Coordination Group for Meteorological Satellites

Socioeconomic Benefits Tiger Team (SETT)

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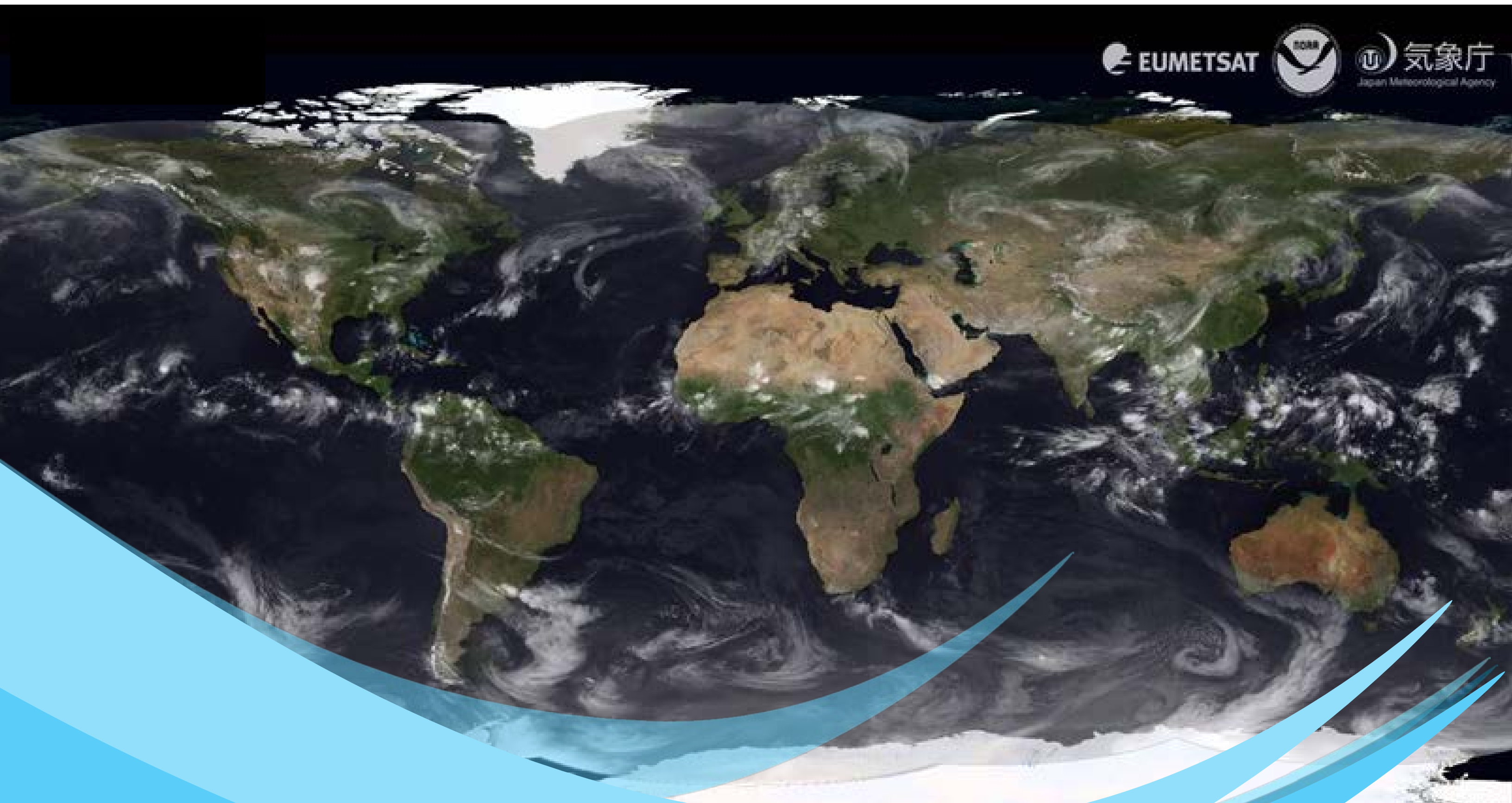
Valuing Meteorological Satellite Programs:
Guidelines for Socioeconomic Benefit Studies



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INTRODUCTION

CGMS established the Socioeconomic Benefits Tiger Team (SETT) to develop credible methodology and common terminology for articulating the socioeconomic benefit of satellite observing systems, and explore the most effective ways to communicate this information to desired stakeholders. The SETT developed this document to provide initial guidance to CGMS Members seeking to undertake a socioeconomic benefit study on a current or planned satellite system.

To that end, SETT members agreed this document must meet three key criteria to ensure its value for CGMS Members, specifically it must be:

- Brief;
- Specific to the challenges of measuring the benefits (quantitatively or qualitatively) of space-based observing instruments and/or systems; and
- General enough to address the range of motivations that may drive a CGMS member to undertake a socioeconomic benefit analysis.

The SETT recognized that most CGMS members would be contracting out their study. In order to guide the sponsor/agency in this process, the guidance document offers a structural construct for how to frame a SEB study, formulate the statement of work, choose methodology, assess one's resource requirements and communicate the study results. Also, insights into challenges typically experienced by study executors are explored. The provided guidance is derived from analyses of existing socioeconomic studies and meteorological and environmental satellite systems, from where the Team has taken note of lessons learned in addition to considering numerous other resources and primers on the subject.

This guidance document does not attempt to duplicate existing resources, but rather to highlight the most relevant aspects of those resources for CGMS members. In addition, several CGMS-relevant examples are examined to provide concrete examples from which CGMS members can learn.

1. CONTEXT

Prior to undertaking a socioeconomic benefit study, the sponsor must identify the drivers (motivation) of the study, the primary audience for the study, what questions face that audience and how they will use the study's results to make decisions. This context will inform the study question, needed resources including data, and any time constraints.

IDENTIFYING MOTIVATION/DRIVERS

There can be many motivations for a sponsor/satellite agency to value its activities through a "socioeconomic benefit" (SEB) study. The main driver is usually to provide a sound justification for planned activities, such as a future satellite programme, to policymakers, governing bodies, user communities, and the general public. Many CGMS members face increasing pressure to ensure that their resources are efficiently and effectively utilized. "Socioeconomic benefits" can be assessed in many ways, in both qualitative and quantitative terms, as outlined below.

Subject of an SEB study could be satellite datasets, instruments, missions, or programmes ("satellite assets"). Although benefit studies usually target planned assets, there can be value in estimating the benefit of past or present satellite assets, for example when the case for sustaining a series of satellites needs to be made. Indeed, planned assets are often evaluated using existing data as a proxy.

The Socioeconomic benefits of satellite assets can be expressed in terms of:

1. monetary value (to a national economy, economic sector, individual actor; includes both added value and avoided costs)
2. increased confidence and reduced error in satellite-based products (e.g., NWP forecast, ice charts)
3. ability to monitor compliance (e.g., with a global protocol, environmental regulation)
4. support to policy formulation and implementation (e.g. agricultural policy)
5. the value of a consistent, long-term data record for climate monitoring and prediction
6. national capacity and security
7. other sector-specific (e.g. energy industry) or anecdotal (i.e. unquantified) benefits

The value of partnerships between satellite operators (e.g., the NOAA-EUMETSAT Joint Polar System) can also be subject of study, for example to highlight the benefits of mutual back-up agreements and sharing of data.

