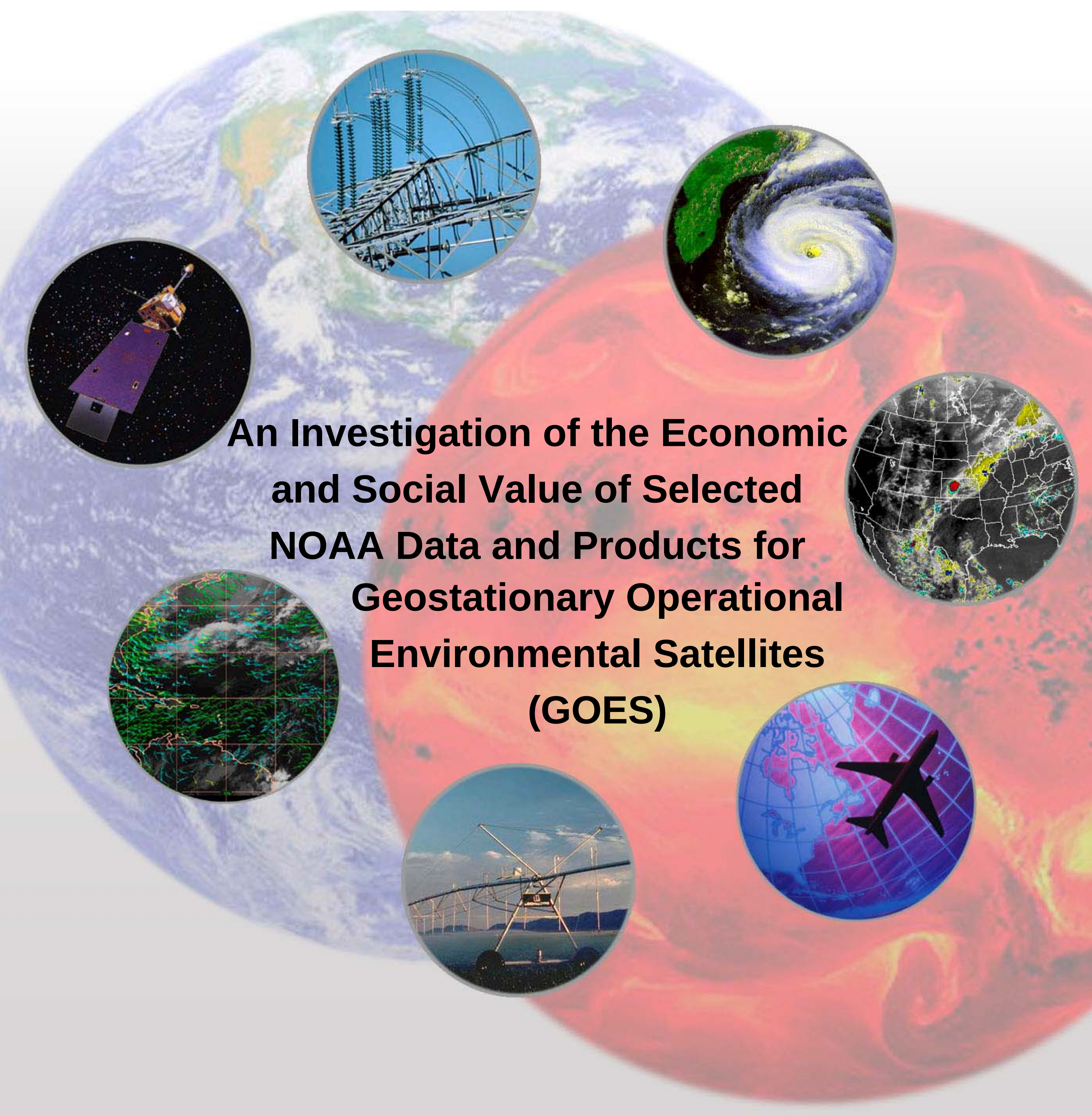

An Investigation of the Economic and Social Value of Selected NOAA Data and Products for Geostationary Operational Environmental Satellites (GOES)

A Report to NOAA's National Climatic Data Center

NOAA Satellite and Information Services

National Environmental Satellite, Data, and Information Service

An Agency within the National Oceanic and Atmospheric Administration

Submitted by:

CENTREC
Consulting Group, LLC

Centrec Business Center
3 College Park Court
Savoy, IL 61874
Phone: 217.352.1190
Web site: www.centrec.com
E-mail: centrec@centrec.com

February 28, 2007

Acknowledgements

We would like to express our gratitude to the many scientists, researchers and NOAA personnel who contributed time and material to this project. We met and conversed with many individuals during the conduct of this project; many of those consulted are listed in the Experts Contacted section, but we apologize in advance for any unintentional omissions. We are very thankful for everyone's contribution, insight, feedback, and support.

Table of Contents

Executive Summary

This report presents findings from an analytical research project entitled, “An Investigation of the Economic and Social Value of Selected NOAA Data and Products for Geostationary Operational Environmental Satellites (GOES)”. The analysis began in May 2006 and was completed in February 2007. An interim report was released in August 2006 that presented initial quantitative estimates plus outlined a framework for analyzing and valuing the benefits of improved GOES information. This final report includes quantitative economic estimates of the potential benefits of improved tropical cyclone forecast information along the Gulf and Atlantic coastlines and of the benefits from application of improved information in four specific sectors of the economy. These sectors are aviation, energy (both electricity and natural gas), irrigated agriculture, and recreational boating.

In modern society, information is one of the first lines of defense employed to protect the health and well-being of citizens and to optimize the effectiveness of economic and social systems in response to the dynamics of ever-changing weather conditions. Information from earth-observing satellites, including the current Geostationary Operational Environmental Satellite System (GOES), forms a critical component of today’s capabilities. The planned GOES-R set of satellite innovations would further enhance this system.

Information from the GOES-R system has the potential to affect a vast array of human activities in the United States meaningfully. Even though the scope of activities is wide and quite apparent, valuation of information often is not as obvious. For example, hurricanes can have devastating impacts including loss of life, destruction of property, and disruption of economic operations. While improved information as to the path and intensity of each potential hurricane is of obvious interest, estimation of the value of that information can be difficult. Information has economic value only to the extent that it can improve the quality of decisions made. The instruments and services of GOES and GOES-R will have economic value if the information provided by those satellites can enable improved decision-making. Because of 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.

While the economic estimates provided in this report describe significant and broad economic impacts (effects of tropical storms, hurricanes and economic performance of four significant economic sectors), it should be stressed that the actual benefit values reported most likely understate the potential total benefits of the GOES-R satellite system. First, conservative assumptions relative to the effect on potential value are consistently employed throughout the analysis. Second, the four sectors analyzed, while important in their own right, do not include several other major activities of economic importance to the nation. For example, sectors likely to benefit also from enhanced information from GOES-R include commercial fishing, commercial transportation (over-the road trucking, railroad, and ocean and barge traffic), and tourism. Even though addressing only a portion of the potentially relevant components of the nation’s economy, the quantitative estimates discovered in this analysis are indeed meaningfully large in their own right.

Tropical cyclones clearly have massive economic impact. Existing analyses of the damages resulting from hurricanes tend to be event specific. The capability to provide improved hurricane forecasts, however, would be available on a continual basis, both in terms of time and geographic coverage. A methodology is developed and employed in the analysis described in this report that assesses the potential value of improved hurricane forecast capabilities but is not limited to analysis of individual tropical storm or hurricane events. The regions included in the analysis extend along the entire U.S. coastline from Texas to Maine.

The annual non-discounted net benefits estimated for improved tropical cyclone forecasts exceeded $450 million for the year 2015. (This assumes that population growth in the target regions would be 1.5% per year from now to the year 2027.) This benefit would average about $130,000 for each mile of the more than 3,000 coastline miles along the Gulf and Atlantic coastlines. Using a 7 % discount rate (and with no inflation), the present value of sum of benefits from 2015 to 2027 would be almost $2.4 billion, averaging more than $690,000 per coastline mile. More detail is provided relative to the methods and assumptions underlying the tropical cyclone forecast analysis in Sections 4.1 and 5.1 of the report. Extensive sensitivity analyses are conducted relative to key decision parameters and to important economic factors. The findings from those efforts are reported in Section 5.1.

In addition to the evaluation of potential benefits of improved tropical cyclone forecasts, this report's analysis explored the potential for economic benefit from improved information from GOES-R satellites as it would impact four specific sectors of the economy (aviation, energy–both electricity and natural gas, irrigated agriculture, and recreational boating). This analysis was an update of previous cost-benefit analyses conducted for the Department of Commerce in 2002 and 2004 when the HES was part of the proposed instrument platform. The resulting values for improved weather forecasts due to GOES-R ABI and the formerly proposed HES sounder are impressive. Annual values are estimated for the year 2015, after GOES-R is launched. Those annual values, just for the target sectors, exceed $772 million for the year 2015. The analysis also calculates the stream of benefits that would result over the timeframe 2015 to 2027 and the present value for that stream of benefits. At a 7% discount rate, the estimated present value amounts to more than $4.5 billion. Based on expert judgment provided by scientists consulted during this project, the ABI benefits are estimated to be 49% of the $4.5 billion or $2.2 billion.

In summary, this analysis found estimated potential benefits from improved information from GOES-R satellites for the following five specific types of economic activities:

- Improved tropical cyclone forecasting resulting in more effective action to protect property and to enable evacuation of individuals residing in the path of the storm: $0.450 billion in 2015 (average of $130,000 per U.S. coastline mile from Maine to Texas) and $2.4 billion from 2015 to 2027 (average of $690,000 per U.S. coastline mile from Maine to Texas)
- Enhanced aviation forecasting resulting in improvements in avoidable delays, value of passenger time avoided, avoidable repair costs due to volcanic ash, and avoidable risk of aircraft/life lost: $0.169 billion in 2015 and $0.768 billion from 2015-2027
- More accurate temperature forecasts contributing to improved energy demand expectations and savings in the electricity and natural gas sectors: $0.512 billion in 2015 and $2.56 billion from 2015-2027
- Enhanced forecasts leading to more efficient irrigation of crops — resulting in water savings, energy savings by not having to pump water, and revenue gains from selling excess water: $0.061 billion in 2015 and $1.09 billion from 2015-2027
- Improved forecasting of tropical cyclones resulting in reduced losses to the recreational boating industry: $0.031 billion in 2015 and $0.141 billion from 2015-2027
- Across the five activities, the combined annual value for 2015 exceeds $1.2 billion. The present value of the combined estimated benefits for the 2015-2027 period approaches $7 billion.

The magnitude of the economic benefits estimated for just the five types of economic activities included in this study (reduced economic effects of tropical cyclones and improved economic performance in four sectors of the economy) provides strong evidence of the potential for societal gain when the GOES-R satellites are available to provide improved information.

1. Background and Purpose

The mission of the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) is[1]:

> *"…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."*

This mission is motivated with the following vision:

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

For more than three decades, the Geostationary Operational Environmental Satellite (GOES) system 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 the citizens of the United States.

Circling the earth in a geosynchronous orbit, these instruments provide the continuous data streams necessary for intensive monitoring of weather and environmental conditions. Since 1975, when this series was first launched, the capabilities of the GOES system have been periodically advanced by application of innovative technologies as additional and replacement satellites were added to the GOES system. Currently GOES 11 and 12 are operating to protect and enhance human well-being and economic sustainability in the nation. Plans for continued enhancement of these capabilities with the next generation of GOES-R satellites are envisioned to provide unparalleled capabilities in the future. The next generation, the GOES-R series, will replace the GOES-N series no earlier than 2014[2]

The purpose of this report is to present findings from an investigation of the economic and social value of selected NOAA data and products for GOES. It represents the completion of an analysis that began in May 2006. An interim report was released in August 2006 that presented initial quantitative estimates plus a framework for analyzing and valuing the benefits of improved GOES information to tropical cyclone monitoring and forecasts. This final report includes the valuation of improved forecast information along the Gulf and Atlantic coastlines as well as the quantitative benefits described in the preliminary report that pertained to aviation, energy (both electricity and natural gas), irrigated agriculture, and recreational boating.

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

[2] The GOES-R series encompasses multiple satellites that will be launched and made operational sequentially. However, for the purpose of the socioeconomic analysis conducted for this study, the benefits accrued from multiple GOES-R series satellites over a 13-year time period are calculated.

2. Organization of Report

The remainder of this report is presented in sections addressing the follow topics:

- Information from the current GOES system and from the improvements associated with the GOES-R implementation has multiple impacts across a wide range of activities within the United States. The broad range of these effects is described in Section 3 of the report.
- An overview of the project's findings is described in Section 4 of the report. These findings assess the economic benefits emanating from the GOES-R technology through improved tropical storm and hurricane forecasts and when improved information from GOES-R is applied to four specific sectors of the economy.
- The fifth section of the report describes in more detail the analytical processes used to prepare the economic estimates as well as providing a more complete explanation of the economic results.
- The report's final substantive section identifies a number of opportunities where further analysis could lead to enhanced understanding of the potential additional economic benefits associated with the GOES-R technology.

3. GOES-R Information and the Economy

In modern society, information is one of the first lines of defense employed to protect the health and well-being of citizens and to optimize the effectiveness of economic and social systems in response to the dynamics of ever-changing weather conditions. Information from earth observing satellites, including the current Geostationary Operational Environmental Satellite System (GOES), forms a critical component of today's capabilities. The planned GOES-R set of satellite innovations will further enhance this system[3]. The National Science and Technology Council's Interagency Working Group on Earth Observations has identified nine areas of societal benefit that can be associated with enhanced earth observation capabilities. As noted by Timothy J. Schmit[4] and shown in Table 1, an advanced GOES system can contribute to enhanced societal well-being by providing information useful within each of those areas of societal benefit.

---

[3] This report evaluates potential benefits based on the proposed baseline instruments for the GOES-R satellite system as of September 2006. At that time, the proposed GOES-R baseline instrumentation consisted of the Advanced Baseline Imager (ABI); the Solar Imaging Suite (SIS) and Space Environmental In-Situ Suite (SEISS); and the Geostationary Lightning Mapper (GLM). Prior to September 2006, a Hyperspectral Environmental Suite (HES) which consisted of two instruments, the infrared sounder and the coastal water imager, was also part of the platform.

[4] Timothy J. Schmit is with the NOAA/NESDIS/Satellite Applications and Research Advanced Satellite Products Branch (ASPB) Madison, WI.

Table 1. Advanced GOES Societal Benefit Areas

Societal Benefit Area	Example Applications
Enhanced human health	Improved data for air quality forecasts; Better hot spot detection and characterization; Monitoring of ecological events such as harmful algae blooms and forest fires
Reduced disaster losses	Enhanced hurricane predictions; Lightning observations; Severe storm/heavy precipitation monitoring; Volcanic ash tracking; Search and rescue episodes; Space weather and satellite maintenance
Improved weather forecasts	Improved general weather announcements and forecasts of high stress (heat and cold) events; More effective efforts to evacuate populations at risk and protect property vulnerable to hurricanes; Enhanced monitoring of weather characteristics such as fog, thunderstorms, clouds, etc.
Better management of energy resources	More efficient energy system operations (electricity and natural gas generation and distribution); Reduced energy consumption by airplane and other transportation systems due to avoidance of unfavorable weather conditions; Monitoring of solar disturbances that interfere with GPS use, communications, and electric power grid operations
Enhanced protection and utilization of water resources	Monitoring of the coastal environment; Data collection of river flows and reservoir management; Monitoring of water quality (chlorophyll, turbidity and sediment transport)
Improved understanding of climate variability and change	Measurements to resolve climate-relevant changes in atmosphere, ocean, land and cryosphere; Development of diurnal signatures for fires, clouds, lightning and other climatic factors
Support for sustainable use of ag, forest and natural resources	Monitoring of surface vegetation changes; Measurement of burn scars areas; Improved knowledge of moisture/thermal fields to enhance forecasting for ag and forestry operations
Development of capability to make ecological assessments	First time ever, characterization of diurnal ocean color relative to tidal conditions; Improved coastal environment monitoring; Better tracking of the location of hazardous materials such as oil spills and noxious algal blooms
Protecting and monitoring ocean resources	Monitoring of sea surface temperature near corals in the Western hemisphere; Better depiction of ocean currents, low level winds, major storms and hurricanes to benefit ocean transportation

As Table 1 demonstrates, information from the GOES-R system (as originally designed with a fully capable Sounder and Coastal Water imager), has the potential to affect a vast array of human activities in the United States meaningfully. Even though the scope of activities is wide and quite apparent, valuation of information often is not as obvious. For example, hurricanes can have devastating impact including loss of life, destruction of property, and disruption of economic operations. While improved information as to the path and intensity of each potential hurricane is of obvious interest, estimation of the value of that information can be difficult.

Information has value to the extent that it can improve the quality of decisions made. As shown in Figure 1, the instruments and services of GOES and GOES-R have value because the information provided by those tools can enable improved decision-making. Because of the widespread impact of weather events on a broad range of decisions, a vast number of entities are affected, extending from individuals, to managers of commercial enterprises, to public and societal bodies.

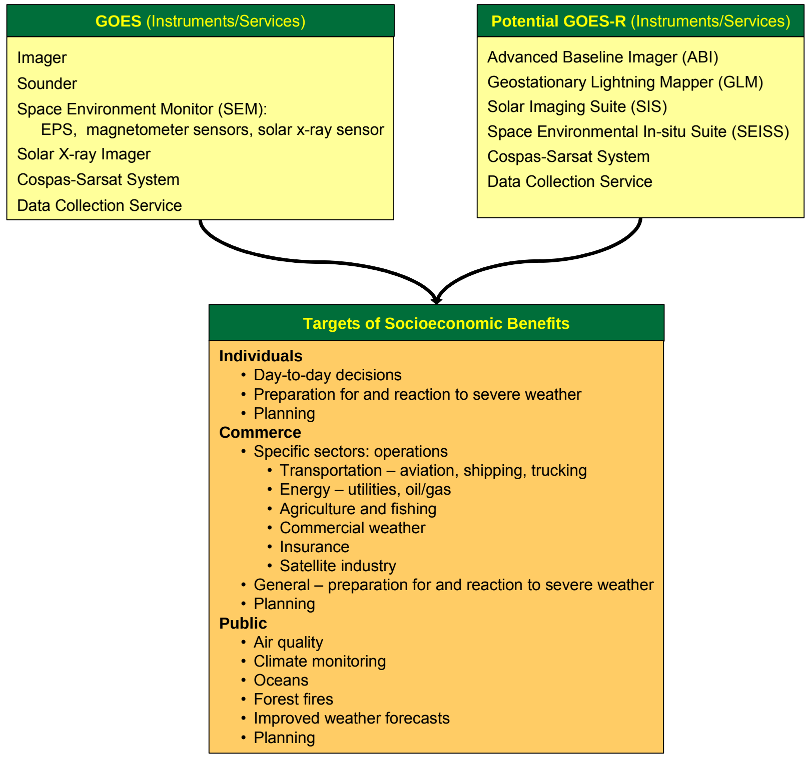

Figure 1. Socioeconomic Benefits from GOES and GOES-R

Appropriately assessing the economic benefits from information requires careful attention to decisions and the effect that the information of interest has upon decision-making, whether at the individual, commercial or public level. Knowledge of the economic impacts of weather events is typically necessary as a component of such an analysis. However, it is important not to confuse the economic impacts of the weather events with the benefits of information regarding those events. Unfortunately, even perfect predictions of an upcoming weather event would not allow decision-makers to avoid all damages of that event (or conversely to maximize favorable effects). Therefore, evaluation of the benefits of enhanced information availability must focus on decisions that can be made with such information and only on the economic gains associated with the better decisions resulting from that information.

4. Overview of Findings

This report summarizes findings based upon an intensive set of analyses initiated in late May 2006. The findings here are of three types. One estimates the potential economic benefits associated with improved forecast information relative to tropical cyclones. The second type of finding provides quantitative estimates of the value of weather forecast information in specific economic sectors: aviation, energy (both electricity and natural gas), irrigated agriculture, and recreational boating. The third type discusses a framework formulated for weather forecasts relating to air quality.

Tropical cyclones clearly have massive economic impact, and the notion that improved forecast information has value to society seems readily apparent. Possibly because the notion is straightforward, relatively little analysis has been conducted to document that magnitude of those benefits. In addition, existing analyses of the damages resulting from hurricanes tend to be event specific. The capability to provide improved hurricane forecasts, however, would be available on a continual basis, both in terms of time and geographic coverage. A methodology is employed in this report that assesses the potential value of improved hurricane forecast capabilities but is not limited to analysis of individual hurricane events. The Tropical Cyclone Forecast Valuation Tool (TCFVT) is a computer program created by Centrec Consulting Group to implement that methodology. The regions included in the analysis extend along the entire U.S. coastline from Texas to Maine.

More detail is provided relative to the methods and assumptions underlying the tropical cyclone forecast analysis in Section 4.1 and in Section 5.1 of the report. The annual net benefits estimated for improved tropical cyclone forecasts exceeded $450 million for the year 2015[5]. (This assumes that population growth in the target regions would be 1.5% per year from now to the year 2027.) Using a 7 % discount rate (with no inflation), the present value of sum of benefits from 2015 to 2027 would be almost $2.4 billion.

Cost benefit analysis reports were prepared for the Department of Commerce in 2002 and 2004 (NOAA, 2002; NOAA, 2004) in which benefits accrued to the proposed GOES-R ABI and HES sounder were calculated. The quantitative estimates calculated for this report were built upon the analysis presented in the 2002 study (henceforth referred to as the CBA Report) and were performed prior to the HES sounder being removed from the GOES-R instrument specifications. The approach taken for this study was to duplicate the CBA Report's methodology for calculating the benefits but to update the estimates to be consistent with current prices and usage patterns. In some instances, some assumptions were revised to be consistent with current conditions as well. Therefore, the updated analyses include benefits accrued from a GOES-R satellite with both an ABI and a HES sounder. A detailed description of these processes along with associated references is provided in Section 5 of this report. Since the HES was removed from the GOES-R instrument specification after these benefits were updated, expert opinions were subsequently obtained from scientists to estimate the portion of benefits that could be attributed to each of the instruments. The benefits accrued to each instrument are then calculated for each sector.

Even though this portion of the analysis only relates to four specific sectors (aviation, energy–both electricity and natural gas, irrigated agriculture, and recreational boating), the values estimated for improved weather forecasts due to GOES-R are impressive. Annual values are estimated for the year 2015, after GOES-R is launched. Those annual values, just for the target sectors, exceed $772 million for the year 2015. The analysis then calculates the stream of benefits that would result over the time frame 2015 to 2027 and calculates the 2005 present value for that stream of benefits. At a 7% discount rate, the estimated present value amounts to more than $4.5 billion[6]. Based on the expert judgment provided by the scientists consulted during this project, the ABI benefits are estimated to be 49% of the $4.5 billion or $2.2 billion. While the sectors addressed in this report represent significant economic components of the economy, they represent only a fraction of the nation's economic activity likely to benefit from improved weather information and forecasts due to GOES-R. Other economic benefits exist within the four specific sectors analyzed. In addition, there are many other sectors of the economy that would also benefit but have not been addressed by this report.

Acceptable air quality is a phenomenon of importance to individuals, commerce and society. The capability to provide better air quality forecast information, therefore, should be of considerable societal benefit. This report presents the findings of an initial investigation regarding improved air quality forecasts, and the issues associated with air quality forecast valuation are assessed. While air quality is an important economic and social factor, valuing the economic benefits of improved air quality forecasts will

[5] While the proposed launch date for the GOES-R satellite is now either late 2014 or early 2015, and the operational period for the GOES-R series is expected to commence in 2017, this analysis retained the timeframe used in the CBA Report of 13 years spanning from 2015 through 2027. This is to permit evaluation of the benefits within comparable timeframes.

[6] See Section 5 for an explanation of how present values are calculated and analysis of the effects of alternative discount rates. The analysis of present values of benefits is often accompanied by the discounting of the costs associated with the federal program providing the benefits. However, this analysis is limited to assessing benefits; calculation of cost factors associated with improved forecasts due to GOES-R is beyond the scope of this study. The aggregate benefit estimates are expressed in present value terms in accordance with accepted practice. However, when comparing benefits to the associated cost estimates, the costs and benefits should be evaluated within the same context - whether the estimates are discounted (and at what rate) and adjusted for inflation. If the discounted benefits are being compared to the associated cost estimates, those cost estimates should be similarly expressed in terms of their present value rather than the undiscounted, expected budget outlays. Since some reported program costs are not discounted and the costs are adjusted for inflation, non-discounted, inflation-adjusted benefits are also provided in this report.

not be straightforward. A framework within which this task can be conducted is provided here, however, the difficulty associated with estimating actual benefits also is recognized. No quantitative estimates relative to enhanced air quality forecasts are estimated in this study.

4.1. Tropical Cyclones

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. The impacts are far reaching, extending from direct impacts (such as property losses associated with wind and water damage and personal injury or death) to secondary impacts (e.g., increases in health or disease problems following a hurricane) to tertiary impacts (those that follow long after the storm has passed, such as a change in property tax revenues collected in the years following a storm and loss of tourism and sales revenue). All aspects of society are affected by tropical cyclones including:

- Individuals in vulnerable residences;
- Businesses who must prepare for the severe weather associated with the hurricane and experience business disruptions during and after its impact;
- Federal, state and local government response to the impending storm;
- Companies that must prepare for and respond to preparation of and recovery from the storm (e.g., retail businesses scheduling delivery of supplies in the vulnerable areas); and
- Businesses outside the affected area, whose operations such as normal delivery of goods and services are disrupted by the hurricanes.

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 estimated damages caused by this storm and by Hurricane Rita in the same year range from $70 billion to $130 billion (Holtz-Eakin). Potential reductions in tropical cyclone damage can be achieved from a myriad of activities, ranging from long-range planning for risk mitigation to short-term preparation and response by the public and private sectors.

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. Numerous commentators have asserted that these decisions have economic implications in the millions if not billions of dollars for any given storm (Whitehead; Willoughby, Rappaport and Marks).

Concepts for Framing an Analysis of Improved Hurricane Forecast Information

While tropical cyclones themselves are specific geographically concentrated events, the GOES-R information system would provide data and information on a continual basis, across a broad geographic area over a number of years. The exact number, location and severity of tropical storm and hurricane events that will occur while the GOES-R series is in operation, of course, are unknown. However, the pattern of prior tropical cyclone events can provide an indication of future likely tropical storm and hurricane events in general terms. An assessment of potential benefits from the information systems driven by GOES-R observations can be obtained by employing these historic event frequencies across the relevant geographic area in the United States that is susceptible to hurricanes. These frequencies need to be linked with the potential behaviors of decision-makers who receive such information and to the structure of economic activity that exists within the relevant geographic areas.

The relevant geographic areas considered for this analysis are the Atlantic coastline counties in addition to selected counties bordering some of the coastline counties (Figure 2). The U.S. Landfall Probability Project has compiled a database of probabilities of tropical cyclones hitting these counties based on data provided by the National Hurricane Center.[7] This database of counties and their probabilities are used as the geographic foundation for this analysis. Based on the Census Bureau's 2005 estimation of population, approximately 57 million people reside in these counties. It is widely acknowledged that many of these areas have realized significant population and economic growth in recent years. According to the 2004 NOAA report titled "Population Trends along the Coastal United States: 1980 – 2008", the nation's coastal population is expected to increase by more than 7 million by 2008 and 12 million by 2015.

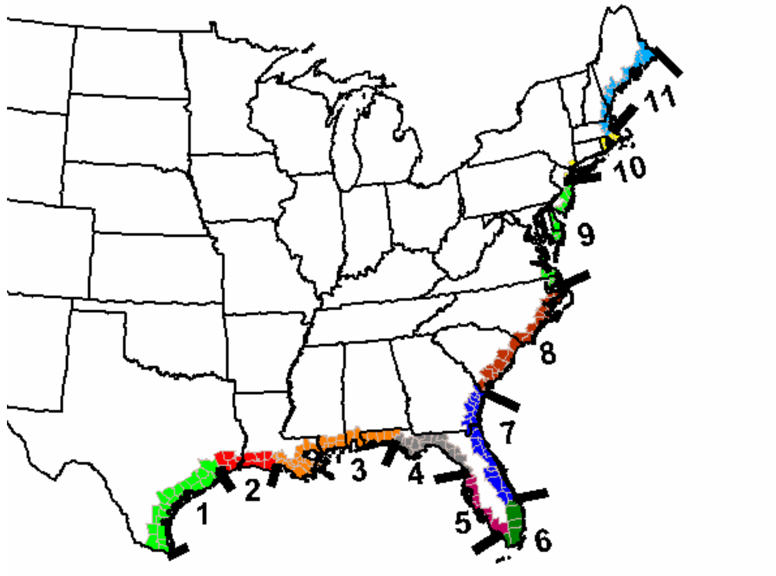

Figure 2. United States Landfall Probability Project Database

As noted previously, tropical cyclone events can have devastating impacts for the individuals, businesses and communities affected. For purposes of this modeling analysis, two specific types of economic actions are evaluated relative to potential benefits arising from improved hurricane forecast information. Figure 3 provides a simplistic illustration of these actions and the associated sources of potential economic benefits.

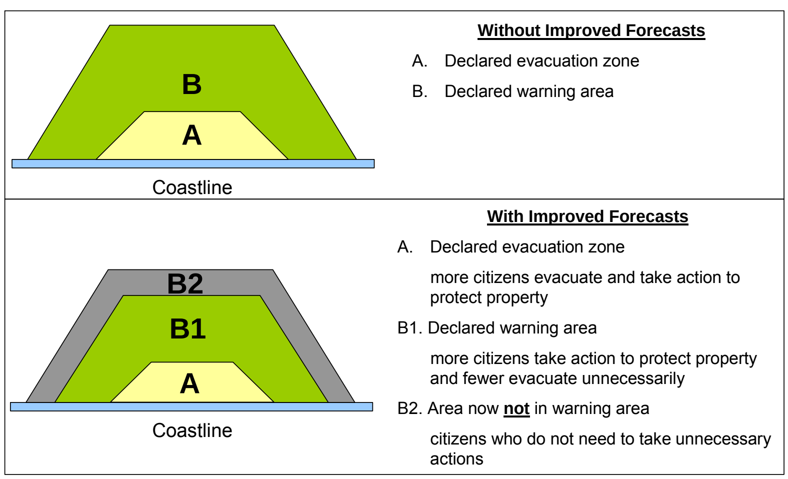

Figure 3. Illustration of Economic Effects of Improved Tropical Cyclones Forecasts

The graphic shown in the top portion of Figure 3 represents an area of coastline that is threatened by a tropical cyclone. Without improved forecast information, the larger shaded area, area B, represents the entire coastal and inland area that would be subject to a tropical storm or hurricane warning. Area A, with the darker shading, represents that portion of the warning area for which evacuation notices would occur. This very general depiction, of course, becomes much more detailed in the context of an actual location and a 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

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

magnitude of the areas affected also increases. For example, the evacuation area may be minimal or nonexistent for a tropical storm but would be significantly larger for a severe (category 4 or 5) hurricane.

The two types of economic activity included in this analysis are 1) protective actions for property (both residential and commercial) and 2) evacuation of individuals residing in the direct path of the storm. The graphic in the bottom portion of Figure 3 illustrates the relationships between these actions and economic activities as modeled in the TCFVT. With improved forecast information, the ordered or recommended evacuation area is reduced, and a greater proportion of the individuals living in the evacuation area are assumed to heed the evacuation notice and remove themselves from the impending danger. The area marked as B in the top portion of Figure 3 is segmented into two portions in the graphic in the bottom portion of the figure. The area indicated as B2 represents that geographic area which would not be included in the warning area because of improved forecast information. The remaining area, B1, would be included in the warning both with and without improved forecast information. However, with improved information, it is assumed that a greater proportion of the people in this area will take some type of action to protect their property from the impending storm. Conversely, fewer people in this area would evacuate the region unnecessarily.

It is important to note that the protection and evacuation actions have both costs and benefits and both types of 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 personnel injury and loss of life.

The two actions just noted and that are quantified in this report are only a portion of the economic factors that potentially could be affected by improved forecast information. For example, business disruption in area B1 and especially in area B2 would be lessened with improved forecast information. However, data are not available which would allow for estimation of these potential benefits. Also, tropical cyclones have wind, rainfall, and flooding impacts that could occur much farther inland than the areas included within this analysis. These include dam failures, wind effects on boats on lakes, evacuation routes, and many others. Any potential benefits to those areas from improved forecasts are not included here. The estimates produced in the analysis described here address only two actions and, therefore, undoubtedly underestimate the potential benefits for the many other economic factors that could benefit by improved forecast information.

The analysis conducted here does not directly consider the location and impact of specific, historic tropical cyclone events. The economic impacts of a storm 20 or 40 years ago would be greatly different than if that same exact storm event occurred today. Especially in the relatively high growth areas along the nation's Gulf and eastern seacoasts, the value of property and the number of residents are significantly greater today. Therefore, a retrospective analysis of actual storms would not adequately assess future events. Estimates and insights from analyses of prior storms and their economic impacts were not relied on to develop coefficients for the TCFVT.

This study's methods combine current economic conditions within the relevant geographies and historic probabilities of storm events in the targeted geographies. The types of storm events modeled are grouped into three categories: Tropical Storms, Saffir-Simpson (S-S) Category 1-2 storms (Hurricanes), and S-S Category 3-5 storms (Intense Hurricanes). Historic probabilities of each of these types of events for each of the counties are employed in the analysis. Annual probabilities of the storms being in the vicinity are also employed in the analysis.

The TCFVT, an Excel-based program developed by Centrec Consulting Group, is a powerful tool to support economic analysis and as such requires considerable amounts of data on a significant number of parameters. These parameters and the processes used to identify the appropriate values for each parameter are described in detail in Section 5.1. In addition, the results of a sensitivity analysis for key parameters are presented in that section. This overview section will provide only a brief depiction of key parameter values and the associated findings as to potential economic benefits.

In total, the geographic area and economic activity information for 213 coastal and border counties along the Gulf and Atlantic seacoasts, which are vulnerable to tropical cyclones, are included in the TCFVT database. The depth of the areas which are assumed to be receiving guidance to take action to protect property and which are receiving evacuation orders, however, is much less than the entire depth of the coastal and border counties. That depth, expressed as miles inland from the coastline, is shown in Table 2.

Table 2. Key Assumption Values Relative to Size of Protection and Evacuation Areas and Reduction in the Size of the Protection Area With an Improved Forecast

	Without Improved Forecast	
Type of Tropical Cyclone	**Depth of Protection Area (miles inland)**	**Depth of Evacuation Area (miles inland)**
Tropical Storm	1.0	0.5
Hurricane (SS 1-2)	10.0	2.0
Intense Hurricane (SS 3-5)	25.0	5.0
Reduction in Size	5.0%	5.0%

For example, with a tropical storm, the depth of protection occurs one mile inland, and the population is quantified and property value is calculated for this defined protection area. Improved forecast information can reduce that area which is alerted to take action. As shown in Table 2, it is assumed that the areas receiving warnings to protect property and to evacuate are reduced by 5% in length with improved forecast information. The 5% reduction is based on assumptions of reduced track forecast errors impacting warning area length along the coastline; the details behind the assumptions are in Section 5.1.

In addition to a reduced warning area, individual actions that lead to economically better outcomes relating to protecting property and whether to evacuate or not are key drivers in the TCFVT. The effect of alternative assumptions relative to individual responsiveness is documented in Section 5.1. For the results included in this section, citizens and decision-makers were assumed to be about 25% more responsive with improved forecast information than they would have been without that information. The extent of property damage by type of storm event and the effectiveness of taking action to reduce property damage also are important factors affecting potential economic benefits. Again, the specific values employed and considerations of the effect of alternative assumptions are presented in Section 5.1. As a reference point, the results described in this section employ property damage and protection cost estimates which are generally consistent with the available published information on these topics.

Table 3 presents, in three sections, results for the study's Base Case[8]. The Table 3 results are annualized values, which can be thought of as being representative of an "average" year's set of tropical cyclone events and current year economic conditions.. Here average refers to both the relative frequency of the types of tropical cyclone events and occurrence of such events along the target geographic region. The uppermost section of Table 3 provides estimates when no improved tropical cyclone forecast information is available. The middle section provides similar types of results, however, improved forecast information is assumed to be available. The bottom section contains values calculated as the difference between the non-improved and the improved information settings. These are the potential economic benefits of the improved tropical cyclone forecast information.

[8] The results presented in the tables are not intended to imply precision about the analysis but are provided for the reader to understand and possibly track the calculations. These results are only estimates, based on many technological, scientific and economic assumptions.

Table 3. Annualized Values for Key Economic Result Factors With and Without Improved Forecast Information for the Base Case (Case A), All Values in Dollars

No Improved Forecasts	Tropical Storm	Hurricane (SS 1-2)	Intense Hurricane (SS 3-5)	Total
Cost of property protection	6,464,156	229,699,940	501,936,546	738,100,642
Loss of life	1,269,692	7,092,372	91,512,513	99,874,577
Cost of injury	1,619,505	1,809,279	3,112,671	6,541,454
Property damage/loss	198,418,339	1,935,635,788	5,456,378,137	7,590,432,264
Cost of evacuation	196,779	11,619,049	10,304,149	22,119,977
Cost of unnecessary evacuation	89,807	19,710,251	12,960,404	32,760,462
Total	208,058,279	2,205,566,679	6,076,204,419	8,489,829,377
Improved Forecasts				
Cost of property protection	7,708,038	273,818,829	598,973,822	880,500,688
Loss of life	1,203,162	4,716,427	69,549,510	75,469,099
Cost of injury	1,615,416	1,266,495	2,490,136	5,372,047
Property damage/loss	180,071,438	1,747,448,975	5,156,942,751	7,084,463,164
Cost of evacuation	234,748	14,410,840	10,494,483	25,140,072
Cost of unnecessary evacuation	63,987	14,043,554	9,234,288	23,341,829
Total	190,896,789	2,055,705,120	5,847,684,990	8,094,286,899
Difference				
Cost of property protection	(1,243,882)	(44,118,888)	(97,037,276)	(142,400,046)
Loss of life	66,531	2,375,945	21,963,003	24,405,478
Cost of injury	4,090	542,784	622,534	1,169,407
Property damage/loss	18,346,901	188,186,813	299,435,386	505,969,099
Cost of evacuation	(37,969)	(2,791,791)	(190,334)	(3,020,094)
Cost of unnecessary evacuation	25,819	5,666,697	3,726,116	9,418,633
Total	17,161,490	149,861,559	228,519,429	395,542,478

Estimates for six types of factors are included in Table 3. The without information estimates in the top section of the table are generally consistent with available findings of published research focused on actual impacts of tropical cyclones. While Tropical Storms and less intense Hurricanes occur with greater frequency, the vast majority of damages are the result of Intense Hurricanes. Property damages of approximately $7 billion annually and the cost of property protection at approximately 10% of damages correspond with published estimates. The loss of life estimate is consistent with a death incidence of slightly less than 20 fatalities per year (Willoughby, Rappaport and Marks).

While the absolute values are important, the difference between the "without" and the "with" information settings is of primary interest for the assessment of potential benefits of forecast information. Two of the factors, cost of property protection and cost of evacuation, are shown with negative values in Table 3. This means that these costs are higher with improved forecast information relative to without improved forecast information. Better forecast information should encourage more citizens and decision-makers to take action to protect property and to evacuate in areas where evacuation should occur. Therefore, the additional costs indicated by the negative values for these factors represent socially good outcomes.

The positive values for the other four factors imply that costs are higher in the without information setting than they are in the with information situation. The difference in loss of life costs is consistent with a reduction of approximately five fatalities annually. The largest difference value is the roughly $500 million higher estimate for property damages and losses. Although a significant amount in absolute terms, it is less than 7% of the estimated property damages in the without information alternative. These benefits also come at the cost of an additional $140 million in costs for property protection. The sum of the benefits is nearly $400 million annually.

In this analysis, the improved forecast information from GOES-R is expected to be available for a 13 year period – starting in 2015 and ending in the year 2027. Simple multiplication of the annual benefit times 13 years results in a cumulative amount of approximately $5.142 billion.

The estimates shown in Table 3 and the $5.142 billion sum are based upon current economic conditions in the geographic regions included in the study. Two economic factors which are not likely to remain constant between now and the 2015 to 2027 period are population and inflation. The study's geographic areas have seen considerable growth in recent years and are likely to remain to be attractive locations to live. Therefore, assuming no population growth does not seem appropriate. An annual population growth of 1.5% is conservatively consistent with recent growth in these areas. If that population growth rate is evaluated in the TCFVT, the estimated benefits in 2015 would be approximately $452 million, roughly $50 million greater than the annual estimate shown in Table 3. The stream of potential benefits from 2015 to 2027 is estimated to be $6.438 billion when population growth of 1.5% is included in the analysis.

