"Potential Socio-Economic Benefits of GOES-R"
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1. Introduction

In modern society, information is one of the first lines of defense employed to protect citizens' health and well-being and to optimize the effectiveness of economic and social systems responding to dynamic weather conditions. Information from earth-observing satellites, including the Geostationary Operational Environmental Satellite System (GOES), forms a critical component of today's weather and climate monitoring capabilities. For more than three decades, GOES has contributed essential information in support of the NOAA/NESDIS mission and vision, and, in so doing, has provided critically important information for the economy and citizens of the United States. The next generation of geostationary satellites, GOES-R, will further enhance these capabilities when it moves into its operational phase.

Information from the GOES-R system has the potential to affect a vast array of human activities in the United States. This advanced system can potentially contribute to enhanced societal well-being in all nine of the societal benefit areas defined by the National Science and Technology Council's Technology Council's Interagency Working Group on Earth Observations (Centrec Consulting Group, 2007). Examples of how the geostationary data would impact the societal benefit areas include improved weather forecasts, resulting in reduced disaster losses, better management of energy resources, and enhanced protection and utilization of water resources.

This paper summarizes the key findings from a project funded by the National Climatic Data Center (NCDC), part of NOAA's National Environmental Satellite, Data, and Information Service (NESDIS). The study was conducted from June 2006 to February 2007. A copy of the full report can be found at www.centrec.com/climate_weather.htm.

Information has economic value only to the extent that it can improve the quality of decisions made. This implies that the geostationary satellite instruments will have economic value if the information they provide enable improved decision-making. Due to the widespread impact of weather events on a broad range of decisions, a vast number of entities are potentially affected, extending from individuals, to managers of commercial enterprises, to public and societal bodies. However, due to time and financial limitations, the scope of the project was limited to analysis of a few of the societal areas that would benefit from the improved information. The objectives of the study were to estimate the potential socio-economic benefits of GOES-R as follows:

1. To estimate the value of improved tropical cyclone forecast information along the Gulf and Atlantic coastlines, and
2. To update quantification of benefits previously estimated for aviation, energy (electricity and natural gas), irrigated agriculture, and recreational boating (NOAA/NESDIS "GOES-R Sounder and Imager Cost/Benefit Analysis," 2002)

2. Tropical Cyclone Forecast Analysis

Hurricanes and tropical storms can have significant social and economic impact on society if they approach a coastline and more importantly if they make landfall. As the population and property value increases in the hurricane-vulnerable areas along the U.S. coastline, timely and appropriate preparation and response to severe weather events are becoming increasingly crucial as witnessed by the issues associated with Hurricane Katrina. The foundation for timely and appropriate tropical cyclone preparation and response is an accurate monitoring and forecasting system. Effective tropical cyclone monitoring and forecasts cannot prevent the storms from making landfall, but they can provide valuable

information during the life of the storm to assist public and private decision-makers in determining appropriate responses for preparation and evacuation. Decisions based on tropical cyclone forecasts can save lives, reduce property damage, ease the stress placed on government response, and create more efficient commercial response.

In estimating the value of improved tropical cyclone forecasts, technological assumptions about the manner in which the improved geostationary data would impact the forecasts were made. To do this, many scientists were extensively interviewed, and existing research using data denial and data assimilation techniques with existing geostationary data were reviewed. Geostationary satellites play an instrumental role in both the tropical cyclone monitoring and forecasting processes. NOAA's Tropical Prediction Center/National Hurricane Center (NHC) employs geostationary imagery, supplemented by additional imager and sounder data and derived products, to track a hurricane and monitor its development, including intensity. In addition, the geostationary data are used in the Numerical Weather Prediction (NWP) model forecasts for hurricane tracking, intensity, storm size and structure, and rainfall prediction. These forecasts are used by the NHC forecasters for guidance when issuing their official forecasts and advisories (Figure 1).