Based on a survey of CGMS Members conducted in April 2015, the SETT identified three primary drivers for socioeconomic benefit studies for CGMS Members:

1. Evaluating the value of a future satellite programme for environmental monitoring and security,
2. Evaluating the societal benefit of a future polar-orbiting meteorological satellite, with a focus on its impact on numerical weather prediction capabilities, and
3. Evaluating the value of remote-sensing data to a specific application (e.g. volcanic ash advisories).

IDENTIFYING AUDIENCES

Knowing the intended audience also drives decisions about the analytical methodology and communication strategy for the study. Understanding the audience for the study and how they may use the study results to make decisions will help CGMS members in framing the study question, and in estimating the appropriate level of resource allocation and the time frame for the study. Figure 1 provides an overview the possible interests of particular audiences in the results of a SEB study on a CGMS member asset/programme. For example, depending on the political context, an audience may be more receptive to a study on the benefits of satellite assets for disaster risk reduction than for understanding climate change impacts.

Figure 1. Primary audiences for socioeconomic benefit studies for the three key questions facing CGMS members as identified by the CGMS SETT poll conducted in April 2015

Audiences	*Purposes*		
	Evaluating a future satellite programme for environmental monitoring and security	*Evaluating the societal benefit of a future polar-orbiting meteorological satellite, with focus on its impact on NWP*	*Evaluating the value of remote-sensing data to a specific application*
Political (ministry, treasury, boards of directors, etc.)	✓	✓	
Technical (Agency Leadership)	✓	✓	✓
User communities			✓

2. Framing an SEB study

Framing the SEB study is critical to its success. First, it is essential to understand the existing or anticipate change(s) in satellite-derived information you anticipate (e.g. improved spatial, spectral or temporal resolution), how that change will enhance an information product used for decision-making and the baseline against which change is measured (e.g., existing satellite system versus no satellite system). In particular, success depends on the ability to understand and to articulate how the satellite-derived information product is used, and how that use impacts the outcome relative to the identified baseline. Framing the SEB study correctly takes time and should be an iterative process between the satellite agency or study sponsor, the intended audience, and the contractor carrying out the study. A significant amount of time should be devoted to framing a study at the outset.

The following assumptions and parameters should be considered:

- Baseline (against which to evaluate benefits)
- Timeframe over which benefits accrue
- Geographic area where benefits accrue
- Information value chain (where do benefits accrue)
- Methodology to establish impact (see below)
- Bottom-up vs. top-down approach: to what extent is scaling possible (over time, area, case-to-sector)
- Context (is the value of a satellite asset estimated while considering other Earth observation assets, or standalone?)
- Availability of socioeconomic data (for example, what percentage of a national economy (GDP) is "weather-sensitive"; are ship tracks available to assess the value of more precise ice charts?)
- Data policy (e.g., are there limitations on data value due to availability constraints?)

In addition, several questions can help determine whether the SEB proposal has the attributes of a strong study, including:

- Are you relying on original research (primary) or an analysis of previous research (secondary), with primary studies considered the stronger of the two?
- Is the economic model generalizable enough to be useful in other contexts?
- If an empirical analysis is proposed, do sufficient data exist to support it?
- Is the case study meant to inform a near-term decision? If so, that may adversely impact the timeline and scope of the SEB study, may lead to overly simplified results, or lead to inappropriate application of the results.
- Can the study be simplified through a set of tenable, defensible assumptions, and can it be subjected to a sensitivity test(s)?

IDENTIFYING IMPACTS TO MEASURE

As part of the framing of a SEB study, the agency must determine which impacts to measure and which impacts will best meet the agency's goals in undertaking the study and resonate most effectively with the intended audience.

Measuring impact in terms of monetary value will resonate most effectively with funding agencies while an non-monetary assessment of the value in terms of product improvements (e.g. forecast accuracy; national sovereignty and defense) may satisfy technical agency leadership (e.g. Directors of National Meteorological and Hydrological Services) or the policy level. It is worth noting that quantifying the monetary value of a meteorological satellite asset will likely depend on determining the impact on products derived from satellite data.

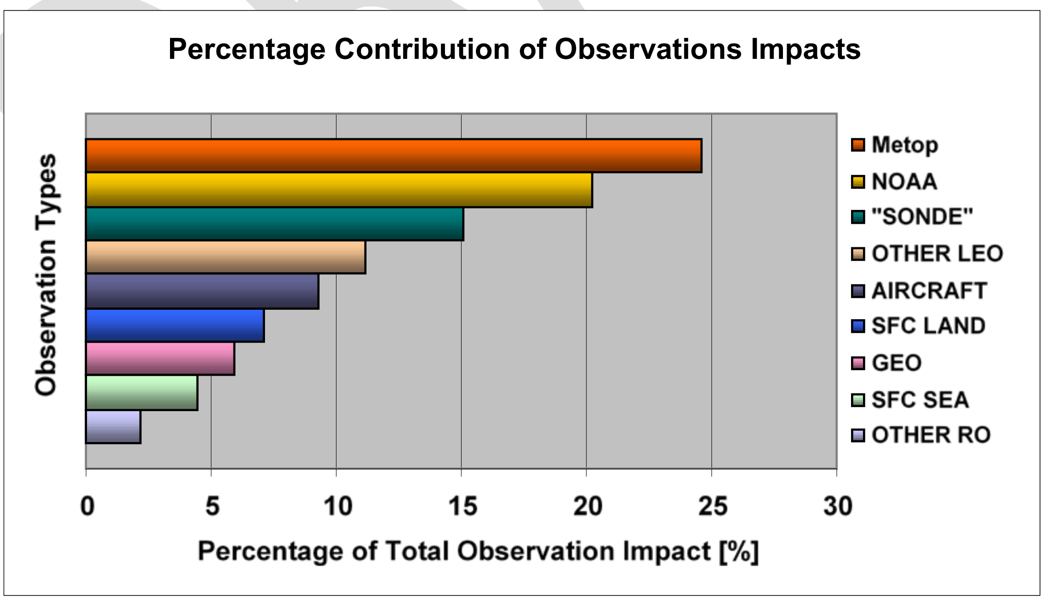


FIGURE 2: The impact of EUMETSAT Metop and other satellite data within the UK Met Office global NWP system using the adjoint-based forecast sensitivity to observations (FSO) method (Joo, Eyre and Marriott, Monthly Weather Review, 141, 3331–3342, 2013). "SONDE": radiosondes; "AIRCRAFT": airborne data; "SFC

LAND”: surface-based data over land; “SFC SEA”: surface-based data over oceans; “OTHER RO”: data derived from radio-occultation.

Numerical Weather Prediction Example: Understanding relative impact of satellite observations is crucial. The WMO and the operational agencies are placing great efforts in using Observing System Experiments (OSE) to understand the role of satellite observations in the context of all observing systems and their relative impact on NWP. Forecast Sensitivity to Observations (FSO) is a metric to estimate this relative impact (See Figure 2). Analysts can use this information to extrapolate the socioeconomic benefits derived from a particular observing system. For example, an indicative “impact per cost” ranking can be generated by dividing the impact by the estimated annual cost for an observing system.

Resource Availability

The value of perfect information may not be worth the cost of acquisition. Cost-benefit analyses can be time-consuming and may become increasing costly to conduct as you move down the value chain toward service delivery (See Figure 3). A decision about the scope and methodology of a proposed study must factor in the cost of conducting the study. Resources here imply money, time, data, and expertise.

