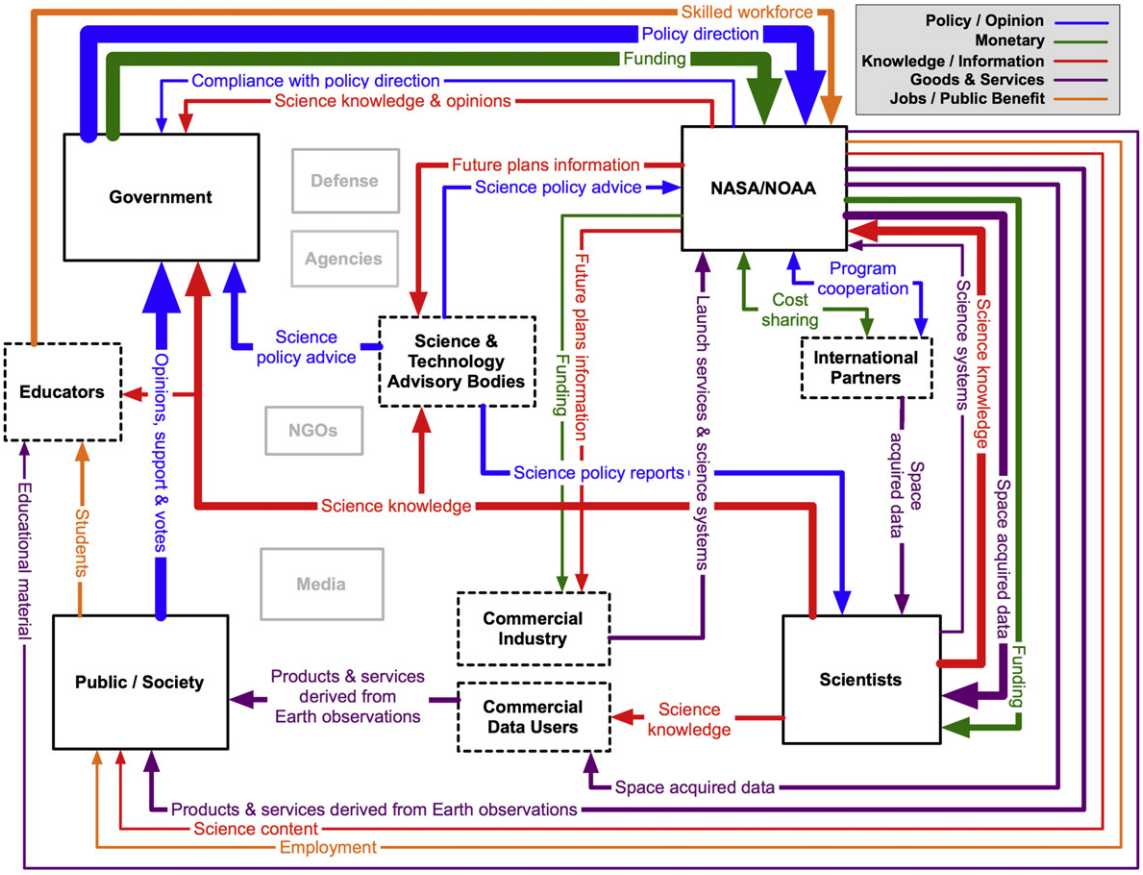

Fig. 5. Simplified stakeholder map showing relative importance of each value flow.