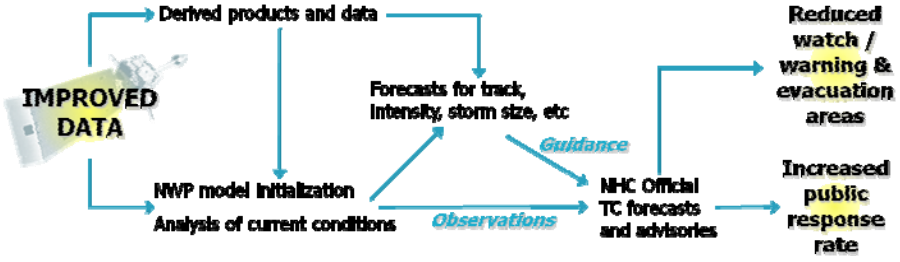

Figure 1. Role of Geostationary Data in the Tropical Cyclone Forecasting Process

For this analysis, the focus was on improved geostationary data generated by the GOES-R Advanced Baseline Imager (ABI) and a possible high resolution spectral sounder (HRSS). The areas in which the improved data could impact the forecasts were identified primarily as a reduction in intensity and track forecast errors; however, secondary implications could be the tightening of wind speed probability fields and improved surge forecasts. It was assumed that the improved geostationary data would ultimately result in more accurate tropical cyclone forecasts and advisories, and this would in turn impact two key areas: reduction of watch, warning and evacuation areas, and increased public response to the forecasts and advisories.

The first area of expected improvement stems from the expectation that the forecasters would have increased confidence in the analysis of the storms' current conditions and the NWP model forecasts. This would hopefully decrease the number of break points included in the watch and warning areas that are part of their official NHC forecasts and advisories (Figure 2). The NHC does not issue evacuation orders for hurricanes. Those orders are issued by local and sometimes state emergency officials. However, these officials rely on the NHC forecasts and advisories when deciding whether or not to issue evacuation orders. It is also expected that if the emergency officials have increased confidence in the tropical cyclone forecasts and advisories, a reduction in evacuation area would occur if and when such an order is issued.

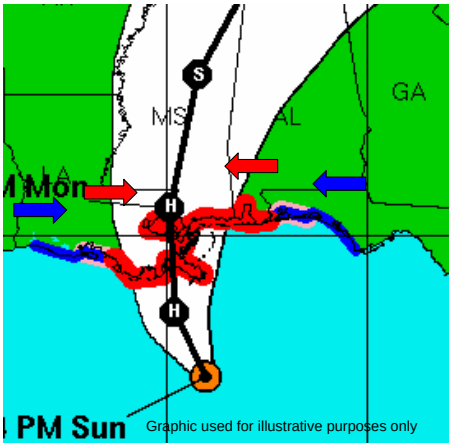

Figure 2. Tropical Cyclone Watch and Warning Area Graphic

Figure 3 helps convey how the impacts of reduced warning and evacuation areas could be quantified in economic terms. The upper diagram in Figure 3 represents the world without improved geostationary data. "A" represents the average evacuation area when an evacuation has been ordered in the event of a tropical cyclone, and "B" represents the average warning area when a tropical cyclone warning has been issued. The lower diagram shows how improved geostationary data and tropical cyclone forecasts could impact these areas by reducing both the evacuation and warning areas, resulting in fewer citizens and businesses affected by the advisories and the evacuation orders.

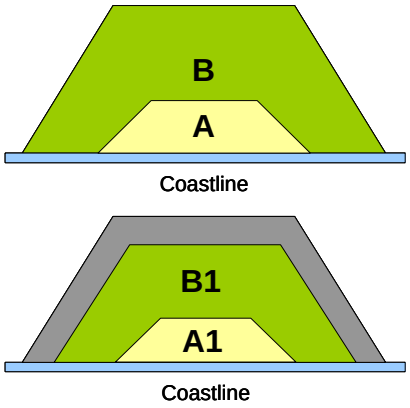

Figure 3. Illustration of Effects of Improved Tropical Cyclone Forecasts

This very general depiction would vary greatly depending on the actual location and the pending tropical cyclone event. The size of these areas is proportional to the severity or expected storm surge of the impending storm. As the expected storm surge of the event increases, the magnitude of the areas affected also increases. For example, the evacuation may be minimal or nonexistent for a tropical storm but would be significantly larger for a severe (category 4 or 5) hurricane.