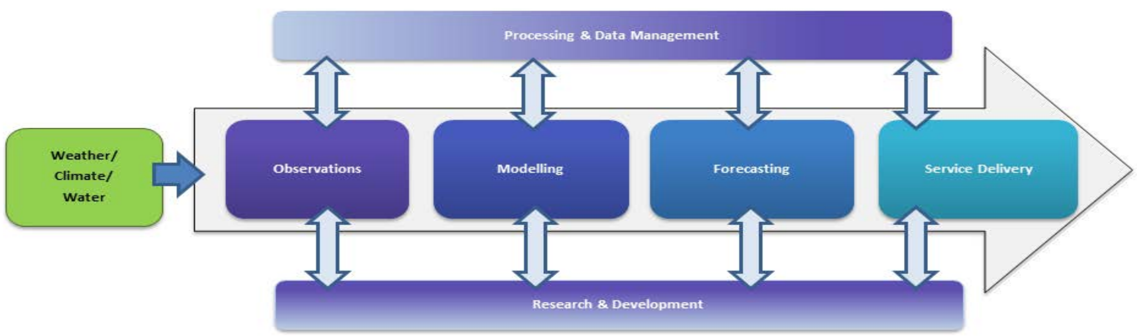


Figure 3: Service production and delivery of weather-climate-water services follows a value chain (WMO, 2015).

Study planning should examine the need for ancillary data, and determine if the data needed to undertake a socioeconomic study is publicly available or commercially restricted. Building relationships with user communities can help facilitate access to ancillary data sets. For example, calculating the costs attributable to Volcanic Ash Advisories requires data from the airline industry, and estimating the contribution of Earth observation to a Malaria Early Warning System requires access to public health data. Developing relationships with end users are an important aspect of planning and completing a study.

The most robust studies bring together experts from across the physical and social sciences over the lifetime of the project allowing for repeat analyses, and recalculation of benefits. For example, undertaking a socioeconomic analysis of the value of Earth observation information to a Malaria Early Warning System (MEWS) in Botswana required a breadth of expertise – including social scientists and public health experts.

3. Methodologies

Social scientists, including economists, have a number of methodologies that can be used to value. Framing the study will help explain the logical connections between the satellite assets and socioeconomic benefits, and guide a determination of which methodology(s) are most appropriate for the purpose and audience. End user engagement must inform the selected methodology because understanding the value in use of an observation or satellite asset requires a demonstration of how and why the data is a component in decision-making.

Understanding the available data, resources and timeline may also drive the selection of a methodology. It is worth noting many of the existing analyses are benchmarking studies even if they are not formal identified as such. Benchmarking is often preferred as a quick method for providing a general value (e.g. GDP X 1[1]% X [% of economy sensitive to weather] = Value) Primary studies (e.g. value of benefits-transfer studies) take more time and resources; however, they are more specific and defensible.

Choosing a Quantitative or Qualitative Approach

While a quantitative approach may be more convincing for many audiences, there are caveats. When employing a quantitative approach, the sponsor must ensure the analysis is sufficiently rigorous to withstand scrutiny by economists and social scientists. In addition, sponsors of quantitative studies must balance the need for economic rigor with the ability to represent the full value of a system or satellite asset recognizing conservative estimates of benefits may lead to undervaluing of the data or products.

Some common methodologies are defined below and in Figure 4.

Figure 4. Socioeconomic Impact Assessment Methods[2]

Approach	Focus	Considerations
Impact Assessment		
Time-Series/ Statistical Analysis	Comparing historical trends before and after project completion	Retrospective; based primarily on objective data; therefore data-intensive and dependent upon availability of data
Expert Opinion	Using expert judgment or prior analyses to estimate project impacts	Can be retrospective or prospective; feasible in situations with limited data, but based on subjective or proxy data
Value of Information	Analyzing decisions under uncertainty with and without information from project	Usually prospective; requires availability and cooperation of decision maker; mix of subjective and objective basis
Cost-Based Assessment		
Benefit-Cost Analysis	Comparing monetized impacts with financial costs of project	Allows financial comparison of projects with different objectives; requires both impact and cost analyses; monetizing impacts can be difficult and controversial

[1] Note: 1% value of information

[2] Derived from *Measuring Socioeconomic Impacts of Earth Observations: A Primer* published by NASA

Cost-Effectiveness Analysis	Comparing costs of achieving desired impacts	Allows financial comparison of projects with similar objectives; requires both impact and cost analyses; does not require monetizing impacts
Impact Monetization		
Market Valuation	Using prices paid in open markets for goods and services related to project impacts	Objective; requires market data; applicable only if markets exist for goods and services related to the project impact
Standards-Based Valuation	Using standardized prices from government or industry for project impacts in lieu of market data	Can be controversial, depending on standardizing source; simplifies monetization process; available for only a limited number of impacts
Benefits Transfer from Prior Research	Adapting existing studies to monetize impacts similar to those from the project	Can be controversial, depending on relative similarity of project benefits to those in prior research
Stated Preferences Valuation	Using surveys, augmented by analysis, to estimate stakeholders' willingness to pay for project impacts (e.g., conjoint analysis)	Tendency for biased responses by stakeholders who are only conceptually spending money for the impacts; requires survey development and analysis
Revealed Preferences Valuation	Using stakeholder behavior to estimate willingness to pay for project impacts (e.g., travel cost analysis, hedonic analysis)	Based on actual behavior rather than conceptual surveys; relationship between priced item and project impact may be indirect and thus controversial

Avoided cost method: A valuation method that assesses actual or imputed costs for preventing environmental deterioration by alternative production and consumption processes, or by the reduction of or abstention from economic activities (OECD, 2008); for example, measuring the benefits of reduced air pollution by assessing the cost of installing indoor air purifiers.

Benefit–cost analysis: The quantification of the total social costs and social benefits of a policy or a project, usually in money terms. The costs and benefits concerned include not only direct pecuniary costs and benefits, but also externalities, meaning external effects not traded in markets. These include external costs, for example, pollution, noise and disturbance to wildlife, and external benefits such as reductions in travelling time or traffic accidents. Benefit–cost analysis is often used to compare alternative proposals. If the total social benefits of an activity exceed total social costs, this can justify subsidizing projects that are not privately profitable. If the total social costs exceed total social benefits, this can justify preventing projects even when these would be privately profitable (Black et al., 2012; from cost–benefit analysis).

Benefit transfer: Transferring benefit estimates developed in one context to another context as a substitute for developing entirely new estimates (Tietenberg and Lewis, 2009).