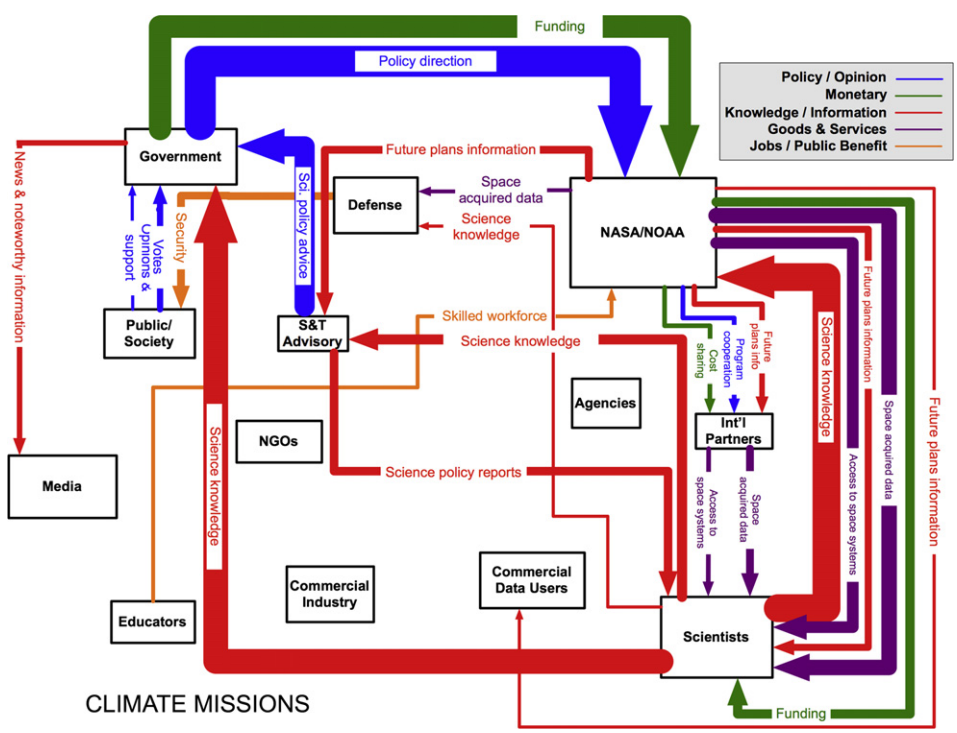

Fig. 6. Top value flows created by climate missions.

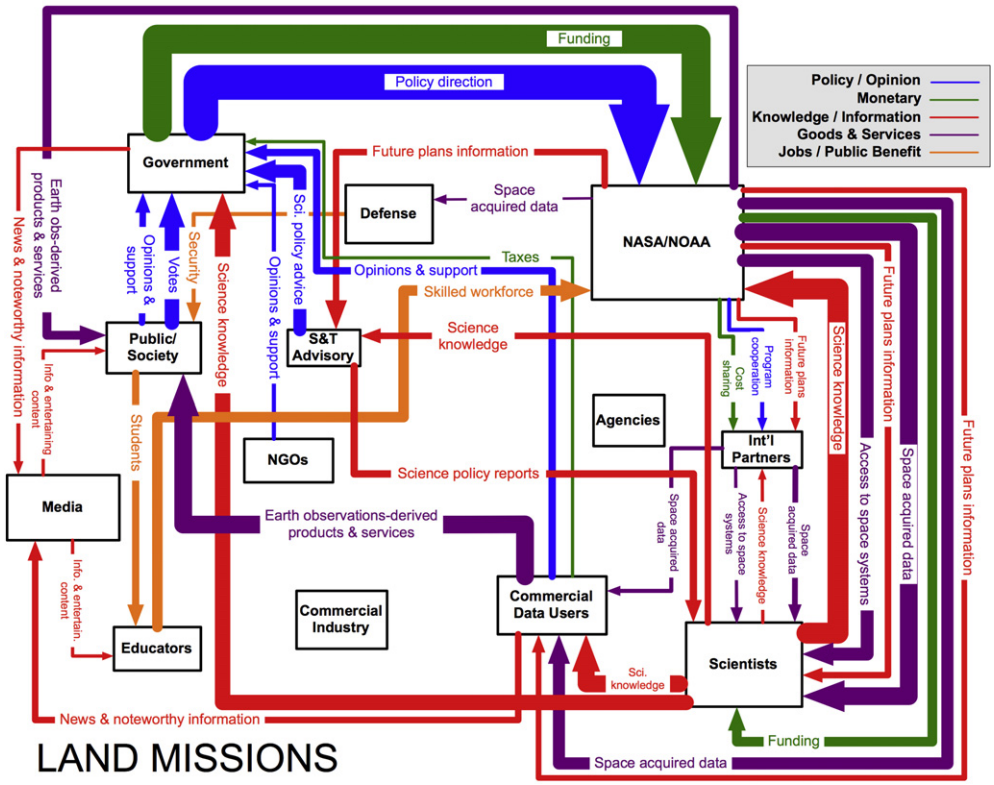

Fig. 7. Top value flows created by land-use missions.

Federal Agencies. The analysis provides an indication of NASA/NOAA's ability to affect each of its inputs by changing the level of its outputs. The lowest-scoring inputs were cost-sharing and collaborative efforts with Defense, International Partners, and Agencies—indicating an inherent difficult in the ability to increase the level of those inputs.

- *NASA/NOAA would reap greater benefits from collaboration with International Partners than it would with Defense or other Federal Agencies*. International Partners are uniquely suited to provide and receive value from collaborative efforts with NASA/NOAA. Because of the lack of high-value feedback loops, collaboration with Defense and Agencies offers less incentive to NASA/NOAA.

Table 6
Substantial differences in recommendations between decadal survey and stakeholder value network analysis.