Inflation similarly is a factor that is difficult to predict for long time periods in the future. However, an assumption of no change in price levels is not realistic. To examine the effect of this factor, an annual inflation rate of 2% is incorporated into the TCFVT and its effects estimated. With a 2% inflation rate (and 1.5% population growth), the 2015 annual estimate of potential benefits increases to $539 million, and the estimated sum of the stream of benefits is $8.686 billion.

A third economic factor that needs to be considered is the discount rate to use to convert the stream of future benefits into dollar values that are consistent with today's expenditures. While the stream of benefits is assessed assuming they would occur during the 2015 to 2027 period, expenditures needed to launch and implement GOES-R would be occurring in the years between now and 2015. Therefore, discounting to a present value is a means to provide comparable economic values.

The appropriate discount rate to employ to convert values which will occur in the future to their equivalent terms today is subject to considerable debate. In Table 4, estimates of economic value for discount rates of 0, 2, 5 and 7 % are presented. (In each case, the population growth rate is set at 1.5% and no inflation is assumed to occur.)

Table 4. Annual Estimates and Sum of Present Value Estimates for Alternative Discount Rates Applied to the Base Case (Case A), All Values in Dollars

Year	No Discount Rate Applied	Discounted at 2% Rate	Discounted at 5% Rate	Discounted at 7% Rate
2015	452,259,304	378,430,354	291,530,380	245,999,096
2016	459,043,193	376,575,303	281,812,700	233,354,282
2017	465,928,841	374,729,346	272,418,944	221,359,436
2018	472,917,774	372,892,437	263,338,312	209,981,147
2019	480,011,540	371,064,533	254,560,368	199,187,724
2020	487,211,714	369,245,589	246,075,023	188,949,103
2021	494,519,889	367,435,562	237,872,522	179,236,766
2022	501,937,688	365,634,407	229,943,438	170,023,661
2023	509,466,753	363,842,082	222,278,657	161,284,127
2024	517,108,754	362,058,542	214,869,368	152,993,821
2025	524,865,386	360,283,745	207,707,056	145,129,653
2026	532,738,366	358,517,649	200,783,487	137,669,717
2027	540,729,442	356,760,209	194,090,704	130,593,237
Totals	6,438,738,644	4,777,469,759	3,117,280,960	2,375,761,769

Because the stream of potential benefits associated with improved GOES-R capabilities are well into the future, the effect of higher discount rates is to markedly reduce the present value of the estimates of potential economic gain. This is true of all technologies for which implementation will occur some time in the future. For decision purposes, the most important concept to employ is that the costs and benefits be assessed consistently with respect to the specific discount rate (and inflation rate).

4.2. Aviation

The aviation industry stands to benefit greatly from better weather information that would increase accuracy in forecasting. This study divides aviation benefits into four parts:

- Avoidable weather-related delays
- Passenger time value from avoidable weather-related delays
- Avoidable repair costs from not flying into volcanic ash plumes
- Avoided loss of life and aircraft from not flying into volcanic ash plumes

Table 5 summarizes the aviation-related savings estimated for this report. A detailed discussion of the methodology (including associated references) employed to develop these estimates is provided in Section 5 of this report. A brief description of the sources of these benefits follows this table.

Table 5. Estimated Aviation Industry Savings

Benefit Area	Annual Benefit (2015)	Present Value (2015-2027)
Avoidable delays	$60,768,216	$276,252,811
Value of passenger time avoided	50,098,031	227,746,060
Avoidable repair costs	2,935,435	13,344,512
Avoided risk of aircraft/life lost	55,263,787	251,229,632
Total	$169,065,469	$768,573,014

Avoidable weather-related delays, airline costs: The first component attempts to estimate the cost savings that are achievable by avoiding weather-related delays due to better forecasting. The HES sounder[9] is expected to provide higher resolution and higher frequency data thereby allowing forecasters to improve forecast accuracy. The resulting improved forecast accuracy is expected to allow U.S. air traffic to fly more efficiently by avoiding a small number of preventable weather-related delays.

On average, there were slightly more than 373,000 weather-related delays in the United States in the years 2004 and 2005. This is nearly 70% of all delays. Using a conservative estimate that information from the HES sounder could reduce those delays by only 5% means that over 18,600 delays could have been avoided with this enhanced technology. Costs to the airline industry of delays include fuel, crew/pilots/flight attendants, maintenance, aircraft ownership, and other costs. Based upon industry data, the annual savings to the airline industry of avoiding these delays exceeds $60 million. Assuming this stream of annual benefits is gained for each year of the period 2015 to 2027 and discounting those benefits to 2005 at a 7% discount rate results in a present value estimate of $276 million.

Value of passenger time avoided: The second component attempts to estimate value of passenger time saved due to avoiding delays as a result of better forecasting. The number of weather-related delays just presented is used in this computation as well. This analysis looks at average wage rates and delay duration to estimate the value of passenger time. The total annual savings of passenger time with the new HES sounder is the product of the delays involving passenger air-carriers, average number of passengers per plane, and the cost of passenger time per delay. Detailed data for these factors are provided in a later section. On an annual basis, the value of lost passenger time is estimated to be slightly more than $50 million. The 2005 present value at a 7% discount rate of that stream of potential benefits for the years 2015 to 2027 is almost $228 million.

9 Prior to September 2006, there were two HES instruments proposed as part of the GOES-R platform: an infrared sounder and the coastal waters imager. This infrared sounder will be referred to as the HES sounder for the remainder of the report.

Avoidable repair costs from avoiding volcanic ash: The third component attempts to estimate the value of better forecasting in avoiding volcanic ash plumes and the associated repair costs of flying aircraft into such a plume. Volcanic ash currently is not readily detectable and airplanes can suffer significant damage from flying into such plumes. Enhanced GOES-R ABI capabilities could greatly enhance the tracking of these plumes, providing advance warning so that pilots could be routed around these sources of damage.

Historical data of volcanic ash incidents worldwide indicates that about $17,600,000, in 2005 dollars, are spent on aircraft repair costs resulting from such events. The GOES-R ABI coverage area is conservatively estimated to relate to 33% of those events, and the percentage of repairs that are avoidable due to GOES-R capabilities is estimated at 50%. The estimate of the annual repair costs avoided considers average annual repair costs, the GOES coverage area, and the percent of incidents which could be avoided. The resulting estimate is almost $3 million in avoided annual repair costs. The corresponding 2005 present value at a 7% discount rate exceeds $13 million.

Avoided risk of aircraft/life loss from volcanic ash: The fourth aviation component attempts to estimate value of better forecasting in avoiding volcanic ash plumes and the potential for loss of aircraft and human life. There are two primary components in this analysis: the value of life of all passengers on board the aircraft and the cost of the aircraft. Historic data indicates that there have been four near fatal crashes due to volcanic ash plumes during the period from 1980 to 2000. (Note, although there was not a fatal crash during that time, this analysis assumes that there is a 19% chance that one flight annually might crash due to volcanic ash.)

Relative to the potential for loss of an aircraft, this report makes a conservative assumption that the average replacement cost of a plane hit by volcanic ash would be $150 million. Further, it is assumed that the lost plane is of the size of a 747 airliner with an occupancy load of slightly more than 320 and that an average economic value of a statistical life of almost $5 million (in 2005 dollars). The annual expected loss, using these assumed values, is slightly more than $55 million and the associated present value estimate exceeds $250 million.

4.3. Energy

For this report, the electricity and natural gas sectors are referred to as the energy industry. These sectors are a major component of the U.S. economy, typically accounting for over 2% of Gross Domestic Product (GDP). Small inefficiencies saved as a result of information provided by advanced imager and sounder capabilities can result in large savings passed on directly to consumers. A key factor in efficiently providing energy is to forecast demand effectively by ensuring that the necessary energy is available and that excess resources are not consumed in generating unnecessary energy. Energy providers rely on demand models to forecast electricity production and natural gas requirements. These demand forecasts are heavily driven by temperature forecasts. According to the CBA Report, the GOES-R ABI and HES sounder could provide the capability to improve temperature forecasts which in turn improve demand forecasts leading to energy industry savings. More accurate forecasts lead to improvements in production and distribution of energy and require less product to "be available", thereby lowering costs. Table 6 summarizes the estimated electricity and natural gas savings computed in this report:

Table 6. Estimated Energy Industry Savings

Sector	Annual Benefit (2015)	Present Value (2015-2027)
Electricity	$501,221,800	$2,512,489,739
Natural gas transmission	4,258,979	19,361,356
Natural gas utilities	6,581,512	31,649,818
Total	$512,062,291	$2,563,500,913

Electricity: Reducing temperature forecast error can lower load forecast error. Load forecast error is the amount of additional production an electrical company must produce to have sufficient quantity in reserve in case weather projections are inaccurate. Reducing the load error by using enhanced weather data and forecast model reduces the excess need to generate electricity that is often wasted.

Based upon 2001 to 2005 data on electricity use and conservative estimates of enhanced forecast capabilities, the amount of electrical energy that would not have to be produced is computed. Valued at regulated energy cost levels (which are lower than actual costs), these savings are estimated to be slightly more than $500 million. The 2005 present value of the stream of those savings from 2015 to 2027 exceeds $2.3 billion.

Natural gas: Savings attributable to natural gas are presented in two components: savings for natural gas transmission companies and natural gas utilities. Natural gas transmission companies operate pipelines across the U.S. and are responsible for forecasting how much natural gas needs to be available at specific locations each day. More accurate demand forecasts, based largely on temperatures, result in more efficiencies in the natural gas transmission process. Natural gas utilities also rely on accurate temperature forecasts to predict demand and the costs associated with storing and preparing natural gas for use. Natural gas that is held in stand-by is referred to as “on-system.” Better demand forecasts reduce the amount of unnecessary natural gas kept “on-system” thereby generating savings.

Cost reduction by pipeline companies transferring natural gas across the U.S. can occur by increased forecast accuracy, similar in concept to the previous discussion of electricity. To determine the potential savings for this sector, annual natural gas volume is obtained and then estimates are made regarding the extent that more accurate forecasts can reduce the unnecessary movement, and, hence, cost of natural gas transmission. Assuming a 25% improvement in 0-3 hour within-day forecasts because of enhanced imager and sounder information, annual savings of about $4.2 million are projected. The corresponding 2005 present value estimate is slightly more than $18 million.

In addition to savings potentially available through improved natural gas transmission, natural gas utilities need to maintain a certain amount of natural gas as “on-system,” which essentially means available for peak demand use by consumers, or in stand-by mode. Better demand forecasts, again largely temperature based, can improve the efficiency of natural gas utilities by requiring less natural gas to be “on-system.” A 10% reduction in the amount of “on-system” reserves, due to better temperature information available through both the ABI and HES sounder, is estimated to offer almost $6.5 million in annual savings by 2015. The associated present value estimate exceeds $29.5 million.

4.4. Irrigated Agriculture

Irrigation, particularly in the western United States, uses significant amount of water, a natural resource that is becoming more scarce and costly as demand for water rises. Increases in population and income heighten the demands for household use of water (drinking, cooking, bathing, watering lawns, etc.) and for recreational use of water. These non-agricultural uses of water are competing with crop irrigation and result in increased water costs for farmers. Improved information from both the ABI and HES sounder will enable researchers and forecasters to produce more accurate forecasts, resulting in irrigation water being used more efficiently. More efficient use of irrigation water benefits irrigating farmers directly by reducing their production costs. Further efficiency gains can lead to surplus farm water being sold for other purposes (at a significant premium to cost for irrigation). This analysis looks at the potential benefits from more accurate forecasts, based upon improved information from GOES-R, to aid decision-makers in more efficiently irrigating crops.

Although the nation’s 11 western states of Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming are the largest users of irrigation water, the analysis provided in this report does consider benefits for improved irrigation efficiency in all 50 states.

The benefits to enhanced forecast accuracy are obtained in four categories:

- Water savings – reductions in the cost of irrigation water purchased;
- Energy savings – reductions in the energy required to pump water;
- Value of increased production – saved water is retained to increase production; and
- Increased revenue from water transfer – water diverted from on-farm uses to non-farm applications with higher economic returns.

Table 7 summarizes the estimated irrigation savings computed in this report:

Table 7. Estimated Irrigated Agriculture Industry Savings

Benefit Area	Annual Benefit* (2015)	Present Value (2015-2027)
Water savings	$4,697,227	$ 84,401,556
Energy savings	14,086,380	253,109,382
Value of increased production	16,031,454	288,059,210
Increased revenue from water transfer	25,842,299	464,344,184
Total	$60,657,360	$1,089,914,332

**The annual benefit of $60 million in 2015 represents a 20% adoption rate. Full adoption occurs by 2019, when annual benefits are estimated to be $303.3 million.*

Although the enhanced forecasts based upon advanced imager and sounder data would be available in 2015, it is assumed that these forecasts are not immediately adopted by all producers. Instead, it is expected to take five years to reach full adoption[10]. Therefore, for the years 2015-2019, the annual economic value is expected to increase at over $60.6 million per year, and then remain constant at about $303.3 million for the remaining eight years. These values are then discounted at 7% per year, resulting in a present value of benefits to agricultural irrigation related to GOES-R of nearly $1.1 billion

4.5. Recreational Boating

Recreational activities are a significant attraction of coastal living in the United States. Recreational boating on the ocean is one of those activities. Nationally, recreational boating is a sizeable industry valued at $20 to 25 billion per year (in 2002 dollars). However, a considerable portion of this industry is vulnerable to significant economic losses due to hurricanes. Boat damages associated with major land-falling hurricanes between 1991 and 1999 have been estimated to exceed $830 million (in 2002 dollars).

A key factor in reducing or avoiding the losses associated with tropical storms and hurricanes is to prepare for landfall of such storms by moving threatened boats to alternative mooring places with greater protection. These protective measures, however, require accurate and timely hurricane track forecasts to be efficiently implemented. If boat owners have confidence in the hurricane track forecasts and have sufficient lead time, they can take protective action to mitigate their potential losses. Enhanced information from the ABI and HES sounder can potentially contribute to improved hurricane track forecasts by reducing the forecast errors. This reduction in errors is particularly important for the longer range forecasts extending past 24 hours to give sufficient time for boat evacuation to safer mooring locations.

[10] If all farmers using irrigation currently used weather forecasts as sophisticated tools in scheduling water applications, there would be no need to employ a phased-in adoption process for improved forecasts. Rather, the improved forecasts would be immediately employed. The actual extent to which and how forecasts are used by irrigated farmers is unknown, therefore a five-year phase-in of benefits is used here.

In 2005 dollars and using conservative estimates of the gains in forecast capability due to GOES-R, an annual estimate of over $31 million was computed. The 2005 discounted present value of this stream of annual benefits (from 2015 to 2027) exceeds $141 million. (Table 8)

Table 8. Estimated Recreational Boating Industry Savings

Benefit Area	Annual Benefit (2015)	Present Value (2015-2027)
Reduced losses	$18,610,614	$ 84,604,005
Reduced damages	12,407,076	56,402,670
Total	$31,017,690	$141,006,675

4.6. Alternative Discount and Inflation Rate Assumptions

Alternative Discount Rates

The CBA Report followed the Office of Management and Budget's (OMB) guidelines in calculating benefits attributed to GOES-R using a real discount rate of 7%. However, the 7% rate is a suggestion and analyses of future benefits using other (lower) rates can be used in the context of sensitivity analysis. In consideration of alternative discount rates to use for a sensitivity analysis, discount rates used by other governmental agencies were explored. The Congressional Budget Office's (CBO) policy is that the discount rate for most analyses be based on the real yield of Treasury debt, estimated at around 2%. The U.S. General Accounting Office's (GAO) discount rate policy is to use the interest rate for marketable Treasury debt with maturity comparable to the program being evaluated. Both the CBO and GAO justify this rate as reflecting the government's cost of funds, and thus is a practical measure of the government's opportunity costs.

Given this information, a sensitivity analysis approach, with an upper bound of 7%, an intermediate rate of 5%, and a lower bound of 2% for the discount rate, will be used for the analysis. This approach reflects the different agency approaches to discount rates and captures potential variability of real yields of Treasury debt.

Table 9 summarizes the discounted benefits as calculated for the sectors included in this analysis. The aggregate benefits discounted at 2% total about $9.7 billion while, when discounted at 7%, the total benefits are approximately $4.6 billion. This shows how sensitive the total benefit estimates are to the discount rates used.

Table 9. Sector Benefits at Different Discount Rates

	Total Discounted Benefits		
Sector	**Discount Rate 2%**	**Discount Rate 5%**	**Discount Rate 7%**
Aviation	$1,605,413,819	$1,023,721,996	$ 768,573,014
Energy	$5,420,996,633	$3,430,984,230	$2,563,500,913
Irrigated Ag	$2,392,014,273	$1,481,387,235	$1,089,914,332
Recreational Boating	$ 294,538,137	$ 187,817,724	$ 141,006,675
Total Benefits	**$9,712,962,861**	**$6,123,911,186**	**$4,562,994,933**

Alternative Inflation Rates

Often when estimating the cost of either an existing or proposed program, the U.S. government does not discount the program's expected costs but does account for inflation. To permit comparable comparison of the proposed costs and the socioeconomic benefits of a program, analogous economic factors should be used to summarize both the estimated costs and benefits. The GOES-R program has reported non-discounted but inflation-adjusted costs for the proposed GOES-R satellite system. Therefore, two inflation indices, a Department of Defense (DOD) set of Weighted Inflation Indices and a NASA set of

Weighted Inflation Indices, have been provided by the GOES-R program office to summarize the expected benefits derived from this updated CBA analysis.

Table 10, Table 11 , and Table 12 present the non-discounted, non-inflation adjusted sector benefits, the non-discounted, DoD-inflation adjusted sector benefits, and the non-discounted, NASA-inflation adjusted sector benefits, respectively. The total non-discounted benefits increase from $10 billion when not being adjusted for inflation to a little over $16 billion when adjusting for inflation using NASA's inflation index.

Table 10. Non-discounted, Non-inflation Adjusted Sector Benefits

	Non-inflation Adjusted Benefits			
Year	Aviation	Energy	Irrigated Ag	Recreational Boating
2015	$169,065,469	$512,062,291	$60,657,360	$31,017,690
2016	169,065,469	512,062,291	60,657,360	31,017,690
2017	169,065,469	512,062,291	60,657,360	31,017,690
2018	169,065,469	512,062,291	60,657,360	31,017,690
2019	169,065,469	512,062,291	60,657,360	31,017,690
2020	169,065,469	512,062,291	60,657,360	31,017,690
2021	169,065,469	512,062,291	60,657,360	31,017,690
2022	169,065,469	512,062,291	60,657,360	31,017,690
2023	169,065,469	512,062,291	60,657,360	31,017,690
2024	169,065,469	512,062,291	60,657,360	31,017,690
2025	169,065,469	512,062,291	60,657,360	31,017,690
2026	169,065,469	512,062,291	60,657,360	31,017,690
2027	169,065,469	512,062,291	60,657,360	31,017,690
Total undiscounted, non-inflation adjusted benefits for each sector				
	$2,197,851,091	$6,656,809,782	$788,545,680	$403,229,970
Total undiscounted, non-inflation adjusted benefits				
	$10,046,436,523			

Table 11. Non-discounted but DoD Index Inflation-adjusted Sector Benefits

	Inflation-adjusted Sector Benefits using DoD Weighted Inflation Indices			
Year	Aviation	Energy	Irrigated Ag	Recreational Boating
2015	$209,941,988	$635,868,320	$75,323,050	$38,517,123
2016	214,560,712	649,857,423	76,980,157	39,364,500
2017	219,281,048	664,154,286	78,673,721	40,230,519
2018	224,105,231	678,765,680	80,404,542	41,115,590
2019	229,035,546	693,698,525	82,173,442	42,020,133
2020	234,074,328	708,959,893	83,981,258	42,944,576
2021	239,223,963	724,557,011	85,828,846	43,889,357
2022	244,486,890	740,497,265	87,717,080	44,854,923
2023	249,865,602	756,788,205	89,646,856	45,841,731
2024	255,362,645	773,437,545	91,619,087	46,850,249
2025	260,980,623	790,453,171	93,634,707	47,880,955
2026	266,722,197	807,843,141	95,694,671	48,934,336
2027	272,590,085	825,615,690	97,799,953	50,010,891
Total undiscounted inflation-adjusted benefits for each sector				
	$3,120,230,856	$9,450,496,156	$1,119,477,371	$572,454,885
Total undiscounted inflation-adjusted benefits				
	$14,262,659,268			

Table 12. Non-discounted but NASA Index Inflation-adjusted Sector Benefits

Inflation-adjusted Sector Benefits using NASA Weighted Inflation Indices				
Year	Aviation	Energy	Irrigated Ag	Recreational Boating
2015	$228,601,956	$692,385,278	$82,017,879	$41,940,585
2016	235,604,198	713,593,536	84,530,146	43,225,255
2017	242,814,575	735,432,188	87,117,087	44,548,111
2018	250,317,626	758,157,288	89,809,034	45,924,662
2019	258,123,879	781,800,719	92,609,764	47,356,841
2020	266,173,573	806,181,480	95,497,835	48,833,682
2021	274,474,302	831,322,571	98,475,973	50,356,580
2022	283,033,891	857,247,690	101,546,985	51,926,970
2023	291,860,413	883,981,295	104,713,767	53,546,333
2024	300,962,195	911,548,599	107,979,307	55,216,196
2025	310,347,820	939,975,604	111,346,685	56,938,135
2026	320,026,139	969,289,111	114,819,075	58,713,773
2027	330,006,280	999,516,773	118,399,753	60,544,785
Total undiscounted inflation-adjusted benefits for each sector				
	$3,592,346,846	$10,880,432,131	$1,288,863,289	$659,071,908
Total undiscounted inflation-adjusted benefits				
	$16,420,714,174			

4.7. Air Quality

Over the past few decades, considerable progress has been made in enhancing air quality in the United States. It is widely acknowledged that "good" air has value. That value was the basis for the decision to put in place a technical infrastructure to measure, model and forecast air quality, and to create a regulatory environment to continue mandating improvements of air quality. However, valuing the systems which provide the data and information necessary to monitor and forecast air quality is different than valuing air quality itself.

GOES and GOES-R information has and will continue to contribute to air quality improvements. The economic benefits of GOES-R relative to air quality will be associated with cost avoidance or increased value as it affects the following stakeholder groups in the clean air debate:

- The nation as a whole as it benefits from more informed policy decisions.
- Local governments will be better off because they will be able to better comply to EPA mandates, avoiding penalties, or in some cases, additional costs of compliance.
- "Polluters" will have more data to make the right decisions in cooperation with local governments.
- Users of clean air will be able to better plan their infrastructure and better manage their operations.
- The general public and more specifically sensitive groups will be able to better plan their daily activities and their spending patterns. New products and services will emerge to satisfy the need for clean air, outside, in the workplace, at home and for personal enjoyment.
- Individuals and services affected by the health-related impacts of air quality.

There are numerous potential methods for valuing the socioeconomic benefits of a reliable and accurate air quality monitoring and forecasting system to any of these five stakeholder groups. These approaches include:

- Formulating case studies of individual cities and analyzing their local conditions
- Developing case studies of individual companies or industries and analyzing their specific situation and constraints
- Evaluating the economic impact of various air quality scenarios on specific demographic groups
- Economic value of products or services based on air quality
- Comparing cost savings of the GOES-R system compared to the alternatives of foregoing the benefit of missing features in GOES-R data that cannot be replicated.

None of these approaches would encompass the complete socioeconomic benefits of the GOES-R system for monitoring and forecasting air quality. Careful case study analysis directly tying economic effects to improved decision-making using enhanced information is necessary to achieve credibility. Assessment across a number of such case studies, which hopefully employs similar methodologies, could provide findings which have more general applicability.

5. Analytical Processes

Detailed descriptions of the analytical processes supporting the general findings are presented in this section. For purposes of clarity, the analytical discussion has been divided as follows:

- Tropical cyclone analysis
- Cost-benefit analysis
    - Aviation
    - Energy (electricity and natural gas)
    - Irrigated agricultural
    - Recreational boating (a separate but related component to the tropical cyclone analysis)
- Air quality analysis framework

5.1. Tropical Cyclone Analysis

Tropical cyclones can have significant social and economic impact on society if they approach a coastline and more importantly if they make landfall. The impacts are far reaching, extending from direct impacts (those most closely related to the event, such as property losses associated with wind and water damage and death) to secondary impacts (related to the direct impacts; e.g., an increase in medical problems or disease following a hurricane) to tertiary impacts (those that follow long after the storm has passed, such as a change in property tax revenues collected in the years following a storm). All aspects of society are affected by these severe tropical storms including:

- Individuals in vulnerable residences;
- Businesses who must prepare for the severe weather associated with the hurricane and experience business disruptions;
- Federal, state and local government response to the impending storm;
- Companies that must prepare for and respond to preparation of and recovery from the storm (e.g., retail businesses scheduling delivery of supplies in the vulnerable areas); and
- Businesses whose operations such as normal delivery of goods and services are disrupted by the hurricanes.

As the population and property value increases in the hurricane-vulnerable areas along the U.S. coastline, timely and appropriate preparation and response to the severe weather is becoming increasingly crucial as witnessed by the issues faced with Katrina. The damage created by this storm and Rita is estimated to range from $70 billion to $130 billion (Holtz-Eakin). The potential reduction of preventable tropical cyclone damage stems from long-range planning for risk mitigation to short-term preparation and response by the public and private sectors.

The foundation for timely and appropriate hurricane preparation and response is an accurate tropical cyclone monitoring and forecasting system. Effective tropical cyclone monitoring and forecasts cannot prevent damages, 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. These decisions have economic implications in the millions, if not billions, of dollars for any given storm (Whitehead; Willoughby, Rappaport and Marks).

Responding to Tropical Cyclone Forecasts and Advisories

The tropical cyclone forecasts and advisories issued by the Tropical Prediction Center/National Hurricane Center (hereafter referred to as NHC) as they currently exist have drastically changed the economic consequences of tropical cyclones making landfall along the Atlantic seaboard. In decades past, hundreds of lives were lost as a result of insufficient information to warn and assist coastline residents to evacuate prior to the storm hitting land. However, while the science and art of tropical cyclone forecasting have improved tremendously and lives lost from hurricanes have drastically declined in recent years, the risks involved in accurate and timely forecasting and advisories have also amplified due to increased population and economic activity in the vulnerable counties. To respond to these increased risks, the NHC is continually revising its services and products provided to the emergency agencies responsible for responding to the oncoming storm threats and the public as it becomes more knowledgeable in its understanding and interpretation of the tropical cyclone forecasts and advisories.

The end result of NHC-issued tropical cyclone forecasts and advisories is a function of multiple permutations and interpretations of the information influencing public official and private decisions about enacting protection and preparation actions, and evacuations (Figure 4).

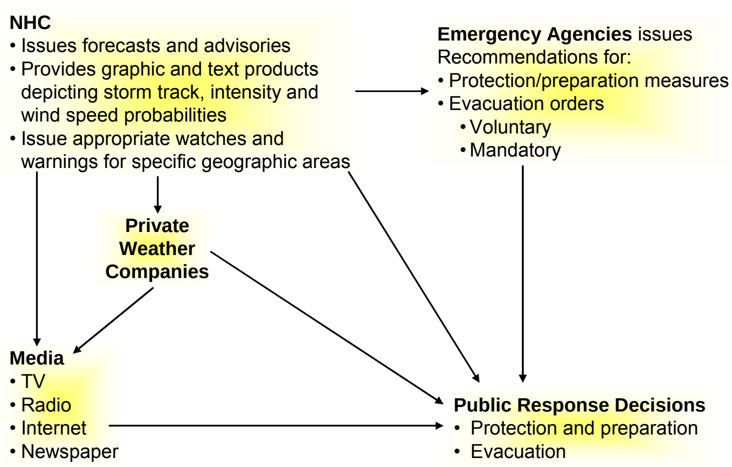

Figure 4. Responding to Tropical Cyclone Advisories and Forecasts

The NHC issues forecasts and advisories at least every six hours when there is an active tropical weather system, and this information is supplemented with graphics and other text products depicting the current state of the tropical weather system's size and structure, location, and intensity, and its forecasted track and intensity. If the weather system has developed or is forecast to develop into either a tropical storm or hurricane, a watch or warning for a specific geographic area might be issued 36 or 24 hours in advance, respectively. The NHC works closely with the media, FEMA and other governmental agencies to disseminate the information to the appropriate agencies responsible for making evacuation and preparation recommendations and to the public so that citizens also can begin assessing their risks directly. The entities authorized to issue evacuation orders differ by state. In some cases such as Florida, the county governments typically have jurisdiction over issuing evacuation orders while the governor can in some instances also order hurricane-related evacuation. In other states such as Louisiana, the state government issues the evacuation orders while home rule prevails in some northeastern states. In addition, private weather companies also utilize the information issued by the NHC and other NOAA agencies for their own tropical cyclone advisories and forecasts. In this information age, the public has numerous means available from which to obtain information about impending tropical cyclones. It relies heavily on the media for information regarding their chances of being affected by a tropical cyclone if it is in the vicinity, in addition to evacuation and protection recommendations made by the responsible emergency agencies. Residents in the designated watch and warning areas then assess the storm's current status and expected forecast in the context of their own risk perceptions to decide whether to take protection and preparation measures and/or to evacuate.

The emergency officials' strategy for managing tropical cyclone response has evolved over time as the quality and timeliness of information available to them has improved and the population for whom they are responsible increases and changes. Their key objectives are first to get the most vulnerable population out of harm's way[11] and then to encourage those vulnerable to wind damage to protect against the possible winds. Experience has shown that minimizing the population targeted for evacuation orders and maximizing the public's response to preparation and protection yield the best results. This strategy's success is fundamentally based on an educated public regarding tropical cyclones and appropriate responses, and an effective communication system when storms are approaching. Another key dimension to successful implementation of the emergency officials' management of tropical cyclone response is temporal. Due to population density, transportation logistics and a myriad of other logistical factors, sufficient lead time is becoming increasing important. As a result, there is growing emphasis on long-term forecasts for tropical cyclones.

While NHC, emergency officials, other governmental agencies, and the media attempt to work together to educate and inform the public, many of the factors that influence individuals' responses to approaching tropical cyclones are beyond these entities' control. The individual's perception of their own risk is presumably the single most important factor influencing their decision whether to evacuate and enact protective measures. This risk perception encompasses both the impending storm and their vulnerability to the storm. To assess their storm-related risk, the public has historically considered the probability of the storm striking their area[12], whether or not they are in the cone area[13], whether or not they are in the watch or warning area, and the storm's intensity and track. The lead time of the advisories and forecasts also impacts individual decision-making. It is human nature to postpone making a decision until more accurate information is available, which is often assumed to be closer to when the event is expected to occur.

Individual risk perceptions also are affected by relating to their impression of how safe they feel their type of residence is. Safety perception differs by type of residence (mobile homes, single-unit houses versus rental units such as apartments) and by the condition and location of the residence.

---

[11] The scope is normally within tens, not hundreds, of miles of the coastline. However, vulnerable inland areas such as mobile home parks may need to evacuate as well.

[12] During the 2006 hurricane season, the NHC replaced the information regarding the probability of a storm striking with the probabilities of tropical cyclone wind speeds. Their intent and hope is that the public will now utilize this metric for assessing their risk of a storm significantly impacting them.

[13] The cone area is the average forecast track error for either the three- or five-day track forecast, depending on the graphic. This cone area is depicted by a white outlined area, and is a common term of reference when assessing a tropical cyclone situation.

People also make evacuation and protection decisions based on factors other than their risk perception. These factors include the individuals' physical ability to evacuate, protect or prepare, the amount and type of information they have received, and economics (the amount of property, personal belongings and lives at risk compared to the cost to protect).

Evacuations

Experience, supported by research, has shown that evacuation decisions are no different from most decisions made by individuals. They are a result of a labyrinth of factors intertwining and influencing the process. The factors impacting evacuation decisions include individual – level indicators (including socioeconomic/demographic; experience/knowledge; location; housing status (renters feel more vulnerable since they have less control over protection than home owners)), event-oriented variables such as hazard-related factors, building safety, the amount of information available, the timing of the storm, the storm's intensity (the more intense the storm, the higher the evacuation rate) and previous experience with tropical cyclones, and lastly, risk perception (Dash and Gladwin).

When people are asked why they did or didn't evacuate, the great majority of people say they either felt safe or they did not. That is, if people didn't evacuate, it was usually because they thought the storm would miss or that if it did strike, it wouldn't be strong enough to pose a danger to their safety, given the location and construction of their home. (Baker)

Evacuation rates are difficult to generalize as they vary greatly by storm and, as described above, are driven by multiple factors. Data from recent storms indicate the following:

1. Katrina – 80% (higher than expected but the timing of storm was a big factor (built up over the weekend, giving people time and opportunity to think about it)) (Gladwin)
2. Ivan – 75% (Gladwin)
3. Andrew (Post, Buckley, Schuh & Jernigan)
    a. Broward: SS 1-2 surge zone: 69%; SS 3 surge zone: 63%; SS 4-5 surge zone: 46%; further inland: 13%
    b. Dade: SS 1 surge zone: 71%; SS 2-3 surge zone: 63%; SS 4-5 surge zone: 33%; further inland: 13%
4. Hugo (1989) – about 70% of the people at risk to dangerous storm surge evacuated to safer locations in the storms (Baker).

According to a post-Andrew survey of people experiencing the storm, the behavioral projections concluded that if public officials ordered evacuation in high and moderate risk areas and were successful in communicating to people that they need to evacuate, 90% of the respondents would leave from high-risk areas, 80% from moderate-risk areas, and 30% from areas outside the zones told to evacuate for flooding (Post, Buckley, Schuh & Jernigan, Inc.).

A key objective in current public policy is to minimize the number of people who evacuate unnecessarily. People are better off if they can protect and stay in their home (other than those susceptible to storm surge)[14]. The vehicle for meeting this objective is to focus on surge risk. Emergency officials have defined evacuation zones based on the geographic area's susceptibility to storm surge. In addition to targeting the surge zones, additional strategies have been employed to minimize risk and reduce unnecessary evacuations. The expectation is that the more prepared people are for an approaching tropical cyclone, the fewer the unnecessary evacuations. Therefore, education about preparation and increasing communication when storms are approaching are methods employed to reduce unnecessary evacuations.

[14] An example of this is Andrew in which 60,000 homes were destroyed but only 7 people died.

Even within the evacuation zones, categories with higher risk exposure have been identified and have proven to be most effective for decreasing loss of life. People residing in mobile home and recreational vehicles are considered to be at high risk and are usually the first group ordered to evacuate when evacuation orders are issued. Evacuations are also targeted to other less sturdy housing, repetitive flood zones and low lying areas (Green).

Protection and Preparation

There are four hurricane hazards – surge (function of intensity); high winds (function of intensity); rainfall/flooding (no correlation to intensity; function of storm size, motion, and topography/land structure); and tornados (possibly a function of intensity) (Green). Each of these hazards can cause property damage or loss. Attempts to decrease the potential damage from tropical cyclones fall into two categories: nonstructural and structural mitigation efforts, and property protection if a tropical cyclone watch or warning has been issued for the area. Mitigation efforts include dune enhancement and protection programs, land use techniques such as a density bonus program for the coastal areas which allow limited increased densities in turn for a property owner incorporating and implementing certain hazard mitigation techniques, and education/awareness programs ("Pilot Study for Pre- and Post-hurricane Mitigation and Development for Fernandina Beach"). Serious mitigation efforts have been made in hurricane susceptible regions of the country by including mitigation requirements in building codes for newly constructed homes. These building codes changes have been made for both single- and multiple-unit residential property.

Property protection includes shuttering windows, applying plywood panels, securing or storing all lawn furniture and other outside objects that could become a projectile in high winds, removing outside antennas, mooring boats securely or moving them to a designated safe place, storing valuables and personal papers in waterproof containers on the highest level of the home, elevating furniture and appliances or moving furniture to a higher floor.

Mitigation efforts generally occur either prior to the hurricane season or to a tropical cyclone approaching. Protective measures are considered those actions that are enacted as a tropical storm or hurricane approach the geographic area. Mitigation efforts and protective measures vary by geographic region; the residents, residential and commercial builders, and government officials in the regions in which tropical cyclones have the highest frequency of making landfall have a heightened awareness of the potential impact of the storm's destruction, and as a result, they exert greater effort in using mitigation efforts and protective measures in reducing potential property loss resulting from a tropical cyclone.

Forecasts and advisories for approaching tropical cyclones are not expected to impact mitigation efforts. However, they are expected to influence protective measures taken by the population at risk and who can decrease property loss that is avoidable through protective measures. The expected timeline for enacting protective measures is that when a watch is issued, supplies should be inventoried and protective measures should begin. If a warning is issued, protective measures should be finalized and evacuations should begin if ordered.

Some general rules of thumb exist for protective measures:

1. Protective measures usually reduce the damage incurred to the home by one S-S storm category. For example, if a homeowner enacts protection measures and an S-S cat 2 storm hits his house, damage comparable to a S-S cat 1 would occur (Willoughby).
2. Protective measures do escalate as intensity increases; a greater protection rate occurs as storms increase in intensity (Green).
3. The lead time to enact protective measures is very valuable for residences in the mid-value range. Protective measures for homes in this range can usually prevent potential damage resulting from the tropical cyclone. However, lead time for warning of oncoming tropical cyclones is not as valuable for homes that are well constructed or very fragile. (Willoughby)

4. As lead time increases in warning of an oncoming storm, the amount of damage that can be prevented increases (Willoughby).
5. At least 10% of property damage can be prevented with protection (Willoughby).

According to a survey conducted by the International Hurricane Research Center in 2005 and 2006, around 48% of the respondents had no hurricane-proof window protection. As part of FEMA's and the Army Corp of Engineer's 2004 post-hurricane assessment process, they found most people did not have hurricane window protection (FEMA/ACE).

Protective measures are enacted for commercial property to a lesser degree. It is difficult to apply window coverings to many commercial buildings so they must be built to withstand storm or re-built if destroyed during a tropical cyclone. However, there is often great value in enacting protective measures for industrial properties related to moving/protecting chemicals, machinery and other industrial inputs among other things.

Property Loss

Property loss and damage resulting from tropical storms and hurricanes is the single largest cost related to these natural hazards. Once the economic factors (such as population growth and changes in wealth) are accounted for, property losses appear to be essentially constant at $6 billion annually ($5 billion before 2005) with no discernable trend resulting from better forecasts or more effective damage mitigation measures (Willoughby, Rappaport and Marks). When evaluating property loss by hurricane category, Pielke and Landsea determined that major hurricanes with winds $\geq$ 96 kt composed 20% of U.S. tropical cyclone landfalls from 1925 through 1995 but caused 80% of property damage.

In general, property damage occurs in the following manner: (Willoughby)

1. 60 to 80 mph winds – superficial damage; fences blown down; screen doors and antennas are blown away; about 10% of the value of the home is lost
2. wind from 80 to 150 mph – serious structural damage begins to occur; the home's envelope is breached (roofs blown off; walls blown down)
3. 150-200 mph winds – complete damage/destruction occurs to the home.

According to the NHC's description of the Saffir-Simpson scale, the following damage occurs:

1. Category One Hurricane: No real damage to building structures; damage primarily to unanchored mobile homes, shrubbery and trees.
2. Category Two Hurricane – Some roofing material, door and window damage of buildings. Considerable damage to shrubbery and trees with some trees blown down. Considerable damage to mobile homes, poorly constructed signs, and piers.
3. Category Three Hurricane – Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Damage to shrubbery and trees with foliage blown off trees and large trees blown down. Mobile homes and poorly constructed signs are destroyed.
4. Category Four Hurricane – More extensive curtainwall failures with some complete roof structure failures on small residences. Shrubs, trees and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Major damage to lower floors of structures near the shore.
5. Category Five Hurricane – Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All shrubs, trees and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Major damage to lower floors of all structures located less than 15 feet above sea level and within 500 yards of the shoreline.

Proportion of property loss is a function of the quality of the home's structure; the more poorly the home is constructed, the greater the property loss. In addition, mobile homes are very vulnerable to significant or complete damage. When Hurricane Andrew struck south Florida in 1992, 97% of the mobile homes in the affected area were destroyed by wind. The more expensive homes are more likely to have hurricane mitigation/protective features, thereby decreasing the proportion of property loss caused by tropical cyclones.

Loss of Life

Most hurricane-related deaths are mostly caused by moving water, not high winds. Historically, it was storm surge that was the greatest source of hurricane mortality but from 1970 through 2000, drowning in floods caused by hurricane rainfall caused the most hurricane-related deaths (Rappaport). Prior to 1970, annual hurricane-related deaths varied greatly from 22 in the 1940s to over 800 at the turn of the century. However, between 1970 and 2004, the average number of deaths attributed to hurricanes from all causes was in the low twenties. (Willoughby, Rappaport and Marks) This reduction in deaths can, in part, be attributed to the improvements in tropical cyclone forecasting.