Market Values: There may be a "market value" for the impact quantities under study. That is, people may have bought or sold items that are used to quantify impacts. For example, if the impacts are increased agricultural yields, the prices paid for the agricultural products in relevant markets (such as local retail purchases or international commodities markets) can be used to place a market value on the increased yields. (NASA Primer)

Government or International Agency Standard Monetary Equivalents: Some governments and international agencies have established standard monetary values for impact quantities under analysis. The U.S. DOT cost per minute for traffic congestion is an example of this. As another example, some governments have developed a "value of a statistical life" to monetize mortality data. (NASA Primer)

Industry and Non-Governmental Organization Standard Monetary Equivalents: Some industries and non-governmental organizations have established standard monetary values for the unit under analysis. For example, there are often industry wage rate and standard costs for common operations that can be used. (NASA Primer)

Monetary Equivalence Estimates from the Literature: Socioeconomic impact analysis is a mature discipline. Previous analytic work has been done on many impacts of interest to develop reasonable conversion methods from physical to monetary terms. This work can be mined to develop simple conversion factors or methods. Some of these methods may include non-use approaches, which are discussed below. The adaption of existing studies to monetize similar, but not identical, benefits in new studies is known as benefits transfer. (NASA Primer)

Non Market Valuation: Stated-preference methods: Methods for valuating non-market goods and services in which respondents are directly asked about their willingness to pay (WTP) for a good or service, such as the preservation of a species. These methods can be direct (such as contingent valuation surveys) or indirect (such as contingent ranking or conjoint analysis) (Tietenberg and Lewis, 2009, p. 39).

Contingent valuation: A survey method used to ascertain WTP for services or environmental amenities (Tietenberg and Lewis, 2009).

Conjoint analysis: A survey-based technique that derives WTP by having respondents choose between alternate states of the world where each state of the world has a specified set of attributes and a price (Tietenberg and Lewis, 2009).

***Non Market Valuation: Revealed-preference methods*:** Methods for valuating non-market goods and services based on actual observable choices and from which actual resource values can be directly inferred. These methods can be direct (such as market prices or simulated markets) or indirect (such as travel costs and hedonic pricing) (Tietenberg and Lewis, 2009, p. 39).

Averting Behavior: Averting behavior techniques observe what an actor (individuals or organizations) do to protect themselves against threats and use information about these behaviors to infer the values for reducing risk. Averting behavior techniques are most often used

Hedonic pricing: The method of pricing a good for estimating the value of the individual characteristics that form the good. For example, a house would be seen as comprised of a number of rooms, a garden, and a location. The values of the characteristics are summed to derive a price for a good (Black et al., 2012).

COMMUNICATING STUDY RESULTS

It is imperative that SEB sponsors develop a strategy for communicating the results of the study to the relevant audiences in the most efficient and effective manner. The communications strategy requires messages tailored to the primary audience(s). Figure 5 provides some information on the communications opportunities and engagement options for various audiences.

The sponsors must able to communicate the results along with any underlying socioeconomic assumptions or limitations so that decision makers understand the findings and their context. It is important to state which factors are measured and which excluded as well as to state any assumptions.

Figure 5. [3]

Audience	Opportunities	Engagement Options
Political (ministry, treasury, boards of directors, and the like)	Governing decision makers are influential advocates for improved infrastructure and/or national policy priorities (e.g. "becoming a technological leader") Public fund investment decision makers are interested in service efficiency. An SEB study can help balance pressures to excessively commercialize Earth observations; it provides information on the overall economic benefits to society	- Finance ministry (use numbers, graphs, visuals; emphasize economic benefit) – Politicians with funding authority (executive or legislative officials) (use numbers, graphs, visuals, social media; emphasize economic benefit and value to the public to whom politicians may be accountable)
Technical [Agency leadership, National Meteorological & Hydrological Services (NMHs)]	NMHSs are influential users and advocates for continuing or improving services from meteorological satellites	WMO Other community meetings (e.g. AMS, EMS) or specially convened seminars Science funding agencies (formal presentations; emphasize Scientific benefit; also include economic benefits)
USER COMMUNITIES		
Regulators	Regulators review the NMHS service provisions, especially aviation	Partner with NMHS to communicate with relevant industry (e.g. Aviation industry) (Annual meetings or specially

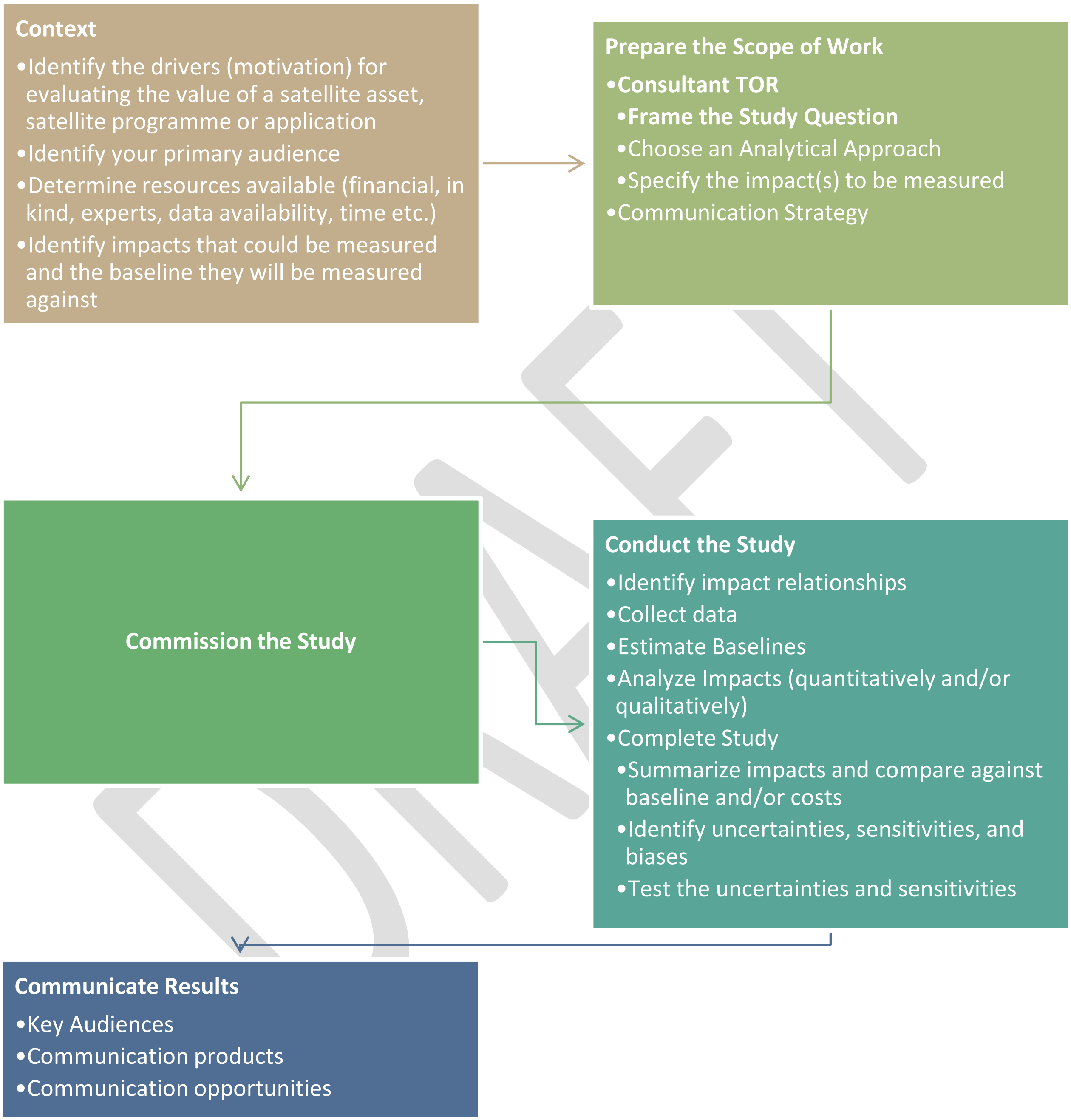
[3] Drawn from the WMO Publication No. 1153 "Valuing Weather & Climate: Economic Assessment of Meteorological and Hydrological Services"