The second expectation of improved tropical cyclone forecasts is increased public response to the tropical cyclone forecasts and advisories. Several studies of the public's response to hurricanes were reviewed and many social scientists were interviewed to develop the assumptions for how the public might respond to more accurate forecasts and advisories.

Two types of economic activity were included in the analysis: 1) protective actions for property (both residential and commercial); and 2) evacuation of individuals residing in the direct path of the storm. The protection and evacuation actions have both costs and benefits, and both economic impacts are assessed in this analysis. The benefits of protecting property are reduced damage to the property from the storm but this benefit comes at the cost of materials and labor. Evacuation has direct costs in terms of fuel, lodging, and food away from home. The benefits of evacuating are the reduced risk of personal injury and loss of life.

It was assumed that increased public responsiveness would result in higher protection and evacuation rates in the warning and evacuation areas, therefore increasing protection and evacuation costs, respectively (Figure 4). However, total property damage and economic loss stemming from lower loss of life and injuries would decline. In addition, with a reduced evacuation area, overall evacuation costs would decline. As a result, positive net economic effects for these three economic activities are generated.

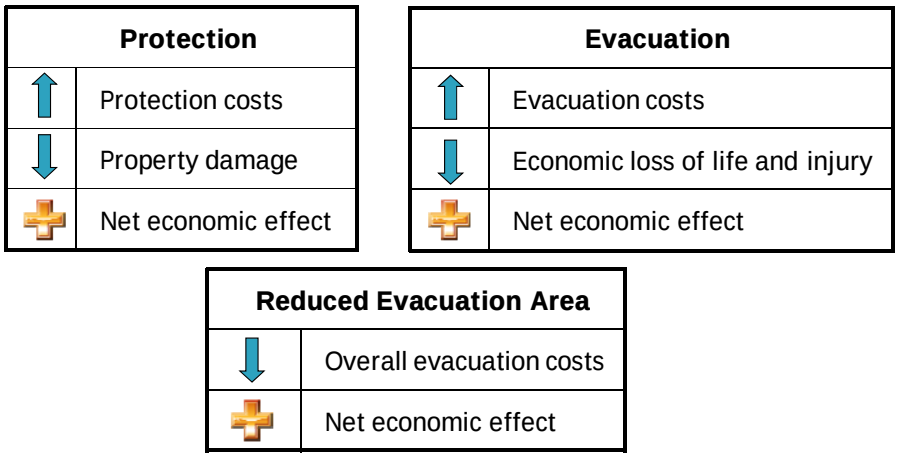

Figure 4. Net Economic Effects of Increased Public Response to Improved Tropical Cyclone Forecasts

While the analysis of the economic impact of individual hurricanes is event-specific, the impact of improved tropical cyclone forecasts should be realized on a continual basis, both in terms of geographic and time coverage. To implement the methodology, the Tropical Cyclone Forecast Valuation Tool (TCFVT) was developed as part of this study. The economic and technological assumptions can be changed in this model, thus permitting sensitivity analysis of several key parameters.

In terms of geographic coverage, the impact of improved tropical cyclone forecasts on the Atlantic and Gulf coastlines was considered. In reference to time coverage, it was recognized that tropical cyclones are not in the vicinity or do not make landfall every year. To accommodate the geographic and temporal dimensions of this analysis, the probabilities developed by the US Landfall Probability Project were used in the TCFVT to quantify the benefits on an annual basis (Figure 5) [1]. This project has compiled a database of probabilities of tropical cyclones being in the vicinity or hitting the Atlantic and Gulf coastline and bordering counties based on data provided by the NHC. The database contains county-level probabilities of landfall or being in the vicinity for three storm categories: (1) tropical storms; (2) Saffir-Simpson (S-S) Category 1 and 2 hurricanes; and (3) S-S Category 3, 4 and 5 hurricanes.