Overview of Tropical Cyclone Forecasting

The tropical cyclone monitoring and forecasting process is multi-layered and complex, involving many components of NOAA, and culminating with the Tropical Prediction Center/National Hurricane Center (NHC) in Miami, Florida. NHC addresses two key temporal dimensions of tropical storms and hurricanes – the current status of the severe storm, and what the storm is expected to do in the future. As a result, NHC's key services are monitoring or diagnosis of the current state of a tropical storm or hurricane, and official forecasts of the storm's path, intensity and size. In providing these services, NHC utilizes current weather observations, derived products and forecasts provided by numerous NOAA entities. The current weather observations come from several data sources including aircraft, rawinsondes, buoys, in-situ sites, and polar and geostationary satellites. These observations form the foundation for monitoring the storm's progress and are used for initialization in the Numerical Weather Prediction (NWP) models that provide guidance for NHC's official track, intensity, storm size and structure, and rainfall forecasts.

Geostationary satellites play an instrumental role in both the tropical cyclone monitoring and forecasting process (Figure 5). The GOES images are the foundation to the monitoring and diagnostic process. A former director of NHC has been quoted as saying that if NHC could have only one tool for monitoring hurricanes, it would be the images from GOES (Figure 6). Visualization is a very powerful and effective means for conveying the magnitude of a hurricane. People seem to comprehend the seriousness of a storm more effectively when they can see it than when it is described to them.

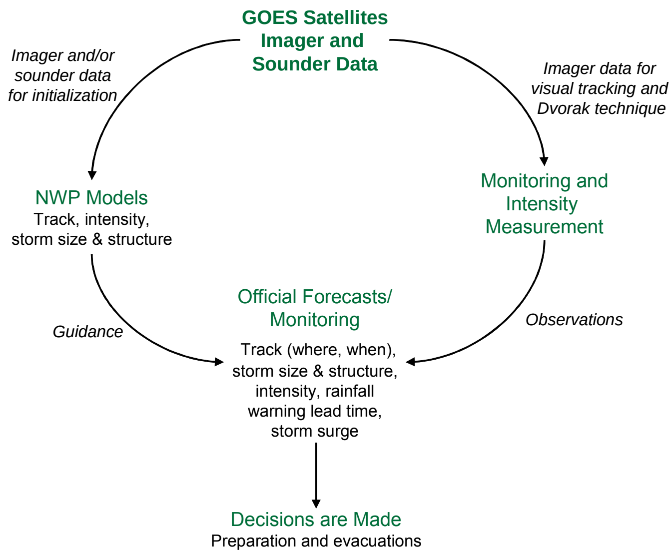

Figure 5. GOES's Role in the Hurricane Monitoring and Forecasting Process

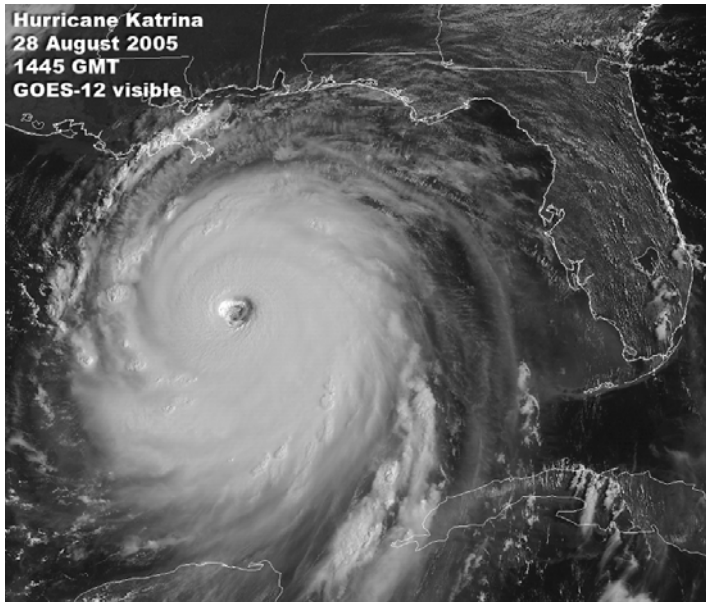

Figure 6. GOES Imagery of a Hurricane

NHC employs GOES imagery, supplemented by additional imager and sounder data and derived products, to track a hurricane and monitor its development, including intensity. The imager and sounder data provide information on wind speed and direction, temperature, and humidity. While these data and derived products are supplemented with additional information from other sources, including polar-orbiting satellites, the GOES data and derived products provide the underpinning for the monitoring process.

Measuring hurricane intensity is important for assessing the seriousness of a storm threat and the extent to which evacuation and protection measures should be taken if a storm is forecasted to make landfall. At this time, the key satellite-based intensity estimation method is the Subjective Dvorak Technique (SDT), which uses forecaster interpretation of cloud patterns and convective vigor detected from GOES images. A more automated method has been developed by researchers at the University of Wisconsin Space Science Engineering Center Cooperative Institute for Meteorological Satellite Studies (SSEC/CIMSS), which also uses GOES imager data to assess hurricane structure. The results from this technique (the Advanced Dvorak Technique or ADT) have the potential to be used not only for intensity estimation, but also for improving the hurricane vortex initialization in the NWP models[15].

These satellite data are mandatory for the monitoring and diagnosis of tropical cyclones. They provide the temporal (frequency of observations) and spatial (observations over the ocean) dimensions not found from other data sources. The development of a storm can sometimes begin several days prior to threatening a U.S. coastal area and at several hundred/thousand miles from land. GOES imager and sounder scans provide the necessary observations for detecting and following the weather systems as they move closer to land and form into more organized storms. These capabilities do not exist from other weather data sources. Specific benefits of GOES over other data sources for monitoring tropical cyclones include:

[15] There are two additional intensity estimation techniques that use GOES data. They are the Hebert-Poteat technique for estimating the intensity of subtropical cyclones, and the Miller-Lander technique for estimating the intensity of tropical cyclones becoming extratropical (losing tropical characteristics).

- Rawinsondes, buoys, ships and other land-based observations are received on a routine basis. However, these other data sources do not provide the spatial coverage over the ocean that GOES data can provide. Also, during severe weather, these mechanisms for collecting data can fail, thus decreasing the effectiveness of monitoring. GOES scans are not impacted by the severe weather, thus providing imager and sounder data on an uninterrupted basis.
- Polar orbiting satellites do not provide the temporal dimension necessary for effective hurricane monitoring. Data from polar-orbiting scans are obtained at best every 6 hours, thus preventing a timely and accurate tracking of the storm. In addition, their scanning swaths are limited in spatial extent, thus overpasses can "miss" a storm partially or entirely. Current GOES continental U.S. (CONUS) imager scans are every 15 minutes while current sounder CONUS scans are every hour. As storm systems develop and increased monitoring is deemed necessary, the frequency of GOES scans can be increased to meet the needs of the hurricane forecasters.
- Aircraft reconnaissance currently provides the most accurate assessment of hurricanes' intensity and other features. However, when aircraft cannot fly into the storm, GOES data can act to provide estimates of key parameters for monitoring hurricane behavior. In addition, the satellite data can help identify intensity trends that occur between the aircraft penetrations.

The NHC forecasters receive guidance from NWP model forecasts for hurricane tracking, intensity, storm size and structure, and rainfall prediction. These forecasts are generated from NWP models run by various NOAA entities, including the Environmental Modeling Center (EMC). The forecasting process begins with initializing the deterministic models with current weather observations through an assimilation process. Global models such as the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) use GOES data, along with other data, for its initialization process. The output from the global models are then used in regional or mesoscale models that forecast expected weather conditions on a regional basis, such as the Geophysical Fluid Dynamics Laboratory (GFDL) and the newly developed Weather Research and Forecasting Model (WRF). In addition, models specifically designed for hurricane track and intensity forecasting, such as the hurricane version of the Weather Research and Forecasting Model (HWRF)[16], have been developed. The GFS uses GOES satellite data for initialization in two forms – radiances and retrieved cloud track winds. Other data used to initialize the models include polar-orbiting, rawinsonde, aircraft, and in-situ observations. Due to decreased in-situ observations over time, GOES data have become increasingly important in the initialization process.

The NHC is constantly striving to improve its forecasts and meet its users' needs. Metrics for measuring improved forecasts include decreasing the track and intensity forecast errors. Track forecast errors have declined significantly over the past few years (Figure 7) but intensity forecasts have not had similar progress (Figure 8), in part due to the complexity of forecasting storm intensity. This complexity is demonstrated by recent events such as rapid strengthening just before landfall (Charley in 2004), rapid weakening just before landfall (Opal in 1995), and rapid strengthening to record low central pressure (Wilma in 2005). Despite the progress realized in track forecast errors, the U.S. Weather Research Program (USWRP) has identified a priority for hurricane research of reducing landfall track and intensity forecast errors by 20% (Willoughby, Rappaport and Marks). This objective translates into improving the quality of data used for initialization, in addition to improved deterministic models. Improved geostationary data should be able to contribute to the reduction of the track and intensity forecast errors, thus helping meet that research priority.

[16] This NWP model is expected to be operational sometime in 2007.

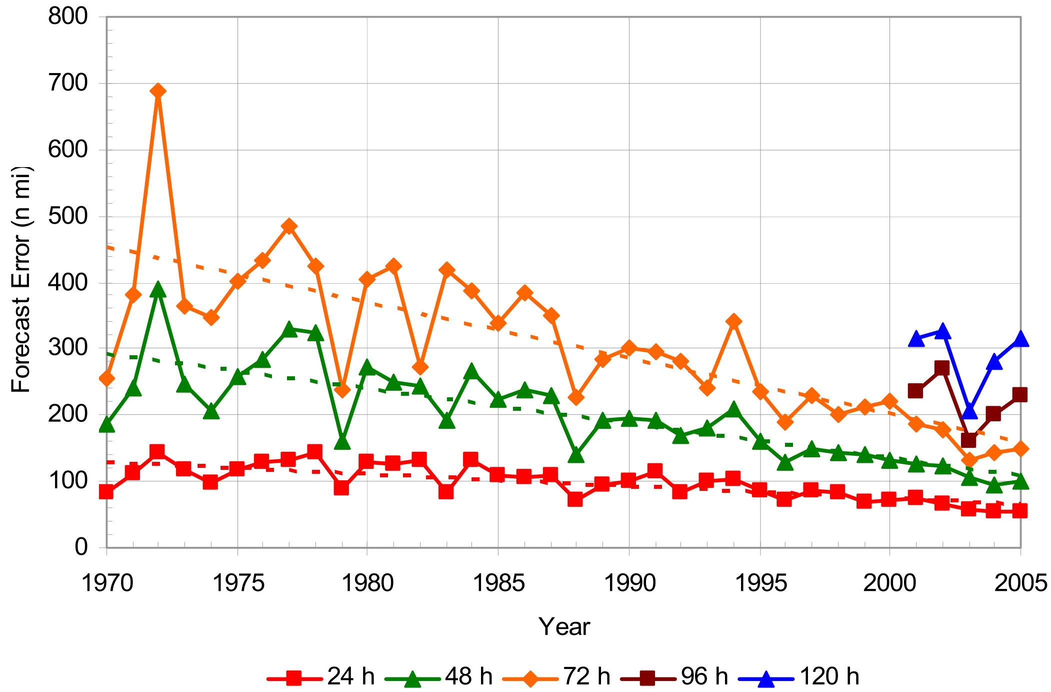

Figure 7. NHC Official Annual Average Tropical Cyclone Track Forecast Errors

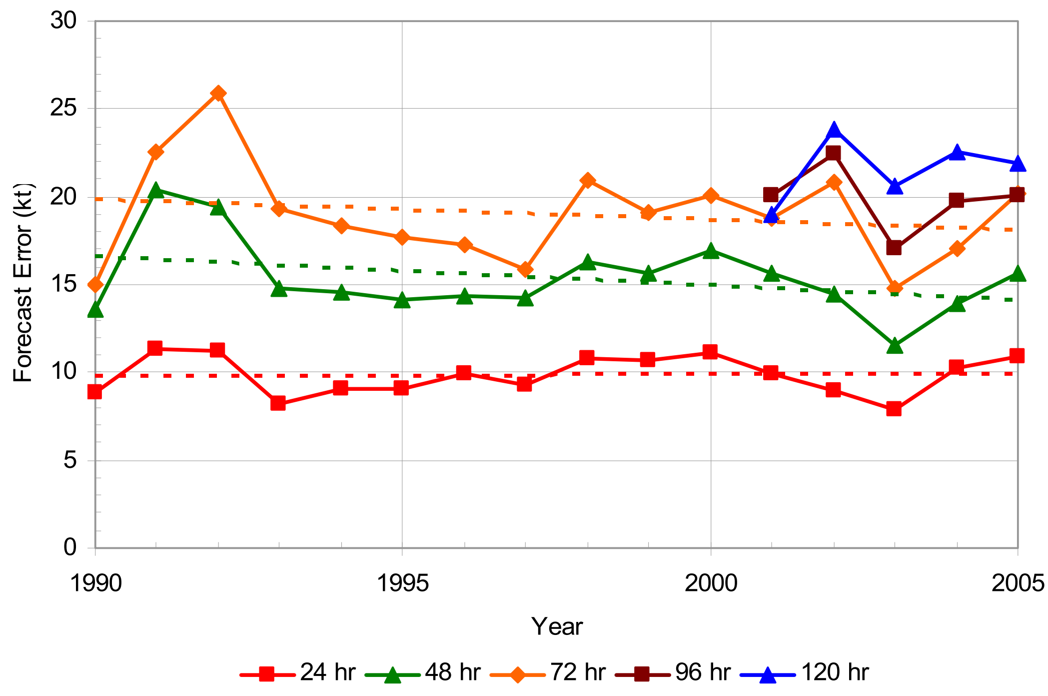

Figure 8. NHC Official Annual Average Tropical Cyclone Intensity Forecast Errors

Reduced NWP model track and intensity forecast errors gives the NHC forecasters increased confidence in the numerical guidance and thus the ability to provide improved hurricane forecasts. The guidance from the NWP model forecasts is only one component factored into the NHC forecasts; the other component is storm monitoring. Improving the monitoring process can also increase the forecasters' confidence in their hurricane forecasts, ultimately translating into more accurate and timely forecasts. Improved monitoring is also another opportunity for improved geostationary data to provide richer data and derived products for the monitoring process.

The NHC communicates its interpretation of tropical cyclones' current conditions and forecasts through a systematic issuance of a suite of tropical advisories including discussion, forecasts, probabilities and graphics (Figure 9).[17]

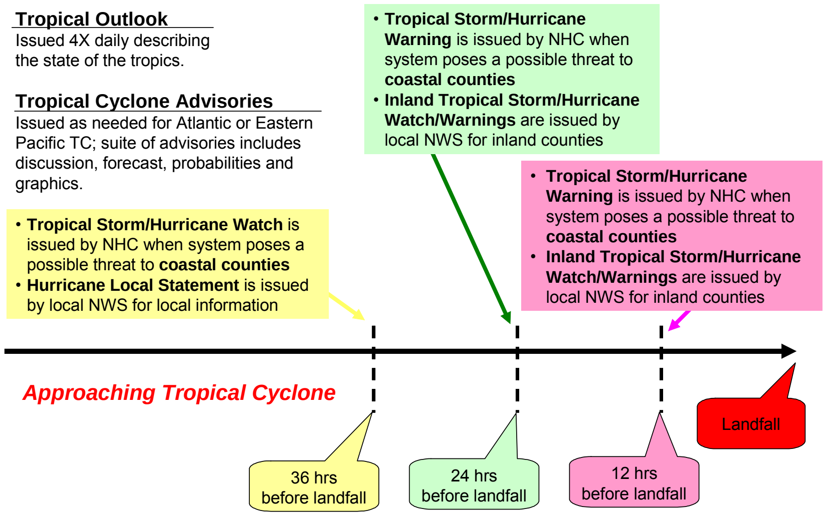

Figure 9. Timeline for Issuing Information on Impending Tropical Cyclones

The text products contained in the suite of tropical advisories consist of:

1. Forecast advisories
2. Public advisories
3. Discussion
4. Tropical cyclone surface wind speed probabilities
5. International Civil Aviation Organization advisory (an advisory product created especially for aviation needs)

The advisories and discussions include information on the weather system's current location and winds, expected track, intensity, surge and rainfall, and any necessary watches or warnings for specific locations. While watches and warnings are generally, but not always, issued 36 and 24 hours in advance of the tropical cyclone's expected landfall, discussion of current conditions and forecasts for track and intensity, and high wind probabilities typically cover periods of up to 120 hours from the initial time of the forecast. These text products are typically issued on an as needed basis or at least every six hours when a tropical cyclone is active.

[17] This analysis is very NHC/Atlantic-centric. GOES-R will also have forecasting benefits for eastern Pacific hurricanes, including those storms that occasionally threaten Hawaii. The NHC forecasts the eastern Pacific storms east of 140W longitude, while those between 140W and the International Dateline are forecast by the Central Pacific Hurricane Center in Honolulu, Hawaii. These eastern Pacific forecasting benefits could also translate into additional socioeconomic benefits.

The NHC operationalized a new metric for assessing tropical cyclones in 2006 – the tropical cyclone surface wind speed probabilities text and graphical products. These products replaced the strike probabilities used in the past, in an attempt to predict more accurately the risk posed by approaching tropical cyclones. The probabilities are based on errors during recent years in the official track and intensity forecast issued by the NHC. Variability in tropical cyclone size (wind radii) is also incorporated. Two types of probability values are produced: cumulative probabilities of occurrence, and individual period probabilities of onset. The cumulative probabilities tell decision-makers the chances that the event will happen at all. The individual period probabilities tell decision-makers when the event is most likely to start (NHC).

The NHC also issues the following graphics products for each tropical cyclone:

1. 3 Day Track and Watch/Warning
2. 5 Day Track and Watch/Warning
3. Wind History
4. Wind Speed Probabilities Table
5. 34-kt Surface Wind Speed Probabilities (120 Hours)
6. 50-kt Surface Wind Speed Probabilities (120 Hours)
7. 64-kt Surface Wind Speed Probabilities (120 Hours)

Examples of the 3 Day and 5 Day Track and Watch/Warning products are shown for Tropical Storm Ernesto in Figure 10 and Figure 11. These graphics contain a lot of information. The storm's current location is displayed along with its maximum sustained winds (current intensity) and current movement direction and speed. The graphic visually presents the forecasted track of the storm for specific times, in addition to the storm's expected intensity. The white and lightly shaded areas are universally referred to as the cone of uncertainty area and represent the average track forecast error for three and five days out, respectively. The cone area is commonly referenced by both public officials and the population in general and frequently used to assess qualitatively the risk associated with the impending tropical cyclone. The graphic also depicts the targeted coastline for tropical storm and/or hurricane watches and/or warnings if watches and/or warnings have been issued for the said named tropical cyclone.

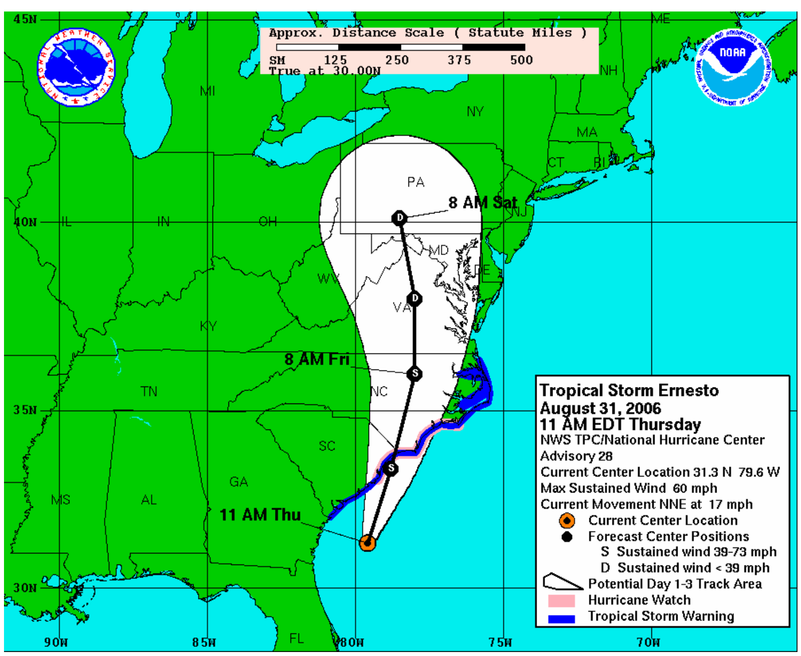

Figure 10. 3 Day Track and Watch/Warning Graphic

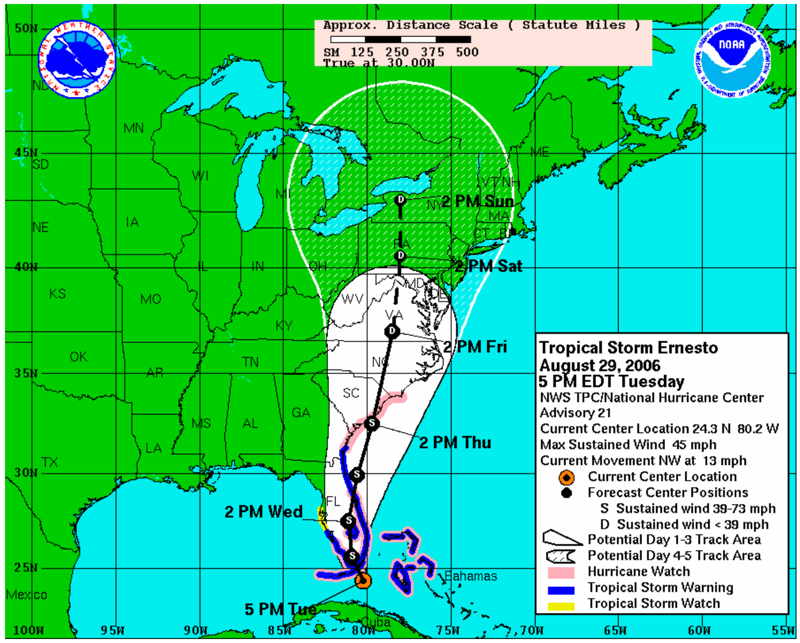

Figure 11. 5 Day Track and Watch/Warning Graphic

An example of the 50-knot wind speed probabilities graphic for Tropical Storm Ernesto is shown in Figure 12. It shows the approximate geographic area and probabilities over which 50-knot winds might occur.

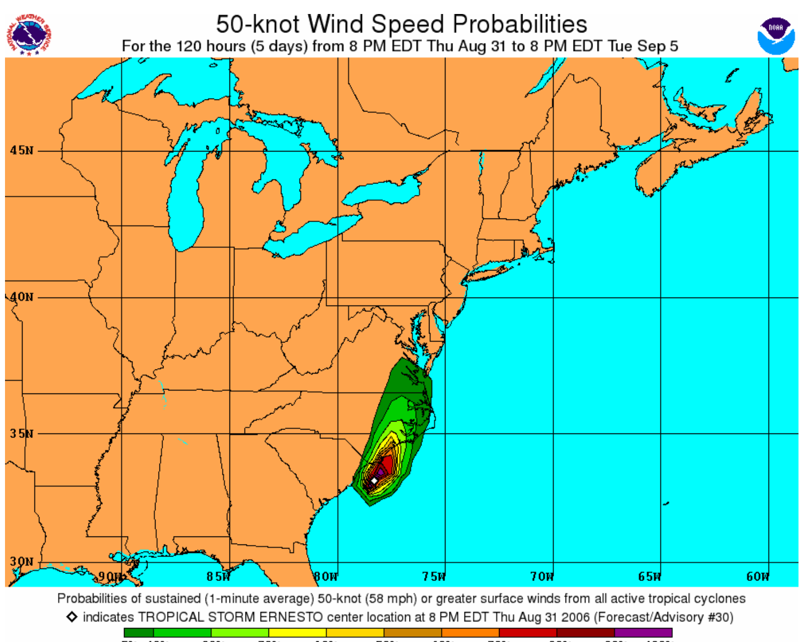

Figure 12. 50-knot Tropical Cyclone Wind Speed Graphic

Many factors influence whether or not watch or warnings are issued and the location and size of the areas. While the forecast storm track, size, and structure impact the location and size of the watch and warning areas, the tropical cyclone's forecasted intensity acts as a switch in determining whether or not a certain type of watch or warning is issued (e.g., tropical storm or hurricane watch/warning). In other words, if the maximum sustained winds are expected to reach a certain threshold, a watch or warning might be issued. When watch or warnings are issued, they are communicated in both the text and graphics products. Figure 13 displays an instance when a tropical storm warning, and hurricane watch and warning were simultaneously issued, in this example for Katrina.

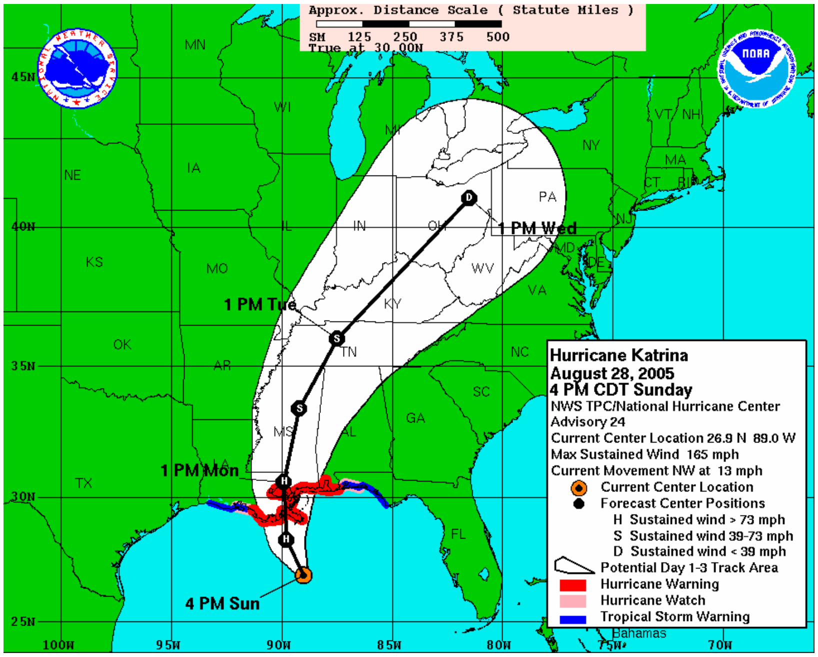

Figure 13. Example of Watch and Warning Area Designation

The NHC utilizes tropical cyclone breakpoints to determine the end points of the watch and warning areas. These breakpoints are pre-defined geographic points along the Atlantic seaboard (Figure 14), and are typically defined by county borders, geographic landmarks, political boundaries and possibly other factors. These breakpoints are around fifteen miles apart, and average warning areas might include approximately fifteen breakpoints (Jarrell and DeMaria). The use of these breakpoints facilitates the communication of the geographic location of the watch and warning areas and the emergency agencies' response to the watches and warnings.

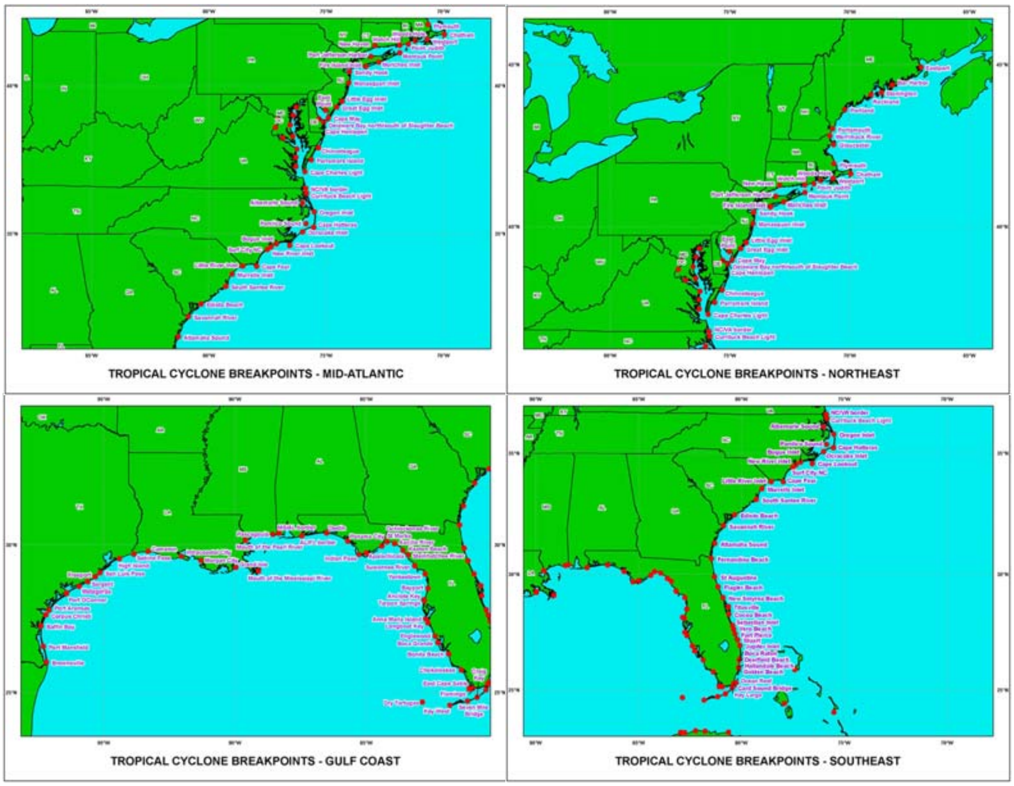

Figure 14. Tropical Cyclone Breakpoints

To improve response efficiency and effectiveness, there has been a push to increase the lead time for tropical cyclone advisories and forecasts. Simultaneously, economic theory suggests that reducing warning area size would decrease unnecessary preparation, warning and emergency-related costs. However, despite decreased track forecast errors, Jarrell and DeMaria found that average warning area increased from 1967 to 1997. This could possibly be due to the increase in the lead time of the warning and the desire to minimize the lives and property lost unnecessarily due to insufficient warning. Track forecast errors continue to decline and updated analysis indicates that average warning area size has declined since 2000 (DeMaria). Nonetheless, there is still emergency-response and economic motivation for decreasing tropical cyclone watch and warning areas, and the means by which it can be done.

GOES Role in Tropical Cyclone Monitoring and Forecasting

GOES imager and sounder data play multiple roles in the tropical cyclone monitoring and forecasting process (Figure 15)[18]. These data provide key information for derived products and initialization of current weather conditions in the Numerical Weather Prediction (NWP) models. The derived products provide observations of current conditions, and the model output provides guidance to NHC forecasters for making official forecasts and issuing advisories. The following sections describe the dimensions of tropical cyclone forecasts in which GOES imager and sounder data play a role.

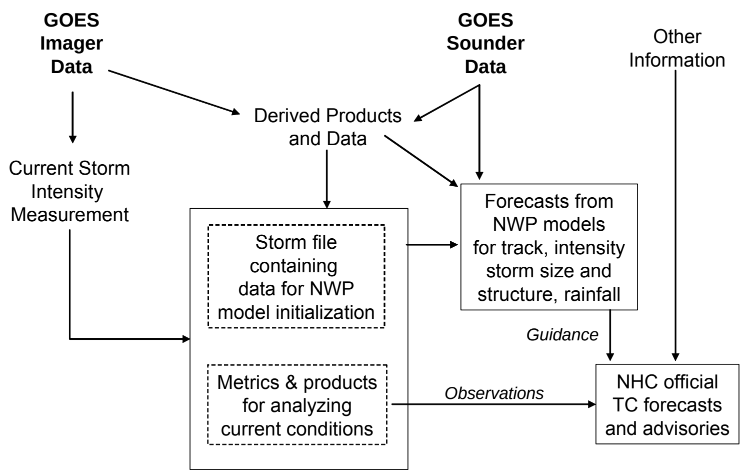

Figure 15. Overview of GOES Data's Role in Tropical Cyclone Monitoring and Forecasting

[18] The information regarding the role the current geostationary data and the potential GOES-R ABI and hypothetical high spectral sounder data was obtained from numerous discussions and communications with the following scientists: Chris Velden, Mark DeMaria, Tim Schmit, Jim Jung, Jack Beven, Jean-Noel Thepaut and Jim Goerss. However, the authors of this report remain solely responsible for any errors or omissions contained in this report.

Intensity Monitoring and Forecasting

GOES imager data contribute significantly to analyzing the current intensity conditions of tropical cyclones through multiple intensity estimation techniques, including the Subjective Dvorak Technique (SDT) and the recently developed Advanced Dvorak Technique (ADT). Both techniques use the imager longwave infrared channel to measure the cloud top heights and temperatures (Figure 16). At this time, the NHC forecasters use their expert judgment in determining which technique (ADT or SDT) results to include in their official forecasts and in the storm file sent to the EMC for the NWP model initialization process. In addition, the Dvorak technique results are used to estimate the Maximum Sustained Winds (MSW) and Minimum Sea Level Pressure (MSLP), which are also used in the initialization process.

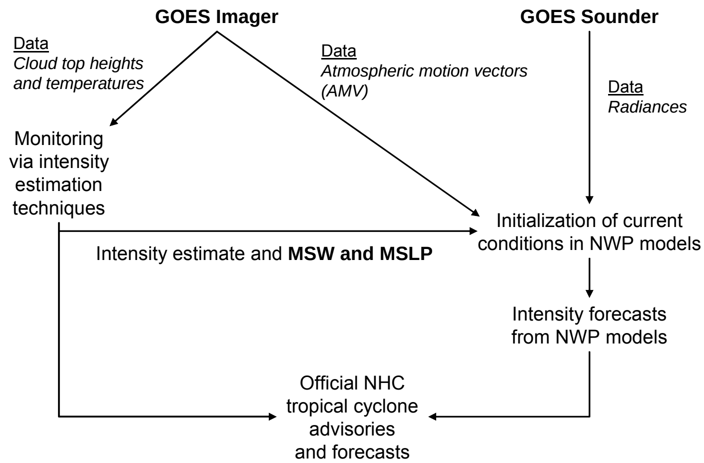

Figure 16. Tropical Cyclone Intensity Monitoring and Forecasting

Intensity forecasting has not made the same progress in improving accuracy in recent years that track forecasting has. This is because of the limitations in understanding the physics of how the tropical cyclones change, and the ability to observe storm core structure changes at high temporal frequency. However, global models have improved recently due to the increased use of satellite data to help initialize the model environment, and the introduction of better model physics. These improvements are hoped to reduce intensity forecast errors, but there still is research to be done.

GOES sounder radiances and imager atmospheric motion vectors (AMVs) are routinely used in the initialization process for both the global and some mesoscale models. Therefore, these data are used directly in the global models and either directly or indirectly (if the mesoscale model takes output from the global models as part of its initialization process) in the mesoscale models. One technique used for the initialization process is direct radiance assimilation. This method uses primarily sounder radiances (mostly polar-orbiting, but some geostationary soundings)[19] to assess the environment around the storm, but not in its core.

Due to the challenges with intensity forecasting and limited skill in a single forecast, forecasters rely on an ensemble of NWP global and mesoscale model forecasts to issue their official intensity forecasts. The mesoscale models are frequently relied on to a greater extent due to their higher resolution. In addition, another intensity forecast aid is a statistical-dynamical model called the Statistical Hurricane Intensity Prediction System (SHIPS) that directly uses GOES data in addition to data from the global GFS model. The guidance from SHIPS is weighed higher than the global models' output.

[19] Work is under way to use some GOES imager radiances also.

Track Forecasting

Track forecasting utilizes both GOES sounder and imager data in the data initialization process, primarily at the global model level (Figure 17). The imager's cloud track winds are utilized to determine storm steering currents. Sounder radiances over the oceans are used through the retrieval process to create vertical profiles of moisture and temperature. In addition, some sounder channels are used to track water vapor motions to derive winds or three dimensional AMVs.

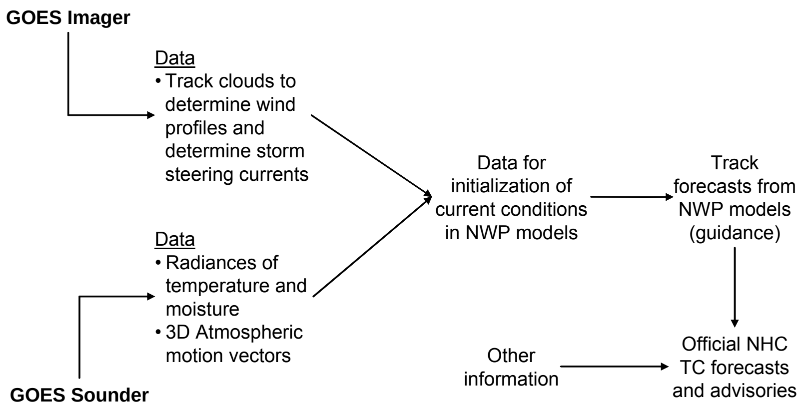

Figure 17. Tropical Cyclone Track Forecasting

Other Use of GOES Data in Tropical Cyclone Monitoring and Forecasting

GOES imager and sounder data are also used to assess the current conditions of storm size and structure and indirectly for initialization of current conditions in the NWP models for forecasting storm size and structure, and rainfall. In addition, GOES imager data are used to measure sea surface temperature (SST) which is an input into the NWP global models for the SST field.

As previously described, the NHC's recently developed tropical cyclone wind speed probabilities are based on errors in the official track and intensity forecasts. While the geostationary data are not used directly in developing these probabilities, their utilization in the track, intensity and size forecasting process does indirectly contribute to these wind speed probabilities.

Another use of the GOES data is for model validation of current conditions.

Potential Contributions of GOES-R in Improving Tropical Cyclone Monitoring and Forecasting

While the proposed GOES-R instrument platform consists of several instruments, the instrument of relevance in tropical cyclone monitoring and forecasting is the Advanced Baseline Imager (ABI)[20]. This instrument provides numerous enhancements over the current GOES system, thus the opportunity for improved forecasts and weather monitoring. Table 13 summarizes some of the key differences between the current GOES imager and the GOES-R ABI instrument.

[20] Prior to September 2006, a Hyperspectral Environmental Suite (HES) was part of the GOES-R instrument specifications. However, the instrument was dropped in September, and the sounding capabilities of the GOES-R satellite system have yet to be specified. A brief discussion is included in this report pertaining to the potential benefits of a high spectral sounder. This will not necessarily imply a HES sounder but at least an instrument with high spectral features.

Table 13. Summary of Current GOES and GOES-R Features

Instrument	Feature	Current	GOES-R ABI
Imager	Spectral coverage	5 bands	16 bands
	Spatial resolution		
	0.64um visible	Approx 1 km	0.5 km
	Other visible/near-IR	n/a	1.0 km
	Bands (>2 µm)	Approx 4 km	2 km
	Spatial coverage		
	Full disk	Every 3 hours	4/hour
	CONUS	Approx 4/hour	12/hour
	Mesoscale	n/a	Every 30 sec

The key benefits of the GOES-R ABI include:

- Increased spatial resolution to depict a wider range of phenomena better
- Faster scanning to improve temporal sampling and to scan additional regions
- Additional spectral bands to enable new and improved products

These improvements should translate into more accurate tropical cyclone monitoring and forecasting, and higher quality data (more frequent observations on a finer scale) that could be used in the NWP models that generate forecasts relevant to tropical cyclone such as track and intensity. These improvements have the potential to be realized through improved tropical cyclone forecasts.

GOES-R with Broadband Sounder Capabilities

The GOES-R ABI's enhanced data and broadband sounder data (comparable to today's geostationary sounder data) might impact tropical cyclone forecasting in the following manner:

- Intensity:
  - Monitoring current conditions: The ABI data should provide higher quality data for assessing the current storm conditions through the ADT and SDT due to the greater number of channels, higher resolution and more frequent scans. This could provide more accurate estimates of current sustained winds and thus the categorization of the storm on the Saffir-Simpson hurricane scale.
  - These intensity measurements of current conditions can also indirectly benefit intensity forecasts through their role as estimates of current intensity conditions for initialization of the global and/or mesoscale NWP models.
  - Direct utilization of imager data in the initialization process for the NWP models: Since imager AMVs are used in the NWP models, the ABI will provide improved imager data with higher spatial, spectral and temporal resolution for winds, thereby providing better information for winds and vertical shear determination.
  - Even though NWP model initialization is using some geostationary sounder radiance via direct radiance assimilation in the NWP models, broadband sounder data, as they currently exist, are not expected to provide additional changes to the intensity forecasts other than what would be expected with increased utilization and/or possibly development of new uses of the current sounder data in the assimilation process.

