11.12 GOES-R COST/BENEFIT ANALYSIS

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1. INTRODUCTION

Approximately 20% of the United States economy, or two trillion dollars per year [Dutton], is weather sensitive. Each year, the U.S suffers billions of dollars in losses due to lost time; property and crop damage and lost lives due to weather and environmental conditions, e.g.,

- In the commercial aviation community, weather is responsible for approximately two-thirds of air carrier delays, a cost of $4 billion annually, $1.7 billion of which is *avoidable* [National Aeronautics and Space Administration (NASA), http://awin.larc.nasa.gov].
- In 1997, the Red River Floods caused more than $400 million in losses when the Red River rose several feet above projected levels [Disaster Information Task Force].
- In 2000, $9 billion in crop damage was incurred due to weather (e.g., floods, convective weather, winter storms, drought, and fire weather) [National Weather Service (NWS)].

However, some proportion of these losses is avoidable with improved environmental information, and some proportion of the improved environmental information is attributable to enhanced satellite technology and performance. Improvements in satellite performance that, for example, (1) result in the ability to better predict with increased lead time and accuracy, the location of severe weather manifestation; (2) provide increased temperature accuracy; (3) and offer improved monitoring of volcanic ash, can result in substantial economic benefits to a variety of public sectors. These economic benefits result from the ability of the data users to improve their operational decision-making. For example, airlines will make safer and more efficient routing decisions; the agricultural sector can make crop selection decisions and realize irrigation efficiencies; and, the utilities industries can improve the accuracy of their energy load forecasting decisions.

The National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) is developing the next-generation Geostationary Operational Environmental Satellites, Series R (GOES-R), which are expected to provide significant advances in earth coverage and weather and environmental information and prediction capabilities. Two of the key instruments within this GOES suite of sensors are the GOES-R Imager and Hyperspectral Environmental Sounder (HES). To provide a firm foundation for the formulation of instrument development and procurement budgets, NOAA initiated an analysis of the marginal cost and benefit differences (in economic terms) between continuation of instruments with similar performance to today's imager and sounder and the planned GOES-R imager and sounder. The benefits from improved data and products will not only be critical to the economic well being of our users but will further national interests such as homeland security and national well being. New instruments for the GOES-R series will need to be developed because the imagers and sounders in service from now through 2010 cannot be replicated due to obsolescence of key components. Off the shelf instruments with similar capabilities could be purchased but this would not allow us to incorporate any new technologies.

This paper will present the methodology used to establish the linkage from satellite performance improvements to product improvements to user operational decision making that results in economic benefits to each industry discussed. It will also present the results of three out of the eight case studies developed that represent a diversity of economic sectors in this country, including, agriculture, aviation, electric power, natural gas, recreational boating and trucking. Economic benefits are presented in annual savings ($2002) and discounted present value (representing the discounted benefits over the life of the program). All estimates presented are preliminary and will be updated as our research continues.

2. ANALYSIS OVERVIEW

In FY02, a study was initiated to estimate the marginal benefits obtained by using the planned GOES-R imager and sounder as the primary GOES-R weather sensors in place of technological equivalents to the current GOES imager and sounder. These benefits are net of the marginal costs of developing and acquiring the GOES-R imager and sounder. The marginal benefits are based on case studies that estimate economic changes (primarily cost reduction) due to the changes in the performance of the GOES-R imager and sounder. These benefits are those expected to be achieved over

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and above current or future benefits from the current imager and sounder or future instruments with the same performance as the current instruments.