Earth science decadal survey	Stakeholder value network analysis
Achieving the vision of the decadal survey:	
A formal interagency planning and review process should be put into place that focuses on effectively implementing the committee recommendations and sustaining and building the knowledge and information systems for the next decade and beyond. (pp. 3–16)	A science & technology advisory body should periodically review the status of the Earth Observation Program and should continually *reassess key assumptions* from the Decadal Survey. The advisory body should *use sophisticated stakeholder analysis and system architecture modeling tools* to recommend changes to the program based on the updated progress and key assumptions.
Assimilation and distribution of science measurements:	
As new Earth observation missions are developed, there must also be early attention to developing the requisite data processing and distribution system, and data archive. Distribution of data should be free or at low-cost to users, and provided in an easily-accessible manner. (pp. 3–10)	Distribution of data should be free for scientific and academic purposes. To take advantage of the emerging commercial uses for Earth observation data, NASA & NOAA should consider *innovative approaches to partnerships with commercial data users, including mission cost-sharing, development of new commercial markets for data, and commercial licensing agreements for data access*.

Additional recommendations from stakeholder value network analysis:

- *NASA & NOAA should prioritize cooperative efforts with International Partners over cooperation with the Department of Defense or other Federal Agencies*. Investing resources to cooperate with International Partners provides the strongest feedback loops to deliver value to the entire stakeholder network and return value to NASA & NOAA.
- *NASA & NOAA should seek some cooperation with other Federal Agencies for missions related to human health & security and solid Earth hazards & natural resources*. These missions return relatively less value to NASAA & NOAA than weather, climate change, and land-use missions. Partners for these missions might include USGS, Department of Energy, National Institutes of Health, Environmental Protection Agency, or Center for Disease Control.
- *NASA should provide funding and other resources to support the development of low-cost, reliable medium-lift launch vehicles by commercial industry*. The potential retirement of the Delta II launch vehicle and the excess cost of using larger launch vehicles are major issues currently facing NASA. A commercially available medium-lift launch vehicle would generate significant value to NASA/NOAA and the entire stakeholder network.
- *NASA & NOAA should investigate the use of marketing, branding or other means to inform recipients of knowledge and users of Earth observation-derived products and services that the information originated with NASA & NOAA Earth observation missions*. In long value chains involving multiple stakeholders, it may be difficult or impossible to know that a particular value flow is part of a chain that originated with an output from NASA & NOAA. Keeping the public, beneficiaries, and advocacy groups more aware of NASA & NOAA's programs will help increase public support for favorable policy direction and funding for NASA & NOAA in the future.

- *One of Commercial Industry's most important outputs is launch services to NASA/NOAA.* A commercially available medium-lift launch vehicle, at reasonable cost and high reliability, would generate significant value to NASA/NOAA and the entire stakeholder network.
- *NASA/NOAA's third most leveraged input is the flow of skilled workers from Educators, after policy direction and funding from the Government.* This ranks higher than science knowledge from Scientists, which is one of the primary benefits of the Earth Observation Program. This indicates that NASA/NOAA has a major role to play in using science knowledge to inspire students to pursue careers in science and engineering.
- *Weather and land-use missions provide roughly the same value as climate-related missions.* Weather, climate, and land-use missions provide the most value to the stakeholder network. Climate provides value primarily through the delivery of science knowledge to NASA/NOAA and the Government, while weather and land-use missions provide value primarily through the delivery of Earth observation-related products and services from Commercial Data Users to the Public. Because of this, Commercial Data Users have a potentially significant role to play in delivering value from weather and land-use missions.

Table 6 highlights two substantial differences in recommendations between this analysis and the Decadal Survey, as well as additional recommendations from the stakeholder value network analysis that were not mentioned in the Decadal Survey. Recommendations from the Decadal Survey include the page number from the report in parentheses. Suggested changes to the Decadal Survey recommendations are emphasized in bold.

7. Conclusions

The stakeholder analysis conducted in this paper provides a succinct description of the role of each major stakeholder in the Earth Observation Program, its most important contributions to the program, and the specific inputs and outputs that contribute the most value to the stakeholder network. This analysis is intended as a counter-point to the prioritization created by the Earth Science Decadal Survey, which did not merge the priorities of the science stakeholders with those of the non-science stakeholders. Additionally, this counter-point indicated the relative importance of each science category corresponding to the six science-themed Decadal Survey panels, which can be useful for prioritizing missions.