- Track:
  - ABI data could contribute to reducing track forecast errors due to increased precision through better spatial resolution (better edge detection) and temporal resolution; better signal-to-noise ratio; better image navigation and more channels/bands generating better cloud height detection. These features would provide higher quality data for initialization of current conditions into the NWP models.
  - Broadband sounder data, as they currently exist, are not expected to provide additional changes to the track forecasts other than what would be expected with increased utilization and/or possibly development of new uses of the current sounder data in the assimilation process.
- Tropical storm wind speed probabilities:
  - Indirect benefit of GOES-R data due to reduced intensity and track forecast errors
- Storm size and structure
  - Higher quality imager data for initialization of current conditions in HWRF and other models; this would be due to providing better viewing and resolution with more channels for winds and convective clouds.
- Sea surface temperatures (SST)
  - Higher resolution for measuring SST

These improved data might benefit or improve tropical cyclone monitoring and forecasting as follows:

- Increased accuracy of assessing current conditions (maximum sustained winds and size) is expected. GOES imager AMVs play a small role either directly or indirectly in the NWP intensity forecasts; however, use of either the ADT or SDT (and therefore the ABI data) for model initialization of current conditions could positively impact intensity forecasts by reducing forecast errors. The broadband sounder data are not expected to contribute to the reduction of intensity forecast errors unless the data are used to a greater extent or their assimilation techniques are advanced. Intensity forecast skill is low in part due to the limited understanding of the physics involved, and no research was found documenting the extent to which geostationary data impact intensity forecasts. Therefore, an estimate of how geostationary satellite data could impact tropical cyclone intensity forecasts is difficult to quantify. For this analysis, it is asserted simply that the improved GOES-R data will contribute to the reduction of intensity forecast errors, therefore increasing numerical intensity forecast accuracy. This will increase the forecasters' confidence in the numerical intensity forecasts which will be reflected in their official forecasts and advisories released to the public.
- Some decrease in track forecast errors due to improved ABI data impacting initial position and cloud track winds, but little impact from the broadband sounder is expected. Goerss and Hogan employed a data assimilation inclusion technique whereas specific sets of data (e.g., geostationary and MODIS polar satellite feature-track winds as one data set) were assimilated along with the conventional observations (i.e., rawinsonde and pilot balloon, aircraft, surface, etc.) but without other satellite data. They reported combined statistics for the Atlantic and North Pacific basin track forecast errors, and the weighted average for overall TC track forecast improvement due to the assimilation of the geostationary and polar satellite observations was 20%.

Zapotocny, et. al, used a data denial technique based on the scenario "What if this data type is removed". This approach begins with all the data available for the track forecasts, and then denies specific data. This technique is designed to account for the considerable data redundancy in the system; therefore, smaller impacts from the removal of single sources of data are expected. The authors found that when geostationary AMVs were denied from the forecasts, the weighted average for increased track forecast errors for all forecast periods was 38% and 4% for the Eastern Pacific and Atlantic basins, respectively.

These studies provide some benchmarks for the manner in which geostationary satellite data impact NWP tropical cyclone track forecasts even though the data sets, techniques and forecasts differ. However, the extent to which the ABI data could improve track forecasts is difficult to predict. Improvements in NWP forecasts will not only be due to better data, but also due to enhanced models, more sophisticated assimilation techniques and the synergistic interaction of all three components of the NWP forecasting process. Based on this evidence of the current data's impact on track forecasts, the ABI data could be expected to reduce track forecast errors beyond the progress expected with improved forecast models and data assimilation techniques, and better data from other sources. This reduction in track forecast errors will directly increase the accuracy of track forecasts, therefore, reducing the 3 and 5 day track forecast cone area over time. They should also theoretically increase the public's confidence in the forecasts. The track forecast error reduction could indirectly decrease the safety margin the forecasters build into the size of the watch and warning areas they designate. This reduction in track forecast errors could also have significant implications for the longer-range forecasts, therefore, increasing their credibility.

- Decreased intensity and track forecast errors will indirectly benefit the tropical cyclone wind speed probabilities by tightening the probability fields.
- The more accurate current storm monitoring and forecasts are expected to increase the emergency officials' and public's confidence in the NHC's forecasts and advisories. This increased confidence is expected to impact positively the emergency official recommendations for evacuation and protective measures (by making their orders and recommendations more accurate and credible) and to increase the public's responsiveness to the recommendations and orders.

GOES-R with High Spectral Sounder Capabilities

Prior to September 2006, a Hyperspectral Environmental Suite (HES) sounder was part of the proposed GOES-R instrument package. This proposed instrument would have provided enhanced capabilities beyond the current GOES sounder's capabilities. Table 14 summarizes the features of the current GOES sounder and the enhanced features outlined for the formerly proposed HES sounder.

Table 14. Summary of Features of the Current GOES Sounder and the Formerly Proposed HES

Instrument	Feature	Current	Formerly Proposed HES
Sounder	Coverage rate	CONUS/hr	Sounding disk/hr
	Horizontal resolution		
	Sampling distance	10 km	4-10 km
	Sounding FOR	30-50 km	10 km
	Vertical resolution	Approx 3 km	1 km
	Accuracy	2 deg K	1 deg K
	Relative humidity	20%	10%

Variations of a high spectral sounder are possible. However, specifications of the specific features of a high spectral sounder are beyond the purview and scope of this project. Nonetheless, it is possible to consider the potential socioeconomic benefit that could be accrued from having a high spectral sounder as part of the GOES-R system. Therefore, if the GOES-R system were to have a high spectral sounder instead of a broadband sounder, the enhanced sounder might have the potential to impact tropical cyclone monitoring and forecasting in the following manner:

- Intensity:
    - A new method for measuring current intensity conditions is being developed utilizing data from multiple instruments. This technique is expected to improve upon the Dvorak technique and could possibly use high spectral geostationary data due to its high resolution resulting from its frequent scans.
    - Less benefit to intensity forecasting would be expected from a high spectral sounder in terms of observing the storm core variables; however, through direct radiance assimilation of clear-sky environment surrounding the storm, a positive impact in the NWP model forecasts would be possible. A high spectral sounder could be expected to provide temperature and moisture soundings with much finer vertical and horizontal resolution, in addition to increased temporal coverage. This would have provided improved environmental soundings of wind, temperature and moisture, in addition to a synergistic and beneficial effect with ABI data.
- Track:
    - High spectral sounder could provide retrieval profiles of 3D winds (vertical profiles) with higher spatial and vertical resolution, in addition to improved information on temperature and moisture. The 3D wind fields with higher vertical resolution can define the storm environmental steering currents better.
- Tropical storm wind speed probabilities
    - Indirect benefit of high spectral sounder data due to reduced intensity and track forecast errors.
- Sea surface temperatures (SST)
    - Higher resolution for measuring SST; while imager data are currently being used, high spectral data could possibly be used.
- Storm size and structure
    - Higher quality sounder data for initialization of current conditions in GFS and HWRF; the high spectral data could provide eye soundings for storms with eyes, and improved environmental data in non-cloudy regimes around the periphery.
- Rain fall estimation
    - A high spectral sounder could provide better capability with the moisture field around the storm.

If a high spectral sounder were to be included on the GOES-R system, these improved sounder data might benefit or improve tropical cyclone monitoring and forecasting as follows (this would be additive to the benefits of the ABI):

- Increased accuracy of assessing current conditions. While the potential improvement might be less than the possible improvement realized from ABI data, improved sounder radiances have the possibility of contributing to improved intensity forecasts. As in the case with the ABI data, the reduced intensity forecast errors will result in increased intensity forecast accuracy. This reduction in intensity forecast errors is expected to extend to the longer-range forecasts, therefore, increasing the credibility of the longer-range forecasts.
- A decrease in track forecast errors could be expected due to high spectral sounder data. The high spectral data could be expected to contribute to the track forecast error reduction to a much greater degree than the ABI data. Again, as in the case with the ABI data, this reduction in track forecast errors will directly increase the accuracy of track forecasts, therefore, reducing the 3 and 5 day track forecast cone area over time. They should also theoretically increase the public's confidence in the forecasts. The track forecast error reduction could indirectly decrease the safety

margin the forecasters build into the size of the watch and warning areas they designate. This reduction in track forecast errors could also have significant implications for the longer-range forecasts, therefore, increasing their credibility.

- The combination of high spectral sounder data and the synergistic effect with the ABI information is likely to have an even greater impact on reducing track and intensity forecast errors than from the ABI alone
- Decreased intensity and track forecast errors will indirectly increase the accuracy of the tropical cyclone wind speed probabilities.
- The more accurate current storm monitoring and forecasts are expected to increase the emergency officials' and public's confidence in the NHC's forecasts and advisories. This increased confidence is expected to impact positively the emergency official recommendations for evacuation and protective measures (by making their orders and recommendations more accurate and credible) and to increase the public's responsiveness to the recommendations and orders.

Societal Implications of Improved Tropical Cyclone Forecasts

There are significant societal implications with improved tropical cyclone forecasts. Economic losses associated with recent hurricanes have been estimated to be in the billions of dollars (NHC). Improved hurricane forecasts cannot prevent the hurricane from hitting the coastline, but they can reduce the forecast errors in predicting where the storm will make landfall and the intensity of the hurricane if it hits the coast.

Hurricanes do not discriminate. They impact every sector of society from the individual to the multi-national company that has operations in the impacted area. As a result, preparation and evacuation decisions based on hurricane forecasts permeate every layer of the social fabric. This includes public and private, individual and business, preparation and response. Figure 18 displays the role tropical cyclone forecasts play in the decisions made for hurricane evacuation and preparation.

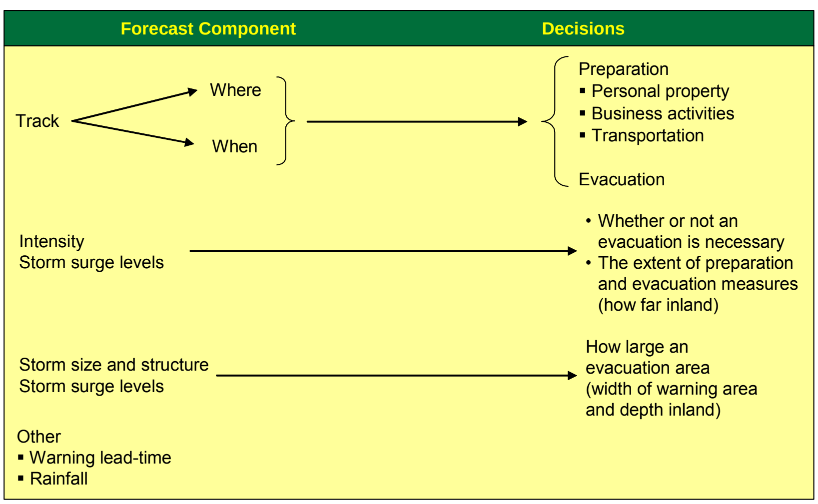

Figure 18. Role of Tropical Cyclone Forecasts

Improved tropical cyclone forecasts imply improved accuracy which can result in direct economic benefits:

- Decreased track forecast errors (more accurate assessment of where a storm will hit land) can decrease the "cone" area and tighten the wind speed probability fields, theoretically reduce watch and warning area sizes, in turn, decreasing recommended or ordered evacuation areas and the extent of suggested preparation measures. This outcome can decrease evacuation and preparation costs.

- Increased warning lead time (more accurate assessment of when storm will hit land) can improve evacuation procedures, therefore, decreasing evacuation costs.
- Decreased intensity forecast errors (more accurate assessment of storm's expected intensity at landfall) can also contribute to the tightening of the wind speed probability fields, improve "appropriate" evacuation and preparation response (to or not to evacuate; the extent of preparation and evacuation). This could decrease unnecessary evacuation and preparation costs when unwarranted, and decrease loss of life and injury, and property loss and damages when evacuation is necessary.

The improved hurricane forecasts can also accrue direct benefits to society:

- Decreased area recommended for evacuation or order to evacuate leads to fewer people and businesses impacted. This lowers evacuation and protection costs and theoretically decreases economic impact on commerce (net loss for retail businesses might be insignificant due to evacuation-related purchases).
- Greater "faith" in forecasts should increase response when evacuations are recommended or ordered, resulting in decreased loss of life and injury and public service-related costs for rescue and emergency operations. When warnings are issued early and people take protective actions, the earlier those actions are taken, the greater the chance the actions become unnecessary. The phenomenon of people taking action when a storm misses is sometimes called "crying wolf". Public officials worry that the public will lose confidence in warnings after crying wolf occurs and will be less likely to respond in the future.
- Fewer false alarms lead to decreased unnecessary evacuations and protection measures. This should decrease evacuation and protection costs and business interruptions.
- Improved evacuation targeting (where/when needed) decreases loss of life, injury and mobile property damage (e.g., high-value mobile homes, boats).

There are several dimensions to assessing tropical cyclone impacts on society. These dimensions include:

1. Societal sectors (households, commerce, and government) – Each sector has its own set of implications of how to respond to a hurricane forecast and prepare for an impending hurricane in case it hits land.
2. Impact levels – Direct, secondary, and tertiary impacts differ in temporal and spatial context. Direct impacts typically affect the area in which the hurricane hits whereas the secondary and tertiary impacts can extend far beyond the geographic area in which the hurricane makes landfall.
3. Economic cost components – These components include protection measures, evacuation costs, and business disruption. These costs depend on many factors including geographic location, population density, and demographic make-up of the population in the affected area.
4. Evacuation response:
    - Household evacuation – Local and state emergency officials make recommendations for evacuation and protective measures. These recommendations are based on information such as storm surge (which is a function of wind or intensity), storm size and structure, and geographic factors such as coastline orientation. As a result, evacuation recommendations directly impact the costs involved in responding to a storm.
    - Commerce – Commerce is impacted by tropical cyclone watches and warnings and the actual event in three dimensions: business closures; responding to societal needs for preparation, evacuation, and the aftermath; and operations planning (e.g., railroads, ships, oil/gas production). Businesses must decide whether or not to protect their facilities and close when a warning has been issued. This decision is influenced by many factors, and affects the businesses' bottom line – profits. However, other companies might be in a position to benefit from the impending severe weather through positioning supplies and services needed for

preparation, evacuation, and recovery from the hurricane. The third dimension is operations impacted by the tropical cyclones. These operations include transportation (persons and freight) sectors such as aviation, rail and shipping sectors, and the oil and gas industry.

Table 15 summarizes some sources of economic losses stemming from tropical storms and hurricanes. Each of the above mentioned dimensions contribute to the economic implications of tropical cyclone watches and warnings and the aftermath of the storms actually hitting land and causing damage and loss. These components contribute to the complexity of assessing the economic costs of these severe weather events, and thus to the benefits that could be accrued from improved tropical cyclone forecasts.

Table 15. Sources of Economic Losses Stemming from Tropical Cyclones

	Applicable Area			
Losses Resulting from Tropical Cyclones	**Evacuation Costs**	**Business Response/ Disruption Costs**	**Replacement Costs**	**Secondary or Tertiary Impacts**
Household				
Housing			✓	
Consumer durable goods	✓		✓	
Mobile property – motor homes, recreational boats, yachts, etc.	✓		✓	
Commercial				
Energy				
Oil/gas		✓	✓	
Off-shore production		✓	✓	
Refining				
Electric power				
Planning and operations		✓		
Structure			✓	
Transportation				
Air		✓	✓	
Rail		✓	✓	
Trucking		✓	✓	
Shipping		✓	✓	
Public		✓	✓	
Recreation				
Ship-based casinos	✓	✓		
Other gambling and entertainment		✓		
Recreational boating	✓	✓		
Retail		✓	✓	
Agriculture and forestry	✓	✓	✓	
Other commerce				
Commercial structures and equipment			✓	
Government				
Levees			✓	
Water and sewage treatment plants			✓	
Roads and bridges			✓	
Airports			✓	
Public buildings			✓	
Out-of-area Impacts				
Insurance premiums				✓
Oil/gas supply				✓
Grain shipping				✓

Analysis Framework

It is widely known that assessing the damages of tropical storms and hurricanes and the socioeconomic value of improved tropical cyclone forecasts is complex and multi-dimensional. One complicating factor is that the publicly available information on damages and losses from tropical cyclones presents wide ranges of property damage estimates in the millions and sometimes billions of dollars at the aggregate level[21]. This aggregation of data makes it difficult to look at incremental differences in losses when a single contributing factor is changed. In addition due to the geographic scope of tropical cyclones impacting the Atlantic coastline and the fact that each storm impacts society in a unique manner due to its individual "personality", it has been difficult to quantify the economic value of improved tropical cyclone forecasts. These factors have contributed to the scarcity of empirical analysis of losses due to hurricanes and the value of improved tropical cyclone forecasts.

The socioeconomic benefits of improved forecasts for tropical cyclones can be evaluated at the individual decision-maker level or at the societal level. Since an objective of this study is to look at the socioeconomic value of GOES and GOES-R data to society as a whole, the analysis will evaluate the benefits, or actually reduced costs, to society.

GOES and GOES-R data can potentially contribute to advances in tropical cyclone monitoring and forecasting methods through improved diagnostic tools and/or by providing critical data input to the NWP models. It is not possible for this study to evaluate every possible way in which GOES and/or GOES-R data could help improve tropical cyclone forecasts. Therefore, a realistic scope is defined, recognizing that the results will represent only a fraction of the total benefits the data can provide to society. Their contribution is assessed by first determining the scope:

1. Identifying which role that the data play in the tropical cyclone forecasting and monitoring process.
2. Determining the manner in which either enhanced use of existing GOES data or new GOES-R data can contribute to a quantifiable improvement in either tropical cyclone forecasting or monitoring.
3. Since tropical cyclone forecasts cannot prevent tropical storms or hurricanes from making landfall, improved forecasts can only help reduce loss and damage to society. As a result, the implications of the specific forecast improvements on society need to be defined.

The goal of improved tropical cyclone forecasts is to reduce evacuation costs, minimize loss of life and injury, and increase protection measures resulting from increased credibility of forecasts, thus reducing overall property loss and damages, deaths and injuries. Therefore, the intent of the analysis is to assess the impact of one source (GOES-R data) for forecast improvements on society. It is acknowledged that there most likely will be other contributing factors to the improved forecasts, and these other sources are not factored into the analysis.

There are several dimensions not considered at this time:

1. Benefits from potential contribution of improved long-range forecasts. The temporal component of hurricane warnings is not addressed at this time. However, this dimension has the potential for significant benefits to society through decreased loss of life. As coastal area population density increases and the transportation infrastructure is pressed to full capacity, the ability to evacuate in a timely manner becomes increasingly important. In some areas, the transportation infrastructure might not be sufficient to evacuate the residents in the event of a hurricane if there is insufficient lead time. In response to this issue, the NHC has recently begun issuing 96 and 120 hour forecasts. However, the consequence of the longer range forecasts is larger forecast errors. The user community is willing to accept the larger error margin at this time so they can have the information contained in the forecasts. These large errors might not be acceptable in

[21] The insurance industry has analyzed and assessed damages and losses resulting from the storms. However, their information is proprietary and generally not publicly available.

the long run. As a result, the application of GOES data to the long-range forecasts has potential due to their ability to capture information of storm development at a distance from land.

2. The costs incurred by the public sector in providing evacuation and protection assistance and by private industry as they prepare for the possibility of the tropical hurricane making landfall in an area that would impact their operations.
3. This analysis considers only the situation when a tropical storm or hurricane warning has been issued. It does not consider the circumstances when a hurricane warning has not been issued and a hurricane makes landfall.
4. The synergistic effect of data assimilation and NWP model advancements along with the improved data.

This analysis is focused on the implications of improved tropical cyclone forecasts resulting from more accurate intensity and track forecasts; a secondary implication would be the tightening of the wind speed probability fields. These improvements could be expressed in the following manner:[22]

- Reduced intensity forecast errors would more accurately predict the level of maximum sustained winds and thus the categorization of the storm on the Saffir-Simpson hurricane scale. This increased accuracy could also be manifested in more accurately predicting the behavior of the storm as it approaches the coastline (for example, whether the storm will experience rapid strengthening or weakening before landfall). More accurate intensity forecasts will positively impact society by increasing their confidence in the forecasts and advisories provided by the NHC and other entities providing similar information and in the recommendations and ordered issued by the emergency officials. This will result in increased responsiveness to protection recommendations and evacuation recommendations and orders.

- Reduced track forecast errors and tightened wind speed probability fields should positively impact the public response to tropical cyclone advisories by possibly reducing the warning cone size, and attendant watch and warning areas. The GOES data impact studies by Goerss and Hogan, and Zapotocny, et al., and the general improvements in global model skill from satellite data such as seen in the European Centre for Medium-Range Weather Forecasts (ECMWF) (Kelly; and Simmons and Hollingsworth) clearly suggest that geostationary data do positively impact track forecasts. Furthermore, given the aforementioned advances expected in geostationary satellite data and products with GOES-R, it is reasonable to assume that the improvements in the data quality could further improve track forecasts. Based on the results of Goerss and Hogan and Zapatocny, et al. as benchmarks, the assumption that improved data from GOES-R will reduce track forecast errors by 15% is utilized for this report's analysis. Due to the uncertainty in the state of numerical forecasting and data assimilation techniques ten years from now (when GOES-R should be activated), it is very difficult to state with certainty what the actual impact of the geostationary data will be on track forecasts at that time. Therefore, this assumption applies a reasonable possibility, but may turn out to be conservative. The following assumptions result:

    - The average track forecast error for 24 hour forecasts from 2000 to 2005 was 70 miles. A 15% reduction in this forecast error would reduce the track errors by 10.5 miles. If the average warning area is assumed to be 300 miles and the average distance between

[22] The application of the potential GOES-R ABI data and hypothetical high spectral sounder data to NWP models is either still in the research phase or hypothetical in nature. In addition, the state of the NWP models and data assimilation processes ten years from now is very unclear. Therefore, it is not possible to assert with certainty the extent to which ABI and hypothetical high spectral sounder data will actually improve track or intensity forecasts. The objective was to formulate reasonable and conservative estimates of what might be possible. The assumptions used for this study are guided by the scientists' best guess estimates of what might be possible. However, the authors relied on the consulting scientists for understanding the technology and the possible implications of advanced geostationary data. The scientists played no role in making the assumptions for this analysis, and the authors take full responsibility for the assumptions and logic implied behind them.

breakpoints is 15 miles (Jarrell and DeMaria), then it is possible that one breakpoint or 15 miles could be eliminated from the average warning area. This would result in a 5% reduction in warning area size (Figure 19)[23].

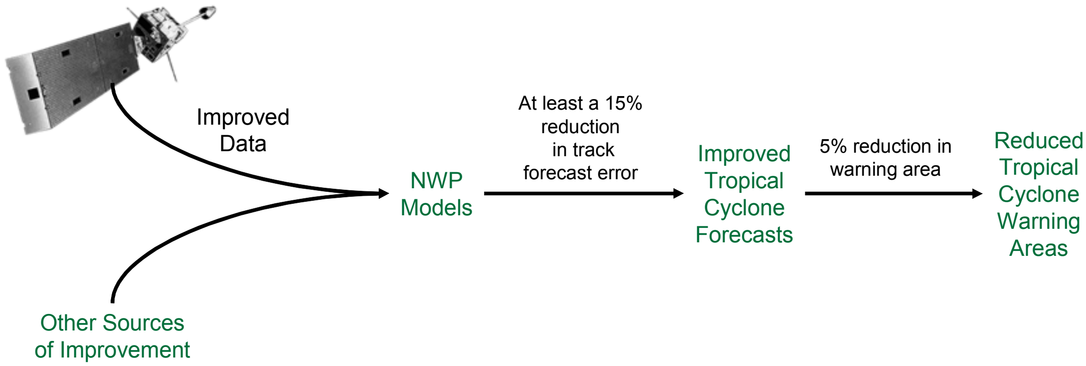

Figure 19. Impact of GOES-R Data on Reduced Tropical Cyclone Warning Areas

Improvements in any type of forecasts are a function of better data, enhanced NWP models and improved data assimilation techniques. The proposed GOES-R data are expected to be utilized in approximately a decade from now. It is anticipated that between the current state of the art of tropical cyclone forecasting and the future state of forecasting, significant improvements in the NWP models and the data assimilation processes will be realized. This expected progress, coupled with the improved geostationary data, is expected to improve tropical cyclone forecasting significantly. However, this analysis is not quantifying the improvements to be expected in the NWP models and data assimilation techniques as it is out of the scope of this project. Therefore, the potential socioeconomic benefits from the GOES-R data might be understated as a result. In addition, it is acknowledged that numerous factors are expected to help reduce track and intensity forecasting errors; however, it is assumed that the improved data from the GOES-R ABI will be one of those many factors contributing to the forecast improvements.

Reduced intensity and track forecast errors should theoretically give emergency officials and residents increased confidence in the forecasts. As a result, the decision-makers have increased confidence in making the "right" evacuation and protection decisions. As a storm approaches, residents must decide whether to enact protective measures for their residence such as covering windows and storing unsecured outside items such as patio furniture. In addition, they much decide whether to take preparation measures for themselves and other family members, such as purchasing batteries, food, bottled water, possibly generators, and gasoline.

Research pertaining to behavioral changes to improved tropical cyclone forecasts is very limited. Lazo and Chestnut found that the survey respondents place significant value on improving severe weather forecasts. It is common sense to assume that as forecasts improve in accuracy and residents' confidence in the forecasts increases, the portion of the population that respond to forecasts increases. Therefore, it will be assumed:

- The increased level of confidence in the intensity forecasts will be expressed through increased responsiveness to evacuation orders and protective measure recommendations.
- The increased level of confidence in the track forecasts will also be expressed through increased responsiveness to evacuation orders and protective measure recommendations.

[23] This is based on the premise that forecasters will have the confidence in the guidance provided by the NWP track forecasts and, as a result, reduce the warning area size. In addition, DeMaria and Franklin have found that the average length of NHC hurricane warnings has decreased in the 2000's, reversing a 35-year trend of increases. This recent trend supports the possibility of further reduction in warning area size if forecasters have increased confidence in the numerical track forecasts.

If residents decide not to prepare and protect and/or evacuate if evacuation orders are issued and a tropical cyclone hits, consequences of not taking the following measures for those residents is possible:

- Protection and preparation – avoidable property loss will be incurred
- Evacuation – a portion of the population remaining in the ordered evacuation zone will experience loss of life and injury

It will be assumed for this analysis that the improved forecasts will be quantitatively realized in two manners:

1. A reduction in warning area in which protection measures will be recommended for a smaller population base
2. An increased responsiveness by the population in the remaining warning area to protection recommendations and evacuation orders.

The improved forecasts could possibly impact decision-making in the following manner:

- Evacuation decisions
  - Those in an evacuation zone that have been ordered to evacuate – a higher proportion of population would evacuate, therefore, decreasing total loss of life and injury as a result of staying and experiencing a storm surge
  - Those NOT in an ordered evacuation zone – a decrease of unnecessary evacuations, therefore, eliminating unnecessary evacuation costs
- Preparation measures – a higher portion of those in the protection area would enact protection measures, therefore decreasing avoidable property loss

The socioeconomic value of an improved tropical cyclone forecast is the difference in costs between the current or "without improved" forecast and the "with improved" forecast. The benefit realized in this analysis is the cost savings incurred by increased evacuations, therefore, reducing loss of life and injuries, increased protective measures thereby reducing preventable property loss, and a reduction in unnecessary evacuations, therefore, lowering total evacuation-related costs.

Implications of GOES-R Plus High Spectral Sounder Data

If the GOES-R series would have a high spectral sounder, additional improvements to the tropical cyclone forecasts would be expected. These improvements would be expected to impact both the warning area size and responsiveness to evacuation orders and protection recommendations. A high spectral sounder along with the ABI would be expected to make a greater contribution to reducing track forecast errors than the ABI alone. However, a quantification of the degree to which joint data from both instruments would reduce track forecast errors, thereby potentially reducing the warning area size, is extremely difficult to estimate due to the uncertainties surrounding the assumptions.

In addition, the track and intensity forecast errors would be further reduced, thus improving the accuracy of their respective forecasts and further tightening the wind speed probability fields. It is expected that the increased forecast accuracy would thus further increase the public's confidence in the tropical cyclone forecasts. This would further increase the public's responsiveness to evacuation orders and protection recommendations above the responsiveness realized from the improved forecasts due to GOES-R with only broadband sounder capabilities. This increase in responsiveness would impact protection behavior (more would protect), evacuation behavior in the ordered evacuation zone (more would evacuate), and evacuation decisions in the non-evacuation zones (fewer would evacuate).

Valuation Tool Overview

The Tropical Cyclone Forecast Valuation Tool (TCFVT) developed to analyze the economic impacts of improved tropical cyclone forecasts is an Excel-based program that allows the user to assess different hurricane response scenarios resulting from improved forecasts impacting the tropical and hurricane watch/warning areas and the public's responsiveness to the tropical cyclone advisories. This tool is probabilistic-based, permitting expected annual benefits due to improved Atlantic tropical cyclone forecasts to be estimated.

While circular cyclonic storms occur in the Pacific Ocean (referred to as either cyclones or typhoons, depending on the location) and tropical cyclones occur in the Indian Ocean, tropical cyclones (either tropical storms or hurricanes) occurring along the Atlantic coastline from Texas to Maine (Figure 23) is the geographic scope defined for this analysis. The U.S. Landfalling Hurricane Probability Project (a joint project between Colorado State University's Tropical Meteorology Research Project and GeoGraphics Laboratory at Bridgewater State College[24]) has developed a database of historic probabilities of tropical storms and hurricanes hitting land and being in the vicinity for Atlantic coastline counties plus some counties bordering the coastline counties. The bordering counties are included in the database due to their proximity to the coastline and the fact that they are considered meteorologically and economically relevant in the analysis. In some instances, the depth inland considered for the protection area exceeds the depth of counties directly on the coast; as a result, portions of the counties bordering the coastline county are included in the defined protection area.

The high wind probabilities defined by the project are calculated for three tropical cyclone categories:

1. Tropical Storms (wind speed range of 40 to 75 mph)
2. Hurricanes categorized as categories 1 and 2 on the Saffir-Simpson (S-S) hurricane scale (wind speed range of 75 to 115 mph)
3. Intense Hurricanes categorized as 3, 4 and 5 on the S-S hurricane scale (wind speeds greater than 115 mph)

The economic costs and benefits in this valuation tool are calculated and summarized by these categories. This is consistent with other literature in which economic costs associated with tropical cyclones are reported (e.g., Pielke and Landsea).

It is well known that estimating costs associated with tropical storms and hurricanes and benefits related to improved hurricane forecasts is very complex and challenging to measure. Each tropical storm and hurricane is a unique event due to its storm "personality" and when and where it makes landfall, thus impacting unique sets of populations. Every expert with whom discussions were held emphasized the uniqueness and individuality of past tropical cyclone events, thus underscoring the difficulty in making generalizations about future events. As a result, costs and benefits cannot be calculated with certainty. An approach is adopted for this analysis in which ranges of possible outcomes based on assumptions formulated from expert opinion and available research are presented. To facilitate this "sensitivity analysis" approach, the TCFVT contains inputs or assumptions that can be changed by the user. These assumptions are typically for each tropical cyclone category, and they are:

- Protection
  - The depth inland within the warning area for which the population might take protective measures for an approaching tropical cyclone

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

    - Percent of the population within the protection area that enacts protection measures without improved forecasts.
    - Protection costs – represented as a percent of property value
- Property loss
    - Unavoidable property damage – the percent of property value estimated to be damaged or lost as a result of the tropical storm or hurricane that cannot be avoided by protective measures.
    - Property Damage Scaling Factor – a magnitude factor representing an increase in property loss as hurricane intensity increases
    - Property damage/loss when not protecting – the percent of property value that will be lost in the event of a tropical storm and no protection occurs.
    - Commercial property multiplier – a factor that implies a value relationship between residential and commercial property.
- Evacuation
    - The depth inland within the warning area for which the population might heed evacuation orders and evacuate due to an approaching tropical cyclone.
    - Percent of the population within the evacuation area that might evacuate without improved forecasts.
    - Additional adjustment to the evacuation rate for the population that is in the protection area but not in the evacuation zone that evacuate.
- Loss of life and tropical cyclone-related cost of injury
    - Loss of life – the statistical value of a loss of single life
    - Loss of life in the event of a tropical cyclone hitting land and no evacuation occurs – represented a portion of the population in the evacuation zone for which loss of life will occur
    - Injury percent in the event of a tropical cyclone hitting and evacuation not occurring – the portion of the population in the evacuation zone for which injury will occur
    - Per capita cost of injury – the estimated medical costs associated with injury resulting from a tropical cyclone hitting
- Impact of improved tropical cyclone forecasts/advisories
    - Warning area length – reduction in warning area length along the coastline
    - Public responsiveness to improved forecasts/advisories – increased responsiveness as percent of response rate without improved forecasts

These inputs are used to calculate the portion of the population that takes and does not take protective action and evacuate in the affected areas for each tropical cyclone category. Costs and savings resulting from these actions are calculated on a per capita basis for each county, annualized based on the probabilities of the storms making landfall in that county, and then aggregated for the entire geographic area. The data driving the calculations are census population and property value data, in addition to estimates for evacuation costs and the assumptions that can be changed by the user.

The results of these computations are aggregated net economic benefits stemming from the improved tropical cyclone forecasts resulting from a reduction in warning area size, an increased response rate for protective measures and necessary evacuations, and a reduction in unnecessary evacuations outside the ordered evacuation zones. These aggregated net economic benefits can be evaluated at different discount, population growth and inflation rates.

Economic Assumptions

This section describes in greater detail the rationale behind the assumptions and the baseline values utilized for the case scenarios.

Protection

The depth inland within the warning area for which the population might take protective measures for an approaching tropical cyclone

Baseline assumption – This is defined by the depth inland from coastline and varies by storm category. There were no statistics found about the extent inland that the population protects. However, since protection is performed to minimize wind damage, the extent to which tropical cyclone force winds can impact inland was explored by reviewing charts of hurricane wind decay published by the NHC (http://www.nhc.noaa.gov/HAW2/english/wind/risk_areas.shtml). Figure 20, Figure 21, and Figure 22 depict the depth inland that winds for each hurricane category could be expected to impact. These graphs indicate that winds resulting from hurricanes can pose damage-related risk several hundred miles inland.

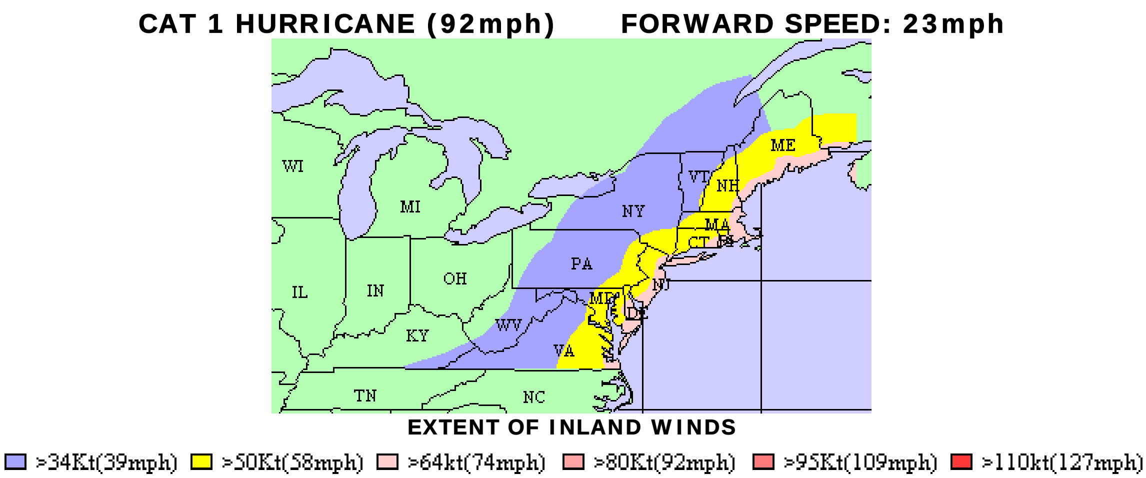

Figure 20. Extent of Inland Winds for a Cat 1 Hurricane (92 mph) with Forward Speed of 23 mph

Source: NHC

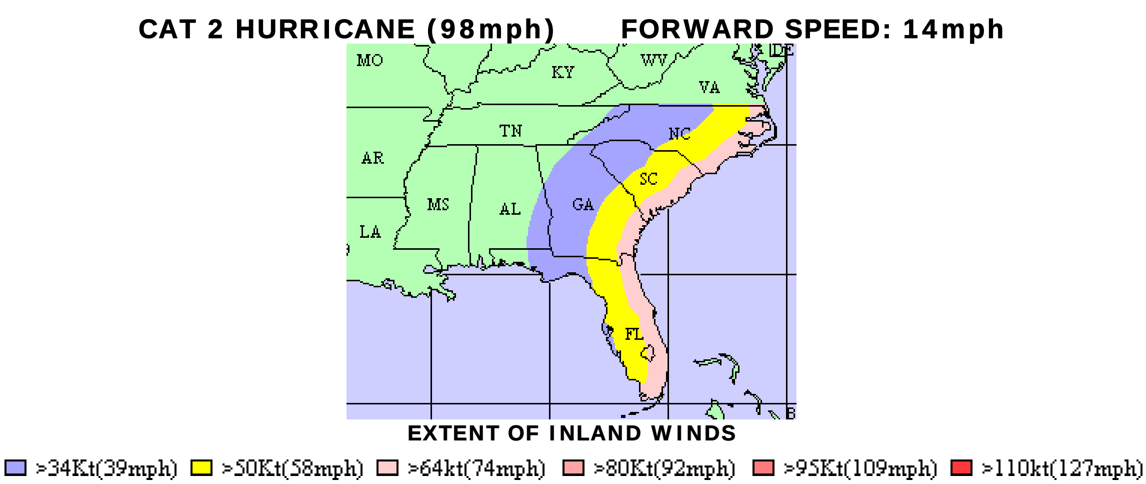

Figure 21. Extent of Inland Winds for a Cat 2 Hurricane (98mph) with a Forward Speed of 14 mph

Source: NHC

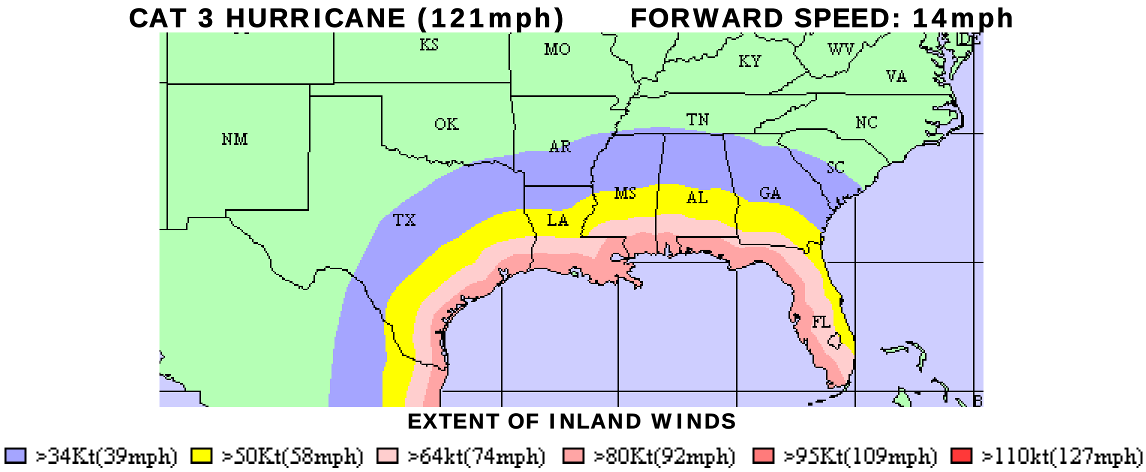

Figure 22. Extent of Inland Winds for a Cat 3 Hurricane (121mph) with a Forward Speed of 14 mph

Source: NHC

Another basic assumption made was that the more intense the storm, the further inland the population protects. The Baseline values for this analysis are 1.0, 10.0 and 25.0 miles inland from the coastline for Tropical Storms, Hurricanes and Intense Hurricanes, respectively. These values are based on reasonable estimates of protection behavior formulated after discussions with experts in the area of the public's reaction to hurricanes and review of NHC graphics of inland winds.[25]

For the second case scenario, it is assumed that the full area of the coastline and border counties is considered to be within the protection area. Given that the maximum depth inland from the coastline for the geographic region is estimated to be 189 miles, protection impacts high wind damage, and high winds resulting from hurricanes making landfall can be felt many miles inland, it is deemed reasonable to assume that a portion of the all population in the coastal counties might consider enacting protection measures.

Percent of the population within the protection area that enacts protection measures without improved forecasts.