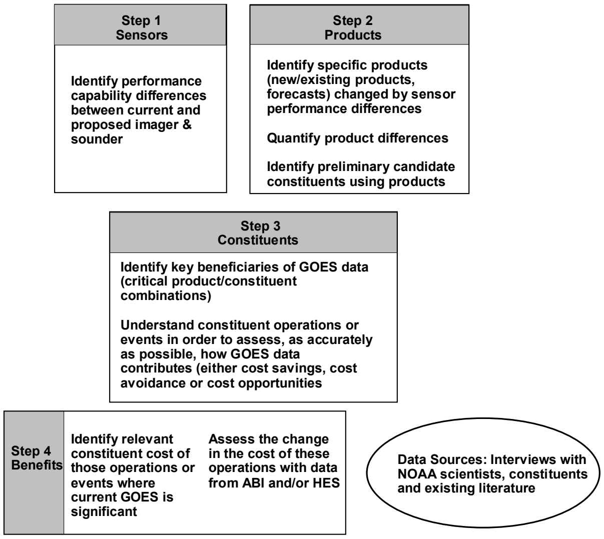
In general, changes in products using GOES-R imager and/or sounder data over current sensor data can be attributed to: (1) more frequent refresh rates; (2) finer horizontal resolution; and, (3) finer spectral resolution. More frequent updates provide valuable information on phenomena that change quickly, such as thunderstorm formation. A faster coverage rate also allows more regions to be scanned. Finer horizontal resolution allows for observation of phenomena of a smaller scale (usually of a few kilometers or less) with more accuracy. Finer spectral resolution allows scientists to observe phenomena that might not have been observable before (for example, super cooled water in clouds, or temperature inversions).

Benefits are received across a variety of application areas and by many individuals and organizations in the public and private sector. In general, benefits are derived from an improved ability to:

1. Predict when and where severe weather will manifest itself;
2. Predict farther in advance (increased lead time) when severe weather will occur;
3. Predict, with improved accuracy, the characteristics of severe weather initiation (e.g., temperature, humidity);
4. Observe phenomena more clearly, sooner, and with greater frequency from improved imagery;
5. Track weather more accurately, and observe the previously unobservable.

Figure 1 illustrates the overarching steps for the benefits analysis that are needed to identify marginal operational benefits resulting from and traceable to advanced GOES sensor technologies.

Ideally, the analysis should consider total expected benefits across <u>all</u> industries and applications. To put a perspective on the magnitude of the potential number of beneficiaries, consider the taxonomy in *Figure 2*. Notice that this taxonomy captures beneficiaries ranging from preventable loss of life and property on infrequent but catastrophic events to the general public benefiting in everyday decisions related to weather.



Step 1
Sensors
Identify performance capability differences between current and proposed imager & sounder

Step 2
Products
Identify specific products (new/existing products, forecasts) changed by sensor performance differences

Quantify product differences

Identify preliminary candidate constituents using products

Step 3
Constituents
Identify key beneficiaries of GOES data (critical product/constituent combinations)

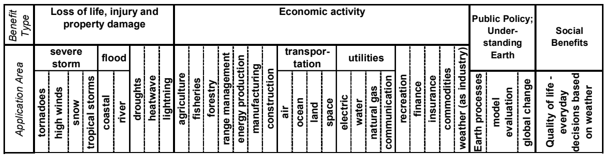
Understand constituent operations or events in order to assess, as accurately as possible, how GOES data contributes (either cost savings, cost avoidance or cost opportunities

Step 4
Benefits
Identify relevant constituent cost of those operations or events where current GOES is significant

Assess the change in the cost of these operations with data from ABI and/or HES

Data Sources: Interviews with NOAA scientists, constituents and existing literature

Figure 1. Steps of the Benefits Analysis Process



Benefit Type	Loss of life, injury and property damage									Economic activity																				Public Policy; Under-standing Earth			Social Benefits
Application Area	severe storm				flood		droughts	heatwave	lightning	agriculture	fisheries	forestry	range management	energy production	manufacturing	construction	transpor-tation				utilities				recreation	finance	insurance	commodities	weather (as industry)				
	tornadoes	high winds	snow	tropical storms	coastal	river											air	ocean	land	space	electric	water	natural gas	communication						Earth processes	model evaluation	global change	Quality of life - everyday decisions based on weather