[1] The project's web site is http://www.e-transit.org/hurricane/welcome.html.

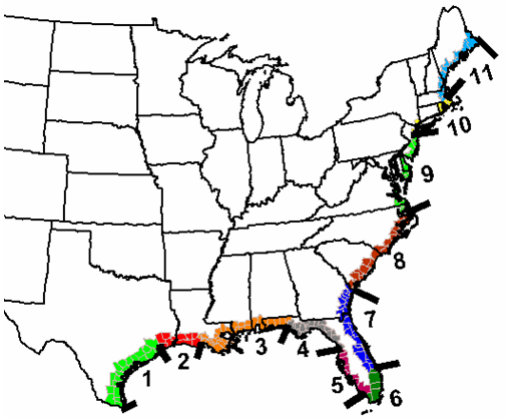

Figure 5. United States Landfall Probability Project Database

Due to the flexibility in the model, eight scenarios were considered using different technological and public response rate assumptions. While results from the eight scenarios are summarized and presented in the full report, only two are summarized in this paper.

The first scenario is called the "Base Case" scenario. The instrument of focus is the ABI, and the scenario represents the scientists' and analysts' approximations of how the improved geostationary data would impact tropical cyclone forecasts. It was estimated that these conservative assumptions would reduce the watch/warning and evacuation areas by 5% (Table 1). In addition, it was expected that the public's responsiveness to the advisories would increase protection and evacuations in the applicable areas, and unnecessary evacuations outside of the evacuation-ordered areas would be reduced.

The second scenario is referred to as the "Enhanced Technology" scenario. This case considers data from both the ABI and an instrument with more accurate technology performance such as an HRSS. These assumptions generate more aggressive estimates of how the improved geostationary data would impact tropical cyclone forecasts. The resulting estimation is a 15% reduction in the watch/warning and evacuation areas, triple of the Base Case scenario, and increased public responsiveness to the forecasts and advisories are expected.

Table 1. Summarized Technological Impacts of Improved Geostationary Data on Tropical Cyclone Forecasts

	Base Case (ABI)	Enhanced Technology (ABI plus HRSS)
Instrument focus	ABI	ABI plus more accurate technology performance such as a high resolution spectral sounder (HRSS)
Improved GEO data's impact on TC forecasts	Analysts' most conservative estimates	More aggressive estimates[2]
Impact on watch/warning and evacuation areas	5%	15%

[1] Only two of eight different scenarios considered in the report are presented.

[2] The assumptions made for this scenario are intentionally aggressive values and are not based on social behavior or scientific evidence due to the limited research on this topic. Nonetheless, while these assumptions might not be scientifically expected today, they are meant to illustrate the potential benefits if proved true in the future.

In addition to different technological and responsiveness assumptions, the analysis considered different economic parameters such as expected population growth rates, inflation, and various discount rates. The results using the different economic parameters are presented in detail in the full report (Centrec Consulting Group, 2007). However, Table 2 highlights the results of the two scenarios just described at a 7% discount rate with no inflation and a 1.5% annual population growth. The first set of numbers shows

non-discounted net benefits for a single year, while the following line reports the total Net Present Value (NPV) for the expected life-time of the satellite series. The NPV benefits for the scenario with the ABI only are estimated at $2.4 B while the total NPV benefits almost doubles to $4.3 B for the Enhanced Technology scenario.

The benefits are also considered on a per coastline mile basis. The net benefits per mile have similar relative levels compared to the total benefits, but help put the benefits in context of the relevant geographic area of the Atlantic and Gulf coastlines.