This input assumption varies by storm category. It represents the portion of the population in the protection area that is likely to protect, and the assumption is made that the more intense the storm, the higher the rate of percent of the population that will protect. Survey results from Florida indicate that around 52% of the residents have some form of window protection and only 38% of the residents have garage door protection. However, Florida has one of the highest rates of preparedness due to the high likelihood that a tropical cyclone of some magnitude will hit its coastline; therefore, residents of states with lower probabilities of a tropical cyclone hitting are less likely to enact mitigation measures prior to the hurricane season, but are as or more likely to enact protective measures as a tropical cyclone approaches, particularly as the hurricane's intensity increases.

The "baseline" values are 30%, 40%, and 60% for Tropical Storms, Hurricanes and Intense Hurricanes, respectively. These values are based on reasonable estimates of protection behavior formulated after discussions with experts in the area of the public's reaction to hurricanes and review of studies of public response to hurricanes.

[25] While some U.S. hurricanes have caused hurricane-force winds 50 to 100 miles inland such as Hugo in 1989, the values for the Baseline were purposely deemed conservative.

Protection costs – represented as a percent of property value

Protection costs consist of

1. Costs associated with protecting home – protecting windows, automobiles, and outside mobile property (e.g., lawn furniture), securing boats, etc.
2. Costs associated with protecting belongings – waterproof containers for storing personal property; moving/protecting furniture and appliances, etc.

This input assumption also varies by storm category. The protection costs are expressed as a proportion of total property value at the county level, increasing as the storm's intensity increases. This is based on the presumption that as the approaching storm's expected intensity increases, the residents' investment in protective measures increases. Due to the limited data available, protection cost estimates are "ground-truthed" by comparing the average protection costs to the average costs reported in the studies found. The average protection costs by storm category calculated by this analysis model fall below the average protection costs found in the Florida studies. Given that Florida residents are expected to enact more protective measures than the average Atlantic coastal resident, the protection costs as a percentage of property value are considered to be conservative.

Property Loss or Damage

Unavoidable property damage

A portion of any property will be either damaged or destroyed when a tropical cyclone makes landfall, despite fully employed mitigation and protective measure efforts. Discussions with experts indicated that unavoidable property loss resulting from high winds increases with hurricane intensity. In addition, they provided insight to the types of damages that occur at the different wind speed levels. Based on this information, the following percentages for unavoidable property loss are used in the "Baseline" case scenario.

1. Tropical storm – 10%
2. Hurricanes (SS 1-2) – 30%
3. Intense hurricanes (SS 3-5) – 70%

The aggregate results generated by the valuation tool were validated by being compared to other studies: results from Pielke and Landsea's article (80% of the property damage being caused by intense hurricanes); the statistic of property loss averaging $6 billion annually reported in Willoughby, Rappaport and Marks; and Landsea, et. al. where they report the average annual normalized damage in the continental U.S. to be about $10 to $11 billion. The "Baseline" case's net economic results for no improved forecasts appeared consistent with their results. In addition, according to Hurricane Research Division, the estimated amount of damage prevented by warnings ranges from 10% to 50% of property value, with conservative estimates being around 20%. When annualized across all tropical cyclone categories, the results from the valuation tool fall within this range.

Property damage scaling factor

Review of literature and discussions with experts indicated that a four-fold increase is a reasonable approximation of increase in property damage/loss caused by tropical cyclones as they increase in categorization on the Saffir-Simpson hurricane scale. To be conservative, a four-fold increase is utilized from Tropical Storms to Hurricanes and from Hurricanes to Intense Hurricanes.

The percent of property value that will be lost in the event of a tropical storm and no protection occurs.

This value represents the portion of property value that would be damaged or destroyed in the event of a tropical cyclone making landfall and no protection measures are performed. It is recognized that an individual tropical storm can cause a lot of damage, but from a historical perspective, tropical storms at the aggregate level have caused only about 2% of the total property damage attributed to tropical cyclones (Pielke and Landsea). Therefore, the baseline assumption is that four percent of the property's value can be lost in the event of a Tropical Storm and no protection occurs.

The portion of property value that would be damaged or destroyed in the event of a Hurricane or Intense Hurricane if no protective measures are taken are increased by the property damage scaling factor.

Commercial property multiplier

This is a factor that implies a value relationship between residential and commercial property. Since U.S. census data do not include commercial property value, a proxy for commercial property is included in the valuation tool. Discussions with a commercial real estate expert provide guidance for a general relationship between commercial and residential property. This relationship varies by location, and the differentiation is designated by the degree to which the county is urbanized. The general relationship is that the more the urbanized a county, the greater the existence of commercial property relative to residential property. The following commercial property multiplier is considered to be conservative and is used in the TCFVT to estimate commercial property at the county level:

- If a county is considered to be a rural or micropolitan area, the multiplier is 3.
- If the county is classified as a metropolitan area, the multiplier is 4.
- If the county is classified as a metropolitan division, the multiplier is 5.

Evacuation

The depth inland within the warning area for which the population might heed evacuation orders and evacuate due to an approaching tropical cyclone.

The evacuation area defined in the valuation tool is smaller than the protection area. It is also the length of the warning area, but at a reduced depth inland. To determine an appropriate range of depth inland, maps of Evacuation and Surge Zones prepared by various emergency agencies along the Atlantic seaboard were reviewed to understand the extent inland for which evacuations might be ordered. The Evacuation or Surge Zones are categorized by perceived risk to high winds and surge, and typically vary greatly depending on the geography and bathymetry of the area. The Evacuation or Surge Zones are pre-defined by local emergency officials, based on the results of storm surge forecast models and SLOSH basins. The Zone immediately along the coastline is the first zone for which an evacuation would be ordered, often for hurricanes categorized at least as an S-S 1 and possibly S-S 2. This zone is frequently within a mile of the coastline. The second Evacuation or Surge zone is often for hurricanes categorized as a 3 and often ranges from one to two miles inland. Therefore, an evacuation order might be issued for a Category 3 hurricane, impacting residents in the first and second Evacuation or Surge Zones. At least a third zone is typically defined and reserved for intense hurricanes categorized as a 4 or 5. These zones are the farthest inland, sometimes extending up to or beyond five miles off the coastline.

The manner in which these evacuation or surge zones are defined implies that the more intense the storm, the farther inland the population might be ordered to evacuate. As a result, the default evacuation area depth for the valuation tool is 0.5, 2.0 and 5.0 miles for Tropical Storms, Hurricanes, and Intense Hurricanes, respectively. While evacuation or surge zones vary tremendously by region due to differences in topography, etc., generic assumptions across all coastline counties needed to be defined for the valuation tool. Therefore, these depths are intended to represent the pre-defined Evacuation or Surge Zones loosely.

Percent of the population within the evacuation area that might evacuate without improved forecasts.

This input assumption varies by tropical cyclone category. It represents the portion of the population in the evacuation area that is likely to evacuate, whether or not they are aware a mandatory evacuation order has been issued, and the assumption is made that the more intense the storm, the higher the rate of percent of the population that will evacuate. The Baseline values are 1%, 50%, and 70% for Tropical Storms, Hurricanes and Intense Hurricanes, respectively. These values are based on reasonable estimates of evacuation behavior formulated after discussions with experts in the area of the public's reaction to hurricanes and review of studies of public evacuation response to hurricane. It is recognized that evacuation response varies greatly by storm due to a multitude of factors. However, these Baseline values appear to be within the range of possibility for any of the geographic regions along the Atlantic coastline.

Additional adjustment to the evacuation rate for the population that is in the protection area but not in the evacuation zone that evacuate.

Hurricane-related evacuations are not constrained to the evacuation zones along the coast. People in areas vulnerable to tropical cyclone events have been known to evacuate because they have assessed themselves to be at risk, even though they have not been ordered to evacuate. There are economic benefits to be gained by decreasing the number of unnecessary evacuations for the population in the protection area but not considered to reside in the evacuation areas. Therefore, the TCFVT accounts for the population in the protection area that does not reside in the evacuation zones defined by the evaluation tool.

No data were found for the rate of unnecessary evacuations. Therefore, a conservative assumption for the Baseline value is that the evacuation rate of those not in the evacuation zone but in the protection area is half that of the rate in the evacuation zone. For example, the evacuation rate in the evacuation zone for Hurricanes is assumed to be 50% and the resulting rate for unnecessary evacuations in the event of a Hurricane is 25%.

Loss of Life and Tropical Cyclone Related Cost of Injury

Loss of life

The statistical value of a loss of a single life is defined in Section 5.2 at $4.9 million.

Loss of life in the event of a tropical cyclone hitting land and no evacuation occurs

The data have shown that during the last thirty or so hurricane seasons there have been around 20 hurricane-related deaths annually. A rate for loss of life for the population that remains in the evacuation area is defined for each storm category. The rates, 0.002%, 0.02% and 0.75% for Tropical Storms, Hurricanes, and Intense Hurricanes, respectively, result in around 20 deaths annually and are thus used for the Baseline. When improved forecasts increase the rate of evacuation in the ordered evacuation zones, this ultimately decreases the number of deaths resulting from the storm and generates a benefit to society.

Injury percent in the event of a tropical cyclone hitting and evacuation not occurring

In addition to deaths, tropical cyclones cause injuries for the population that does not evacuate. Reduction of the portion of the population in the evacuation zone for which injury will occur will also benefit society. Published or reported costs related to hurricanes typically represent only property loss, and do not include medical costs relating to injury and other health-related expenses. Unfortunately, no publicly-available statistics or data were found relating to this area. Therefore, conservative percentages were developed to estimate the portion of the population remaining in the evacuation zone that might be susceptible to injury. The Baseline percents are 1%, 2%, and 10% for Tropical Storms, Hurricanes, and Intense Hurricanes, respectively.

Per capita cost of injury

A per capita cost of injury is also utilized in the TCFVT to estimate the aggregated medical costs associated with injury from a tropical cyclone hitting. The only information found was a FEMA Benefit Cost Analysis of Hazard Mitigation Project in which a Tornado and Hurricane Shelter Model was developed. The model projects injury costs to be $12,500 per occurrence. This projection is used in the TCFVT.

Impact of Improved Tropical Cyclone Forecasts/Advisories

Four dimensions in the TCFVT reflect the manifestation of improved forecasts and advisories resulting from the GOES-R data. These dimensions are reduced warning area length along the coastline, higher protection rates by the population prone to protect, higher evacuation rates in the ordered evacuation zones, and lower unnecessary evacuations.

- Warning area reduction
  - This represents a reduction in warning area length along the coastline as a percent of the average warning area in recent years of 300 miles.
- Public responsiveness to improved forecasts/advisories – increased responsiveness as percent of the response rate without improved forecasts
  - Population that protects – no research that investigated the populace's response to tropical cyclone protection with improved forecasts was found. As a result, the Baseline case assumes a 25% increased responsiveness to improved forecasts as a percent of the scenario of no improved forecasts for each tropical cyclone category.
  - Population that evacuates from within the evacuation zone – Similarly, no information was found on how improved forecasts might influence evacuation decisions. However, a linear responsiveness to evacuations is not assumed as with protection. There is a certain portion of the population that will not evacuate, no matter how strong the reasons for evacuating and clear the evacuation orders are. As a result, it is assumed for the Baseline, a 0.25%, 15% and 5% increase in evacuation rates will be realized with improved forecasts, resulting in adjusted evacuation rates of 1.25%, 65% and 80% for Tropical Storms, Hurricanes, and Intense Hurricanes, respectively.
  - Population that unnecessarily evacuates in the protection area – The proportion of the population that unnecessarily evacuates will also be reduced as a result of improved forecasts. The reduction rate for unnecessary evacuations is the same proportion (25%) as the increased responsiveness rate to protective measures.

Conversion to annualized estimates

The TCFVT assesses and summarizes the costs and benefits associated with numerous factors described previously in this section. The county is the basic unit of observation, although only a portion of the county may be relevant for a particular analysis, depending upon the depth inland assumed for the analysis. Tropical cyclones occur as specific events and the TCFVT uses the previously described variables and its database (discussed below) to evaluate the economic impacts associated with a tropical cyclone being in the vicinity of each county and with the occurrence of a tropical cyclone striking the county.

In contrast to the occurrence of tropical cyclones, GOES-R satellites will be providing enhanced information continually both in time and across geography. Observations of annual landfall probabilities for tropical cyclones (discussed below) are included in the TCFVT database on a county basis. Observations are provided by type of tropical cyclone and include the likelihood of a tropical cyclone being in the vicinity and actually striking each county.

These probabilities are combined with the cost and benefit estimates relative to each type of tropical cyclone to compute annualized estimates. For example, assume that a tropical storm is expected to inflict $1,000,000 worth of property damage in a particular county. Further, assume that the likelihood of a tropical storm for that county is 3%. The estimate of the annualized value of property damages from tropical storms for that county is $30,000. In the TCFVT, this computational process is done for both the likelihood of each type of tropical cyclone being in the vicinity and striking land for all counties. Similarly the process is applied across all the benefit and cost categories in the analysis. Summation across all these factors results in the total annualized estimate for each county.

Underlying Database

The underlying foundation of the TCFVT is a county-level database containing landfall probabilities and economic data. The following sections provide an overview of these data.

Annual Landfall Probabilities

As previously mentioned, the geographic scope of the analysis is the Atlantic seaboard. The U.S. Landfalling Hurricane Probability Project utilized National Hurricane Center data to calculate the probabilities of tropical storms and hurricanes hitting land annually, in addition to the probability of a tropical storm or hurricane being in the vicinity[26]. There are 213 counties, 11 regions and 55 sub-regions in the database[27]. The variables utilized from this database for the TCFVT are the following:

- Coastline or border county designation[28]
- Coastline length
- The probability of storm in each category (Tropical Storms, Hurricanes, and Intense Hurricanes) hitting the county on an annual basis
- The probability of storm in each category being in the vicinity each year

In some instances, due to no tropical cyclone making landfall in that particular county during the time period for which data were used to calculate the probabilities, the Tropical Meteorology Project indicated that the probability was less than 0.1% of a tropical cyclone hitting. After consultation with one of the project's researcher, Philip Klotzbach, the following criteria were used to assign probabilities if the original database's probabilities indicated less than 0.1%:

- If the probabilities of a tropical storm or hurricane being in the vicinity were greater than 0.1%, then the counties were assigned a probability of 0.1% for the correlating tropical cyclone hitting land.
- If the probability of an Intense Hurricane (IH) being in the vicinity was less than 0.1%, the probability assigned to the county for the IH being in the vicinity was 0.1%, and the probability of the IH hitting land is 0.011% (0.1% divided by 9).
- If the probability of a Hurricane (H) and IH hitting the county were both less than 0.1%, then the probability of an H hitting the county was calculated as the probability of an H being in the vicinity divided by 9.
- In some instances, particularly for counties in Region 10, if nearby counties had probabilities of an IH hitting, the same probabilities were assigned to those counties designated as having a probability of less than 0.1% of the IH hitting.

---

[26] For the purpose of the Project, vicinity is considered the geographic area in which the county might be included in the watch or warning area and/or the residents of the county would be inconvenienced by or have to pay attention to the tropical cyclone's advisories or forecasts. The probabilities of a tropical cyclone being in the vicinity are calculated at the sub-region level.

[27] The U.S. Landfalling Hurricane Probability Project database has 205 counties in its database. It does not include Connecticut's coastline counties due to the presence of Long Island. However, after talking to a researcher associated with the project, it was determined reasonable to consider Connecticut's coastline counties as border counties; thus they are included in the database for the TCFVT and the probabilities calculated for the Suffolk County in New York are assigned for the Connecticut counties.

[28] Thirteen bay counties were originally designated as border counties, but due to their proximity to the Atlantic Ocean, they were re-classified as coastline counties.

Since the designated protection area in the TCFVT sometimes extends further than the depth of the coastline county, border counties should be included in the protection area. To accommodate this, all bordering counties were assigned to the appropriate coastline county. Therefore, if the protection area extends beyond the depth of the coastline county, additional area in bordering counties is included in the calculation so the full extent of the defined protection area in the analysis tool can be included.

County-level Economic Data

To capture the economic benefits of improved tropical cyclone forecast resulting from greater protection measures, reduced property damage, increased evacuations in ordered evacuation zones resulting in decreased loss of life and injuries, and decreased unnecessary evacuations, evacuation costs and property value on a per capita basis are needed. The following provides an overview of the data used for these calculations and Appendix B details the manner in which the calculations were made.

- County-level data pertaining to the estimated 2005 population and county area were obtained from the U.S. Census Bureau.
- Residential property value was calculated at the county level using data from the U.S. Census Bureau 2000 Census of Population and Housing. These values include owner-occupied, renter-occupied and vacant housing units.
- Evacuation costs were based on evacuation costs and revealed evacuation destinations reported in Whitehead. Research and discussions with numerous experts did not uncover any updated survey information or research relating to survey costs. Therefore, the reported evacuation costs in Whitehead were inflated to 2005 values and adjusted by a cost of living index to reflect the difference in cost of living between North Carolina and the counties in the database.

Resulting Net Economic Benefits

The TCFVT calculates the net annual economic benefit from improved tropical cyclone forecasts, in addition to the net benefit due to the reduced warning area and increased responsiveness. To accommodate various economic dimensions such as inflation, projected population growth and discount rates, the valuation tool permits the user to input different levels of these variables. The net economic benefits are then summed over the expected operational lifetime of the GOES-R satellite system as defined in the original CBA studies (13 years spanning from 2015 through 2027).

The Baseline value for population growth of 1.5% is used, based on review of a NOAA study projecting coastline growth from 2003 to 2008 and the U.S government's projected population growth. According to NOAA's coastal growth study published in 2004, population growth between 2003 and 2008 was estimated to average annually 2.6 to 4.6% for the 10 leading counties in the Northeast (no regional growth rate was given), 1.6% for the Southeast and around 1.4% for the Gulf region. According to cia.gov, population growth is expected to be 0.91%, while census.gov is projecting population growth to range from 0.8 to 0.85% (depending on the time period). These estimates are for the entire U.S., and population growth along the coastline is expected to be greater.

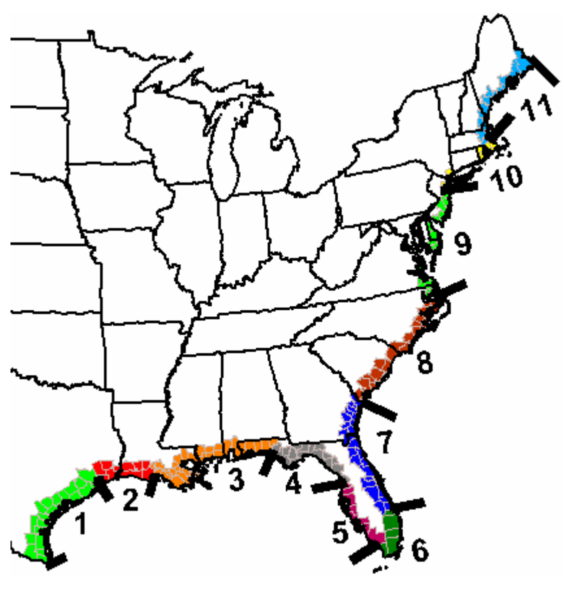

Figure 23. United States Landfall Probability Project – Counties included in Database

It has been well documented, in the media and through analytical reports, that tropical cyclones can have massive economic impacts. And, when a tropical cyclone is approaching, citizens and public and private decision-makers desperately crave more and better information as to the geographic areas at risk from the approaching cyclone. In those instances, individuals are likely to assert that improved forecast information would be invaluable.

Assessing the expected benefits from the information systems needed to provide improved information, however, is not as straightforward as one might initially think. Data on damages from specific storm events have been assessed and converted to annualized estimates. However, even perfect information as to the track and severity of a tropical storm or hurricane will not eliminate damages from the event. Forecast information has value to the extent that it allows people to make decisions that have better outcomes than those which would occur if the information was not available.

Human decision-making and the effect of forecast information on the decision-making process are complex to say the least. In the context of dramatic events, such as an impending tropical cyclone, the pressure of making choices intensifies. And the outcomes from the choices are uncertain. The decision to evacuate is likely to be quite wise, if an intense hurricane does strike your residence. However, evacuation has costs and risks. If the hurricane turns out not to be intense or does not strike the area of your residence, evacuation may have been an inferior choice to "riding out the storm".

The diagram in Figure 3 is repeated below as Figure 24 to provide a visual depiction of the economic effects captured within the TCFVT framework. Within the evacuation area, the benefits of improved forecast information are derived from a greater portion of the population who undertake to protect property and from an increased rate of evacuation. In areas struck by a tropical cyclone, protecting property results in reduced property damages, and greater evacuation is linked to fewer deaths and injuries. Within the area noted as B2 in the bottom portion of the Figure 24 with improved forecast information, citizens do not need to take protection actions which would turn out to be unnecessary. Fewer unnecessary evacuations provide economic benefits by reducing the associated costs of evacuation (transportation, lodging, etc.) In the third area, labeled B1, economic benefits result from a greater portion of the population who protect property and from a reduced rate of unnecessary evacuation.

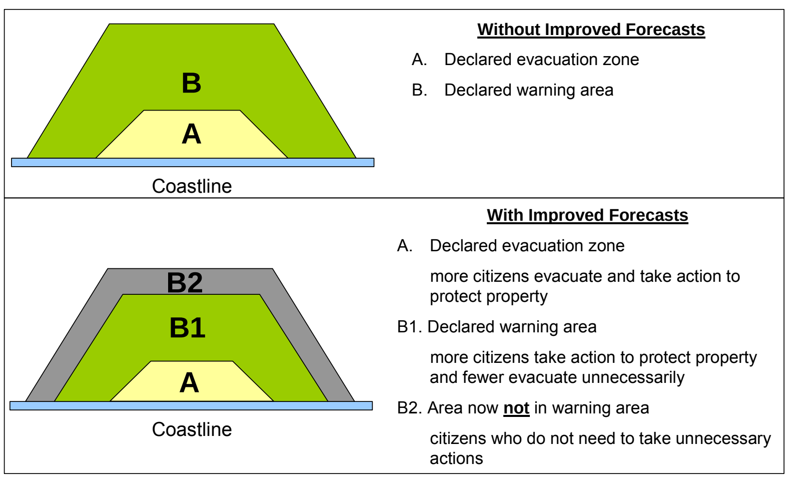

Figure 24. Illustration of Effects of Improved Tropical Cyclones Forecasts

While the economic effects incorporated within the current assessment are significant and important, it should be noted that they do not encompass the entire set of potential economic effects associated with improved forecasts. For example, business disruption is typically associated with an impending storm. Firms and retail outlets in the area noted as B2 in Figure 24 would benefit from not disrupting operations unnecessarily. Also, the version of the TCFVT employed for this analysis includes the geography most susceptible to tropical cyclones (coastal and border counties). However, rain and wind effects of tropical cyclones can extend well inland from those areas. Although the damaging impacts are much reduced relative to those that occur near the coast, they still can have economic impact. These effects are not included in this analysis. In that sense, the estimates provided in this analysis probably understate the true level of potential benefits from improved tropical cyclone forecast information.

While routinely available data, such as population and property values, are used in this assessment, secondary data sources are not available for many of the key decision-related variables of importance in this analysis. For those variables, an investigative process needed to be undertaken to provide informed assessments of the values to employ. This process integrated findings from published literature with the judgment of experts relevant to the topic relevant for each variable. In some cases, published literature provided an assessment of the aggregate value of a variable. An example would be the estimated number of deaths annually from hurricanes nationally over the last few decades. In those instances the estimates from the TCFVT were calibrated to be consistent with the published estimates.

Because secondary data sources or prior research estimates were not readily available for a number of key variables, a sensitivity analysis approach is employed to allow the user of the estimates to assess the effect of alternative assumed values for these key variables. Estimates of the potential economic benefits for the following scenarios will be presented:

- Case A: The Base Case employing values that represent the analysts' assessments of the most useful, conservative values with which to assess improved forecast information.
- Case B: The Expanded Geography Case illustrates the effects of extending the benefits of improved forecasts to include the entire area within the 213 coastal and border counties in the TCFVT database.
- Case C: The Greater Response Rate Case examines the effects of a greater proportion of the people in the affected areas who take protection and evacuate where necessary.
- Case D: The Lower Response Rate Case examines the effects of a reduced proportion of the people in the affected areas who take protection and evacuate where necessary.
- Case E: The Increased Protection Effectiveness Case evaluates the impact of protective actions being more effective than specified in the Base Case.
- Case F. The Enhanced Technology Effectiveness Case evaluates the effects of more accurate technology performance which results in greater responsiveness and a larger reduction in the size of the warning area than in the Base Case
- Case G: The Increased Protection Cost Case assumes the cost of taking protective action is higher than in the Base Case.
- Case H: The Decreased Protection Cost Case assumes the cost of taking protective action is lower than in the Base Case.

The values employed for specific variables in each of the cases will be presented in the section that describes the economic results for that case.

In addition to the variables specific to forecast information and tropical cyclones, any analysis of future benefits must consider that the future economic situation can change for reasons unrelated to the topic under study. Two key economic variables are the population growth rate and the rate of inflation in the target geographic regions. Also because the topic of this analysis, potential benefits from improved forecast information, will occur several years in the future, it is useful to discount the stream of future benefits to convert them to a current financial value. Estimates for alternative assumptions relative to the rate of inflation, population growth rate, and the discount rate will be presented in a separate section to follow.

Base Case Results (Case A)

As noted previously, the Base Case represents the analysts' assessment of the most useful, conservative values with which to assess improved forecast information. An alternative characterization might be that the Base Case is a good starting point for the evaluation. In conjunction with the other cases analyzed and considering alternative economic assumptions relative to factors such as population growth, inflation rates and discount rates, an informed understanding of the likely magnitude of the potential benefits from improved forecasts of tropical cyclones in the United States can be obtained.

While data sources and values for many of the TCFVT's variables are defined and presented in other sections of the reports, the values employed for a number of key variables will be identified within this section. Table 16 presents the values assumed relative to the proportion of the population in an area who take action as information about an impending tropical cyclone is received. Across the protection area (Area A and B in Figure 24), it is assumed that the proportion of people who act to protect their property increases from 30% for Tropical Storms, to 40% for less intense Hurricanes (SS 1-2), to 60% with Intense Hurricanes (SS 3-5). For the Base Case, that response rate is assumed to increase by 25% when improved forecast information is available.

Table 16. Key Assumption Values Relative to Percentage of the Population Who Protect and/or Evacuate With and Without Improved Forecast Information for Base Case (Case A)

	Percentage of the Population Who Acts to Protect Property		Percentage of the Population Who Evacuate from Evacuation Area		Percentage of the Population Who Evacuate Unnecessarily from Protection Area	
Type of Tropical Cyclone	Without Improved Forecast	With Improved Forecast	Without Improved Forecast	With Improved Forecast	Without Improved Forecast	With Improved Forecast
Tropical Storm	30.0%	37.5%	1.0%	1.25%	0.50%	0.40%
Hurricane (SS 1-2)	40.0%	50.0%	50.0%	65.00%	25.00%	18.80%
Intense Hurricane (SS 3-5)	60.0%	75.0%	75.0%	80.00%	37.50%	28.10%

Relative to evacuation, the percentages of people who would evacuate (without improved forecasts) is 1% for Tropical Storms, 50% for Hurricanes, and 75% for Intense Hurricanes. With improved forecast information, the rates of evacuation increase to 1.25% for Tropical Storms, 65% for Hurricanes and 80% for Intense Hurricanes. Evacuation by individuals who are not in the evacuation area results in wasted spending as well as adding to confusion and risk. Therefore, for those individuals who are in the protection area, but not in the evacuation area (the area labeled B1 in Figure 24), economic benefits would result from a reduced rate of evacuation. Without improved information, it is assumed that people who might evacuate unnecessarily would do so at 50% of the rate of individuals who are in the evacuation zone. With improved forecast information, that rate is reduced by 25%.

The factors considered in determining the geographic area included in this analysis are discussed in detail in Section 5.3. In total, the geographic area and economic activity information for 213 coastal and border counties along the Gulf and Atlantic seacoasts, which are vulnerable to tropical cyclones, are included in the analysis database. For the Base Case, however, the depth of the areas receiving guidance to take action to protect property and of the areas receiving evacuation orders is much less than the entire depth of the coastal and border counties. That depth, expressed as miles inland from the coastline, is shown in Table 17.

Table 17. Key Assumption Values Relative to Size of Protection and Evacuation Areas and Reduction in the Size of the Protection Area With an Improved Forecast for Base Case (Case A)

	Without Improved Forecast	
Type of Tropical Cyclone	Depth of Protection Area (miles inland)	Depth of Evacuation Area (miles inland)
Tropical Storm	1.0	0.5
Hurricane (SS 1-2)	10.0	2.0
Intense Hurricane (SS 3-5)	25.0	5.0
Reduction in Size of Protection Area	5.0% (with an improved forecast)	

Improved forecast information can reduce that area which is alerted to take action. For the Base Case, it is assumed that the areas receiving warnings to protect property and to evacuate are reduced by 5% with improved information.

Alternative assumptions relative to the effectiveness of actions to protect property will be considered in this analysis. The Base Case values are shown in Table 18. All values in this table are expressed as percentages of the value of residential and commercial property. The values in the Unavoidable Property Damage column reflect the reality that damage can not be completely eliminated, regardless of protective actions taken. These values increase, of course, with the severity of the tropical cyclone. The impact of alternative assumptions relative to the cost of protecting and the extent of damage will be examined in sections to follow. The set of values shown in Table 18 provide aggregate cost and damage estimates that are consistent with recent studies identifying the historic magnitude of these variables.

Table 18. Key Assumption Values Relative to Property Damage and The Effectiveness and Cost of Protection for Base Case (Case A)

Type of Tropical Cyclone	Unavoidable Property Damage	Protection Costs	Property Damage with No Protection	Property Damage with Protection
	(Percentage of Property Value)			
Tropical Storm	10%	0.0250%	4.000%	0.400%
Hurricane (SS 1-2)	30%	0.2500%	16.000%	4.800%
Intense Hurricane (SS 3-5)	70%	0.7500%	64.000%	44.800%

The TCFVT is a powerful analytical capability, which can quickly and easily calculate many numeric estimates. Only a portion of those estimates can be presented effectively here. For the Base Case, the first result estimates will focus on annualized estimates for six key result factors that summarize additional costs and benefits associated with improved forecast information. These annualized benefits are calculated for current economic conditions (population and property values).

For purposes of this analysis, improved information from the GOES-R capability will be available for the time period 2015 thru 2027. The magnitude of the stream of benefits associated with that capability will be described following the discussion of the annualized benefits.

Table 19 presents annualized results in three sections. The uppermost section provides estimates for the setting where no improved forecast information is assumed available. The middle section provides similar types of results, however, improved forecast information now is assumed to be available. The bottom section contains values calculated as the difference between the non-improved and the improved information settings. The annualized values can be thought of as being representative of an "average" year's set of tropical cyclone events. Here average refers to both the relative frequency of the types of tropical cyclone events and occurrence of such events along the target geographic region.

Table 19. Annualized Values for Key Economic Result Factors With and Without Improved Forecast Information for the Base Case (Case A), All Values in Dollars

No Improved Forecasts	Tropical Storm	Hurricane	Intense Hurricane	Total
Cost of property protection	6,464,156	229,699,940	501,936,546	738,100,642
Loss of life	1,269,692	7,092,372	91,512,513	99,874,577
Cost of injury	1,619,505	1,809,279	3,112,671	6,541,454
Property damage/loss	198,418,339	1,935,635,788	5,456,378,137	7,590,432,264
Cost of evacuation	196,779	11,619,049	10,304,149	22,119,977
Cost of unnecessary evacuation	89,807	19,710,251	12,960,404	32,760,462
Total	208,058,279	2,205,566,679	6,076,204,419	8,489,829,377
Improved Forecasts				
Cost of property protection	7,708,038	273,818,829	598,973,822	880,500,688
Loss of life	1,203,162	4,716,427	69,549,510	75,469,099
Cost of injury	1,615,416	1,266,495	2,490,136	5,372,047
Property damage/loss	180,071,438	1,747,448,975	5,156,942,751	7,084,463,164
Cost of evacuation	234,748	14,410,840	10,494,483	25,140,072
Cost of unnecessary evacuation	63,987	14,043,554	9,234,288	23,341,829
Total	190,896,789	2,055,705,120	5,847,684,990	8,094,286,899
Difference				
Cost of property protection	(1,243,882)	(44,118,888)	(97,037,276)	(142,400,046)
Loss of life	66,531	2,375,945	21,963,003	24,405,478
Cost of injury	4,090	542,784	622,534	1,169,407
Property damage/loss	18,346,901	188,186,813	299,435,386	505,969,099
Cost of evacuation	(37,969)	(2,791,791)	(190,334)	(3,020,094)
Cost of unnecessary evacuation	25,819	5,666,697	3,726,116	9,418,633
Total	17,161,490	149,861,559	228,519,429	395,542,478

Estimates for six types of factors are included in Table 19. The without information estimates in the top section of the table are generally consistent with available findings of published research focused on actual impacts of tropical cyclones. While Tropical Storms and less intense Hurricanes occur with greater frequency, the vast majority of damages are the result of Intense Hurricanes. Property damages of approximately $7 billion annually and the cost of property protection at approximately 10% of damages correspond with published estimates. The loss of life estimate is consistent with a death incidence of slightly less than 20 fatalities per year. The extent of injury due to tropical cyclones evidently is not well documented. Per person evacuation costs were found from published sources, however, the extent of evacuations also is not well known.

While the absolute values are important, the difference between the "without" and the "with" information settings is of primary interest for the assessment of potential benefits of forecast information. Two of the factors, cost of property protection and cost of evacuation, are shown with negative values in Table 19. This means that these costs are higher with than without forecast information. Better forecast information should encourage more citizens and decision-makers to take action to protect property and to evacuate in areas where evacuation should occur. Therefore, the additional costs indicated by the negative values for these factors represent socially good outcomes.

The positive values for the other four factors imply that costs are higher in the without information setting than they are in the with information situation. The difference in loss of life costs is consistent with a reduction of approximately five fatalities annually. The largest difference value is the roughly $500 million higher estimate for property damages and losses. Although a significant amount in absolute terms, it is less than 7% of the estimated property damages in the without information alternative. These benefits also come at the cost of an additional $140 million in costs for property protection. The sum of the benefits is nearly $400 million annually.

As noted previously, the improved forecast information from GOES-R is expected to be available for a 13 year period – from 2015 to 2027. Simple multiplication of the annual benefit times 13 years results in a cumulative amount exceeding $5.1 billion. However, a dollar earned in the future does not have the same value as a dollar available today. Therefore, the financial estimates for the period 2015 to 2027 need to be discounted to be equivalent to the same amount of dollars today. Also economic activity is related to the population base of an area. Population growth has been pronounced in the areas that are the target of this analysis. Therefore, economic activity is likely to increase, which means that both a larger population and greater property values will reside in the study target areas during the future period of interest.[29]

Table 20 presents four alternative sets of economic estimates. The first column displays the annualized net benefit for each of the 13 years from 2015 to 2027. The next column shows the annual estimates for the 2015 to 2027 period, after discounting those values at a 7% rate, to convert them to today's purchasing power. The sum of these values is approximately $1.9 billion. The third column allows for population growth at the rate of 1.5% per year (with a zero discount rate). The sum of the annual estimates for this assumption, $6.4 billion, exceeds the estimates in the first data column because population growth fuels economic activity and because the larger population implies greater expenditures for evacuation. The last column combines the assumptions of a 7% discount rate and of population growth of 1.5% per year. The sum of potential benefits for this setting is almost $2.4 billion, even when discounted at the 7% level.

Table 20. Annual Estimates and Sum of Present Value Estimates for Various Economic Assumptions for Base Case (Case A), All Values in Dollars

Year	Current Dollars (with No Change in Future Years)	Discounted at a 7% Rate	Population Growth at 1.5%	Discounted at a 7% Rate Population Growth at 1.5%
2015	395,542,478	215,148,900	452,259,304	245,999,096
2016	395,542,478	201,073,739	459,043,193	233,354,282
2017	395,542,478	187,919,382	465,928,841	221,359,436
2018	395,542,478	175,625,590	472,917,774	209,981,147
2019	395,542,478	164,136,066	480,011,540	199,187,724
2020	395,542,478	153,398,192	487,211,714	188,949,103
2021	395,542,478	143,362,797	494,519,889	179,236,766
2022	395,542,478	133,983,922	501,937,688	170,023,661
2023	395,542,478	125,218,619	509,466,753	161,284,127
2024	395,542,478	117,026,747	517,108,754	152,993,821
2025	395,542,478	109,370,791	524,865,386	145,129,653
2026	395,542,478	102,215,693	532,738,366	137,669,717
2027	395,542,478	95,528,685	540,729,442	130,593,237
Totals	5,142,052,210	1,924,009,122	6,438,738,644	2,375,761,769

[29] More detail on the calculation of the effect of present values and of population growth are provided in Section 5.2.

Expanded Geography Results (Case B)

The Base Case results serve as an initial benchmark and the results of each of the seven other case analyses are then compared to the Base Case results. In describing each of the seven other cases, the differing assumptions associated with the case will be presented first. This will be followed by discussion of the key results for that case.

As described previously, the geographic area for which potential benefits are estimated in the Base Case employed a conservative assessment of the area that would be affected. Measured in terms of miles inland from the coast, the areas for which property protection warnings would be issued are 1 mile for Tropical Storms, 10 miles for Hurricanes, and 25 miles for Intense Hurricanes. For the Expanded Geography Case, the protection area is assumed to include all of the area within the 213 coastal and border counties included in the TCFVT. The average protection area depth is about 54 miles. The evacuation area in the Expanded Geography Case is expanded to include the entire area of the coastal counties included in the database. The average depth for these coastal counties is about 29 miles.

The resulting annualized values associated with this set of assumptions are shown in Table 21. An obvious implication of examining these results is that size of the geographic region has direct and significant effects on the potential benefits estimated. Using the Expanded Geography Case assumptions, the overall estimate of annual potential benefits exceeds $1.4 billion. Again, the largest component of the potential gains is related to reduced property losses, even though the estimated additional costs of taking protective action exceed $350 million. It should be noted that these values are far higher than available published estimates of property damages and protection costs.

Table 21. Annualized Values for Key Economic Result Factors With and Without Improved Forecast Information for Expanded Geography Case (Case B), All Values in Dollars

No Improved Forecasts	Tropical Storm	Hurricane	Intense Hurricane	Total
Cost of property protection	198,743,780	803,814,775	858,143,210	1,860,701,765
Loss of life	50,924,893	73,318,683	389,865,317	514,108,892
Cost of injury	64,955,220	18,703,746	13,260,725	96,919,691
Property damage/loss	5,834,913,358	6,586,911,354	8,605,095,731	21,026,920,442
Cost of evacuation	7,879,012	118,760,844	43,097,713	169,737,569
Cost of unnecessary evacuation	2,212,024	32,968,314	10,791,800	45,972,138
Total	6,159,628,287	7,634,477,715	9,920,254,495	23,714,360,498
Improved Forecasts				
Cost of property protection	236,944,922	958,103,674	1,023,656,691	2,218,705,287
Loss of life	48,256,480	48,756,924	296,297,641	393,311,045
Cost of injury	64,791,192	13,092,622	10,608,580	88,492,394
Property damage/loss	5,295,383,698	5,946,517,194	8,132,864,867	19,374,765,760
Cost of evacuation	9,397,408	147,277,541	43,888,976	200,563,925
Cost of unnecessary evacuation	1,576,067	23,489,924	7,689,157	32,755,148
Total	5,656,349,768	7,137,237,879	9,515,005,913	22,308,593,559
Difference				
Cost of property protection	(38,201,142)	(154,288,898)	(165,513,481)	(358,003,522)
Loss of life	2,668,413	24,561,759	93,567,676	120,797,848
Cost of injury	164,028	5,611,124	2,652,145	8,427,297
Property damage/loss	539,529,660	640,394,159	472,230,863	1,652,154,682
Cost of evacuation	(1,518,396)	(28,516,697)	(791,263)	(30,826,356)
Cost of unnecessary evacuation	635,957	9,478,390	3,102,642	13,216,990
Total	503,278,519	497,239,837	405,248,582	1,405,766,938

Table 22 presents estimates of the stream of potential benefits over the 2015-2027 period when the effects of population growth and discounting are considered. With neither of those factors in effect, the sum of the potential benefits exceeds $18.2 billion. Adding the effects of a 1.5% annual population growth rate swells the sum of the estimated potential benefits to almost $23 billion. The effect of discounting (at the 7% rate) significantly reduces the estimated sum of potential benefits, to approximately $8.4 billion.