Figure 2. Taxonomy of Benefits

3. CASE STUDY DEVELOPMENT PROCESS

During October 2001, NESDIS conducted studies to better identify users needs and benefits that would be accomplished with improved capabilities of the GOES sensors. In support of these studies, public meetings improvement that would be of great benefit to our users in the accomplishment of their missions or services. During these meetings, vital information on economic benefits was obtained through discussions held with constituents in the public and private sector. At each of the public meetings, GOES-R imager and sounder changes and potential product improvements (as a result of these changes)[1] were summarized. Three examples of these changes that were key to the development of our case studies are given in *Table 1*, below. Meeting participants were then asked to describe the economic impact or benefits of these changes/product improvements to their operations. This information was essential to our understanding of how GOES data is used and valued. Participants provided information on a variety of application areas including aviation, ocean shipping, electric power, agriculture, and benefits to weather value-added resellers.

3.1 Case Study Overview

Agriculture and electric power generation are believed to be two of the largest identifiable beneficiaries of improved sensor data, while airline routing and electric power are two of the industries best structured and motivated to use improved forecast information, since they already have extensive experience in profitably applying forecast information. The following sections

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[1] Based on the expert knowledge and judgement of NOAA/NESDIS/NWS and NASA engineering staff, scientists and product managers with whom twelve meetings were held.

Table 1. Sample Sensor Improvements

Product	Current Imager and Sounder	GOES-R imager and GOES-R sounder
1. Cloud Drift Winds	Cloud-drift (imager) wind speed has a root mean square error of about 3 m/sec (about 7 mph).	Increasing the frequency and spatial resolution of imager and sounder measurements could double the accuracy and density of wind-speed measurements. In addition, the GOES-R sounder with 5 per hour updates, and 1-2 km vertical resolution will permit timely assignment of water-vapor winds to 1-2 km elevation accuracy, a 3 to 5 fold increase in wind vector elevation data.
Water-vapor Winds	Sounder-based water-vapor winds are constrained by the low spatial resolution, limited geographic coverage, and infrequent update cycle (1 per hour). Sounder (water vapor) winds have a root mean square error of about 7.5 m/sec (17 mph).	
2. Volcanic Ash Advisory Statements	Current imagery accurately detects dense ash clouds in visible imagery, but has limited ability to detect attenuated ash. Eruptions and plumes that develop outside of CONUS may be missed due to infrequent update cycle.	GOES-R imagery will add an IR channel that will show attenuated ash plumes. The imagery will also be more able to see initial eruptions due to 5 to 15 minute update cycles. Small-scale eruptions will be more readily detected due to higher spatial resolution. More frequent, accurate assignment of winds to specific elevations (see cloud drift and water vapor winds above) will also allow the direction and speed of ash plume movement to be forecast much more reliably than today.
3. Vertical Temperature and Moisture Profiles	GOES sounder moisture profiles are key inputs into NWS forecast models and convective weather forecast products. Current horizontal resolution is 30 to 50 km; humidity accuracy 20 percent; temperature accuracy 2 deg. K. Vertical resolution is currently 3 km layers.	GOES-R sounder vertical and temperature profiles will be improved in horizontal resolution to 4 km (a factor improvement of 56-156 times); in humidity accuracy to 10 percent and temperature accuracy to 1 deg. K. Resolution will improve to 0.5 to 1 km layers.

present highlights of case studies for constituent operations and other applications that represent processes and data that are actually used in decision making, and where the significance of GOES data is identified.

3.2 Case Study 1: Convective Weather Products: Benefits to Aviation

3.2.1 Problem Statement

U.S. airlines/air-transport companies and FAA air traffic managers collaborate every day to set and modify flight plans intended to ensure that flights depart and arrive on schedule with a minimum of delays due to weather. Typically, dispatch decisions are made 1 hour to 5 hours in advance of take-off depending on the length of the flight. However, the initiation of severe convective weather, such as spring and summer thunderstorms, cannot be accurately predicted today. When these storms occur, they cause delays on the ground as flights are held or in the air as they are re-routed to avoid weather hazards. As these delays back up, flights are often diverted to different airports or cancelled.