While this analysis produced a number of recommendations which are judged consistent with those of the Decadal Survey, it provides several results which are not consistent with it and which merit attention by Earth Observation Program planners. In particular, the analysis concludes that international partnerships represent a strong potential partner for certain science missions, representing greater potential value delivery than currently-prioritized efforts with defense stakeholders. Additionally, the analysis concludes that weather and land-use missions, in addition to climate missions, should be given highest priority; water, human health, and solid Earth missions should be given lower priority based on each science category's potential for delivering value to the entire stakeholder network. Finally, we suggest that the long and diffuse value delivery chains present in Earth Observation Programs represent an opportunity for greater brand leverage, particularly where end-products do not currently reflect the original satellite assets used.

References

[1] National Research Council (US). Earth science and applications from space: national imperatives for the next decade and beyond. Washington DC: National Academy Press; 2007.
[2] Harris R, Miller L. Earth observation and the public good. Space Policy 2011.
[3] Freeman RE. Strategic management: a stakeholder approach. Boston Pitman 1984.
[4] Mitchell RK, Agle BR, Wood DJ. Toward a theory of stakeholder identification and salience: defining the principle of who and what really counts. Academy of Management Review 1997:853–86.
[5] Baron DP. Integrated strategy: market and nonmarket components. California Management Review 1995;37:47–65.
[6] Handy C. The age of paradox. Harvard Business Press; 1994.
[7] Rowley TJ. Moving beyond dyadic ties: a network theory of stakeholder influences. Academy of Management Review 1997:887–910.
[8] Dyer JH, Nobeoka K. Creating and managing a high-performance knowledge-sharing network: the Toyota case. Strategic Management Journal 2000:345–67.
[9] Hardin G. The tragedy of the commons. Science 1968;162:1243–8.
[10] Albanese R, Fleet DD Van. Rational behavior in groups: the free-riding tendency. Academy of Management Review 1985:244–55.
[11] Homans GC, Schneider DM. Marriage, authority, and final causes: a study of unilateral cross-cousin marriage. Free Press; 1955.
[12] Rowley T, Behrens D, Krackhardt D. Redundant governance structures: an analysis of structural and relational embeddedness in the steel and semiconductor industries. Strategic Management Journal 2000:369–86.
[13] Kauffmann P, Unal R, Fernandez A, Keating C. A model for allocating resources to research programs by evaluating technical importance and research productivity. Engineering Management Journal-rolla 2000;12:5–8.
[14] Cameron BG, Crawley EF, Feng W, Lin M. Strategic decisions in complex stakeholder environments: a theory of generalized exchange. Engineering Management Journal 2011;23:37.
[15] Cameron BG, Seher T, Crawley EF. Goals for space exploration based on stakeholder value network considerations. Acta Astronautica 2010.
[16] Cameron BG, Crawley EF, Loureiro G, Rebentisch ES. Value flow mapping: using networks to inform stakeholder analysis. Acta Astronautica 2008;62:324–33.
[17] Fu F, Feng W, Li Z, Crawley EF, Ni W. A network-based modeling framework for stakeholder analysis of China's energy conservation campaign. Energy 2011.
[18] Onoda M. Satellite observation of greenhouse gases: Monitoring the climate change regime. Space Policy 2008;24:190–8.
[19] Macauley MK. Is the vision of the earth observation summit realizable? Space Policy 2005;21:29–39.
[20] The National Aeronautics and Space Act, as Amended; 1958.
[21] NASA. Science plan for NASA's science mission directorate 2007–2016; 2007.
[22] NASA, Department of Defense. Strategic plan for the U.S. integrated earth observation system; 2005.
[23] U.S. Climate Change Science Program. Our changing planet: the U.S. climate change science program for fiscal year 2008; 2007.
[24] CNA Corporation. National security and the threat of climate change; 2007.
[25] Polling Report Inc. Problems and priorities; 2008.
[26] Kingdon JW. Congressmen's voting decisions. University of Michigan Press; 1989.
[27] NASA. NPR 7123.1A: NASA systems engineering processes and requirements. Washington DC: NASA; 2007.
[28] Walden D. Kano's methods for understanding customer-defined quality. Center for Quality Management Journal 1993;2:3–36.
[29] Rowe G, Wright G. The Delphi technique as a forecasting tool: issues and analysis. International Journal of Forecasting 1999;15:353–75.
[30] Sandwell D, Smith WHF. Exploring the oceans basins with satellite altimetry data. National Geophysical Data Center; 2008.
[31] Insurers use satellite data to study risk. Associated Press; 2004.
[32] Tewksbury D. What do Americans really want to know? Tracking the behavior of news readers on the Internet. Journal of Communication 2003;53:694–710.
[33] Koo HYB. A meta-language for systems architecting. MIT; 2005.