Table 22. Annual Estimates and Sum of Present Value Estimates for Various Economic Assumptions for Expanded Geography Case (Case B), All Values in Dollars

Year	Current Dollars (with No Change in Future Years)	Discounted at a 7% Rate	Population Growth at 1.5%	Discounted at a 7% Rate Population Growth at 1.5%
2015	1,405,766,938	764,644,072	1,607,339,825	874,286,367
2016	1,405,766,938	714,620,628	1,631,449,923	829,346,413
2017	1,405,766,938	667,869,746	1,655,921,671	786,716,457
2018	1,405,766,938	624,177,333	1,680,760,497	746,277,761
2019	1,405,766,938	583,343,301	1,705,971,904	707,917,689
2020	1,405,766,938	545,180,656	1,731,561,483	671,529,397
2021	1,405,766,938	509,514,631	1,757,534,905	637,011,531
2022	1,405,766,938	476,181,899	1,783,897,928	604,267,947
2023	1,405,766,938	445,029,812	1,810,656,397	573,207,445
2024	1,405,766,938	415,915,712	1,837,816,243	543,743,511
2025	1,405,766,938	388,706,273	1,865,383,487	515,794,078
2026	1,405,766,938	363,276,890	1,893,364,239	489,281,299
2027	1,405,766,938	339,511,113	1,921,764,703	464,131,325
Totals	18,274,970,200	6,837,972,065	22,883,423,205	8,443,511,221
Base Case Totals	5,142,052,210	1,924,009,122	6,438,738,644	2,375,761,769

Greater Response Rate Results (Case C)

No direct evidence is available relative to the extent to which citizens and decision-makers will increase their responsiveness to improved forecast information. In a strict sense such information, of course, can't be known until the improved capabilities actually exist. However, it is reasonable to assume that, especially for profound events such as tropical cyclones, responsiveness and forecast capabilities would be positively related. It is important to have a sense for the effect of the assumed response rates on the potential benefits estimated in the Base Case. Therefore Cases C and D explore these relationships; Case C with an assumed response rate higher than the Base Case and Case D with an assumed rate that is lower.

Table 23 below lists the responsiveness rates used for the Greater Response Rate Case. These values have responsiveness rates that are approximately 60% greater than are employed in the Base Case. For example, the assumed response rate for protecting property in the Base Case was 25% with additional information. In Case C, the response to additional information rate is assumed to be 40%.

Table 23. Key Assumption Values Relative to Percentage of the Population Who Protect and/or Evacuate With and Without Improved Forecast Information for Greater Response Rate Case (Case C)

	Percentage of the Population Who Acts to Protect Property		Percentage of the Population Who Evacuate from Evacuation Area		Percentage of the Population Who Evacuate Unnecessarily from Protection Area	
Type of Tropical Cyclone	Without Improved Forecast	With Improved Forecast	Without Improved Forecast	With Improved Forecast	Without Improved Forecast	With Improved Forecast
Tropical Storm	30.0%	42.0%	1.0%	1.25%	0.50%	0.30%
Hurricane (SS 1-2)	40.0%	56.0%	50.0%	72.50%	25.00%	15.00%
Intense Hurricane (SS 3-5)	60.0%	84.0%	75.0%	82.50%	37.50%	22.50%

As more citizens and decision-makers respond by protecting property, evacuating where necessary and not evacuating where unnecessary, the potential benefits associated with improved forecast information increase. As shown in Table 24, all four estimates of the sum of potential benefits for Case C exceed those of the Base Case. The undiscounted estimate with 1.5% population growth now would exceed $9.8 billion, more than $3 billion greater than in the Base Case. Discounting that estimate at a 7% rate reduces the estimated value to about $3.6 billion, $1.3 billion more than in the Base Case.

Table 24. Annual Estimates and Sum of Present Value Estimates for Various Economic Assumptions for Greater Response Rate Case (Case C), All Values in Dollars

Year	Current Dollars (with No Change in Future Years)	Discounted at a 7% Rate	Population Growth at 1.50%	Discounted at a 7% Rate Population Growth at 1.5%
2015	606,428,489	329,856,918	693,384,256	377,155,093
2016	606,428,489	308,277,493	703,785,019	357,768,616
2017	606,428,489	288,109,807	714,341,795	339,378,641
2018	606,428,489	269,261,502	725,056,922	321,933,944
2019	606,428,489	251,646,263	735,932,775	305,385,938
2020	606,428,489	235,183,424	746,971,767	289,688,530
2021	606,428,489	219,797,592	758,176,344	274,797,998
2022	606,428,489	205,418,310	769,548,989	260,672,867
2023	606,428,489	191,979,729	781,092,224	247,273,795
2024	606,428,489	179,420,308	792,808,607	234,563,459
2025	606,428,489	167,682,531	804,700,736	222,506,459
2026	606,428,489	156,712,645	816,771,247	211,069,211
2027	606,428,489	146,460,416	829,022,816	200,219,859
Totals	7,883,570,362	2,949,806,939	9,871,593,495	3,642,414,411
Base Case Totals	5,142,052,210	1,924,009,122	6,438,738,644	2,375,761,769

Lower Response Rate Results (Case D)

Table 25 lists the responsiveness rates used for the Lower Response Rate Case. These values have response rates that are approximately 60% lower than are employed in the Base Case. For example, the assumed responsive rate for protecting property in the Base Case is 25% with additional information. In Case D, the response to additional information rate is assumed to be 10%.

Table 25. Key Assumption Values Relative to Percentage of the Population Who Protect and/or Evacuate With and Without Improved Forecast Information for Lower Response Rate Case (Case D)

	Percentage of the Population Who Acts to Protect Property		Percentage of the Population Who Evacuate from Evacuation Area		Percentage of the Population Who Evacuate Unnecessarily from Protection Area	
Type of Tropical Cyclone	Without Improved Forecast	With Improved Forecast	Without Improved Forecast	With Improved Forecast	Without Improved Forecast	With Improved Forecast
Tropical Storm	30.0%	33.0%	1.0%	1.25%	0.50%	0.45%
Hurricane (SS 1-2)	40.0%	44.0%	50.0%	57.50%	25.00%	22.50%
Intense Hurricane (SS 3-5)	60.0%	66.0%	75.0%	78.50%	37.50%	33.75%

Not surprisingly, the effect of lowering the extent to which citizens and decision-makers respond to improved forecast information is to reduce the potential economic benefits associated with the information. (This is the converse of the finding for Case C.) For all four of the estimate types in Table 26, the resulting Case D estimates are less than half of the magnitude of the Base Case estimates. The estimated value in current dollars with no population growth would exceed $2.4 billion while the estimated value with population growth and discounted is slightly more than $1.1 billion.

Table 26. Annual Estimates and Sum of Present Value Estimates for Various Economic Assumptions for Lower Response Rate Case (Case D), All Values in Dollars

Year	Current Dollars (with No Change in Future Years)	Discounted at a 7% Rate	Population Growth at 1.5%	Discounted at a 7% Rate Population Growth at 1.5%
2015	188,127,267	102,328,769	215,102,831	117,001,688
2016	188,127,267	95,634,363	218,329,374	110,987,583
2017	188,127,267	89,377,909	221,604,315	105,282,613
2018	188,127,267	83,530,757	224,928,379	99,870,890
2019	188,127,267	78,066,128	228,302,305	94,737,340
2020	188,127,267	72,958,998	231,726,840	89,867,664
2021	188,127,267	68,185,979	235,202,742	85,248,298
2022	188,127,267	63,725,214	238,730,783	80,866,376
2023	188,127,267	59,556,275	242,311,745	76,709,693
2024	188,127,267	55,660,070	245,946,421	72,766,671
2025	188,127,267	52,018,757	249,635,617	69,026,328
2026	188,127,267	48,615,661	253,380,152	65,478,246
2027	188,127,267	45,435,197	257,180,854	62,112,542
Totals	2,445,654,474	915,094,076	3,062,382,359	1,129,955,933
Base Case Totals	5,142,052,210	1,924,009,122	6,438,738,644	2,375,761,769

Increased Protection Effectiveness Results (Case E)

Three alternative cases (this and Cases G and H) explore the sensitivity of the TCFVT results to the effectiveness of actions to protect property from storm damage. One variable of interest for this case is unavoidable property damage. This variable recognizes that some property damage will occur despite any short-term protection efforts taken immediately before the onset of the tropical cyclone. In the Increased Protection Effectiveness Case, the values assumed for this variable (shown in Table 27) are set lower than in the Base Case.

Because the values for unavoidable property damage are lower, the percentage of property damage that would occur if protective actions are taken (the right-most column of Table 27) also are lower than in the Base Case. The percentages for property damage if no protective actions are taken and for protection costs are held constant in this case with those of the Base Case. Therefore the net effect of these changed values is to illustrate the impact of protection measures which are more effective than those of the Base Case.

Table 27. Key Assumption Values Relative to Property Damage and the Effectiveness and Cost of Protection for Increased Protection Effectiveness Case (Case E)

Type of Tropical Cyclone	Unavoidable Property Damage	Protection Costs	Property Damage with No Protection	Property Damage with Protection
	(Percentage of Property Value)			
Tropical Storm	5%	0.0250%	4.000%	0.200%
Hurricane (SS 1-2)	20%	0.2500%	16.000%	3.200%
Intense Hurricane (SS 3-5)	60%	0.7500%	64.000%	38.400%

Assuming that actions taken to protect property are more effective than in the Base Case results in a marked increase in the potential economic benefits from additional information. The estimates when both discounting and population growth are assumed are $767 million more than are estimated in the Base Case; an increase of more than 30% Table 28.

Table 28. Annual Estimates and Sum of Present Value Estimates for Various Economic Assumptions for Increased Protection Effectiveness Case (Case E), All Values in Dollars

Year	Current Dollars (with No Change in Future Years)	Discounted at a 7% Rate	Population Growth at 1.50%	Discounted at a 7% Rate Population Growth at 1.5%
2015	523,257,376	284,617,343	598,287,238	325,428,616
2016	523,257,376	265,997,516	607,261,546	308,700,977
2017	523,257,376	248,595,810	616,370,469	292,833,170
2018	523,257,376	232,332,532	625,616,027	277,780,998
2019	523,257,376	217,133,208	635,000,267	263,502,535
2020	523,257,376	202,928,232	644,525,271	249,958,012
2021	523,257,376	189,652,553	654,193,150	237,109,703
2022	523,257,376	177,245,377	664,006,047	224,921,821
2023	523,257,376	165,649,885	673,966,138	213,360,419
2024	523,257,376	154,812,976	684,075,630	202,393,295
2025	523,257,376	144,685,025	694,336,764	191,989,901
2026	523,257,376	135,219,649	704,751,816	182,121,262
2027	523,257,376	126,373,504	715,323,093	172,759,888
Totals	6,802,345,882	2,545,243,609	8,517,713,457	3,142,860,599
Base Case Totals	5,142,052,210	1,924,009,122	6,438,738,644	2,375,761,769

Enhanced Technology Effectiveness Results (Case F)

Another factor which can affect potential economic benefits is the effectiveness of the technologies employed in creating the improved forecast. From the perspective of economic benefits, improved technology performance would result in more credible forecasts. In the TCFVT and in this analysis, enhanced credibility would be reflected in a smaller area for which protection warnings are issued and a greater response from citizens and decision-makers to take the appropriate action.

Table 29 presents the response assumptions with and without improved forecasts for the Enhanced Technology Effectiveness Case. The without improved forecast values are the same as are used within the Base Case analysis. The with improved forecast response rates used in this case are the same as those employed in Case C above. These responsiveness rates are approximately 60% greater than are employed in the Base Case. For example, the assumed response rate for protecting property in the Base Case was 25% with additional information. In Case F, the response to additional information rate is assumed to be 40%. This assumption, along with the assumption made about the reduction in warning area size, are intentionally aggressive values. They are not based on social behavior or scientific evidence since little research has been done on the behavioral reaction to improved tropical cyclone forecasts. In addition, as previously stated, the scientific community cannot specify the extent to which track forecasts will be impacted by improved geostationary data with certainty. Therefore, while these assumptions might not be scientifically expected today, they are meant to illustrate the potential benefits if these assumptions proved true in the future.

Table 29. Key Assumption Values Relative to Percentage of the Population Who Protect and/or Evacuate With and Without Improved Forecast Information for Enhanced Technology Effectiveness Case (Case F)

	Percentage of the Population Who Acts to Protect Property		Percentage of the Population Who Evacuate from Evacuation Area		Percentage of the Population Who Evacuate Unnecessarily from Protection Area	
Type of Tropical Cyclone	Without Improved Forecast	With Improved Forecast	Without Improved Forecast	With Improved Forecast	Without Improved Forecast	With Improved Forecast
Tropical Storm	30.0%	42.0%	1.0%	1.25%	0.50%	0.30%
Hurricane (SS 1-2)	40.0%	56.0%	50.0%	72.50%	25.00%	15.00%
Intense Hurricane (SS 3-5)	60.0%	84.0%	75.0%	82.50%	37.50%	22.50%

A smaller geographic region subject to warnings to take action to protect property is another element of enhanced technology effectiveness. Table 30 shows the miles inland for which warning notices to protect and to evacuate are assumed to be in effect without improved forecasts. With enhanced technology it is assumed that these regions would be 15% smaller in size with improved forecast information. Again, this assumption is not based on scientific evidence, but strictly a hypothetical scenario where if the geostationary data were able to impact the track forecasts positively, thereby resulting in a 15% reduction in warning area size, then it might result in the socioeconomic benefits presented here.

Table 30. Key Assumption Values Relative to Size of Protection and Evacuation Areas and Reduction in the Size of the Protection Area With an Improved Forecast for Enhanced Technology Effectiveness Case (Case F)

	Without Improved Forecast	
Type of Tropical Cyclone	Depth of Protection Area (miles inland)	Depth of Evacuation Area (miles inland)
Tropical Storm	1.0	0.5
Hurricane (SS 1-2)	10.0	2.0
Intense Hurricane (SS 3-5)	25.0	5.0
Reduction in Size of Protection Area	15.0% (with an improved forecast)	

The combination of greater responsiveness and reduced areas for which warnings are relevant result in sharply higher estimates of potential economic benefit when compared to the Base Case values. The values for Case F are approximately 80% greater. With both discounting and population growth, the total value of the stream of benefits is almost $4.3 billion Table 31.

Table 31. Annual Estimates and Sum of Present Value Estimates for Various Economic Assumptions for Enhanced Technology Effectiveness Case (Case F), All Values in Dollars

Year	Current Dollars (with No Change in Future Years)	Discounted at a 7% Rate	Population Growth at 1.50%	Discounted at a 7% Rate Population Growth at 1.5%
2015	712,271,670	387,428,595	814,404,287	442,981,972
2016	712,271,670	362,082,799	826,620,352	420,211,871
2017	712,271,670	338,395,139	839,019,657	398,612,195
2018	712,271,670	316,257,140	851,604,952	378,122,783
2019	712,271,670	295,567,420	864,379,026	358,686,565
2020	712,271,670	276,231,234	877,344,711	340,249,405
2021	712,271,670	258,160,032	890,504,882	322,759,950
2022	712,271,670	241,271,058	903,862,455	306,169,485
2023	712,271,670	225,486,970	917,420,392	290,431,801
2024	712,271,670	210,735,486	931,181,698	275,503,064
2025	712,271,670	196,949,052	945,149,423	261,341,692
2026	712,271,670	184,064,535	959,326,665	247,908,240
2027	712,271,670	172,022,930	973,716,565	235,165,293
Totals	9,259,531,710	3,464,652,389	11,594,535,064	4,278,144,316
Base Case Totals	5,142,052,210	1,924,009,122	6,438,738,644	2,375,761,769

Increased Protection Cost Results (Case G)

Reductions in potential property damage have been shown to be a potentially significant factor contributing to the economic benefits of improved forecast information. The cost of protecting property is clearly a contributing factor to that effectiveness. Cases G and H, therefore, examine the sensitivity of the estimated results to changes in the cost of protecting property. Table 32 presents the protection costs assumed for Case G. These costs are 50% greater than those employed in the Base Case. The other values in Table 32 are the same as in the Base Case.

Table 32. Key Assumption Values Relative to Property Damage and the Effectiveness and Cost of Protection for Increased Protection Cost Case (Case G)

Type of Tropical Cyclone	Unavoidable Property Damage	Protection Costs	Property Damage with No Protection	Property Damage with Protection
	(Percentage of Property Value)			
Tropical Storm	10%	0.0375%	4.000%	0.400%
Hurricane (SS 1-2)	30%	0.3750%	16.000%	4.800%
Intense Hurricane (SS 3-5)	70%	1.1250%	64.000%	44.800%

Greater costs for protecting property result in lower economic benefits than are estimated for the Base Case. As shown in Table 33, the assumed 50% increase in the cost of protecting property translates to an approximately 20% reduction in the estimated benefits relative to the Base Case.

Table 33. Annual Estimates and Sum of Present Value Estimates for Various Economic Assumptions for Increased Protection Cost Case (Case G), All Values in Dollars

Year	Current Dollars (with No Change in Future Years)	Discounted at a 7% Rate	Population Growth at 1.50%	Discounted at a 7% Rate Population Growth at 1.5%
2015	324,342,455	176,420,805	370,849,911	201,717,780
2016	324,342,455	164,879,257	376,412,660	191,349,109
2017	324,342,455	154,092,764	382,058,850	181,513,407
2018	324,342,455	144,011,929	387,789,733	172,183,279
2019	324,342,455	134,590,588	393,606,579	163,332,737
2020	324,342,455	125,785,596	399,510,677	154,937,129
2021	324,342,455	117,556,632	405,503,337	146,973,071
2022	324,342,455	109,866,011	411,585,887	139,418,380
2023	324,342,455	102,678,515	417,759,676	132,252,015
2024	324,342,455	95,961,229	424,026,071	125,454,014
2025	324,342,455	89,683,391	430,386,462	119,005,443
2026	324,342,455	83,816,254	436,842,259	112,888,341
2027	324,342,455	78,332,947	443,394,893	107,085,669
Totals	4,216,451,911	1,577,675,918	5,279,726,995	1,948,110,373
Base Case Totals	5,142,052,210	1,924,009,122	6,438,738,644	2,375,761,769

Decreased Protection Cost Results (Case H)

Reductions in potential property damage have been shown to be a potentially significant factor contributing to the economic benefits of improved forecast information. The cost of protecting property is clearly a contributing factor to that effectiveness. Cases G and H, therefore, examine the sensitivity of the estimated results to changes in the cost of protecting property. Table 34 presents the protection costs assumed for Case H. These costs are 33% lower than those employed in the Base Case. The other values in Table 34 are the same as in the Base Case.

Table 34. Key Assumption Values Relative to Property Damage and the Effectiveness and Cost of Protection for Decreased Protection Cost Case (Case H)

Type of Tropical Cyclone	Unavoidable Property Damage	Protection Costs	Property Damage with No Protection	Property Damage with Protection
	(Percentage of Property Value)			
Tropical Storm	10%	0.0167%	4.000%	0.400%
Hurricane (SS 1-2)	30%	0.1670%	16.000%	4.800%
Intense Hurricane (SS 3-5)	70%	0.5000%	64.000%	44.800%

Lower costs for protecting property result in greater economic benefits than are estimated for the Base Case. As shown in Table 35, the assumed 33% decrease in the cost of protecting property translates to an approximately 12% enhancement to the estimated benefits relative to the Base Case.

Table 35. Annual Estimates and Sum of Present Value Estimates for Various Economic Assumptions for Decreased Protection Cost Case (Case H), All Values in Dollars

Year	Current Dollars (with No Change in Future Years)	Discounted at a 7% Rate	Population Growth at 1.50%	Discounted at a 7% Rate Population Growth at 1.5%
2015	442,948,676	240,934,731	506,463,076	275,482,356
2016	442,948,676	225,172,646	514,060,022	261,322,048
2017	442,948,676	210,441,725	521,770,922	247,889,606
2018	442,948,676	196,674,509	529,597,486	235,147,617
2019	442,948,676	183,807,953	537,541,448	223,060,590
2020	442,948,676	171,783,133	545,604,570	211,594,859
2021	442,948,676	160,544,985	553,788,639	200,718,488
2022	442,948,676	150,042,042	562,095,468	190,401,182
2023	442,948,676	140,226,207	570,526,900	180,614,206
2024	442,948,676	131,052,530	579,084,804	171,330,298
2025	442,948,676	122,479,000	587,771,076	162,523,600
2026	442,948,676	114,466,355	596,587,642	154,169,584
2027	442,948,676	106,977,902	605,536,456	146,244,979
Totals	5,758,332,787	2,154,603,718	7,210,428,509	2,660,499,414
Base Case Totals	5,142,052,210	1,924,009,122	6,438,738,644	2,375,761,769

Effect of Economic Factors

The focus of this portion of the study is on discerning the potential economic effects for the United States of improved tropical cyclone forecast information associated with the enhanced technologies contained in the GOES-R satellite system. These potential benefits will occur in the future after the launch and implementation of GOES-R. Any financially-based analysis of future benefits must consider that the future economic situation can change for reasons unrelated to the topic under study.

Two key economic variables are the population growth rate and the rate of inflation in the target geographic regions. Also, because the topic of this analysis, potential benefits from improved forecast information, will occur several years in the future, it is useful to discount the stream of future benefits to convert them to a current financial value. (More detail on the calculation of the effect of present values and of population growth is provided in Section 5.2.) Estimates for alternative assumptions relative to the rate of inflation, population growth rate, and the discount rate are presented in this section of the report.

The three economic variables of interest in this section of the report are relevant and could affect the results for all the eight cases just presented. However the magnitude and direction of change will be very similar in each case, therefore, in this discussion the effects of alternative discount, inflation, and population growth rates will be examined only for the Base Case.

Anticipating population changes 20 years into the future is, of course, subject to considerable uncertainty. However, assuming that population will not change is not necessarily a good assumption. The areas of interest for this study have seen marked population growth in recent years and are likely to continue to be locations which attract additional inhabitants. Table 36 presents estimates of the potential economic benefits of improved forecast information when population is held constant and when population growth is assumed to occur at a rate of 1.5% per year.

Population growth has relevance for the value of forecast information because higher population levels imply more people need to consider evacuation and property protection decisions. Further because the level of property values is assumed to vary directly with population, the amount of damage which can be done by tropical cyclones is higher. In Table 36, the effect of the 1.5 % population growth rate is illustrated by the increase in benefits of approximately $1.3 billion, from $5.1 billion with no population growth to $6.4 billion with growth.

Table 36. Annual Estimates and Sum of Present Value Estimates for Alternative Population Growth Rates Applied to the Base Case (Case A), All Values in Dollars

Year	Population Held at Current Levels	Population Growth at 1.5%
2015	395,542,478	452,259,304
2016	395,542,478	459,043,193
2017	395,542,478	465,928,841
2018	395,542,478	472,917,774
2019	395,542,478	480,011,540
2020	395,542,478	487,211,714
2021	395,542,478	494,519,889
2022	395,542,478	501,937,688
2023	395,542,478	509,466,753
2024	395,542,478	517,108,754
2025	395,542,478	524,865,386
2026	395,542,478	532,738,366
2027	395,542,478	540,729,442
Totals	5,142,052,210	6,438,738,644
Base Case Totals	5,142,052,210	6,438,738,644

As with the potential for population change, inflation is a factor likely to affect the economic valuation of future activity. Costs of evacuation and property values in the future, for example, are unlikely to be equal to their current value. However, predicting inflation over relatively long time periods has a high degree of uncertainty.

In Table 37, the Base Case results (with no inflation) are compared to the results that would be estimated if inflation were assumed to occur at a rate of 2% per year until 2027. The estimated potential economic benefits are higher by more than $2.2 billion in the latter circumstances. This increase results from higher costs to evacuate and from property values which are greater than in the Base Case.

Table 37. Annual Estimates and Sum of Present Value Estimates for Alternative Inflation Rates Applied to the Base Case (Case A), All Values in Dollars

Year	No Inflation	Inflation at 2% Per Year
	(Population Growth at 1.5%)	
2015	452,259,304	539,083,796
2016	459,043,193	557,951,729
2017	465,928,841	577,480,039
2018	472,917,774	597,691,841
2019	480,011,540	618,611,055
2020	487,211,714	640,262,442
2021	494,519,889	662,671,627
2022	501,937,688	685,865,134
2023	509,466,753	709,870,414
2024	517,108,754	734,715,879
2025	524,865,386	760,430,934
2026	532,738,366	787,046,017
2027	540,729,442	814,592,628
Totals	6,438,738,644	8,686,273,535

The appropriate discount rate to employ to convert values which will occur in the future to their equivalent terms today is subject to considerable debate. In Table 38, estimates of economic value for discount rates of 0, 2, 5 and 7% are presented. (In each case, the population growth rate is set at 1.5% and no inflation is assumed to occur.)

Because the stream of potential benefits associated with improved GOES-R capabilities are well into the future, the effect of higher discount rates is to markedly reduce the present value of the estimates of potential economic gain. This is true of all technologies for which implementation will occur some time in the future.

Table 38. Annual Estimates and Sum of Present Value Estimates for Alternative Discount Rates Applied to the Base Case (Case A), All Values in Dollars

Year	No Discount Rate Applied	Discounted at 2% Rate	Discounted at 5% Rate	Discounted at 7% Rate
2015	452,259,304	378,430,354	291,530,380	245,999,096
2016	459,043,193	376,575,303	281,812,700	233,354,282
2017	465,928,841	374,729,346	272,418,944	221,359,436
2018	472,917,774	372,892,437	263,338,312	209,981,147
2019	480,011,540	371,064,533	254,560,368	199,187,724
2020	487,211,714	369,245,589	246,075,023	188,949,103
2021	494,519,889	367,435,562	237,872,522	179,236,766
2022	501,937,688	365,634,407	229,943,438	170,023,661
2023	509,466,753	363,842,082	222,278,657	161,284,127
2024	517,108,754	362,058,542	214,869,368	152,993,821
2025	524,865,386	360,283,745	207,707,056	145,129,653
2026	532,738,366	358,517,649	200,783,487	137,669,717
2027	540,729,442	356,760,209	194,090,704	130,593,237
Totals	6,438,738,644	4,777,469,759	3,117,280,960	2,375,761,769

Alternative Analysis Timeframe

There is significant uncertainty regarding when the first satellite of the GOES-R series will be launched and the length of time the GOES-R series will be operational. To be consistent with the CBA Report, throughout this study the timeframe for which benefits generated by the GOES-R series is assumed to be the 13 year period 2015 to 2027. To provide an indication of the effect of alternative time frame assumptions, an analysis also was conducted examining the expected benefits if the satellites were assumed operational over a 10 year period from 2017 through 2026.

Table 39 presents the estimated stream of potential benefits with the 10 year time period, with all other parameters identical to those of the Base Case. The Table 39 results therefore are directly comparable to the results shown in Table 4. The estimates of Table 39 are approximately 25% lower than those estimated for the Base Case (Table 4). The lower estimates result from a three year shorter time horizon and the two year lag before operations are initiated. (A similar comparison for the estimated benefits associated with the energy, irrigated agriculture, recreational boating, and aviation sectors is presented at the end of Section 5.2)

Table 39. Annual Estimates and Sum of Present Value Estimates for Alternative Discount Rates Assuming an Operational Time Period of 2017 to 2026, All Values in Dollars

Year	No Discount Rate Applied	Discounted at 2% Rate	Discounted at 5% Rate	Discounted at 7% Rate
2017	465,928,841	374,729,346	272,418,944	221,359,436
2018	472,917,774	372,892,437	263,338,312	209,981,147
2019	480,011,540	371,064,533	254,560,368	199,187,724
2020	487,211,714	369,245,589	246,075,023	188,949,103
2021	494,519,889	367,435,562	237,872,522	179,236,766
2022	501,937,688	365,634,407	229,943,438	170,023,661
2023	509,466,753	363,842,082	222,278,657	161,284,127
2024	517,108,754	362,058,542	214,869,368	152,993,821
2025	524,865,386	360,283,745	207,707,056	145,129,653
2026	532,738,366	358,517,649	200,783,487	137,669,717
Totals	4,986,706,705	3,665,703,893	2,349,847,176	1,765,815,154

5.2. Cost-Benefit Analysis

The CBA Report looked at the benefits of GOES-R for many industries in the U.S. The present report updates dollar values to 2005 and, where possible, obtains more accurate data. The following discussion explains in a step-by-step fashion the assumptions and computations originally developed in the CBA Report. Centrec has used the methodology in the original report as a baseline for computing the cost-benefit analysis of the proposed GOES-R ABI and HES sounder instruments. Two key assumptions applied in the CBA Report have changed since it was released. First, the HES has been removed from the proposed GOES-R instrument platform. Since the HES was removed from the GOES-R instrument specification after these benefits were updated, expert opinions were subsequently obtained from scientists to estimate the portion of benefits that could be attributed to each of the instruments. The benefits accrued to each instrument are then calculated for each sector. Secondly, the proposed launch date for the GOES-R satellite is now either late 2014 or early 2015, and the operational period for GOES-R is expected to commence in 2017. The CBA Report calculated benefits for 13 years spanning from 2015 through 2027. This analysis retained the same timeframe used in the CBA Report to permit evaluation of the benefits within comparable timeframes. This portion of the report focuses on the following industries and the expected savings due to improvements in weather forecasting that result from the GOES-R ABI and HES sounder instruments.

Methodology

The Office of Management and Budget has issued guidelines for calculating benefit-cost analysis of federal programs in its Circular No. 94 (revised in 1992)[30]. The memorandum explains that future expected benefits and costs associated with federal programs should be discounted to present values using an appropriate discount rate. The discounting process transforms gains and losses occurring in different time periods to a common unit of measurement, taking into account the time value of money. The memorandum recommends that a real discount rate of 7% be used. A real discount rate is adjusted to eliminate the effect of expected inflation. The 7% discount rate is recommended because it approximates the marginal pretax rate of return on an average investment in the private sector in recent years.

The GOES-R satellite system is expected to be launched in 2014 and to be operational from 2015 to 2027, the period for which socioeconomic benefits are measured. Data are presented as of the year 2005, and future benefits/savings (from 2015 to 2027) have been discounted at 7% to the year 2005 to determine present value of the future streams of expected savings. The purpose of the cost-benefit analysis presented here is to measure the costs avoided or benefits gained by each industry resulting from more accurate forecasts, reduced operations costs, and fewer accidents and deaths due to improved data from GOES-R.

In interpreting the results in this section, it is important to understand that because the future benefits/savings do not begin until 2015, the present value of the benefits is significantly reduced. Also, as the operational date of the GOES-R approaches, there will be fewer years in which to discount the annual savings, thereby raising the estimated present value of sector benefits over time.

[30] Office and Management and Budget Circular No. A-94 www.whitehouse.gov/omb/circulars/a094/a094.html

Discounting Example

Table 40 shows an example of how the socioeconomic benefits are discounted to calculate a present value. One of the benefits to the aviation sector relates to "Avoidable Weather-Related Delays Component." This benefit is discussed in the next section of the report. The computations are included here as an illustrative example of discounting future benefits to a present value. The benefits column shows the annual benefits in real dollars and is conservatively estimated to remain constant. The discount rate illustrates the impact of compounding 7% for each year, from 2005 to 2027. The discounted benefits column is computed as the benefit divided by the discount rate. The sum of the discounted benefits is the present value of the stream of benefits (or savings) that are estimated to begin in 2015 and continue until 2027.

Table 40. Present Value Discounting Example

Year	Benefits	Discount Rate	Discounted Benefits
2006	$ 0	1.0700	$ 0
2007	0	1.1449	0
2008	0	1.2250	0
2009	0	1.3108	0
2010	0	1.4026	0
2011	0	1.5007	0
2012	0	1.6058	0
2013	0	1.7182	0
2014	0	1.8385	0
2015	60,768,216	1.9672	30,891,480
2016	60,768,216	2.1049	28,870,542
2017	60,768,216	2.2522	26,981,815
2018	60,768,216	2.4098	25,216,649
2019	60,768,216	2.5785	23,566,962
2020	60,768,216	2.7590	22,025,198
2021	60,768,216	2.9522	20,584,297
2022	60,768,216	3.1588	19,237,661
2023	60,768,216	3.3799	17,979,122
2024	60,768,216	3.6165	16,802,918
2025	60,768,216	3.8697	15,703,662
2026	60,768,216	4.1406	14,676,319
2027	60,768,216	4.4304	13,716,186
Total	$789,986,808		$276,252,811

This means that $60,768,216 of the estimated benefits in 2027 are equivalent to $13,716,186 today. The concept of discounting is essentially the same as compounding interest (achieved via savings accounts); a dollar in the future is worth less than a dollar today.

Aviation Cost-Benefit Analysis

The aviation industry stands to benefit greatly from better weather data that would increase accuracy in forecasting. This study breaks down the benefits into four parts:

1. Avoidable weather-related delays
2. Passenger time value from avoidable weather-related delays
3. Avoidable repair costs from not flying into volcanic ash plumes
4. Avoided loss of life and aircraft from not flying into volcanic ash plumes

Avoidable Weather-Related Delays Component

The first component attempts to estimate the cost savings that are achievable by avoiding weather-related delays due to better forecasting. The HES sounder is expected to provide higher spatial resolution and higher frequency data, thereby allowing forecasters to improve forecast accuracy. The resulting improved forecast accuracy is expected to allow U.S. air traffic to fly more efficiently by avoiding a small number of preventable weather-related delays.

Avoidable Weather-Related Delays Assumptions

1. The total number of delays and total number of weather-related delays involving U.S. air-carriers are found through the Bureau of Transportation Statistics[31] . Table 41 presents the number of delays in 2004 and 2005. The average number of delays are computed below:

Table 41. Number of U.S. Air Carriers Weather-Related Delays

Year	Total Delays	Weather Delays	Weather Delays as a % of Total
2004	545,788	380,142	70%
2005	539,380	365,930	68%
Average	*542,584*	*373,036*	69%

2. According to the CBA Report, an FAA aviation weather expert estimated that at least 50% of total weather delays, or 186,519, are due to convective weather. Some examples of convective weather include severe storms and tornadoes.
3. The CBA Report assumes that the percent of delays avoided due to reduced watch area is 20%, and the percent of delays avoided due to the HES sounder is 50%. These estimates were obtained via consultations with NOAA experts during the preparation of the CBA Report.
4. The average delays costs per hour are found from the Air Transport Association[32]. Costs of delays include fuel, crew/pilots/flight attendants, maintenance, aircraft ownership, and other costs. These costs total $62.33 per minute. Multiplying the delay cost per minute by sixty minutes results in an average hourly cost per delay of $3,740.
5. The Bureau of Transportation Statistics tracks the total amount of weather-related aircraft delays in minutes. Total minutes of delay were divided by the number of weather delays to compute the average aircraft delay (in minutes) and then as a percent of an hour. (Table 42)

Table 42. U.S. Air Carriers Weather-Related Delays

Year	Delays, Minutes	Weather Delays	Average Delay, Minutes	Average Delay, % of Hour
2005	19,123,783	365,930	52.30	87.1%

6. The average cost of a delay is calculated by multiplying the average hourly cost of delays by the time of the average delay.

   $3,740 average cost of delay x 87.1% average delay, % of hour = $3,258 average cost of delay

7. The avoided delays due to the HES sounder are computed by multiplying the total weather delays by the percent of weather delays due to convective weather, and the percent of delays avoided due to reduced watch area and due to the HES sounder. The implication is that GOES-R will be able to avoid an average 18,652 delays annually. This is only 5% of all weather-related delays. Avoided delays due to GOES-R are an important number in the analysis. It is used in the next section where wasted passenger time due to delays is valued.

   373,036 x 50% x 20% x 50%= 18,652 avoidable delays

---

[31] Airline On-Time Statistics and Delay Causes (http://www.transtats.bts.gov/ot_delay/ot_delaycause1.asp?pn=-22&type=4&display=data&month=6&year=2004) contains a month-by-month breakdown of total delays.
[32] System Capacity: The Cost of Air Traffic System Delays (http://www.airlines.org/econ/d.aspx?nid=5773) contains direct costs for the airlines by the minute.

8. The annual avoided costs of avoidable delays are the Average Costs of Delays ($3,258) times the Total Avoided Delays (18,652) which totals $60,768,216.

Benefit for Avoidable Weather-Related Delays

The annual benefits of $60,768,216 start to be realized in 2015 and go through 2027. These values are then discounted at a 7% rate, per OMB to a present value of $276,252,811.

Value of Passenger Time Avoided Component

The second component attempts to estimate value of passenger time saved due to avoiding delays as a result of better forecasting. The number of weather-related delays from the previous component is used as that starting point for number of flight delays. This analysis incorporates an average wage rate and delay duration to estimate the value of passenger time.

Value of Passenger Time Avoided Assumptions

1. The CBA Report assumes that 80% of aircraft carry passengers. The other 20% are comprised of freight-related aircraft and are excluded from this portion of the analysis.
2. Air-carrier delays are calculated as 14,922, which is 80% of total delays, 18,652. Recall that total weather-related delays are 373,036. Therefore, 14,922 represents only 4% of all weather-related delays that result in potentially saved passenger time due to GOES-R.
3. According to the FAA's Aerospace Forecasts Fiscal Years 2006-2017[33] the average number of seats per aircraft was 136 in 2004 and 135 in 2005. 135 seats per aircraft were used for this report. The load factor[34] (amount of the planes seats occupied) was 74.5% in 2004 and 77.2% in 2005, for an average of 75.85%. Based on these two numbers, the average number of passengers is:

   135 average plane capacity x 75.85% average load factor = 102 passengers impacted per delay

4. In 2000, the average value per hour[35] of personal travel was $33.30 and $40.10 for business travel. Also, 81% of passengers travel for leisure while only 19% travel for business purposes[36]. These percentages are multiplied by the respective wage rates to get an average 2000 wage rate of $34.59, which was inflated to 2005 dollars of $38.43.
5. The costs of the average passenger's time per delay is equal to the average delay time (85% of an hour) times the average wage of passengers per hour ($38.43), and totals $32.79.
6. The total annual savings of passenger time with the HES sounder is the product of the delays involving air-carriers, average number of passengers per plane, and the cost of passenger's time per delay.

   14,922 x 102.4 x $32.79= approximately $50,098,031 saved annually

Benefit for Value of Passenger Time Avoided

The annual benefits of $50,098,031 are expected to begin in 2015 and continue through 2027. These values are then discounted at a 7% rate per OMB to a present value of $227,746,060.

---

[33] http://www.faa.gov/data_statistics/aviation/aerospace_forecasts/2006-2017/media/FAA%20Aerospace%20Forecasts%202006-17.pdf

[34] Bureau of Transportation Statistics, http://www.bts.gov/press_releases/2006/bts013_06/html/bts013_06.html

[35] Memorandum from Emil H. Frankel, Assistant Secretary for Transportation, Re: Revised Departmental Guidance: Valuation of Travel Time in Economic Analysis (2/11/03) http://ostpxweb.dot.gov/policy/Data/VOTrevision1_2-11-03.pdf.

[36] Travel Volume and Top Activities from the Travel Industry Association of America, http://www.tia.org/pressmedia/domestic_activities.html

Avoidable Repair Costs from Avoiding Volcanic Ash Component

The third component attempts to estimate value of better forecasting in avoiding volcanic ash plumes and the associated repair costs of flying aircraft into such a plume.

Avoidable Repair Costs from Avoiding Volcanic Assumptions

1. According to the CBA Report, based on historical data of volcanic ash incidents, $16,500,000 are spent on aircraft repair costs in 2002 values. For this report, the 2002 value is inflated to 2005 dollars using historical CPI's to obtain $17,612,610 in average repair costs related to volcanic ash incidents.
2. The GOES-R coverage area is conservatively estimated in the CBA Report at 33% while the percentage of repairs that are avoidable due to the GOES-R ABI is estimated in the CBA Report at 50%.
3. The annual repair costs avoided is a product of the average annual repair cost, the GOES coverage area percent, and the percent avoidable due to the ABI. This totals a $2,935,435 in avoided annual repair costs.

Benefit for Avoidable Repair Costs from Avoiding Volcanic Ash

The annual benefits of $2,935,435 are expected to begin in 2015 and continue through 2027. These values are then discounted at a 7% rate per OMB to a present value of $13,344,512.

Avoided Risk of Aircraft/Life Loss from Volcanic Ash Component

The fourth component attempts to estimate the value of better forecasting in avoiding volcanic ash plumes and subsequent value of avoided life lost. There are two primary components in this analysis: the value of life of all passengers on board the aircraft and the cost of the aircraft.

Avoided Risk of Aircraft/Life Loss from Volcanic Ash Assumptions

1. Volcanic ash incidents are expected to occur only over the course of trans-Atlantic and trans-Pacific flights based on the assumptions in the CBA Report. Taking this into account, the typical aircrafts used for these flights are Boeing 747, 767, or 777. According to the jet prices on Boeing's website[37] most versions of the 747, 767, and 777 models cost over $200 million with a range of $178 million to $282 million. This report makes a conservative assumption that the average replacement cost of a plane hit by volcanic ash would be $150 million.
2. The CBA Report uses the 747 as the average plane traveling across areas where volcanic ash incidents most likely will occur. This plane's capacity is 410 passengers and 12 crew members.
3. The two-year average load factor, described in the second section of this analysis, is 75.85%. Accordingly, an average 747 carries 311 passengers at a load factor of 75.85% plus 12 crew for a total of 323 people on board.
4. In 2004, Professors Joseph Aldy and Kip Viscusi from Harvard Law School wrote an extensive report on the value of statistical life in their paper titled "Age Variations in Workers' Value of a Statistical Life"[38] based 1996 dollars. The U.S. Census Bureau estimates population by age categories[39], and the latest numbers available were for 2004. Table 43 illustrates the computations used in deriving the average value of a statistical life.