Today, the best available 4- to 6-hour forecast product, the Collaborative Convective Forecast Product (CCFP), shows a large box within which storms have some probability of occurring. The lifted index product is currently the primary GOES sounder product, which is used to produce the CCFP. This box is typically several hundred miles long and often over 100 miles wide, resulting in a watch area typically 10,000 to 30,000 square miles or more. With advanced sounder data, according to NCEP, NASA, and NOAA's National Aviation Center (AWC) experts, forecasters looking 1 to 2 hours in advance will likely be able reduce the watch area significantly, by approximately 90 percent. This reduction in watch area will result in more efficient use of the air space by reducing flight delays. In addition, the greatly increased amount of information on the size and energy content of parcels of unstable air will enable forecasters to provide substantially more information about the intensity and rapidity of development of convective weather.

3.2.2 Benefits Calculation

This case study addresses the cost of delays that could have been *avoided* with better weather information from the advanced GOES sounder. The total number of delays for all traffic at U.S. airports in the year 2000 was 450,289, with 309,482, or approximately 69 percent, due to weather [Federal Aviation Administration (FAA), Operations System Network (OPSNET)]. An FAA aviation weather expert estimated that at least 50 percent, or 154,741, of these delays were due to convective weather. Furthermore, since the focus of this benefits study is on the impact to U.S. aviation only, it is conservatively estimated that 75 percent of the delays at U.S. airports impacts U.S. carriers. Thus, the number of delays due to weather and impacting U.S. carriers is estimated to be 116,056 in 2000. Given the potential to reduce convective weather watch areas by nearly 90 percent, it is reasonable to assume that a significant number of delays due to the over-extending of the watch area would be avoided. No research has been found to estimate this number, so for this analysis, a conservative 20 percent reduction was assumed. Although no study has been conducted to estimate the contributions of other sensor systems, the contribution of the advanced sounder is further reduced by half to allow for the potential contribution of improvements in other sensor systems. Delay costs are assumed to be the cost of operations of the airlines.

Table AV1A-1. Data Input Summary

Variable	Variable Description	Value
TD_{US}	Total delays for all traffic at U. S. airports	450,289
TD_{Wx}	Total delays due to weather	309,482
PD_{CWX}	Percentage delays due to Convective weather	50%
PD_{US}	Percentage of delays impacting US carriers	75%
PD_{RWA}	Percentage of delays avoided due to reduced watch area	20%
PD_{AS}	Percentage of delays avoided due to advanced sounder	50%
C_{PD}	Cost per 3/4 hour delay	$2,121

The weighted average of the delays by aircraft class is approximately $2,121 per ¾ hour (the average duration of a delay) in 2002 dollars, based on the proportion of delays experienced primarily by commercial (80 percent) and air taxi (16 percent) [FAA, 1998, Section 4]. *Table AV1A-1* summarizes these data.

Thus, the *number of avoidable delays attributed to the advanced sounder* is computed as:

$$TD_{Wx}*PDC_{Wx}*PD_{US}*PD_{RWA}*PD_{AS}=$$
$$309{,}482*0.5*0.75*0.2*0.5 = 11{,}606$$

and the annual cost of delay reductions due to the advanced sounder would be:

11,606 * $2,121 per ¾ hour/delay
= $24.6M in 2002 dollars with a discounted PV of $91.3M