Table 2. Net Economic Benefits from Improved Tropical Cyclone Forecasts

Total Net Benefits	Base Case (ABI)	Enhanced Technology (ABI plus HRSS)
Non-discounted net benefits for the single year 2015	$452 M	$814 M
Total NPV[1] benefits for 2015 - 2027	$2,376 M	$4,278 M
Per Coastline Mile		
Non-discounted net benefits for the single year 2015	$130 K	$233 K
Total NPV[1] benefits for 2015 - 2027	$690 K	$1,227 K

[1] NPV – Net Present Value discounted at 7% with 1.5% population growth and no inflation

3. Cost-Benefit Analysis

The second part of the analysis consisted of updating a 2002 study of four economic sectors where the higher quality geostationary data are expected to increase the accuracy of the applicable forecasts (NOAA/NESDIS "GOES-R Sounder and Imager Cost/Benefit Analysis," 2002). The original analysis, referred to as CBA, included benefits attributed to both the Advanced Baseline Imager (ABI) and the Hyper-spectral Environmental Suite (HES) sounder because it was on the instrument platform at that time. Benefits accruing from both instruments were updated in this analysis. The four economic sectors and the expected benefits from improved geostationary data are:

1. Aviation - fewer weather-related flight delays and airline incidences with volcanic plumes
2. Energy (electricity and natural gas) – improved production and distribution of electricity and natural gas
3. Irrigated agriculture – increased efficiency in irrigated water usage in agriculture
4. Recreational boating - higher protection rates for recreational boats in the event of a tropical storm or hurricane

The energy sector is poised to reap the largest economic benefits of these four sectors with a potential gain of $2.6 B over the lifetime of the satellite series (Figure 6). The effects of the improved forecasts on all four economic sectors are estimated to result in total NPV benefits of $4.6 B over the lifetime of the GOES-R satellite series.

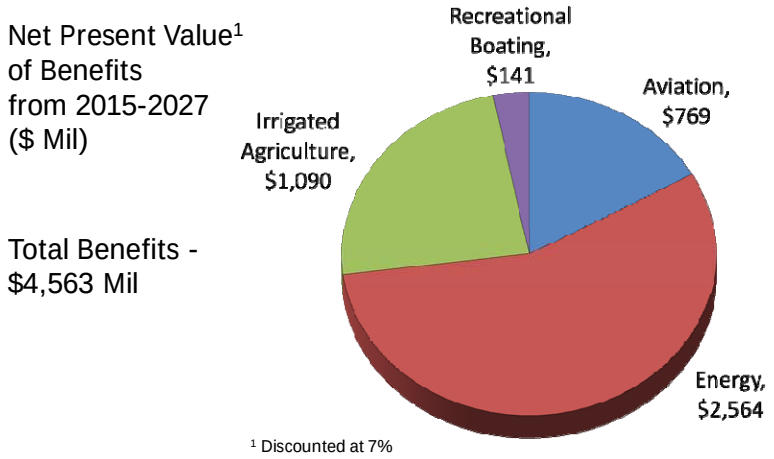

Figure 6. Updated CBA Benefits for GOES-R

4. Summarized Benefits

Since the original CBA evaluated the ABI and HES sounder, several scientists were consulted to help estimate the benefits related to each instrument separately. The total NPV benefits attributed to the ABI data for both analyses (improved tropical cyclone forecasts and the CBA) are $4.6 B while the benefits attributed to improved sounder data for both analyses are $4.2 B, totaling almost $9 B for both analyses and instruments (Figure 7). These socio-economic benefits are the estimated benefits above and beyond the current GOES system.

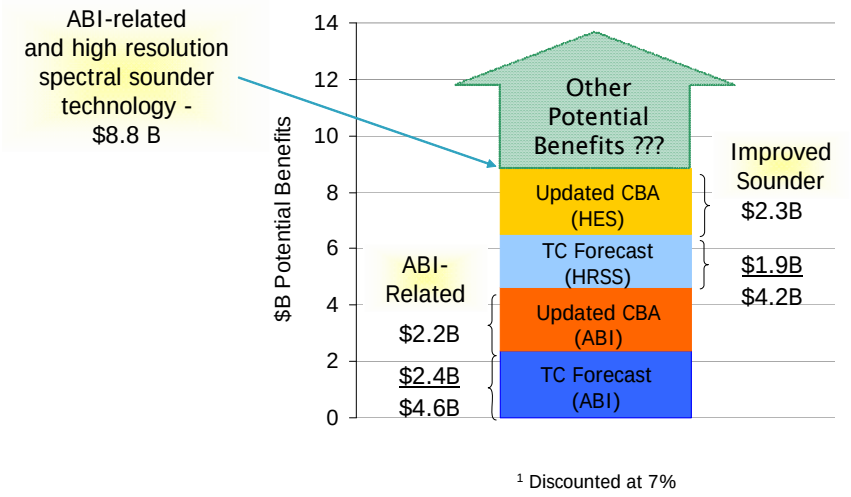

Figure 7. Summarized Potential Socio-economic Benefits for GOES-R beyond the Current GOES System