		convened seminars; emphasize industry-specific benefits)
Service Users	Service users and taxpayers expect efficiency, so publicize realized benefits and potential benefits	Business leaders (Media, conferences, and professional clubs, publications in industry journals; emphasize return on investment, value to private sector)
Emergency Managers	Emergency managers have a strong interest in the resilience of weather services generally and in improved severe weather forecasts in particular. Their voice carries considerable weight with decision makers – especially investment in meteorological infrastructure	Emergency management users, Stakeholders (One-on-one meetings, conferences, and industry publications; emphasize forecast improvements)
Researchers/Academia	Scientists value continuity of data as well as increasing variety, quality, accuracy, resolution, and reliability of data	Scientific Conferences & workshops (formal presentations, journal articles, social media; emphasize scientific improvements)
Development Banks & other funding agencies	Development banks may support investment in Earth Observing technologies to facilitate applications (e.g. malaria early warning systems) that contribute to their goals	Project funders (formal presentations, journal publications, social media, third-party statements of value (e.g. user testimonial); emphasize economic benefit or enhanced efficiency of projects)

Liberally adapted from the WMO [WMO-No. 1153]

4. General Framework

Figure 3. Steps for Undertaking a Socioeconomic Benefit Study



Liberally adapted from the WMO [WMO-No. 1153]

5. Lessons Learned

Some space agency representatives with experience in commissioning SEB studies shared general experience with the authors of this document:

- SEB studies are an important contribution to secure public commitment to satellite assets
- SEB studies are necessary but not sufficient to secure satellite assets
- Often, the largest benefits accrue outside the constituency that pays for the assets (e.g., in developing countries; when monitoring the efficacy of global protocols such as the Montreal protocol)
- Often, the most realistic results are qualitative - but tend to be less convincing to audiences such as finance ministries
- The benefits of environmental/climate programmes mostly lie in avoided costs rather than wealth creation, job growth or competitiveness
- The audience often judges the credibility of a SEB study by those who perform the study (e.g., a large auditor firm) rather than by its content
- Very few SEB studies get published that show an asset is not “worth” funding.

APPENDIX A: KEY TERMINOLOGY

Every discipline has its own language. This Appendix provides a glossary of key terminology to assist CGMS members in understanding the language of economics and other related social sciences. These definitions have been compiled from the resources listed in Appendix E.

Baseline: A reference case, assuming no changes in historical trends, that can be compared to actual outcomes or impacts to measure changes due to both project outputs and confounding factors.

Benchmarking: A process in which a business evaluates its own operations (often specific procedures) by detailed comparison with those of another business (especially a competitor), in order to establish best practices and improve performance; the examination and emulation of other organizations' strengths (Oxford English Dictionary).

Benefit: A quantified gain of an action (Tietenberg and Lewis, 2009; from benefit–cost analysis).

Cost: The value of the inputs needed to produce any good or service, measured in some units or numeraire, generally money (Black et al., 2012).

Cost-effectiveness: The achievement of results in the most economical way. This approach assesses efficiency by checking whether resources are being used to produce any given results at the lowest possible cost. Cost-effectiveness is most relevant as a concept of efficiency in cases such as the provision of defence, education, health care, policing or environmental protection, where it is sometimes difficult to measure the monetary value of the results achieved (Black et al., 2012).

Demand: The desire and ability to acquire a good or service, or the quantity of a good or service that economic agents are willing to buy at a given price (Black et al., 2012).

Discounting: Placing a lower value on future receipts than on the present receipt of an equal sum. The fundamental reason for discounting the future is impatience: immediate consumption is preferred to delayed consumption (Black et al., 2012; from "discounting the future").

Expenditures: Spending, by consumers, investors or the government. Consumer expenditure is restricted to purchasing real goods and services; acquiring assets of making transfers to others by individuals does not count as expenditure. Government expenditure is treated differently; some government expenditure is on real goods and services, but government interest payments and transfer payments to individuals, such as pensions, are counted as government expenditure, and government spending is not clearly divided between current and capital account items, possibly because these are hard to distinguish. National expenditure is what a country spends (Black et al., 2012).

Impact: A positive or negative benefit.

Loss: The result of a business operation where expenditures exceed receipts. Business losses may arise internally, through failure to produce enough of anything the market will buy to cover production expenses, or externally, through failure of others to pay bills due, or to repay debts. (Black et al., 2012).

Tangible impact: A directly quantifiable impact. Example: Reduced timber losses due to more timely detection of wildfires.

Intangible impact: An impact that is difficult to quantify directly. Example: Attractiveness of a national park due to lower old-growth forest destruction from wildfires.

Macroeconomics: The macro aspects of economics, concerning the determination of aggregate quantities in the economy. Macroeconomics considers what determines total employment and production, consumption, investment in raising productive capacity, and how much a country imports and exports. It also asks what causes booms and slumps in the short run, and what determines the long-term growth rate of the economy, the general level of prices, and the rate of inflation. Macroeconomics considers how these matters can and should be influenced by government through monetary and fiscal policies (Black et al., 2012).

Marginal benefit: The additional benefit from an increase in an activity. This is the addition to total benefit resulting from a unit increase if it varies discretely, or the addition to total benefit per unit of the increase, if it varies continuously. Marginal private benefit is marginal benefit accruing to the person or firm deciding on the scale of the activity, excluding any external benefits; marginal social benefit includes external benefits as well as private benefits accruing to the decision taker (Black et al., 2012).

Marginal cost: The additional cost from an increase in an activity. This is the addition to total cost resulting from a unit increase in output if it varies discretely, or the addition to total cost per unit of the increase, if it varies continuously. Marginal cost may be short run, when only some inputs can be changed, or long run, when all inputs can be adjusted. Marginal private cost is marginal cost falling on the person or firm deciding on the scale of the activity, excluding any external costs; marginal social cost includes external costs as well as private cost falling on the decision maker (Black et al., 2012).

Market: A market is any medium that allows providers and consumers for the exchange of goods and services to interact to facilitate an exchange. A market can be physical or virtual. The cost applied to the exchange may be defined or goods/services may be exchanged for free. Markets may be regulated with price established by a government entity or "free" wherein price is determined by supply and demand.

Microeconomics: The micro aspects of economics, concerning the decision making of individuals. Microeconomics analyses the choices of consumers (who can be individuals or households) and firms in a variety of market situations. Its aim is to explore how choices should be made, and to provide an explanation of the choices that are made. Microeconomics also considers economics composed of individual decision makers, and studies the existence and properties of economic equilibrium. The effect of government choices upon consumers and firms is also analysed, with the aim of understanding economic policy (Black et al., 2012).

Monetized impact: An impact that has been converted into the equivalent amount of money. This usually represents the maximum amount of money that a person or group would be willing to pay to obtain or avoid the impact.

Monte Carlo method: A method of investigating the behaviour of economic models which are too complicated for analytical solutions to be possible. A system is started off at a large number of initial positions chosen at random, and followed through a numerical simulation to see how it evolves. Monte Carlo methods can be used to check whether a system has an equilibrium, and whether this is stable for any starting point, or some limited region of possible starting points (Black et al., 2012).