[37] http://www.boeing.com/commercial/prices/
[38] http://www.law.harvard.edu/programs/olin_center/papers/pdf/468.pdf. Page 44 shows the value of life in nine age categories.
[39] http://www.census.gov/popest/national/asrh/NC-EST2004/NC-EST2004-01.xls

Table 43. Average Value of a Statistical Life

Worker Age	2004 Census	Percent of Population	VSL* by Age	Average VSL
18-22	20,971,302	12%	$3,130,000	$373,359
23-27	19,560,906	11%	4,140,000	460,624
28-32	20,471,032	12%	5,760,000	670,687
33-37	21,052,318	12%	5,680,000	680,151
38-42	23,056,334	13%	4,830,000	633,424
43-47	22,122,629	13%	3,630,000	456,773
48-52	19,496,176	11%	3,120,000	345,988
53-57	16,489,501	9%	2,850,000	267,307
58-62	12,589,423	7%	2,510,000	179,737
Totals	175,809,621	100%		$4,068,051

** VSL stands for Value of a Statistical Life.*

The average value of a statistical life in 1996 dollars is $4,068,051. Using historical CPI, the inflated 2005 value for average value of statistical life is $4,938,614.

5. The total value of all life lost if the plane would crash is the product of the total amount of people on board and the average value of life.

   323 x $4,938,614 = approximately $1,595,172,221

6. The total value of a plane crash due to volcanic ash in the sum of the replacement cost of the aircraft, $150,000,000 and the total value of life, $1,595,172,221. Thus, the total value is $1,745,172,221.
7. According to the CBA Report, from 1980-2000 there were four near crashes which would have proven fatal, but no actual crashes due to volcanic ash during that 21 year time period. By dividing the near crashes by the number of years observed, there is a 19% chance that one flight annually will crash due to volcanic ash.
8. The CBA Report assumes that 50% of the losses can be avoided due to the GOES ABI.
9. The CBA Report assumes that one-third of the airspace is allocated to GOES coverage.
10. The total economic annual benefit of volcanic ash avoidance due to the GOES ABI is:

    $1,745,172,221 value of loss x 19% chance of fatal crash x 50% costs avoided due to GOES-R ABI x 33.33% GOES-R coverage area = approximately $55,263,787

Benefit for Avoided Risk of Aircraft/Life Loss from Volcanic Ash

The annual benefits of $55,263,787 are expected to begin in 2015 and continue through 2027. These values are then discounted at a 7% rate per OMB to a present value of $251,229,632.

Total Estimated Aviation Savings

The analysis suggests annual savings to the aviation sector of nearly $170 million. The present value of a stream of savings totaling $169,065,469 is $768,573,014. The non-discounted sum of cash flows is estimated at $2,197,851,091 over the life of the GOES-R satellites. Thus, the discounted present value reduces the real value of cash flows by about 65%. Table 44 summarizes the above aviation-related savings:

Table 44. Estimated Aviation Industry Savings

Sector	Annual Benefit	Present Value (2015-2027)
Avoidable delays	$60,768,216	$276,252,811
Value of passenger time avoided	50,098,031	227,746,060
Avoidable repair costs	2,935,435	13,344,512
Avoided risk of aircraft/life lost	55,263,787	251,229,632
Total	$169,065,469	$768,573,014
Non-discounted sum of benefits	$2,197,851,091	

Energy Cost-Benefit Analysis

The energy industry, identified here strictly as electricity and natural gas, accounts for a significant part of the U.S. economy and over 2% of Gross Domestic Product (GDP). Small inefficiencies in the energy industry can be reduced as a result of the GOES-R satellite system and produce large savings that can be passed on directly to consumers. One large cost of providing energy relates to the ability to forecast demand and then to supply the necessary energy on time. Energy providers rely on demand models to forecast electricity production and natural gas requirements. Demand forecasts for energy production are largely based on temperature forecasts. According to the CBA Report, GOES-R ABI and HES sounder data as described below provide the capability to improve temperature forecasts thereby improving demand forecasts which lead to energy industry savings. Increasing the accuracy of forecasts leads to improvements in production and distribution of energy and requires less product to "be available", thereby lowering costs. For the energy industry, this report looks into key forecasts and the potential for reducing the amount of forecast error.

Electricity Component

Savings attributable to electricity generators are due to the ability to improve forecasts for electricity demand load. The ability to forecast electricity demand accurately in advance prevents utilities from costly spot purchases of electricity, or beginning spinners unnecessarily. Spinners are reserve or "on-demand" electricity generation plants that electricity generators fire up as demand increases. Avoiding use of spinners prematurely and the purchase of electricity on the spot market are significant costs that electricity generators can reduce with more accurate forecasts.

Electricity Assumptions

The following discussion enumerates the assumptions and sources used for computing the benefits to the electricity sector of the energy industry.

1. By reducing temperature forecast error, load forecast error is reduced. Load forecast error is the amount of additional production an electrical company must produce to have sufficient quantity in reserve in case weather projections are inaccurate. Reducing the load error by using enhanced weather data and forecast models reduces the excess need to generate unnecessary electricity. According to the CBA Report, a manager of a "large utility" estimated that temperature forecast error accounts for about 40% of load forecast error. This assumption is also used for the updated analysis. It is assumed that the GOES-R ABI and HES sounder will provide more frequent, higher quality data, allowing forecasters and researchers to improve forecasts and forecast model accuracy, thereby reducing temperature forecast error. It is assumed that each instrument contributes equally to the reduced forecast errors.
2. The CBA Report consulted experts from National Centers for Environmental Prediction (NCEP) and Cooperative Institute for Meteorological Satellite Studies (CIMSS) to obtain estimates of how the GOES-R instruments could reduce the forecast errors. They estimated that errors in 3-hour temperature forecasts using data on clouds and winds from the GOES-R ABI and humidity profiles from the HES sounder could possibly decrease by 25% compared to the current forecasts made with the current GOES data.
3. The CBA Report cites that PJM Interconnect, a major independent systems operator that provides interconnection and energy trading services to electric utilities, estimated average load forecast error of 2.60% as typical of the national load forecast error rate. The interpretation of this estimate is that 2.60% electricity is over or under-generated on average.

4. The decrease in average load error is computed by multiplying the forecast error percentages together:

   Temperature Error (0.4) x Temperature Forecasts Error Reduction (0.25) x Average Load Error (0.026) = 0.0026 or 0.26%

   With new GOES-R ABI and HES sounder data, 3-hour weather forecasts should allow electricity generators to forecast more accurately and generate electricity by about a quarter of a percentage point, 0.26%.

5. The new load forecast error is found by subtracting the decrease in error due to the GOES-R instruments of 0.26% from the current average load error of 2.60% experienced with current forecast capabilities. The resulting new load forecast error is 2.34%, suggesting that GOES-R information should allow researchers and forecasters to improve forecasts from a current average error of 2.60% to an average error in the future of 2.34%.

6. Information for total electricity production was found at the Energy Information Administration (EIA)[40]. Four years of electricity production is shown in Table 45, measured in megawatt hours (MWH). The trend in electricity production is up roughly 2-3% percent per year and increased over 6% from 2001 to 2004. Production data for 2005 was not available at the time of the analysis, therefore, these computations use the 2004 electricity production number as a conservative estimate for 2005 production.

Table 45. Electricity Production

Year	Electricity Production, MWH
2001	3,410,538,000
2002	3,504,788,000
2003	3,525,486,000
2004	3,624,101,000
2005*	3,624,101,000

**2004 production held constant for 2005.*

7. The average 2001-2002 cost of regulated electricity per MWH is $41.30 as reported by PJM Interconnect. While market prices vary widely, a conservative number based on regulated prices is used. Because a more recent cost estimate could not be obtained from PJM Interconnect nor located via other sources, this number was then inflated to 2005 values using the CPI inflator for 2002 to 2005 of 1.067:

   $41.3/MWH in 2002 dollars x 1.067 = $44.07/MWH in 2005 dollars

8. The amount of electricity that utilities avoid purchasing due to improved load demand forecast is computed by multiplying the total electricity production by the decrease in error attributed to the GOES-R ABI and HES sounder data. In this case, 2004 electricity production (3,624,101,000) is multiplied by 0.26% for a total production purchase avoided of 9,422,663 MWH.

9. Total annual savings is computed by multiplying the production purchases avoided by the cost per MWH. Therefore, the improvement in temperature forecast accuracy that results in more accurate electricity generation, based on 2004 production, produces annual savings of over $415 million in today's dollars. This value is based on regulated electricity costs, not actual costs, which are higher than regulated costs. Using regulated costs provides a more conservative estimate of this benefit.

   9,422,663 MWH saved x $44.0671/MWH = $415,229,415

[40] Net Generation by Energy Source by Type of Producer http://www.eia.doe.gov/cneaf/electricity/epa/epat1p1.thml

10. According to the 2005 edition of the Annual Energy Outlook published by the United States Department of Energy, electric spot purchases are expected to grow at 1.9% per year. This is used as a growth proxy for all electricity production. Since GOES-R is not expected to be operational until 2015, energy use from 2005 to 2015 is expected to grow per the following growth formula:

$$(1 + 0.019)^{10} = 1.21$$

11. For the year 2015, when GOES-R is operational, improvements from GOES-R satellites should yield the following benefits to the electricity sector:

    $415,229,415 savings in 2005 x 1.207 growth rate for 2015 = approximately $501,221,800

Benefit for Electricity

This report uses the annual economic benefit of $501,221,800 growing at a rate of 1.9% from 2015 to 2027 and then discounted to 2005 using a 7% discount rate, per OMB. Therefore, beginning in 2015, expected savings of $501,221,800 begin and grow at 1.9% per year until 2027. This entire stream is then discounted to 2005, using a 7% discount rate and results in a present value of potential savings of $2,512,489,739.

Natural Gas Transmission Component

Natural gas transmission companies operate pipelines across the U.S. and are responsible for forecasting natural gas demand at specific locations each day. More accurate demand forecasts, based largely on temperatures, result in more efficiencies in the natural gas transmission process. Natural gas utilities also rely on accurate temperature forecasts to predict demand and the costs associated with storing and preparing natural gas for use. Natural gas held in stand-by is referred to as “on-system.” Better demand forecasts reduce the amount of unnecessary natural gas kept “on-system”, thereby generating savings.

Cost reduction by pipeline companies transferring natural gas across the U.S. can occur by increased forecast accuracy, similar in concept to the previous discussion of electricity. To determine the potential savings for this sector, annual natural gas volume is obtained and then estimates are made regarding the extent that more accurate forecasts can reduce the unnecessary movement and, hence, cost of natural gas transmission.

Natural Gas Transmission Assumptions

The components used in estimating savings for gas transmission companies resulting from improved forecasts due to the GOES-R ABI and HES sounder are detailed below.

1. According to the April 2006 Edition of Natural Gas Monthly, total consumption for the pipeline industry has been steadily decreasing from 2001-2005. This is shown in Table 46 where consumption is measured in billions of cubic feet (BCF).

Table 46. Nautral Gas Monthly, Total Consumption

Year	Natural Gas Consumption, BCF
2001	625
2002	667
2003	591
2004	572
2005	560

2. While much higher load errors for day-ahead load forecasting models exist, within-day forecasting model errors are more conservative and, therefore, used in this study. Research has shown that average absolute load error for within-day forecasting models have an average error between 0.94% and 1.24%.[41] The midpoint of 1.09% is used in this study.
3. Temperature is the most heavily weighted input when calculating load forecast error. Telephone conversations between energy industry employees[42] and CBA Report authors indicated that 50% of load forecast error is due to weather forecast error.
4. According to the CBA Report, researchers from the NOAA believe that the improvements in the GOES-R information will yield a 25% improvement in the 0-3 hour within-day forecasts. As previously mentioned, it is assumed that the ABI and HES sounder contribute equally to the reduced weather forecast error.
5. The costs of natural gas pipelines were calculated using tables SR7 and SR9 of the Departments of Energy's (DOE) 2004 version of U.S. Natural Gas Imports and Exports[43]. These numbers were found by using a weighted average of the costs of imports and exports of U.S. natural gas. Table 47 presents the volume and average price of U.S. natural gas imports and exports. To find the weighted average cost of natural gas, a weighted average import/export price was computed for each year. The weighted average price is then multiplied by one million to convert to dollar per BCF.

Table 47. Volume and Average Price of U.S. Natural Gas Imports and Exports

	2001	2002	2003	2004	2005
Volume of U.S. natural gas					
Imports	3,738,814	3,786,733	3,498,395	3,606,543	3,552,469
Exports	307,060	452,391	613,848	791,671	702,760
Average price of U.S. natural gas					
Imports, $	$4.44	$3.13	$5.23	$5.80	$5.52
Exports, $	4.14	3.32	5.66	6.18	5.92
Weighted, $	4.42	3.15	5.29	5.87	5.58
Pipeline cost, $/BCF	4,417,232	3,150,276	5,294,188	5,868,399	5,581,887

6. The volume of natural gas saved (in billion cubic feet) due to GOES-R is calculated by multiplying the annual natural gas pipeline industry volume times the average load forecast error times the percent of forecast error due to temperature times the expected improvements due to GOES-R. This results in a potential annual reduction in natural gas transmission of 0.76 billion cubic feet.

560 BCF x 1.09% x 50% x 25%= 0.763 BCF saved annually

7. The industry savings due to enhanced data collected by the GOES-R instruments is the reduced volume of natural gas pipeline transmissions, in BCF, times the cost of the pipelines in $/BCF and results in total annual industry savings of over $4 million.

0.763 BCF saved x $5,581,887 cost of pipelines, $/BCF = $4,258,979 industry savings

Benefit for Natural Gas Transmission

The present value is calculated similar to the electricity computation above, except there is no assumption about growth in natural gas pipeline transmissions. Beginning in 2015 and ending in 2027, annual savings of $4,258,979 are discounted at a 7% rate per OMB. This results in a present value of $19,361,356 due to efficiencies in natural gas pipeline transmission stemming from better forecasts enabled by GOES-R.

[41] "Short Term Gas Demand Forecasting" by Piggot, Perchard, and Whitehand
[42] Lamb and Montroy were the energy industry employees.
[43] Department of Energy's 2004 version of U.S. Natural Gas Imports and Exports.
http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2005/ngimpexp/ngimpexp.pdf

Natural Gas Utilities Component

Natural gas utilities need to maintain a certain amount of natural gas as "on-system," which essentially means available for peak demand use by consumers, or in stand-by mode. Better demand forecasts, again largely temperature based, can improve the efficiency of natural gas utilities by requiring less natural gas to be "on-system."

Natural Gas Utilities Assumptions

The computations described below detail the potential savings to natural gas utilities resulting from better forecast demand of natural gas use. Again, this is due to more accurate temperature forecasts resulting from GOES-R ABI and HES sounder data assuming each instrument contributes equally to the reduction in forecast errors.

Consumption of natural gas by consumers for 2001 through 2004 was found in Table SR1 of DOE's 2004 natural gas report and shown in Table 48. At the time of analysis, 2005 data was not yet available, so consumption is held constant for 2005.

Table 48. Natural Gas Consumption

Year	Consumption, BCF
2001	22,239
2002	23,007
2003	22,375
2004	22,432
2005*	22,432

**2004 consumption held constant for 2005.*

8. The CBA Report cites an industry source[44] who estimates about 2% of utilities' daily flow of natural gas occurs during peak periods. This rate accounts for the extra energy consumed and needed to meet unexpected demand due to weather volatility. The resulting computation is 448.6 BCF of natural gas.

   22,432 Consumption, BCF x 2% = 448.6 BCF

9. The same industry source also provided information about price per trillion cubic feet (TCF) of natural gas. The 2002 cost of $480,000 per TCF and was inflated to a 2005 value of $525,988. This price is not the cost of natural gas. Rather, it is a "balancing fee", representing the cost paid to suppliers for the flexibility in load volume.
10. The CBA Report assumes that roughly 25% of the time natural gas companies are in a peak period, which follows logically from the winter season, roughly three months of the year.
11. The peak period weather-related swing is computed by multiplying the amount of natural gas in the 2% peak period and multiplying it by the frequency of the year in peak periods times the price per TCF.

    448.64 BCF x 25% x $525,988 = $58,994,850

12. According to DOE, the growth rate for natural gas usage is expected to be 1.1% through the year 2030[45]. Compounding the growth rate from 2005 to 2015, the year benefits from the GOES-R instruments are expected to begin, yields the following:

    (1 + 0.011)^10= 1.12

13. The CBA Report assumes that the new GOES-R data will improve savings by 10%. This percentage is multiplied by $58,994,850 to get a total annual savings of $5,899,485 as of 2005. By 2015, using the above growth rate, total savings will have grown to $6,581,512.

---

[44] Obtained for the CBA Report from a natural gas industry employee.

[45] International Energy Outlook 2006 by Energy Information Administration, an agency within the U.S. Department of Energy.

Benefit for Natural Gas Utilities

To compute the present value, the annual savings of $6,581,512 begins in 2015 and grows by 1.1% year through 2027. This entire stream of expected savings is discounted at a 7% rate per OMB and results in a present value for natural gas utilities of $31,649,818.

Total Estimated Energy Savings

The analysis suggests annual savings to the energy sector of over $500 million. The present value of a stream of savings totaling $512,062,291 is nearly $2.6 billion. The non-discounted sum of cash flows is estimated at $7,459,795,043 over the life of the GOES-R satellites. Thus, the discounted present value reduces the real value of cash flows by about 66%. Table 49 summarizes the above electricity and natural gas savings:

Table 49. Estimated Energy Industry Savings

Sector	Annual Benefit	Present Value (2015-2027)
Electricity	$501,221,800	$2,512,489,739
Natural gas transmission	4,258,979	19,361,356
Natural gas utilities	6,581,512	31,649,818
Total	$512,062,291	$2,563,500,913
Non-discounted sum of benefits	$7,459,795,043	

Irrigated Agriculture Cost-Benefit Analysis

The following discussion explains the assumptions and computations originally developed by the CBA Report for calculating the expected savings due to improvements in weather forecasting due to GOES-R instruments for agricultural irrigation. Centrec's use of the report as a baseline to update the analysis is also described. The expected savings are estimated to result from more accurate information on evapotranspiration made possible by the advanced sounder and imager data, thereby improving the efficiency of agricultural irrigation.

Terminology
Western States

The 11 western states in the analysis are: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. All other states are grouped and referred to as the "39 states." As a group, these "11 states" are considered the largest users of water for agricultural irrigation purposes in the U.S.

Irrigation in the western U.S. uses significant amounts of water, a natural resource that is becoming more scarce and costly as demand for water rises. Increases in population are driving the demand for household use of water (drinking, cooking, bathing, watering lawns, etc.) and recreational use of water. These non-agricultural uses of water are competing with crop irrigation and result in increased water costs for farmers. To the extent GOES-R information enables researchers and forecasters to produce more accurate forecasts, irrigation can be used more efficiently. More efficient use of irrigation can lead to surplus farm water to be sold for other non-farm purposes (at a significant premium to cost for irrigation) and ultimately less water utilized for agriculture because it is applied in a more productive and efficient manner. This analysis looks at the potential savings from more accurate forecasts, as a result of GOES-R, to aid decision-makers in more efficiently irrigating crops.

Irrigated Agriculture Assumptions

The following discussion enumerates the assumptions and sources used to compute the benefits to the irrigation sector.

1. The CBA Report conservatively assumed that irrigation efficiency can increase at least 5% with new GOES-R data. The analysis herein uses that same efficiency assumption of the 5% increase. After consultation with Tim Schmit[46] with the NOAA/NESDIS/Satellite Applications and Research Advanced Satellite Products Branch (ASPB) in 2006, it is hypothesized that the ABI and HES sounder could contribute 50% each (2.5%) to the 5% efficiency increase.
2. The quantities of water from different sources were found in the 2003 Farm and Ranch Irrigation Survey (FRIS)[47]. The total number of acre-feet applied in 2003 was 86,894,030. Table 11 of FRIS divides water quantity by on or off-farm sources as shown in Table 50.

Table 50. Water Volume by Source

Water Source, 2003 Volume	Acre-Feet
Water from on-farm wells	43,473,978
Water from other on-farm surface sources	11,781,586
Total on-farm sources	55,255,564
Water from other off-farm surface sources	31,638,466
Total water volume, all sources	86,894,030

3. Dividing water volume from on and off-farm sources among the 11 state and 39 state regions results in the following allocation (Table 51)of irrigation water quantity:

Table 51. Water Volume by Source and Region

Water Region and Source, 2003 Volume	Acre-Feet
11 State Region	
Off-farm water quantity	28,810,977
On-farm water quantity	27,736,334
39 State Region	
Off-farm water quantity – 39 states	2,827,489
On-farm water quantity – 39 states	27,519,230
Total water volume, all sources	86,894,030

4. Studies by Lu, and Anderson and Heimlich show that adoption rates of new technologies in U.S. agriculture typically take 10-15 years to reach a 50% level and 18-24 years to reach full adoption (1983, U.S. Congress). In this case, it is assumed that adoption of this technology has already begun since many farmers already use the GOES data indirectly. The CBA Report assumed a 10% adoption rate which would make full adoption happen in 10 years. Given that the technology will not be new, just the accuracy of the forecasts, the adoption rate is doubled to 20%. The adoption of herbicide-tolerant biotechnology soybean seed (e.g., Round-up Ready) in the U.S. serves as a recent example of rapid adoption rates achievable in agriculture.
5. In the 11 western states, surplus water pumped from on-farm wells to increase farm revenues but not used for own farm irrigation purposes is assumed to be 25%. This is a CBA Report assumption.

[46] Tim Schmit is a GOES-R expert with whom the CBA Report authors consulted during their analysis. Therefore, as part of this updated analysis, discussions were held with Tim in 2006 to clarify the assumptions made for the CBA Report.

[47] FRIS is a study conducted by the National Agricultural Statistics Service (NASS) and is completed every five years. The survey provides information on acres irrigated by category of land use, acres and yields of irrigated and non-irrigated crops, quantity of water applied and method of water distribution system, and number of irrigation wells and pumps. 2003 Farm and Ranch Irrigation Survey Census of Agriculture, USDA-NASS. http://www.nass.usda.gov/census/census02/fris/fris03.htm.

6. Due to improved weather data from the GOES-R ABI and HES sounder, less surplus water in the 11 western states is pumped and, therefore, results in assumed savings of 75%. This is a CBA Report assumption.
7. Improved weather data from the GOES-R ABI and HES sounder will allow the 39-state region to save costs by reducing energy needs on surplus water. This is assumed to be 100% and is a CBA Report assumption.
8. Farmers from the 11 western states will retain 25% of surplus off-farm water and will try to increase production. This is a CBA Report assumption.
9. The CBA Report assumes that in the 11 western states, 25% of surplus water will be transferred or used to increase production and that 75% will be left at the source.
10. The CBA Report assumes that in the other 39 states 0% of surplus water will be transferred or used to increase production, therefore 100% is left at the source.
11. The CBA Report assumes that 25% of surplus water will be sold to entities for a higher price than it was acquired.
12. In 2003 dollars, the cost of water was $18.29[48] per acre-foot. Cost is inflated to 2005 dollars by the following formula:

    $18.29/acre-foot in 2003 dollars x 1.051 = $19.22/acre-foot in 2005 dollars

13. The CBA Report value for 2002 was $354[49] per acre-foot for water price transfers. In 2005 dollars, this amount is $378.01.
14. Increased revenue is computed by subtracting the cost of water for irrigation, $19.22, from the average price transfer of $378.01, resulting in water transfer revenues of $358.78.
15. The CBA Report assumes that 30% of average price transfers result in increased value to farmers. Multiplying $378.01 by 30% results in value to farmers of $113.40 per acre-foot.
16. The energy costs are divided into four categories that equal the total energy costs of $1,551,847,000 and are found on FRIS Table 20. The categories are on-farm and off-farm energy costs for both the 11-state and 39-state regions. The inflated amount for 2005 is $1,630,991,000 (Table 52).

Table 52. Energy Cost for Water Pumps

Pump Source	Pumps, %	Energy Cost, $
On-farm	89.4	$1,457,957,000
Off-farm	10.6	173,034,000
Total		*$1,630,991,000*

On-farm water expense is computed by adding the total number of on-farm pumps divided by the total pumps powered, which is 89.4%. Subtracting this amount from 100% leaves 10.6% of pumps as off-farm pumps. The number of pumps in the U.S. is found in Tables 15 and 19 of the FRIS report. The ratio of on-farm and off-farm pumps is used to allocate energy costs of $1,630,991,000.

[48] The cost of water for irrigation purposes was determined from the Irrigation Survey Results Released November 15, 2004, from the 2003 Farm and Ranch Irrigation Survey (http://www.nass.usda.gov/census/census02/fris/frisfeaturestory.pdf).

[49] Gollehon, Noel R, "Water Markets: Implications for Rural Areas of the West", Rural Development Perspectives, Vol.14, No. 2, United States Department of Agriculture, Economic Research Service.

Energy costs are allocated among on-farm and off-farm use and by region according to the quantity of water applied as shown in Table 53.

Table 53. Energy Cost for Water by Source and Region

Water Source and Region	Source, %	Region, %	Energy Cost, $
Off-farm	10.6		
11-state region		91.1	$157,570,176
39-state region		8.9	15,463,819
On-farm	89.4		
11-state region		50.2	731,842,819
39-state region		49.8	726,114,376
Total energy cost			$1,630,991,000

Benefit for Irrigated Agriculture

The following section describes the computation of benefits from the above discussion in four different components:

- Water Savings—expected savings from using less water for irrigation
- Energy Savings—expected savings from using less energy because less water is applied to irrigated crops
- Value of Increased Production—expected benefit from being able to increase production through additional water use or higher value crops
- Increased Revenue from Water Transfer—expected benefit from being able to sell surplus water to non-farm uses.

The first portion of the benefit computation relates to farmers who avoid purchasing off-farm water without losing yields on crops. This is accomplished by more efficient application of irrigation resources. (Table 54)

Table 54. Water Savings from More Efficient Irrigation

Off-farm Water Savings	11 States	39 States	All States
Quantity of water	28,810,977	2,827,489	
Surplus water not retained	75%	100%	
Water cost, $/acre-feet	$19.22	$19.22	
Efficiency improvement	5%	5%	
Adoption rate	20%	20%	
Total	$4,153,705	$543,522	$4,697,227

The second portion of the benefit computation relates to the energy savings by farmers who reduce on-farm and off-farm water use without losing yields on crops (Table 55). This is accomplished by more efficient application of irrigation resources.

Table 55. Energy Savings from More Efficient Irrigation

Energy Savings	11 States	39 States	All States
Off-farm			
Cost of energy	$157,570,176	$15,463,826	
Surplus water not retained	75%	100%	
Total*	$1,181,776	$154,638	$1,336,415
On-farm			
Cost of energy	$731,842,819	$726,114,376	
Surplus water not retained	75%	100%	
Total*	$5,488,821	$7,261,144	$12,749,965

**Includes 5% improvement in irrigation efficiency, and a 20% adoption rate.*

The third portion of the benefit computation relates to farmers in the 11 Western States who retain off-farm surplus water and use it to increase productivity (Table 56).

Table 56. Off-Farm Surplus Water Used to Increase Productivity

Value of Increased Production	Off-farm	On-farm	Total
Quantity of water, acre-feet	28,810,977	27,736,334	
Surplus water retained by farmers	25%	25%	
Value of increased production to farmers	$113.40	$113.40	
Improvements due to GOES-R	5%	5%	
Adoption rate	20%	20%	
Totals	$8,168,060	$7,863,393	$16,031,454

The fourth and final portion of the benefit computation relates to increased revenue to water suppliers (farmers) in the 11 Western States when water is transferred from farm to non-farm use via the average sales price. (Table 57)

Table 57. Off-Farm Source Transfer Revenue

Off-Farm Source Transfer Revenue	
Quantity of water	28,810,977
Surplus off-farm water transferred	25%
Increased revenue per acre-foot	$358.78
Improvements due to GOES-R	5%
Adoption rate	20%
Total	$25,842,299

Total economic benefits to the irrigation industry from the above components total $60,657,360. Irrigation is expected to take five years to reach full adoption (Table 58). Therefore, from years 2015-2019 the annual economic value is expected to increase at $60,657,360 per year, and then remain constant at $303,286,800 for the remaining eight years. These values are then discounted at 7% annually per OMB, resulting in a present value of benefits to agricultural irrigation related to the GOES-R ABI and HES sounder of $1,089,914,332. The non-discounted sum of cash flows is estimated at $3,336,154,800 over the life of the GOES-R satellites. Thus, the discounted present value reduces the real value of cash flows by about 67%.

Table 58. Estimated Irrigated Agriculture Industry Savings

Sector	Annual Benefit	Present Value (2015-2027)
Water savings	$4,697,227	$ 84,401,556
Energy savings	14,086,379	253,109,382
Value of increase production	16,031,454	288,059,210
Increased revenue from water transfer, annual	25,842,299	464,344,184
Total	*$60,657,359*	$1,089,914,332
Non-discounted sum of benefits	$3,336,154,800	

Recreational Boating Cost-Benefit Analysis

A significant reason for people to reside on the coastal areas of the U.S. is the recreational opportunities created by the coastal environment, and includes recreational boating on and near the ocean. In the CBA Report, it was acknowledged that recreational boating is a sizeable industry estimated in 2002 at $20 to $25 billion per year. This industry has suffered significant economic losses due to hurricanes as evidenced by boat damages associated with major landfalling hurricanes between 1991 and 1999 estimated at $837 million in 2002 dollars.

A key factor to reducing or avoiding the boat-related losses associated with tropical storms and hurricanes is to prepare for landfall by using alternative mooring places with greater protection. These protective measures can be efficiently implemented with accurate and timely hurricane track forecasts. If the boat owners have confidence in the hurricane track forecasts and have sufficient lead time, they can take protective action to mitigate their potential losses.

The earlier hurricane analysis framework discussion identified that GOES-R can potentially contribute to improved hurricane track forecasts by reducing the forecast errors. This reduction in errors is particularly important for the longer range forecasts extending past 24 hours to give sufficient time for boat evacuation to safer mooring locations. The CBA Report outlines the GOES-R ABI and HES sounder information that could be attributed to both improved hurricane track and intensity forecasts:

- Increased spatial resolution and update cycle for GOES-R sea surface measurements provides more frequent capture of sea surface temperatures (SST) readings As a result, the SST data can be re-initialized into the numerical forecasting models more frequently, thus improving hurricane intensity forecasts.
- More frequent scans by GOES-R will help better understand the divergence, or lift, of the storm and thus the potential for hurricane intensification.
- Increased resolution and frequency of scans will improve the accuracy and density of wind-speed measurements and provide better information on when and where a storm will make landfall.

Consultation with Tim Schmit in 2006 yielded a clarifying assumption that 25% of the potential benefits as outlined in this particular case study could hypothetically be attributed to the HES sounder with the remaining 75% of the benefits being attributed to the ABI. The CBA Report calculates the potential benefits that could be realized from GOES-R technology using an annual boat loss and damage estimate as the foundation for the analysis. The discussion below lists the key assumptions used in valuing GOES-R benefits for recreational boating.

1. An annual estimate of total boat loss and reparable damage of $510 million for the year 2002 was obtained for the CBA Report from the Boat Owners Association of The United States (BoatUS).[50] This estimate, considered to be on the low end, was privately obtained for the original report and not updated for this report. Therefore, the original loss and damage estimate was updated to 2005 dollars, resulting in an estimated annual total boat loss and reparable damage cost of $544.2 million.
2. Of the total annual boat loss and reparable damage, 34.2% is attributable to hurricanes. This assumption is not changed for this report and results in an estimated cost incurred by boat owners due to hurricanes of $186 million. This reflects both damages to boats as well as losses.
3. For the CBA Report, a BoatUS contact estimated that approximately two thirds of the losses and damages attributable to hurricanes are avoidable. The two thirds can be divided equally between losses and reparable damages. These assumptions are not changed for this updated analysis. Therefore, it is estimated that roughly $62 million ($186 million × 1/3) of hurricane losses are avoidable and $62 million ($186 million × 1/3) of hurricane damages are avoidable.
4. The CBA Report evaluates separately the GOES-R-attributed cost savings for boat losses and reparable damages. The report acknowledges there is uncertainty associated with the proportion of hurricane-caused boat losses and damages avoided due to improved GOES-R data. As a result of the uncertainty, a benefits sensitivity table is calculated where the GOES-R-attributed cost savings is a proportion of the total losses and of the total reparable damages. The percentage allocations range from 1% to 50%. The CBA Report assumes that 30% of the cost of boat losses could be avoided due to GOES-R ABI and HES sounder information , resulting in an estimate of $18.6 million ($62 million × 30%). The CBA Report assumes that 20% of the cost of reparable boat damages can be avoided due to GOES-R, resulting in an estimate of $12.4 million ($62 million × 20%). The two components provide a total estimated annual savings of over $31 million related to forecast improvements due to GOES-R.

[50] http://www.boatus.com

5. Using a discount rate of 7%, the annual benefit of GOES-R to reducing recreational boat loss and reparable damage of $31,017,690 results in a present value of $141,006,675 (Table 59). The non-discounted sum of savings is $403,229,970 over the lifetime of the GOES-R satellites. Thus, the discounted present value reduces the real value of cash flows by about 65%.

Table 59. Estimated Recreational Boating Industry Savings

Sector	Annual Benefit	Present Value (2015-2027)
Reduced losses	$18,610,614	$ 84,604,005
Reduced damages	12,407,076	56,402,670
Total	$31,017,690	$141,006,675
Non-discounted sum of benefits	$403,229,970	

CBA Benefits by Instrument

A scientist who had provided guidance in the CBA report (Tim Schmit) and others familiar with proposed GOES-R ABI and HES sounder features (scientists including Paul Menzel) were consulted when it was learned that the HES is no longer a proposed instrument on the GOES-R satellite system. These scientists provided guidance for estimating the portion of benefits that could be attributed to each instrument. Table 60 summarizes the allocation of benefits by instrument. It is estimated that the ABI and the formerly proposed HES sounder could possibly have contributed $2.2 million and $2.3 million of benefits, respectively, to society for the updated sectors.

Table 60. Allocation of Benefits by Instrument

	Benefit Portion		Present Value of Benefits ($M)		
Case Study	HES	ABI	HES	ABI	Total
Aviation					
Avoidable weather-related delays	100%		$504		$504
Volcanic ash plumes		100%		$265	265
Energy					
Electricity	50%	50%	1,256	1,256	2,512
Natural gas transmission	50%	50%	10	10	19
Natural gas utilities	50%	50%	16	16	32
Irrigated agriculture	50%	50%	545	545	1,090
Recreational boating		100%		141	141
Total			$2,331	$2,232	$4,563
Portion of benefits			51%	49%	

Non-Discounted and Inflation-Adjusted Benefits

Alternative Discount Rates

The CBA Report followed the Office of Management and Budget's (OMB) guidelines in calculating benefits attributed to GOES-R. As part of their guidelines, the OMB recommends using a real discount rate of 7%. This 7% discount rate approximates the marginal pretax return on an average investment in the private sector in recent years, and reflects the opportunity cost of capital (implying that it is better to invest in higher return private projects than in lower return public opportunities). However, the 7% rate is a suggestion and analyses of future benefits using other (lower) rates can be used in the context of sensitivity analysis. OMB Circular A-94 also discusses a cost-effectiveness approach (which utilizes a lower discount rate). This approach is appropriate for purchase versus leasing decisions where the lease payments should be discounted at the government borrowing rate.

For the sensitivity analysis, discount rates used by other governmental agencies were obtained. The Congressional Budget Office's (CBO) policy is that the discount rate for most analyses be based on the real yield of Treasury debt, estimated at around 2%. The U.S. General Accounting Office's (GAO) discount rate policy is to use the interest rate for marketable Treasury debt with maturity comparable to the program being evaluated. Both the CBO and GAO justify this rate as reflecting the government's cost of funds, and thus is a practical measure of the government's opportunity costs. The GAO also suggests sensitivity analysis to address various issues such as consideration of other agency discount rates.

Given this information, a sensitivity analysis approach, with an upper bound of 7%, an intermediate rate of 5%, and a lower bound of 2% for the discount rate will be used for the analysis. This approach would consider the different agency approaches to discount rates and captures potential variability of real yields of Treasury debt.

Table 61 summarizes the discounted benefits as calculated for the sectors included in this analysis. The aggregate benefits discounted at 2% total about $9.7 billion while when discounted at 7%, the total benefits are approximately $4.6 billion. This shows how sensitive the total benefit estimates are to the discount rates used.

Table 61. Sector Benefits at Different Discount Rates

	Total Discounted Benefits Discount Rate		
Sector	**2%**	**5%**	**7%**
Aviation	$1,605,413,819	$1,023,721,996	$ 768,573,014
Energy	$5,420,996,633	$3,430,984,230	$2,563,500,913
Irrigated agriculture	$2,392,014,273	$1,481,387,235	$1,089,914,332
Recreational boating	$ 294,538,137	$ 187,817,724	$ 141,006,675
Total benefits	**$9,712,962,861**	**$6,123,911,186**	**$4,562,994,933**

Alternative Inflation Rates

Often when reporting the cost of either an existing or proposed program, the U.S. government does not discount the program's expected costs but does account for inflation. To permit comparable comparison of the proposed costs and the socioeconomic benefits of a program, consistent economic factors should be used to summarize both the estimated costs and benefits. The GOES-R program has reported non-discounted but inflation-adjusted costs. Therefore, two inflation indices have been provided by the GOES-R program office to summarize the expected benefits derived from this updated CBA analysis.

The first set of inflation indices were developed from factors issued by the Department of Defense (DoD). These indices are for use in the presentation of the Fiscal Year (FY) President's Budget and supporting congressional justification materials, the Program Objective Memoranda (POM), Selected Acquisition Reports, unit cost reports, and other cost estimates. These indices are to be used for inflating life cycle cost estimates.

The second set of inflation indices is from NASA's New Start Inflation Index. It is a hybrid of multiple price indexes that have different sampling strategies and update the underlying market basket at different frequencies. The index is highly germane to CBO's analysis because it focuses on the particular subset of contractors, vendors, and suppliers most relevant to NASA.

Table 62, Table 63, and Table 64 present the non-discounted, non-inflation adjusted sector benefits, the non-discounted, DoD-inflation adjusted sector benefits, and the non-discounted, NASA-inflation adjusted sector benefits, respectively. The total non-discounted benefits increase from $10 billion when not being adjusted for inflation to a little over $16 billion when adjusting for inflation using NASA's inflation index.