3.3 Case Study 2: Volcanic Ash Advisories: Benefits to Aviation

3.3.1 Problem Statement

Aircraft must avoid airborne plumes of volcanic ash to avoid the risk of catastrophic failure of aircraft or costly damage to engines, instruments, and airframes. Ash plumes are usually undetectable by radar and are often invisible or indistinguishable from clouds. Today, according to experts from the AWC, the ability of the GOES imager to automatically and unambiguously detect ash plumes or differentiate ash from other environmental conditions is quite limited due to lack of data in certain spectral bands. There is no signature to automatically detect the sulfuric acid associated with volcanic ash. Other experts have said that the ash plumes are not detectable via the current GOES once they reach a certain degree of attenuation even though they are still hazardous. Also, the current GOES imager only collects data for areas outside the continental U.S. (CONUS) once every 30 minutes to an hour, and even longer during hurricane season when the GOES imaging is concentrated on that task. However, most of the active volcanic areas that threaten aviation are outside of CONUS. When ash does erupt from volcanoes, it often reaches flight altitudes in the normal cruising range for commercial aircraft, e.g., 25,000 to 40,000 feet, within minutes. As a result, with the current GOES imager, volcanic ash may not be detected at all, or may be detected 30 minutes or more after it poses a risk. Moreover, the current GOES sensors have limited ability to assign elevations to winds, hampering ability to determine which way a plume is moving or how quickly.

Aircraft ash warnings and advisories will be improved by the GOES R Series Advanced Baseline Imager (ABI) in several ways. First, the ABI will have an 8.5 micron channel that is highly sensitive to the sulfur dioxide component of ash plumes. This means that the ABI will provide data that will support the automatic and unambiguous detection of volcanic ash, even when it becomes attenuated or diluted in the atmosphere hundreds or thousands of miles from its source. Second, the ABI will gather data from active volcanoes much more frequently than the current GOES imager and should be able to detect eruptions within minutes after they occur. Thirdly, the ABI will have more detailed resolution and be able to detect small-scale eruptions that might not be visible with the coarser resolution of the current imager. Finally, the advanced sounder will provide three to five times the number of wind elevation readings, enabling much more accurate forecasts of the direction and speed of plume dispersion.

This case study addresses the cost savings associated with improved detection and avoidance by commercial aircraft. Note that, while sensors on NOAA's polar orbiting satellites are also capable of detecting ash plumes, these satellites do not revisit commercial airspace, even at high latitudes, often enough to detect ash eruptions and plumes before they reach flight altitudes. The ABI will be the only planned sensor system capable of detecting ash plumes within the time frame that they initially occur.

3.3.2 Benefits Calculation

3.3.2 .1 Avoided Repair Costs

Avoided repair costs are estimated using the following assumptions based on data from public sources and interviews with government and industry experts.

Avoided repair costs are based conservatively on historical data for damages incurred from in-flight encounters with ash. Aircraft damages from volcanic ash reported for 1982 to 2000 were approximately $313 M in 2002 dollars, by assuming a base year of 1991 (the midpoint of 1982 – 2000). This is probably an under-estimate of total costs since the cost of one encounter alone was about $80 M. Taking the average annual worldwide repair costs to be $16.5 M[2] we conservatively allocated one third to airspace within GOES coverage area. Experts at the National Centers for Environmental Prediction (NCEP) and AWC have said that the GOES R series ABI will be able to unambiguously detect concentrations of volcanic ash at flight levels that pose a hazard within 15 minutes of eruption. We conservatively assume that volcanic ash advisories based on GOES ABI will enable aircraft to avoid 50 percent of the ash they would otherwise encounter in the GOES coverage area. Annual benefit to U.S. and foreign flag carriers will therefore be about $2.75 M in 2002 dollars, computed as follows:

$16.5 M (avg. annual worldwide repair cost)
**** 1/3 (fraction of GOES coverage)***
**** 0.5 (proportion of ash avoidable due to ABI) =***
$2.75 M annually in
$2002

U.S. airlines accounted for about 50 percent of the flights to and from the U.S. in 2000 [United States Department of Commerce]. In this analysis, it is assumed that this proportion will persist during the full lifecycle (2012 to 2027) used in this report, and that this proportion applies to U.S. airlines flying to other countries in the GOES coverage area. Thus, the annual benefit to U.S. airlines is:

$2.75 M (annual benefit to all carriers)
**** 0.5 (proportion of US carriers)***
= $1.4 M annually in
$2002.