Net benefits: The excess of benefits over costs resulting from some allocation (Tietenberg and Lewis, 2009).

Net present value: The present value of a security or an investment project, found by discounting all present and future receipts and outgoings at an appropriate rate of discount (see discount rate). If the NPV calculated is positive, it is worthwhile investing in a project (Black et al., 2012).

Non-excludability: A property of a good or service that exists when no individual or group can be excluded from enjoying the benefits that good or service may confer, whether they contribute to its provision or not (Tietenberg and Lewis, 2009).

Non-market goods and services: Goods and services not distributed through markets (Black et al., 2012, from "non-marketed economic activities"), for example, clean air and water, scenic vistas and beach visits.

Non-market valuation: The economic valuation of goods and services not distributed through markets (Black et al., 2012; from "non-marketed economic activities"). Methods can be based on either revealed-preference or stated-preference methods, and assessed either directly or indirectly.

Non-rivalry: A property of a good or service that exists when consumption by one consumer does not reduce the quantity available for consumption by any other (Black et al., 2012; from "public good").

Opportunity cost: The cost of something in terms of an opportunity forgone. Opportunity cost is given by the benefits that could have been obtained by choosing the best alternative opportunity. For example, for a farmer the opportunity cost of growing wheat is given by what they would have earned if they had grown barley, assuming barley is the best alternative (Black et al., 2012).

Pareto efficiency: A form of efficiency for an economic allocation. An allocation is Pareto efficient if there is no feasible reallocation that can raise the welfare of one economic agent without lowering the welfare of any other economic agent. The concept of Pareto efficiency can be applied to any economic allocation whether it emerges from trade, bargaining, strategic interaction, or government imposition (Black et al., 2012).

Present value: The value today of a future payment, or stream of payments, discounted at some appropriate compound interest – or discount – rate (Downes and Goodman, 2010). See also discount rate.

Price elasticity: The ratio of a proportional change in quantity supplied or demanded to a proportional change in price. The price elasticity of supply is $Es = (p/q)(dq/dp)$, where p is price and q is quantity. The price elasticity of demand is often defined as $Ed = -(p/q)(dq/dp)$ so that it is positive, but the minus sign is not universally used (Black et al., 2012).

Proxy: A tangible quantity used to infer information about a related intangible impact. Example: Contributions to charities that work for species preservation might be a proxy for happiness due to biodiversity.

Public good: A good that no consumer can be excluded from using if it is supplied and for which consumption by one consumer does not reduce the quantity available for consumption by any other. The first property is referred to as non-excludability, whereas the latter is termed non-rivalry. As a consequence of these properties, public goods cause market failure (Black et al., 2012).

Social benefit: The total benefit from any activity. This includes benefits accruing directly to the person or firm conducting the activity, as well as external benefits outside the price system accruing to other people or firms (Black et al., 2012).

Socioeconomic: Concerning the use of resources belonging to a group of people.

Social welfare function: (a) The level of welfare in an economy or society expressed as a function of economic variables. Social welfare is expressed as a function of the aggregate consumption levels of goods. Alternatively, an individualistic social welfare function is a function of individual utility levels. (b) A process for aggregating individual preferences into social preferences (Black et al., 2012).

Supply: The amount of a good or service offered for sale. The supply function relates supply to the factors which determine its level. These include the price of the good, the prices of factor services and intermediate products employed in producing it, the number of firms engaged in producing it, and their levels of capital equipment (Black et al., 2012).

Trade-off: The requirement that some of one good or one objective has to be given up to obtain more of another. The need to trade off goods or objectives against one another is a sign of economic efficiency; if it is possible to get more of one good without accepting less of another, or to achieve one objective without sacrificing another, the economy is not Pareto efficient (Black et al., 2012).

Transaction costs: The costs incurred in undertaking an economic exchange. Practical examples of transaction costs include the commission paid to a stockbroker for completing a share deal, and the booking fee charged when purchasing concert tickets. The costs of travel and time to complete an exchange are also examples of transaction costs. The existence of transaction costs has been proposed as the explanation for many of the economic institutions that are observed. For example, it has been argued that production occurs in firms rather than through contracting via the market because this minimizes transaction costs. Transactions costs have also been used to explain why the market does not solve externality problems (Black et al., 2012).

Value added: The amount by which the value of information, services or goods is increased at each stage of its production (Oxford English Dictionary).

Value chain: The process or activities by which value is added to information, services or goods, from production to final use or consumption (Stevenson and Waite, 2011).

Value of information: The value of the outcome of action taken with the information less its value without the information (West and Courtney, 1993, p. 230).

Willingness to pay: The maximum amount that an economic agent is willing to pay to acquire a specific good or service. The WTP is private information but may be obtained using revealed-preference methods or stated-preference methods (Black et al., 2012).

APPENDIX B: EXAMPLES

B.1 SOCIO-ECONOMIC BENEFITS ANALYSIS OF GMES

DATE OF COMPLETION: 2006
COMMISSIONED BY: European Space Agency, in close consultation with the Directorate General for Enterprise & Industry of the European Commission
AUTHORED BY: Price Waterhouse Coopers

Principal Audience: Policy Level

Study Description: Assessing the prospective benefit of a European GMES (now Copernicus); The Global Monitoring for Environment and Security (GMES) programme [now: Copernicus] is a joint initiative of the European Commission (EC), the European Space Agency (ESA), and European Member States. It is intended to provide autonomous and operational information tools required by European environment and security policies. It will also be the main European contribution to the implementation of Global Earth Observation System of Systems (GEOSS) international cooperative effort to improve the monitoring and management of our global environment.

GMES represents a significant investment. Therefore, the EC and ESA Member States recommended that a review of the resulting socio-economic impacts should be conducted. A consortium led by PricewaterhouseCoopers was awarded a contract to study GMES impacts and benefits. The study has assessed qualitative and quantitative impacts of GMES, and has characterised and - where possible – quantified the resulting benefits. The assessment of GMES implementation costs did not fall within the scope of this study.

The main objectives of the study were:

- To determine the extent of the impact resulting from GMES with respect to a reference baseline
- To characterise the benefits resulting from GMES with respect to the strategic and political dimension, and to the economic and social dimension

Study Questions and Assumptions:

- *Timeframe over which benefits were considered: 2006-2030*
- *Geographic area where benefits were considered: Europe; Global*
- *Results discounted at 4%/annum*

Principal Findings / Benefits*:*

- *Policy formulation in Europe (15b€ accumulated)*
- *Global action formulation and implementation (climate, desertification, development aid, humanitarian response, resource management) (120b€ accumulated)*
- *Efficiency gains in applying current policy (3b€ accumulated)*
- *European economy (potentially 0.2% of annual EU GDP)*
- *Strategic*

Methods:

Four steps:

1. *Determine policy context*
2. *Develop counterfactual baseline ("without GMES" scenario)*

3. *Develop a "with GMES" scenario*
4. *Quantify benefits enabled by GMES, through*
    - *Expert and stakeholder elicitation*
    - *Use of sector-specific indicators of value*
    - *Quantitative analysis of macro-benefits and micro-economic efficiency savings*

Lessons learned:

The analysis of the inputs obtained from an extensive stakeholder consultation indicated that GMES would enable benefits significantly in excess of the levels of investment currently being discussed. These benefits are of a public good nature and relate to the opportunity to make significant cost savings over the next 25 years and beyond.