5. Concluding Remarks

This analysis indicates that additional socio-economic benefits for improved tropical cyclone forecasts and only four economic sectors due to the ABI are about $4.6 B, while benefits stemming from improved sounder data are estimated to be $4.2 B, totaling almost $9 B. While these economic estimates convey significant and broad economic impacts, the reported benefits most likely understate the potential total benefits of the GOES-R system. First, conservative assumptions relative to the effect of improved geostationary data on potential benefits are consistently employed throughout the analysis.

Second, this analysis addresses only a few of the many areas in which geostationary data are used, resulting in an estimation of only a portion of the total potential socio-economic benefits that improved geostationary data could provide. To illustrate, the following areas are not analyzed in this study for which the socio-economic benefits could be estimated:

- Tropical cyclone forecast analysis for business interruptions and inland rain and wind damages
- Instruments - Geostationary Lightning Mapper (GLM); Solar UV Imager (SUVI); Extreme UV/X-Ray Irradiance Sensor (EXIS); Space Environmental In-Situ Suite (SEISS); Magnetometer (MAG) and Unique Payload Services
- Users – international; retrospective; Department of Defense; data collection services
- Economic sectors including commercial transportation, tourism, television
- Societal benefit areas such as human health, climate, ecological, ocean

Examples of potential analyses include the impact of improved tropical cyclone forecasts to help decrease business interruptions and inland rain and wind damages caused by tropical cyclones. The benefits stemming from the application of the space weather instruments' data or the value that the enhanced geostationary data provides to the international community or Department of Defense users are other examples. In addition, commercial transportation such as railroads, and ocean and barge traffic are other instances of economic sectors that would benefit from improved geostationary data. Since many areas are not included in this analysis, additional benefits attributed to improved geostationary data could be quantified, including expansion of the TCFVT model developed for this project (through high levels of disaggregation), and benefits from improved severe storm forecasts.

It should be noted that GOES-R program costs were not considered in this study. It would be very effective to state that for every dollar spent on a satellite system, or any climate or weather-related program for that matter, society receives X dollars of benefits. To be able to put the costs and benefits in this context, however, the costs and benefits must be compared in comparable economic terms, such as whether or not inflation is included and at what rate the dollars are discounted.

It has been stated that NOAA/NESDIS's mission is:

> *"…to deliver accurate, timely and reliable satellite observations and integrated products and to provide long-term stewardship for global observations data in support of the NOAA mission."* [2]

This mission is motivated with the following vision:

> *"To be the world's premiere source of comprehensive environmental data and information."*

This illustrates the enormous public service role NOAA/NESDIS serves by providing its services and products such as the geostationary data. Without a doubt, the research and development being conducted for the future generations of geostationary satellites such as GOES-R will move into application for the advancement of society. However, because of NOAA's important societal role and the dynamic nature of climate and weather research and application, it is imperative to understand how these products and services will enhance society in the future.

6. References

Centrec Consulting Group, LLC, 2007. "An Investigation of the Economic and Societal Value of Selected NOAA Data and Products for Geostationary Operation Satellites (GOES)." Submitted to NOAA/NESDIS/NCDC, February, 28, 2007. Available at www.centrec.com/climate_weather.htm

NOAA/NESDIS, 2002. "GOES-R Sounder and Imager Cost/Benefit Analysis." November 15, 2002.

[2] NOAA Satellite and Information Services Annual Report, 2004, National Environmental Satellite, Data, and Information Service (NESDIS).