3.3.2.2 Avoided Risk of Aircraft Loss

According to the International Civil Aviation Organization (ICAO), approximately 77 jet aircraft have reported encounters worldwide with volcanic ash for the period 1980 to 2000 [International Civil Aviation Organization, Appendix I, Table 2]. On at least 4 occasions, large commercial jetliners temporarily lost sufficient engine power to maintain flight and were able to restart only after dropping to lower altitudes [International Civil Aviation Organization, Appendix I, Table 4]. As a result of these encounters, ICAO states that volcanic ash has the clear potential to cause a major aircraft accident [International Civil Aviation Organization, Foreword]. Thus, economic benefits can be realized through volcanic ash avoidance due to improved GOES detection capability. The computation of economic benefits is as follows:

1. The replacement cost of an average commercial aircraft is valued at $38.8 M ($2002) [Federal Aviation Administration, 1998, Table 5-1].
2. The estimated cost associated with passenger and crew loss is approximately $922 M computed as follows. Flights most likely to encounter volcanic ash are long haul, typically transoceanic flights utilizing a 747 class of aircraft. The 747 has a crew size of 12, an average capacity of 410 and a passenger load factor of 74.7 percent, resulting in an average passenger load of 410*74.7 percent =306 and a total load of 318 (i.e., 306 + 12) people. A proxy for the economic value of life lost from catastrophic aircraft failure is $2.9 M in $2002, or approximately $2.9*318 people = $922 M per lost aircraft. [FAA, OPSNET, 1998].
3. The expected number of annual aircraft losses (although none have been lost to date due to volcanic ash) is estimated by assuming that the 4 near fatal aircraft encounters with volcanic ash could have been lost over the 21 year period between 1980 and 2000. Thus, 4/21 = 0.19 represents the expected number of aircraft losses per year due to encounters with volcanic ash.
4. Assume that volcanic ash advisories based on GOES ABI will result in 50 percent of the losses being avoided.
5. Assume that fifty percent of the aircraft volcanic ash losses impact U.S. flag carriers.
6. Assume that one-third of the airspace is allocated to GOES coverage.

Consequently, the expected annual number of aircraft losses avoided by U.S. carriers due to improvements in GOES is:

(Expected aircraft losses per year)*(Proportion of losses avoided)*(Proportion of losses impacting U.S. flag carriers)*(Proportion of airspace allocated to GOES coverage) = 0.19*0.5*0.5*(1/3) = 0.0158

The total cost per aircraft loss is $38.8 M/aircraft + $922 M for loss of passengers and crew = $960.8 M.

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[2] ($313 M)/19 years = $16.5 M).

Therefore, the total economic annual benefit for U.S. carriers of volcanic ash avoidance due to GOES is:

0.0158 * $960.8 M = approximately $15.2M

Note that (1) there are some volcanoes whose eruptions are capable of rendering large portions of major transatlantic flight routes unsafe in which the traffic density may reach 100 flights per hour and (2) future long-haul aircraft passenger capacities are expected to increase. As a result, actual loss of life due to aircraft encounters with volcanic ash could be substantially higher than estimated here.

3.4 Case Study 3: Temperature Forecasts: Cost Savings to Electric Utilities

3.4.1 Problem Statement

Electric power is a substantial component of the U. S. Gross Domestic Product. Sales to U.S. consumers in 2000 totaled about 3,400 billion kilowatt hours with revenues from these sales approximately $228 B [United States Department of Energy, *Electric Power Annual 2000*]. Electricity generation costs are sensitive to uncertainty about short-term temperature changes and consumer demand based on temperature fluctuations. Therefore electric utilities typically have a portion of their generating capacity running in automatic generation control (AGC) and an additional portion in a stand-by mode known as spinning reserve [Hirst]. However, it is expensive to operate this spinning reserve and it is wasteful of energy. Running units under AGC also entails costs because the units may be forced to run at an output other than the optimal level, above or below the most efficient or economic output level [Utility].