The three main categories of benefit (Efficiency gains; Policy formulation; Global action) have important implications for rolling out GMES. The most significant economic benefits are associated with the use of GMES information in achieving international cooperation in areas such as climate change mitigation, reduced deforestation and improved management of land degradation. However, these benefits will not be realised until 2025 due to the timescales implicit in setting up such policies. At the other end of the spectrum, some relatively modest (but still worthwhile) economic benefits can be achieved almost immediately with very little additional requirements on the capacity to deliver new information services.

This indicates elements of an implementation strategy that should look to provide a short term response to support the potential efficiency gains related to monitoring and reporting for current policies while progressively expanding the service portfolio to ensure that the information required by Europe to support its global role is available at the appropriate time. This gives time to ensure appropriate mechanisms are put in place to ensure that the benefits of these new European and international policies can deliver the expected benefits and impacts.

Finally, many of the benefits cited are dependent on the capacity that GMES brings to improve forecast information integrating diverse models and data streams. This is a significant added value that GMES brings over systems currently in place or under development today. It is clear that to ensure that the benefits in these areas (e.g. climate change, air quality, risk and civil protection, humanitarian aid), it is essential that GMES progresses as a truly integrated evolution of the four components. Many of the investments underpinning the developments of these components (in particular in-situ data sets, models and data assimilation, databases and decision support systems) are presently financed at national level. Continued coordination of these investments with the GMES components financed at European level must therefore be ensured.

B.2 Cost-Benefit Analysis for GMES

Date of Completion: 2011
Commissioned by: Directorate General for Enterprise & Industry of the European Commission
Authored By: Booz & Co.

Principal Audience: Policy Level

Study Description: The study undertook a cost-benefit analysis of the GMES programme. The main focus of this study is the assessment of four broad funding options for GMES and its operational services.

- *Option A (Baseline option): augment pre-2014 investments by small amount, no new investments as part of GMES, and no long-term service availability guarantee*

- *Option B (Baseline option extended): in addition to investments in A, recurrent duplicates of the Sentinel missions are built, launched and operated; no upgrade or expansion of other space infrastructure; no long-term service availability guarantee*
- *Option C (Partial continuity): in addition to option B, upgrades and long-term availability of the Sentinel space component guaranteed; limited support for continued data from GMES Contributing missions; no upgrade or expansion of infrastructure for meeting new requirements; EU to increase its investment in the in-situ component of GMES*
- *Option D (Full continuity): in addition to option C, EU to assure long-term availability of all significant data to meet its strategic objectives, through replacing Contributing missions by Sentinels, or by supporting the continuation of Contributing missions; no upgrade or expansion of infrastructure for meeting new requirements; EU to increase its investment in the in-situ component of GMES*

In carrying out this exercise, it is important to bear in mind that GMES represents a unique public investment programme which is designed to support a wide array of public policy objectives. To capture benefits across all of those objectives, the authors have developed a strategic evaluation framework. This framework is based on an understanding of the space and EO sectors, and the role EO infrastructure plays in supporting the implementation of government policies aimed at better managing the environment and issues related to security. The study investigates the space, in-situ, and service elements of GMES, and their contribution to strategic priorities of the EU, such as addressing climate change, preserving biodiversity, improving air quality, responding to disasters, improved targeting of humanitarian aid and assistance, and compliance with the common agricultural policy. Benefits of GMES to the EU space sector and to wider economic development are also reviewed.

Study Questions and Assumptions:

- *Quantified assessment of the cost-benefit of four broad investment options for GMES and its operational services;*
- *Timeframe over which benefits were considered: 2014-2030*
- *Geographic area where benefits were considered: Europe; Global*
- *Results discounted at 4%/annum*

Principal Findings / Benefits*:*

- *Cumulative benefits of the four options (at 2010 prices):*
    - *Option A: -0.1b€*
    - *Option B: 10b€*
    - *Option C: 34.7b€*
    - *Option D: 52.3b€*
- *Strategic benefits (unquantified)*

Methods:

Cost-benefit analysis, based on:

- *Literature review on economic value of information*
- *Expert interviews*
- *Attribution of incremental improvements in outcomes/decision-making as a result of GMES investment options*
- *Sensitivity analysis (using Euro-GEOSS FeliX model) to assess uncertainty in results*

Lessons learned:

The study has confirmed through qualitative and quantitative analysis that GMES has the potential to be developed into a powerful tool for the EU. GMES enables the EU to engage positively at the global level, but also to work towards achieving EU-wide policy objectives. The quantified cost-benefit analysis assessed four broad funding options.

When comparing the four scenarios, Option D would provide the space and downstream sectors, including SMEs, with the highest practicable certainty of the supply of a wide range of EO data over the medium term. This is expected to provide the greatest opportunity to develop capabilities and competitiveness within the sector, including the widest range of services. This can support future industrial development and support competitiveness with non-EU competitors and firmly secure the EU EO sector in the longer term. In particular, it is important for businesses – and actors in general - to have sufficient confidence that investments are supported by a long term funding commitment on the EO side. If this is not in place, it is likely that benefit realisation could fall short of expectations, particularly in relation to realising benefits from climate change action. However, it remains clear that Option D requires the EU to make a substantial – and sustained - funding commitment over a long time period. Option D represents a significant step-change in commitment, and would establish GMES as a key tool to inform climate change mitigation and adaptation.

If the governance of GMES is addressed properly, it can also provide a strategic foundation for the EU developing GMES as a world-class, leading base for EO with a downstream sector that is growing to its potential. Given the sheer scale of investment involved, it would be in the best interests of the EU to maximise the potential return from this, and to take GMES from being partially dependent on a set of research and development projects delivering pilot and preoperational services, to a fully-fledged operational programme providing a valuable contribution to a wide range of public policy and private purposes. It can do this with a body that is empowered, strategically focused, user oriented and dynamic.

B.3 Volcanic Ash Advisories & Aviation Safety

Date of Completion: 2011
Commissioned by: NASA, Earth Science Division, Applied Sciences Program
Methodology: Impact Analysis

Principal Audience: NASA, NOAA, FAA, Airline Industry

Study Description: The case study uses a specific event—the eruption of Iceland's Eyjafjallajökull volcano in 2010—to assess the impact of the observations in avoided costs and losses. In a retrospective analysis, this example uses a combination of time-series and VOI approaches. This case also presents a prospective extrapolation for a global estimate of aver-age annual benefits to civil aviation.

Principal Question(s):

If better VAAC information and more reliable predictions on the location and movement of the volcanic ash clouds results in better decision making by air traffic control authorities and airlines regarding the closure of airspace, the cancellation of flights, and route adjustments, how much could airlines reduced revenue losses through more-targeted flight cancellations, and (b) avoid or reduce aircraft damages from better route adjustments and ash cloud avoidance.

Principal Finding(s):
Overall, the team estimated that use of the data following the Eyjafjallajökull eruption saved $24 million to $72 million in avoided revenue losses due to unnecessary delays and avoided aircraft damage costs. If the data had been used from the beginning of the eruption, the total potential impact in avoided losses and costs could have been around $200 million.

Methods:

- *Combined time series and VOI approach were used to determine how much the introduction of Aura data would reduce the uncertainty about the level of ash threat.*
- Two impact metrics: avoided revenue losses and avoided aircraft dam-ages.

Lessons Learned:

The number of potential impacts of a project may be large and may require prioritization for analysis. There were many different potential impacts for this project, including multiple benefits in terms of time and safety to both the traveling public and the airline operators. A full, comprehensive socioeconomic impact analysis would quantify each separately and add them together. Otherwise, if resources for the analysis are limited, analysts may be required to assess and prioritize the impacts so those that are most likely to be greatest in magnitude are addressed first. Additional analyses can be done in priority order until the resources are exhausted. In this case, the sum of the benefits analyzed would be a floor for the total benefits.

Historical data alone may not be sufficient to develop a single baseline case; it may be necessary and appropriate to examine multiple baselines. The historical record on volcanic ash events and the European regulators' past actions was somewhat limited. As such, the analytic team was constrained in making a strong supposition about how the regulators would have behaved in the absence of the Earth observations data—whether they would have reopened the airspace more quickly or more slowly. Thus, the analysis considered two different baseline cases, and it estimated the benefits in each case.

Impacts that accrue during infrequent events may be more difficult to estimate statistically than impacts that occur broadly in time. Time-series retroactive analyses typically require data series of reasonable lengths to generate baselines and make statistical inferences. Because of the relatively small number of major volcanic eruptions that influence air flight operations, the analytic team had to use several assumptions and proxies in the Eyjafjallajökull case to get sufficient information to complete the analysis.

Impacts during specific, infrequent events may not necessarily be representative of the steady state; impact analyses should consider the frequency of the event in conveying impacts appropriately to the audience. Events with the magnitude of Eyjafjallajökull are not common occurrences, yet they tend to occur at least every decade. Smaller eruptions and disruptions occur more frequently. For event-driven analyses, the impact assessment report should be upfront about the frequency of such events so that the audience is not misled. Where possible, the impact assessment should analyze and articulate the expected value for an annual basis (or appropriate timeframe) to indicate how representative the event's impacts are of the more routine, steady-state condition.

B.4 Socio-Economic Benefits of the PCW mission

Date of Completion: September 2012
Commissioned by: CSA
Authored By: Euroconsult North America

Study Description:

The study assessed the potential impacts that the Government of Canada would generate from the implementation of the Polar Communications and Weather (PCW) mission and its service components in three areas: high-capacity continuous communication services throughout the Canadian Arctic, continuous and frequent meteorological observations over Canadian northern territories, acquisition of continuous space-weather related observations to support scientific research and forecasting of space weather conditions.

Study Question and Assumptions:

- *Quantified assessment of the benefit of three missions of PCW (communications, meteorology, space weather)*
- *Two satellites flying, no on-orbit spare; design life of this initial constellation is 10 years*
- *Timeframe over which benefits were considered: 2017-2026*
- *Geographic area where benefits were considered: Canadian Arctic*

Principal Findings / Benefits*:*

- *Economic benefits of PCW communication services: CAD 108m, highlighting that PCW complements existing and future commercial solutions*
- *Mission strongly driven by national security and sovereignty considerations*
- *Direct economic benefits of the PCW meteorology services: CAD 245m, noting that access to real-time weather data in the region will develop public information and services for local businesses*
- *Indirect economic benefits of the PCW meteorology services: potentially CAD 540m, mainly through the contribution to meteorological services outside the Arctic region*
- *Driving factors for use of meteorological information in the Arctic in order of priority: knowledge / access to information, safety, business operations, quality of life, , security & sovereignty*
- *Benefits of PCW space weather services not valued quantitatively due to limited number of operational services and insufficient understanding of space weather effects; however, this mission's benefits lie in access to new information, support to research, and information to energy utility companies and satellite operators*
- *Major gaps identified include: local weather service, mobile broadband services; partial gaps include: fixed broadband services, air quality services (for scientific applications and operational users), national weather and climate change, narrowband services.*
-

Methods:

- *Gap analyses for satellite communications, meteorological, and space weather services in the Canadian Arctic; Assessment of PCW contribution to address the identified gaps*
- *Stakeholder consultation; assessment of future benefits and cost-benefit analysis; assessment methods were:*
    - *Communications: Willingness-to-pay, cost avoidance*
    - *Meteorology: Cost avoidance, value of information (using the 1% increase evaluation method proposed by Nordhaus (1986))*
- *Sensitivity analysis of benefits depending on PCW mission scenarios*
- *Market segmentation used for analysis: transport, energy, natural resources, science & research, local population, defense (each including public and commercial end users); with sub-segments such as maritime-land-aviation (for transport), oil & gas, mining (for energy) etc.*
-

Lessons Learned:

- *Meteorological services seen as an economic enabler, offering support to all sectors*
- *Recommendations from the study include:*

- *Implement a continuous monitoring of the Arctic region*
- *Create a committee on satellite services in the Arctic region*
- *Undertake an in-depth business case analysis for PCW*
- *Undertake a full cost benefit assessment of PCW*
- *Undertake focus studies on key vertical markets*
- *Clarify access to service by government departments*
- *Secure long-term support from the Canadian Department of National Defense*
- *Underline the strategic value of PCW*
- *Investigate cost optimization mechanisms*

APPENDIX C: SETT DOCUMENTATION LIST

European Commission Directorate-General for Enterprise & Industry (Prepared by Booz & Co): Cost-Benefit Analysis for GMES

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http://bit.ly/SpacePolicy_Brown2012

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http://bit.ly/USGS_ValueSatelliteImagery

USGS: An Economic Value of Remote-Sensing Information – Application to Agricultural Production and Maintaining Groundwater Quality. Professional Paper 1796, 2012
http://bit.ly/USGS_RemoteSensingApplication

WMO: "Observing System Studies: Cost Benefit Studies for Observing Systems" WMO Document CBS/OPAG-IOS/IPET-OSDE1/Doc 8.4 (03-12-2014)
http://bit.ly/WMO_CostBenefitStudies

WMO: Climate Exchange (case studies in GFCS across various application areas)
http://bit.ly/WMOClimateExchange

WMO Side Meeting Presentations, EUMETSAT 2014

- Alain Ratier: Socio-economic benefits of satellite data
- Lars Peter Riishojgaard: Cost-benefit analysis of satellite observing systems
- Stephan Bojinski: Raising the benefits of meteorological services and satellites

WMO: **TECO PART2: "Understanding and Communicating the Return on Investment through Basic Systems and Services**" CBS-15/Doc.8(1)

FROM NASA PRIMER (RESOURE) SOCIOECONOMIC BENEFITS ANALYSIS FLOW[4]

Choose analytic approach	•Prospective/Retrospective •Time-series/Expert Opinion/Value of Information (VOI)
Specify Impact Metrics	•Physical (e.g. mortality, biodiversity) •Financial (e.g. Net Present Value) •Tangible (e.g. property value)
Identify impact relationships	•From theory •Implied by data •including confounding variables (action or effect, other than the primary factor being analyzed, that might change the value of an impact metric (e.g. political change)
Collect Data	•Idenify •Normalize •Cleanse
Estimate Baselines	•Impacts in absence of project
Quantify Impacts	•Impacts due to project •Uncertainties •Sensitivities
Monetize Impacts (if able/desired)	•Market Valuation •Non-market Valuation
Report Results	•Monetized impacts •Non-monetized impacts •Uncertainties, and Sensitivities •Comparison with Costs

[4] Derived from *Measuring Socioeconomic Impacts of Earth Observations: A Primer* published by NASA