When utility companies overestimate demand loads they incur costs associated with having more power production capability available or more purchased for use than needed. When the utility forecasts underestimate the actual demand, they typically have less capacity or purchase commitments available than needed to meet demand. When this happens, utilities have several options: they can increase the output of units that are already on-line, purchase additional power on the spot market, start up additional combustion (natural gas) turbines, or execute (disconnect) interruptible loads [Utility]. Each of these options has various costs associated with them.

Short-term temperature forecasts have average errors of about 3 degrees Celsius. GOES-R data on clouds, winds, and humidity are expected to reduce these *average error* rates by 25 percent. Utilities will then make more accurate short-term forecasts of load and reduce their operating reserve or make fewer (expensive) commitments on the spot-power market.

Power plant operators use a variety of forecasting and demand-estimation tools to try to anticipate the amount of electricity they will need to produce, purchase, or sell. However, forecasts of local and national hourly and daily loads are uncertain, due in part to uncertainty about ambient temperatures 3 hours in advance. Large utility operators have some ability to balance or average loads across their service areas. However, even a large, efficient independent service operator (ISO) such as PJM Interconnect that brokers, transmits and regulates power over large areas finds that its load forecasts are off by approximately 2.6 percent on average [PJM Interconnect Limited Liability Company (LLC)].

3.4.2 Benefits Calculation

The overall benefits calculation for savings to electric utilities is based on the reduction (due to GOES R Imager and Sounder) in the cost for expensive electricity production (using natural gas turbines, for example) when demand is overestimated plus expensive spot market purchases when demand is underestimated. *Table EP-1* summarizes the variables used in these computations.

Table EP-1 Benefits Computation Input

Variable	Variable Description	Value
TF_{err}	Temperature Forecast error (% of load forecast error)	40%
$T_{err}Red$	Temperature error reduction for 3-hour forecasts	25%
$AvLF_{err}$	Average load forecast error	2.60%
$TProd_{2000}$	Total electricity production (MWH) that was sold to consumers in 2000	3,413,000,000
CReg Serv	Cost of regulation service (per MWH)	$41.3

3.4.2.1 Step 1. Reduction of Electric Utility Load Forecast Error Due to GOES R Imager and Sounder.

Reducing temperature forecast error would reduce electric utility load forecast error. The operational manager of a large utility told us, based on a preliminary analysis, that temperature forecast error accounts for about 40 percent of the utility's average load forecast error. In addition, we take PJM Interconnect's average load forecast error of 2.6 percent (stated above) as typical of the national load forecast error rate. Experts at NCEP and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) consulted stated that errors in 3-hour temperature forecasts using data on clouds and winds from the GOES-R Imager and humidity profiles from the GOES-R Sounder should decrease by about 25 percent compared with 3-hour forecasts made using current GOES data. [Petersen, Schmit] These experts also said that the probability distribution of errors is expected to narrow with GOES R Imager and Sounder, thus increasing electric utilities' confidence in forecast accuracy. Taking 40 percent as the average national contribution of temperature forecast error to electric utility load forecast error, electric utilities' load forecast accuracy should increase by about one-quarter of a point computed as follows:

$$TFerr*T_{err}Red*AvLFerr = 0.4*0.25*0.026 = .0026 \text{ or } 0.26 \text{ percent}$$

That is, we estimate that an electric utility with an average 3-hour load forecast error that is 2.6 percent today would have an average load forecast error of 2.34 percent starting in 2015 due to improved temperature forecasts using data from GOES R Imager and Sounder. The total electricity production that was sold to consumers in 2000 was about 3,413,000,000 Megawatt Hours (MWH). If GOES R Imager and Sounder will reduce forecast load error by 0.26 percent, then the amount of production avoided is computed as:

$$TProd_{2000} * 0.0026 = 8{,}873{,}800 \text{ MWH}$$

3.4.2.2 Step 2. Unit Price (per MWH) of Savings from Reductions in Operating Reserve and Spot Purchases.

The correct value to use for the unit price for electricity production savings is complicated by the different operational decisions that result from improved forecasts and by changes in the structure and conduct of the industry. To be conservative, we chose the lowest of three candidate prices that are representative of costs for wholesale power produced or sold under short-term conditions, $41.3 per MWH. Pricing electricity at $41.3 per MWH is the average 2001-2002 cost of "regulation" services reported by PJM Interconnect, a major Independent System Operator (ISO) that provides interconnection and energy trading services to electric utilities in the Mid-Atlantic states [PJM Interconnect]. This conservative approach is warranted because production of electricity in the U.S. is becoming increasingly competitive and deregulated, both of which will tend to drive down the long-run average and marginal cost of production.

3.4.2.3 Total Economic Benefit.

The total annual economic benefit to utilities is then:

$$TProd_{2000} * CRegServ = 8{,}873{,}800 \text{ MWH} * \$41.3 \text{ per MWH, or about } \$366 \text{ M.}$$

Although this cost represents current year (2002) dollars, it is based on the quantity of electricity produced in 2001. Electric power spinning reserve and spot purchases are assumed to grow at an annual rate of 1.8 percent through 2020, in accordance with the US Department of Energy's (DoE's) outlook for the industry [US DoE, *Annual Energy Outlook 2002 With Projections to 2020*]. No further growth is assumed through 2027. As a result, annual cost savings that begin in 2015 are approximately $479 M ($2002). In summary, we compute the annual economic benefit beginning in 2015 as follows:

$$\$366M * (1.018)^{15} \text{ (growth rate)} = \$479 \text{ M}$$

Improvements in other forecast parameters that affect demand such as humidity, wind speed, and precipitation as well as extending the forecast improvements to the realm of 24-hour forecasts and beyond will result in additional economic benefits not yet included in this analysis. Moreover, improving national demand forecasts will likely also improve system reliability (reduce unplanned or forced outages) with additional substantial economic benefits.

4. CONCLUSIONS

About $2 trillion of the annual United States Gross Domestic Product is weather sensitive. The GOES satellite system, with a unique vantage point, plays a key role in continuously monitoring a wide variety of environmental phenomena and providing weather data used to generate a wide variety of products and forecasts. NOAA plans to launch these satellites with new and improved instruments in the 2012 time frame. The GOES-R imager and HES sounder instruments represent a substantial step forward in spatial, spectral, and temporal resolution compared with the current imager and sounder. NOAA expects that these new sensors will significantly improve the capability of the United States to detect, monitor, track and forecast weather and climate phenomena of great importance to the nation.

In order to assess whether it is justified to proceed with these new instruments, a marginal cost-benefit analysis was carried out. Estimates of the cost to develop and procure the GOES-R imager and sounder, as well as other new instruments that would achieve the same performance as the current imager and sounder were developed and compared. Marginal economic benefits from improved environmental information and products based on GOES-R imager, and GOES-R sounder data were also estimated.

It is important to recall that the eight case studies developed for this study and the subset of three cases presented in this paper represent just a sampling of economic sectors and domains within those sectors from which economic benefits can be realized. The total annual marginal benefits from our eight cases alone range between $600 and $700 million with discounted present value (over the GOES-R series lifecycle) between $3.1B and $3.4B. This value is exclusive of the $4 B in benefits attributed to the value of water to consumers (a benefit computed in an agricultural/irrigation case not presented here). In addition, the benefits presented in this paper were based on extremely conservative (low) estimates of operational improvements or costs (for example, the cost of MWH), which could easily be nominally higher but result in much larger benefits. We expect to determine additional benefits in areas such as commercial shipping and emergency management as well as in a broader examination of agriculture. However, it appears evident with the existing studies that performance improvements achieved by GOES-R will result in billions of dollars in benefits to the industries and the populace of the United States.

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