Table 62. Non-discounted, Non-inflation Adjusted Sector Benefits

	Non-inflation Adjusted Benefits			
Year	Aviation	Energy	Irrigated Ag	Recreational Boating
2015	$169,065,469	$512,062,291	$60,657,360	$31,017,690
2016	169,065,469	512,062,291	60,657,360	31,017,690
2017	169,065,469	512,062,291	60,657,360	31,017,690
2018	169,065,469	512,062,291	60,657,360	31,017,690
2019	169,065,469	512,062,291	60,657,360	31,017,690
2020	169,065,469	512,062,291	60,657,360	31,017,690
2021	169,065,469	512,062,291	60,657,360	31,017,690
2022	169,065,469	512,062,291	60,657,360	31,017,690
2023	169,065,469	512,062,291	60,657,360	31,017,690
2024	169,065,469	512,062,291	60,657,360	31,017,690
2025	169,065,469	512,062,291	60,657,360	31,017,690
2026	169,065,469	512,062,291	60,657,360	31,017,690
2027	169,065,469	512,062,291	60,657,360	31,017,690
Total undiscounted, non-inflation adjusted benefits for each sector				
	$2,197,851,091	$6,656,809,782	$788,545,680	$403,229,970
Total undiscounted, non-inflation adjusted benefits				
	$10,046,436,523			

Table 63. Non-discounted but DoD Index Inflation-adjusted Sector Benefits

	Inflation-adjusted Sector Benefits using DoD Weighted Inflation Indices			
Year	Aviation	Energy	Irrigated Ag	Recreational Boating
2015	$209,941,988	$635,868,320	$75,323,050	$38,517,123
2016	214,560,712	649,857,423	76,980,157	39,364,500
2017	219,281,048	664,154,286	78,673,721	40,230,519
2018	224,105,231	678,765,680	80,404,542	41,115,590
2019	229,035,546	693,698,525	82,173,442	42,020,133
2020	234,074,328	708,959,893	83,981,258	42,944,576
2021	239,223,963	724,557,011	85,828,846	43,889,357
2022	244,486,890	740,497,265	87,717,080	44,854,923
2023	249,865,602	756,788,205	89,646,856	45,841,731
2024	255,362,645	773,437,545	91,619,087	46,850,249
2025	260,980,623	790,453,171	93,634,707	47,880,955
2026	266,722,197	807,843,141	95,694,671	48,934,336
2027	272,590,085	825,615,690	97,799,953	50,010,891
Total undiscounted inflation-adjusted benefits for each sector				
	$3,120,230,856	$9,450,496,156	$1,119,477,371	$572,454,885
Total undiscounted inflation-adjusted benefits				
	$14,262,659,268			

Table 64. Non-discounted but NASA Index Inflation-adjusted Sector Benefits

Inflation-adjusted Sector Benefits using NASA Weighted Inflation Indices				
Year	Aviation	Energy	Irrigated Ag	Recreational Boating
2015	$228,601,956	$692,385,278	$82,017,879	$41,940,585
2016	235,604,198	713,593,536	84,530,146	43,225,255
2017	242,814,575	735,432,188	87,117,087	44,548,111
2018	250,317,626	758,157,288	89,809,034	45,924,662
2019	258,123,879	781,800,719	92,609,764	47,356,841
2020	266,173,573	806,181,480	95,497,835	48,833,682
2021	274,474,302	831,322,571	98,475,973	50,356,580
2022	283,033,891	857,247,690	101,546,985	51,926,970
2023	291,860,413	883,981,295	104,713,767	53,546,333
2024	300,962,195	911,548,599	107,979,307	55,216,196
2025	310,347,820	939,975,604	111,346,685	56,938,135
2026	320,026,139	969,289,111	114,819,075	58,713,773
2027	330,006,280	999,516,773	118,399,753	60,544,785
Total undiscounted inflation-adjusted benefits for each sector				
	$3,592,346,846	$10,880,432,131	$1,288,863,289	$659,071,908
Total undiscounted inflation-adjusted benefits				
	$16,420,714,174			

Alternative Analysis Timeframe

There is significant uncertainty regarding when the first satellite of the GOES-R series will be launched and the length of time the GOES-R series will be operational. To be consistent with the CBA Report, throughout this study the timeframe for which benefits generated by the GOES-R series is assumed to be the 13 year period 2015 to 2027. To provide an indication of the effect of alternative time frame assumptions, an analysis also was conducted examining the expected benefits if the satellites were assumed operational over a 10 year period from 2017 through 2026.

Table 65 presents the estimated stream of potential benefits with the 10 year time period, with all other parameters identical to those of the updated analyses in earlier sections. The Table 65 results therefore are directly comparable to the results shown in Table 61. The estimates of Table 65 are approximately 27% lower than those estimated for the original analyses (Table 61). The lower estimates result from a three-year shorter time horizon and the two year lag before operations are initiated. (A similar comparison for the estimated benefits associated with tropical cyclone forecasts is presented at the end of Section 5.1.)

Table 65. Sector Benefits at Different Discount Rates with Alternative Timeframe

	Total Discounted Benefits		
	Discount Rate		
Sector	2%	5%	7%
Aviation	$1,245,817,797	$801,450,697	$603,636,878
Energy	3,773,309,362	2,427,418,700	1,828,283,950
Irrigated ag	1,756,501,875	1,099,562,472	812,930,565
Recreational boating	228,564,653	147,038,597	110,746,575
Total benefits	**$7,004,193,687**	**$4,475,470,466**	**$3,355,597,968**

5.3. Air Quality Analysis Framework

As the world has enjoyed sustained global economic growth, some of the resources that were deemed inexhaustible are now showing signs of limited availability. Three prominent examples are energy, water and air. Limitations on the availability of clean air became obvious in the early stages of industrialization when air in the industrial cities in Europe and the U.S. literally became unbreathable. However, during the last few decades, the industrialized countries have made major progress towards achieving clean air by better managing and regulating pollution sources.

In the U.S., the EPA has set standards of air quality, largely based on public (human) health considerations. Based on EPA's standards, federal and local authorities have built a framework of regulatory incentives and penalties to achieve good air quality and to define when air quality is not acceptable. By managing sources of pollution better, industry and government have made progress. Nonetheless, air quality occasionally does not meet standards. The fundamental causes can be local, regional and/or global. Local causes are associated with sources of pollution and emissions from transportation in the nearby community. Regional causes are pollution sources that exceed local regulatory authority and simply float in from a neighboring area. Global causes can be major forest fires, volcanic activity, and human-induced catastrophes. Although some of these causes can be avoided (closing or replacing an inefficient factory) or managed (filters on existing facilities), some causes are unavoidable (volcanic ash).

These causes can affect air quality on a continental or even global scale. Even though managing air quality is a global challenge, most decisions are made at the local level, whether by regulating polluting sources or by warning people of pending problems and recommending or imposing mitigating measures or behaviors. To improve air quality decision-making, local authorities rely on different sources of information. These include ground level networks of measuring stations, weather forecasts, and air quality models and forecasts.

Air quality will become an increasingly important issue to address as the race between economic growth, technological advances, and consumer demands for clear air balanced by their desire for economic progress is translated into politically acceptable regulations. As a result, there are several key stakeholder groups who will economically benefit from enhanced air quality and effective monitoring methods for air quality. These groups are:

- The nation as a whole
- Local agencies or cities
- Industrial polluters
- Industrial users of clean air
- Services affected by the health-related impacts of air quality
- The general public

At the national level, policymakers and resource managers can benefit from improved air quality monitoring and forecasting for the following reasons:

- Anticipation of visibility degradation
- Guidance to reduce health impacts
- Short-term decision-making
- Management of long-term emissions reduction programs
- Development of broader environmental protection steps

In addition, air quality is a global issue and as a result, the U.S. frequently addresses air quality issues on the international stage. Improved air quality monitoring and forecasting will help position the country as a leader in air quality issues.

State and local agencies are mandated by EPA to monitor and "improve" air quality. Non-compliance with EPA mandates costs local agencies money, for example, by losing federal highway funding or by incurring additional expenses to comply with EPA mandates, or a combination of both. Monitoring air quality has two dimensions: observing baseline or "typical" sources of pollutants and understanding "exceptional events". These exceptional events are ones out of control of the local authorities and include natural causes such as forest fires or man-induced causes such as Chernobyl.

Local air quality agencies have to balance air quality with the economic and technical constraints of local industry and power generators. Better understanding of the spatial and temporal dynamics and cycles of air quality will enable the local agencies to more effectively target recommendations or mandates they give to industry.

Unsatisfactory air quality can impose additional costs to industrial and commercial enterprises. For example, there are companies such as high tech electronics, chips manufacturing and biotech labs that operate under "clean room" conditions. These "clean room" requirements will increasingly become more important as information technology, biotechnology and nanotechnology make up larger shares of the GDP. To a lesser extent, many industries, offices, entertainment venues and healthcare facilities filter incoming air to meet internal standards.

In general, much of the population is not affected by improved air quality forecasting when making daily decisions. Work and school schedules dictate those participants' activities to the extent that they cannot decide on a daily basis whether or not they will go to work or school based on the air quality for that particular day. However, there is a vulnerable air quality sensitive population (e.g., aging population) for which air quality information is critical so decisions about the content and timing of daily activities can be made. The economic impact of air quality on these populations has been calculated and was part of the arguments to strengthen the current system of air quality measurement, modeling and forecasting.

The needs of these stakeholder groups have defined today's state-of-the-art air quality system. The EPA has traditionally played the major role in developing the mechanisms for air quality tracking, modeling and forecasting. However, the National Weather Service (NWS) has recently been given the mandate to increase its role in this process. The NWS's current capabilities of air quality tracking, modeling and forecasting include:

- 24 hour forecast models
- Models for hourly evolution
- Capability of tracking major events (fires, volcanoes, etc.)
- 12 km resolution (or worse)
- "Ground truthing" and local differentiation of predictions with information from ground networks in many "hot spots" (usually the major cities with history of poor air quality issues.
- Monitoring and forecasting for the eastern half of the U.S. (The geographic coverage will soon expand.)

Satellite data, particularly GOES data, currently play a significant role in the monitoring and forecasting of air quality. GOES imagery data contribute to the visual monitoring of air quality, in addition to providing data for initialization in the forecasting models. Nonetheless, GOES data has potential for a greater role in the forecasting models as they are further developed. Although the final specifications for the GOES-R sounding capabilities are not fully set, data from the ABI and a hypothetical high spectral sounder have the potential for much greater contributions to enhanced and improved air quality monitoring and forecasting. The state-of-the-art ten years from now (if GOES-R would have high spectral capabilities) could be as follows:

- 48-72 hour forecast models
- Models and tracking of hourly (or better) evolution
- Tracking of regional and local events, additional to major global events
- 0.5 - 4 km resolution (1 to 2 orders of magnitude better than the current GOES data)
- Satellite tracking of change complemented by ground tracking
- Global coverage (all U.S. satellite, or in cooperation with other countries)
- Tracking of additional pollutants

Today, hundreds of cities track air quality, and about 300 cities currently use air quality information to publish 24-hour air quality forecasts and alert the public to pollution conditions or the onset, severity and durations of poor air quality. These forecasts and warnings motivate industry decision-makers and individuals to take mitigating measures voluntarily, all with the purpose of complying with air quality standards and avoiding exceeding the allowable limits that trigger sanctions. Industry and individual decisions based on air quality monitoring and forecasts range from long-term decisions (e.g., specifications of a new plant and where to live in retirement) to short-term decisions (e.g., at what level to run the factory or whether or not to venture from home on a particular day). These decisions have serious economic and quality of life implications, and improved air quality forecasting and monitoring will contribute to quality of life issues and to better economic and environmental decisions.

The major step change between the current and future GOES systems in terms of air quality applications will be one of spatial resolution, temporal resolution and expansion of what variables are measured. The better and more detailed the data (higher spatial and temporal resolutions), the more accurate the models, and the better the timing and extent of warnings and mitigating measures. In addition, GOES-R imagery will dramatically improve the capabilities of tracking the "exceptional" plumes (natural or human-induced). As the plumes are tracked, their impact on air quality can be monitored and forecasted.

The socioeconomic contribution of GOES and GOES-R data to monitoring and forecasting air quality might be best made by comparing the cost of alternative systems to achieve the same result as the current process does using GOES data. If GOES-R is unique in its capabilities or is cheaper, then the benefit for the stakeholders will be either cost savings compared to the alternatives or foregoing the benefit of missing features in GOES-R data that cannot be replicated.

Other potential means for collecting comparable data include:

- Launching a cluster (possibly up to 24) of polar satellites to achieve the "near" continuous coverage that GOES currently provides. In addition to the satellites, a sufficient number of back-ups and ground infrastructure would be needed. Polar satellites have better spectral resolution but do not have the temporal resolution that GOES does. The sheer number of required polar orbiting satellites to provide comparable coverage makes this option less economical than the GOES-R system.
- Establishing a ground-based network of sensors. GOES-R will deliver 1 km resolution. In theory, the same results could be achieved by building a ground network with sensors 1 km apart. A ground-based system would allow more sensors at each location and would not be affected by clouds. However, the system would limit observations to ground data and lose the capability to observe weather conditions at higher altitudes and over the oceans. The most significant disadvantage of a ground-based network would be the cost of building and maintaining the network. Even if the resolution would be compromised, the costs of the ground-based network are likely to be substantially higher than for GOES-R.

Air quality in the U.S. has made progress over the past two to three decades, and it is widely acknowledged that "good" air has value. That value was the basis for the decision to put in place a technical infrastructure to measure, model and forecast air quality, and to create a regulatory environment to continue mandating improvements of air quality. GOES and more importantly, GOES-R, data have and will continue to contribute to air quality improvements. The economic benefits of GOES-R relative to air quality can be calculated by translating cost avoidance or increased value as it affects the five stakeholder groups in the clean air debate:

- The nation as a whole is better off with GOES-R because alternatives have much higher costs.
- Local governments will benefit because they will be able to better comply to EPA mandates, avoiding penalties, or in some cases, additional costs of compliance.
- "Polluters" will have more data to make the right decisions in cooperation with local governments.
- Users of clean air will be able to better plan their infrastructure and better manage their operations.
- The general public and more specifically sensitive groups will be able to better plan their daily activities and their spending patterns. New products and services will emerge to satisfy the need for clean air, outside, in the workplace, at home and for personal enjoyment.

There are numerous methods for valuing the socioeconomic benefits of a reliable and accurate air quality monitoring and forecasting system to any of these five stakeholder groups. These approaches include:

- Formulating case studies of individual cities and analyzing their local conditions
- Developing case studies of individual companies or industries and analyzing their specific situation and constraints
- Evaluating the economic impact of various air quality scenarios on specific demographic groups
- Economic value of products or services based on air quality
- Comparing cost savings of the GOES-R system compared to the alternatives of foregoing the benefit of missing features in GOES-R data that cannot be replicated.

None of these approaches encompass the complete socioeconomic benefit of the GOES-R system for monitoring and forecasting air quality. The last approach mentioned above would come closest to capturing the basic contribution of the GOES-R system to the foundation of air quality monitoring and forecasting. The status of air quality forecasting and monitoring would be very different without the geostationary satellite data. Without the current and/or potential future air quality forecasting and monitoring framework, each of the stakeholder groups would face a very different set of conditions on which to make decisions. The cost savings approach is worth further consideration for future analysis.

6. Opportunities for Enhanced Understanding

The project, "An Investigation of the Economic and Social Value of Selected NOAA Data and Products for Geostationary Operational Environmental Satellites (GOES)" focuses on measuring the value from improved forecast capabilities available from the upcoming GOES-R set of satellites. Specifically, estimating the economic benefit of improved forecasts for tropical cyclones is a major component of the project.

There are, however, at least four opportunities to create additional or enhanced understanding of the societal benefits of improved weather forecast from the GOES-R satellites. These include:

1. Expanding use of the Tropical Cyclone Forecast Valuation Tool (TCFVT) in three key areas:
    - Wider geographic area—Inland winds and damaging thunderstorms spawned from tropical cyclones affect a much larger area than the counties reflected in the current project's database. By expanding the tropical cyclone forecast valuation tool to cover additional geographic area further inland, the benefits from protective measures for a larger segment of the U.S. can be measured.

- More granular data—The TCFVT uses county-level data to measure economic benefit from improved forecasts. However, counties are comprised of many census tracts, oftentimes hundreds per county. And, by using this more granular approach to modeling the distribution of property values and population, a more accurate assessment of the economic benefit from improved forecast information can be ascertained.
- The TCFVT has the potential to estimate benefits for subregions along the Gulf and Atlantic coastline. (For this report, only aggregate analyses were conducted.) Focusing on specific key tropical cyclone susceptible regions, especially in conjunction with efforts to obtain key decision specific information in item 3 below, could markedly add to our understanding of the role of forecast information in enhancing economic activities.

2. Adapt TCFVT to incorporate the potential for evaluating potential economic benefits from improved forecast information for severe storms that can impact across the entire nation. Currently, TCFVT focuses only on the potential for economic benefit to Gulf and Atlantic counties from improved tropical cyclone forecasts. The tool could be adapted to look at the entire nation with the purpose of evaluating the potential economic benefit to improved severe storm forecasts. The analysis could then measure the benefit from improved protective measures and improvements in the number of individuals that "take cover" during severe storm and tornado warnings.
3. Conduct primary research on TCFVT assumptions. Some of the assumptions in the model are based on expert judgment instead of on results from scientific studies. This is necessary because some of the inputs required in TCFVT have not been rigorously analyzed. For instance, while there are evacuation plans for many counties along the Gulf and Atlantic coastline, there are not clear guidelines in a hurricane warning for how far inland people should evacuate. Another example relates to the average amount spent per household for protective measures. While some surveys have been done for very specific areas, broad-based studies to understand the type of protective measures and their costs are missing. Conducting focus groups, surveys, and decision experiments with residents living along the coastline would result in better estimates of the assumptions used in the tropical cyclone forecast valuation tool.
4. Expand the cost-benefit analysis to other sectors, where economic benefit can be measured and is likely to be significant. This project looked at the cost-benefit of improved forecasts to agricultural irrigation, aviation, energy, and recreational boating. Significant potential economic benefits have been shown to accrue to these industries from improved planning and actions with better forecast information made available from GOES-R. Other industries that could benefit from improved weather forecasting made available from GOES-R include:
   - Commercial fishing
   - Transportation (over-the road trucking, railroad, and ocean and barge traffic)
   - Other agricultural applications such as frost damage mitigation
   - Recreational tourism.

References

Aldy, Joseph E. and Kip Viscusi. "Age Variations In Workers' Value Of A Statistical Life." Discussion Paper No. 468 03/2004 Harvard Law School Cambridge, MA.

Anderson, M.C., J.M. Norman, G.R. Diak, W.P. Kustas, and J.R. Mecikalski, 1997. "A two -source time – integrated model for estimating surface fluxes using thermal infrared remote sensing", Remote Sensing of the Environment, Elsevier Science, 60:195-216.

Anderson, W., R. Heimlich. 1996-97, Agricultural Resources and Environmental Indicators, Dept. of Agriculture, Economic Research Service, retrieved 7/31/2002 from www.ers.usda.gov/Briefing/ wateruse/.

Anderson, W., R. Heimlich, 2000, Agricultural Resources and Environmental Indicators, Dept. of Agriculture, Economic Research Service, retrieved 7/31/2002 from www.ers.usda.gov/Briefing/wateruse/.

Baker, Earl Jr. "Social Impacts of Tropical Cyclone Forecasts and Warnings", World Organization Bulletin, 2002, pp. 229-235.

Bard, Travis. Commercial Real Estate Agent, Windmere Commercial, Chino Valley, Arizona.

Congressional Budget Office. *The Economic Effects of Federal Spending on Infrastructure and other Investments.* June 1998.

Dash, Nicole and Hugh Gladwin. "Evacuation Decision Making and Behavioral Responses: Individual and Household." Presented at the Hurricane Forecast Socioeconomic Workshop, February 16-18, 2005.

DeMaria, Mark. Analysis conducted for the National Hurricane Center, 2006. Received via personal communication with author, July 2006.

DeMaria, Mark and James Franklin. "Long Term Trends in National Hurricane Center Watches and Warnings." Presented at the Interdepartmental Hurrican Conference, March 8, 2007

Diak, G. R., M. C. Anderson, W. L. Bland, J. M. Norman, J. M. Mecilkalski, and R. A. Aune, 1998, "Agricultural management decision aids driven by real time satellite data". Bulletin of the American Meteorological Society, Vol. 79, No. 7, pp. 1345–1355.

FEMA/ACE. Post Storm Assessment Reports for 2004. chps.sam.usace.army.mil/ushesdata/Assessments/2004Storms/2004_hurricane_season_page.htm

Gollehon, Noel R, "Water Markets: Implications for Rural Areas of the West", Rural Development Perspectives, Vol.14, No. 2., United States Department of Agriculture, Economic Research Service.

Goerss, James S. and Timothy F. Hogan. "Impact of Satellite Observations and Forecast Model Improvements on Tropical Cyclone Track Forecasts." Presented at the AMS 27th Conference on Hurricanes and Tropical Meteorology.

Holtz-Eakin, Douglas. CBO Testimony, Committee on the Budget, U.S. House of Representatives, 10/6/2005.

Hurricane Research Division, "Our Mission", www.aoml.noaa.gov/hrd/hrd_sub/cost_benefits.html Retrieved February 16, 2007.

International Hurricane Research Center. *Hurricane Loss Reduction for Housing in Florida*. August 2006.

Jarrell, Jerry D. and Mark DeMaria. "An Examination of Strategies to Reduce the Size of Hurricane Warning Areas." Preprints: 23rd Conference on Hurricanes and Tropical Meteorology, 10-15 January 1999, Dallas, TX, American Meteorological Society, Boston, MA., 50-52.

Kelly, G., 2004. Observing system experiments of all main data types in the ECMWF operational system. 3rd WMO NWP OSE Workshop, Alpbach, Austria, WMO, Tech Rep., 1228, 36pp.

Lazo, Jeffrey K and Lauraine G. Chestnut. Economic Value of Current and Improved Weather Forecasts in the U.S. Household Sector. Prepared for NOAA/NESDIS/NPOESS by Stratus Consulting. November 22, 2002

Lu, Yao-chi, Forecasting Emerging Technologies in Agricultural Production, Cooperative State Research Service, United States Department of Agriculture, 1983.

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

NOAA/NESDIS, 2004, "GOES-R Sounder and Imager Cost/Benefit Analysis – Phase III." January 2004.

NOAA/NOS "Population Trends along the Coastal Untied States: 1998 – 2008", September 2004.

Office of Management and Budget. Circular No. A-94 Revised, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs." October 29, 1992. Washington, D.C.

Pielke, Jr., Roger A. and Christopher W. Landsea. "Normalized Hurricane Damages in the United States: 1925-95." Weather and Forecasting, September 1998, 621-631.

Pielke, Jr., Roger, Joel Gratz, Christopher W. Landsea, Douglas Collins, Mark A. Saunders and Rade Musulin. "Normalized Hurricane Damages in the United States: 1900 – 2005." Natural Hazards Review. Submitted 6 November 2006.

"Pilot Study for Pre- and Post-hurricane Mitigation and Development for Fernandina Beach" found at http://www.csc.noaa.gov/hes/docs/general_info/Location%20Specific/PILOT%20STUDY%20FOR%20PRE%20AND%20POST%20HURRICANE%20MITIGATION%20AND%20DEVELOPMENT%20FOR%20FERNANDINA%20BEACH.pdf , 1994)

Piggott, J., Perchard, T. and C. Whitehand. "Short Term Gas Demand Forecasting," PSIG 2000, p.8.

Post, Buckley, Schuh & Jernigan, Inc. Hurricane Andrew Assessment: Review of Hurricane Evacuation Studies: Utilization and Information Dissemination. January 1993; retrieved from http://www.csc.noaa.gov/hes/docs/postStorm/H_ANDREW_ASSESSMENT_REVIEW_HES_UTILIZATION_INFO_DISSEMINATION.pdfPiggott, J., Perchard, T. and C. Whitehand. "Short Term Gas Demand Forecasting," PSIG 0011-2000, http://www.psig.org/.

Rappaport, E. N. Loss of Life in the United States associated with Recent Atlantic Tropical Cyclones. Bulletin of he American Meteorological Society, 2000, 81, 2065-2079.

Simmons, A.J. and A. Hollingsworth, 2002. "Some aspects of the improvement in skill of numerical weather prediction." Quart. J. Roy. Meteor. Soc., 128, 647-677.

Whitehead, John C. "One Million Dollars a Mile? The Opportunity Costs of Hurricane Evacuation". March 2000.

Willoughby, H.E., E.N. Rappaport and F.D. Marks. "Hurricane Forecasting, The State of the Art". National Hazard Review. Forthcoming.

U.S. Department of Agriculture, 2003 Farm and Ranch Irrigation Survey Census of Agriculture, USDA-NASS. Washington, D.C.

U.S. Department of Commerce, U.S. Census Bureau web site various years, http://www.census.gov. Washington, D.C.

U.S. Department of Energy, Energy Information Administration. "International Energy Outlook 2006". Washington, D.C.

U.S. General Accounting Office, Office of the Chief Economist, *Discount Rate Policy*, May 1991.

Zapotocny, Tom H., James A. Jung, John F. LeMarshall, and Russ E. Treadon. "A Two Season Impact Study of Four Satellite Data Types and Rawinsonde Data in the NCEP Global Data Assimilation System" Weather and Forecasting. Under peer review.

Experts Contacted

We would like to acknowledge the following scientists who provided invaluable expertise and advice in the discussion of the GOES and future GOES-R data might contribute to improving tropical cyclone forecasting:

- Jack Beven, Senior Hurricane Specialist, NOAA/NWS/Tropical Prediction Center/National Hurricane Center, Miami, FL
- Mark DeMaria, Scientist, NOAA/NESDIS/StAR, Ft. Collins, CO
- Jim Jung, Visiting Scientist, Cooperative Institute for Meteorological Satellite Studies, Camp Springs, MD
- James Goerss, Naval Research Laboratory, Monterey, CA
- Tim Schmit, NOAA/NESDIS/Satellite Applications and Research Advanced Satellite Product Branch (ASPB), CIMSS/SSEC, University of Wisconsin, Madison, WI
- Jean-Noël Thépaut, Head of Satellite Section, Research Department, ECMWF, Berkshire, UK
- Chris Velden, Assistant Scientist, Cooperative Institute for Meteorological Satellite Studies (CIMSS)/Space Science and Engineering Center (SSEC), University of Wisconsin, Madison

We would also like to acknowledge the following individuals who provided invaluable expert knowledge and advice in the design and development of the tropical cyclone approach:

- Jay Baker, Jr., Associate Professor, Department of Geography, Florida State University
- Brandon Bolinski, FEMA, Atlanta, Georgia
- Hugh Gladwin, Director, Institute for Public Opinion Research, SJMC; Assoc. Professor, Sociology/Anthropology, Florida International University
- Matthew Green, FEMA, at TPC/NHC, Miami, FL
- Chris Landsea, Chief Operations Officer, TPC/NHC
- Betty Hearn Morrow, Consulting Sociologist, SocResearch, Miami
- Hugh Willoughby, Department of Earth Sciences, Florida International University

Appendix A: Counties Included in TCFVT Database

Counties included in Tropical Cyclone Forecast Valuation Tool Database

State	County	Hurricane Region
Alabama	Baldwin	3
Alabama	Mobile	3
Connecticut	Fairfield	10
Connecticut	New Haven	10
Connecticut	New London	10
Connecticut	Middlesex	10
Delaware	Kent	9
Delaware	Sussex	9
Florida	Bay	4
Florida	Broward	6
Florida	Calhoun	4
Florida	Charlotte	5
Florida	Citrus	4
Florida	Clay	7
Florida	Collier	5
Florida	Dixie	4
Florida	Duval	7
Florida	Escambia	3
Florida	Flagler	7
Florida	Franklin	4
Florida	Gadsden	4
Florida	Gilchrist	4
Florida	Gulf	4
Florida	Hernando	5
Florida	Hillsborough	5
Florida	Brevard	7
Florida	Holmes	3
Florida	Indian River	7
Florida	Jefferson	4
Florida	Lafayette	4
Florida	Lee	5
Florida	Leon	4
Florida	Levy	4
Florida	Liberty	4
Florida	Madison	4
Florida	Manatee	5
Florida	Martin	6
Florida	Miami-Dade	6
Florida	Monroe	6
Florida	Nassau	7
Florida	Okaloosa	3
Florida	Okeechobee	7
Florida	Orange	7
Florida	Osceola	7
Florida	Palm Beach	6

State	County	Hurricane Region
Florida	Pasco	5
Florida	Pinellas	5
Florida	Putnam	7
Florida	St. Johns	7
Florida	St. Lucie	7
Florida	Santa Rosa	3
Florida	Sarasota	5
Florida	Seminole	7
Florida	Taylor	4
Florida	Volusia	7
Florida	Wakulla	4
Florida	Walton	3
Florida	Washington	4
Georgia	Brantley	7
Georgia	Bryan	7
Georgia	Camden	7
Georgia	Charlton	7
Georgia	Chatham	7
Georgia	Effingham	7
Georgia	Glynn	7
Georgia	Liberty	7
Georgia	Long	7
Georgia	McIntosh	7
Georgia	Wayne	7
Louisiana	Acadia	2
Louisiana	Ascension	3
Louisiana	Assumption	3
Louisiana	Calcasieu	2
Louisiana	Cameron	2
Louisiana	Iberia	3
Louisiana	Iberville	3
Louisiana	Jefferson	3
Louisiana	Jefferson Davis	2
Louisiana	Lafayette	3
Louisiana	Lafourche	3
Louisiana	Livingston	3
Louisiana	Orleans	3
Louisiana	Plaquemines	3
Louisiana	St. Bernard	3
Louisiana	St. Charles	3
Louisiana	St. James	3
Louisiana	St. John the Baptist	3
Louisiana	St. Martin	3
Louisiana	St. Mary	3
Louisiana	St. Tammany	3

State	County	Hurricane Region	State	County	Hurricane Region
Louisiana	Tangipahoa	3	New York	New York	10
Louisiana	Terrebonne	3	North Carolina	Beaufort	8
Louisiana	Vermilion	2	North Carolina	Brunswick	8
Maine	Androscoggin	11	North Carolina	Camden	9
Maine	Cumberland	11	North Carolina	Carteret	8
Maine	Hancock	11	North Carolina	Currituck	9
Maine	Knox	11	North Carolina	Columbus	8
Maine	Lincoln	11	North Carolina	Craven	8
Maine	Sagadahoc	11	North Carolina	Dare	8
Maine	Waldo	11	North Carolina	Hyde	8
Maine	Washington	11	North Carolina	Jones	8
Maine	York	11	North Carolina	New Hanover	8
Maryland	Somerset	9	North Carolina	Onslow	8
Maryland	Wicomico	9	North Carolina	Pamlico	8
Maryland	Worcester	9	North Carolina	Pasquotank	9
Massachusetts	Barnstable	10	North Carolina	Pender	8
Massachusetts	Bristol	10	North Carolina	Perquimans	9
Massachusetts	Dukes	10	North Carolina	Tyrrell	8
Massachusetts	Essex	11	North Carolina	Washington	8
Massachusetts	Middlesex	11	Rhode Island	Bristol	10
Massachusetts	Nantucket	10	Rhode Island	Kent	10
Massachusetts	Norfolk	11	Rhode Island	Newport	10
Massachusetts	Plymouth	10	Rhode Island	Providence	10
Massachusetts	Suffolk	11	Rhode Island	Washington	10
Mississippi	George	3	South Carolina	Beaufort	8
Mississippi	Hancock	3	South Carolina	Berkeley	8
Mississippi	Harrison	3	South Carolina	Charleston	8
Mississippi	Jackson	3	South Carolina	Colleton	8
Mississippi	Pearl River	3	South Carolina	Dorchester	8
Mississippi	Stone	3	South Carolina	Georgetown	8
New Hampshire	Rockingham	11	South Carolina	Horry	8
New Hampshire	Strafford	11	South Carolina	Jasper	8
New Jersey	Atlantic	9	South Carolina	Williamsburg	8
New Jersey	Burlington	9	Texas	Aransas	1
New Jersey	Cape May	9	Texas	Bee	1
New Jersey	Cumberland	9	Texas	Brazoria	1
New Jersey	Essex	10	Texas	Brooks	1
New Jersey	Hudson	10	Texas	Calhoun	1
New Jersey	Monmouth	9	Texas	Cameron	1
New Jersey	Ocean	9	Texas	Chambers	2
New Jersey	Union	10	Texas	Fort Bend	1
New York	Bronx	10	Texas	Goliad	1
New York	Kings	10	Texas	Hardin	2
New York	Nassau	10	Texas	Harris	1
New York	Queens	10	Texas	Hidalgo	1
New York	Richmond	10	Texas	Jackson	1
New York	Suffolk	10	Texas	Jefferson	2
New York	Westchester	10	Texas	Jim Wells	1

State	County	Hurricane Region
Texas	Kenedy	1
Texas	Kleberg	1
Texas	Liberty	2
Texas	Matagorda	1
Texas	Galveston	1
Texas	Nueces	1
Texas	Orange	2
Texas	Refugio	1
Texas	San Patricio	1
Texas	Victoria	1
Texas	Wharton	1
Texas	Willacy	1
Virginia	Accomack	9
Virginia	Gloucester	9
Virginia	Isle of Wight	9
Virginia	Lancaster	9
Virginia	Mathews	9
Virginia	Middlesex	9
Virginia	Northampton	9
Virginia	Northumberland	9
Virginia	York	9
Virginia	Chesapeake	9
Virginia	Hampton	9
Virginia	Newport News	9
Virginia	Norfolk	9
Virginia	Portsmouth	9
Virginia	Virginia Beach	9

Appendix B: TCFVT Database Calculations

The database used for the Tropical Cyclone Forecast Valuation Tool (TCFVT) consists of five categories of variables: (1) Geographic Information, (2) Landfall Probability Information, (3) Evacuation Cost Information; (4) Residential Property Value Information; and (5) Commercial Property Value Information (Table 66). The following sections describe either the data sources and/or how the variables are either derived from underlying data or based on assumptions for the evacuation cost, residential property value and commercial property value information.

Table 66. TCFVT Database Variables

Database Variables	Data Source
Geographic Information	
FIPS	US Census Bureau
State Name	US Landfalling Hurricane Probability Project
County Name	US Landfalling Hurricane Probability Project
Region	US Landfalling Hurricane Probability Project
Sub-region	US Landfalling Hurricane Probability Project
Coastline/border designation: 1=coastline county; 2=border county; 3=2nd tier border	US Landfalling Hurricane Probability Project plus Centrec designation
Population, 2005	US Census Bureau
Area, sq mi.	US Census Bureau
Population Density, 2005	Derived
Latitude (N)	US Census Bureau
Longitude (W)	US Census Bureau
County Length, mi.	US Landfalling Hurricane Probability Project
County Depth, mi.	Derived
Landfall Probability Information	
Tropical Storm in Vicinity	US Landfalling Hurricane Probability Project
Tropical Storm Hits	US Landfalling Hurricane Probability Project
Hurricane (SS1-2) in Vicinity	US Landfalling Hurricane Probability Project
Hurricane (SS1-2) Hits	US Landfalling Hurricane Probability Project
Intense Hurricane (SS3-5) in Vicinity	US Landfalling Hurricane Probability Project
Intense Hurricane (SS3-5) Hits	US Landfalling Hurricane Probability Project
Evacuation Cost Information	
Average Household Size, 2000	US Census Bureau
Cost of Living Index, 2005	ACCRA Cost of Living Index
Average Evacuation Cost per Capita, 2005	Derived
Residential Property Value Information	
Housing Units, 2000	US Census Bureau 2000 Census of Population and Housing
Owner-occupied Units, 2000 (%)	US Census Bureau 2000 Census of Population and Housing
Renter-occupied Units, 2000 (%)	US Census Bureau 2000 Census of Population and Housing
Vacant Units, 2000 (%)	US Census Bureau 2000 Census of Population and Housing
Owner-occupied Housing Value	Derived
Renter-occupied Housing Value	Derived
Vacant Single Units Value	Derived
Vacant Multiple Units Value	Derived
Vacant Mobile Home	Derived
Vacant Van, Boat, etc	Derived
Total Property Value, $	Derived
Per Capita Residential Property Value, $	Derived
Commercial Property Value Information	
MSAs	US Office of Management and Budget (OMB)
Commercial Property Value Estimate, $	Derived
Per Capita Commercial Property Value, $	Derived
Per Capita Total Property Value, $	Derived

1. Evacuation Cost Information

Evacuation costs for the TCFVT were estimated for each county based on household evacuation costs obtained from Whitehead's survey in North Carolina. The survey was conducted in 1998 so these costs were adjusted for inflation to 2005 values. In addition, the survey captured data on evacuation costs by destination on a revealed (what the respondents actually did) and stated basis. The average evacuation costs were weighted by revealed destination, resulting in a weighted average household evacuation cost adjusted to 2005 values. This cost was then calculated on a per capita basis (Table 67 and Table 68).

Table 67. Evacuation Costs Calculation, 1998 $

Costs	Hotel/ Motel	Shelter	Friends/ Family	Other
Lodging	$162.73	$0	$0	$0
Food	94.03	62.54	45.88	17.40
Entertainment	12.70	0.39	2.41	0.30
Other	5.24	23.31	4.81	2.15
Total	274.70	86.24	53.10	19.85
Travel	106.47	35.25	69.70	64.46
Time	88.59	22.75	50.80	54.30
Total	$469.76	$144.24	$173.60	$138.61
'05 Evac Costs-NC	$544.45	$167.17	$201.20	$160.65
'05 Cost of Living				
Raleigh-Cary, NC	100.9			
Baldwin, AL	81.10			
Adjustment	0.804			
'98 Evac Costs-Baldwin, AL	$377.58	$115.94	$139.53	$111.41
'05 Evac Costs-Baldwin, AL	$437.61	$134.37	$161.72	$129.12

Table 68. Average Evacuation Cost per Capita Calculation

Evacuation Destination	Hotel/ Motel	Shelter	Friends/ Family	Other	Total
Revealed	15.7%	5.5%	70.2%	8.5%	99.9%
Stated	23.6%	12.2%	59.9%	4.3%	100.0%
Other					0.0%
Updated evacuation cost weighted by evacuation distribution					$200.60
Weighted avg '05 evacuation cost for Raleigh-Cary, NC					$249.57
Avg Household size					2.50
Avg evacuation cost per capita					$80.24

Due the cost of living differences between North Carolina and the balance of the areas in the database, the evacuation costs for each county were adjusted for cost of living differences. Since Cost of Living (COL) indices were not found at the county level, COL indices for metropolitan areas nearest the specific counties for which COL indices were found were used to adjust the evacuation costs at the county level. Table 69 reports the Cost of Living Indices used to adjust the evacuation costs at the county level.

Example: Baldwin County is located in Alabama, so the Cost of Living index is assumed to equal to Mobile County that is 81.1

Table 69. Cost of Living in Metropolitan Area for 2005

State	City	Overall	Food	Housing	Utilities	Health	Transpor-tation	Misc.	Adj. Factor
TX	Houston	81.7	93.9	53.1	95.4	106.1	103.6	96.3	0.810
TX	Corpus Christi	77.8	79.9	53.7	100.9	94.8	94.2	94.3	0.771
LA	New Orleans	88.6	107.6	61.4	104.2	107	107.0	98.4	0.878
MS	Jackson	72.9	89.6	41.0	81.8	86.9	98.5	92.4	0.722
AL	Mobile	81.1	92.7	55.0	105.4	83.9	97.3	97.3	0.804
FL	Miami	136.2	107.2	186.0	104.9	122.1	111.2	104.8	1.350
FL	Jacksonville	94.0	101.6	88.7	86.1	86.5	98.7	99.3	0.932
FL	Tampa	97.0	99.0	91.2	101.5	98.0	100.7	101.2	0.961
GA	Savannah	89.4	106.5	68.6	91.1	100.2	98.5	101.9	0.886
SC	Charleston	107.2	102.4	120.4	91.5	99.4	98.0	101.5	1.062
SC	Columbia	84.4	101.0	64.0	94.4	93.1	90.4	96.1	0.836
NC	Raleigh Cary	100.9	102.2	97.7	93.9	106.0	100.3	106.5	1.000
VA	Virginia Beach	109.6	98.3	122.4	131.5	92.7	106.9	95.4	1.086
VA	Norfolk	99.7	95.9	94.8	140.9	93.8	105.9	94.2	0.988
WA	D.C.	137.4	112.1	188.5	84.7	120.1	113.5	109.3	1.362
DE	Wilmington	98.8	108.4	85.3	121.4	111.8	97.8	102.3	0.979
MD	Baltimore	116.0	92.8	146.2	119.5	94.2	101.7	96.3	1.150
NJ	Newark	121.5	111.7	132.5	121.7	119.3	118.8	112.8	1.204
CT	Bridgeport	125.4	127.2	121.5	144.8	154.5	112.1	122.2	1.243
CT	New Haven	111.8	111.4	112.2	129.3	107.3	104.7	110.1	1.108
NY	New York City	172.3	140.6	225.3	163.3	183.9	119.2	136.6	1.708
MA	Boston	145.1	113.1	195.3	131.0	129.0	115.7	111.6	1.438
RI	Providence	137.2	112.4	180.1	111.8	137.7	117.0	105.2	1.360
NH	Portsmouth	130.8	105.6	162.4	146.5	112.9	108.7	108.8	1.296
ME	Portland	114.3	101.0	122.4	150.8	108.9	104.6	104.5	1.133

Source: http://www.bestplaces.net (The data from this source is relevance to the data from ACCRA, 4232 King St., Alexandria, VA 22302-1507, ACCRA Cost of Living Index, Fourth Quarter 2004 (copyright).)

2. Residential Property Value Information

Residential property values were calculated at the county level using 2000 Census of Population and Housing. The following sections outline the variables used in the calculations, provide definitions for the variables, and explain how the residential property values were calculated.

2.1. Census Data

The property values were calculated using the population and housing data from Census 2006 CD-ROM and website www.census.gov. The values were calculated at the census tract level and summarized at the county level. The data from Census 2006 are categorized in the following manner.

Occupancy Status

- Occupied
- Vacant

Total Housing Units

Tenure

- Owner Occupied
- Renter Occupied

Total Occupied Housing Units

Vacancy Status

- For Rent
- For Sale Only
- Rented or Sold, Not Occupied
- For Seasonal, Recreational, or Occasional use
- For Migrant Workers
- Other Vacant

Total Vacant Housing Units

Units in Structure

- 1, detached
- 1, attached
- 2
- 3 or 4
- 5 to 9
- 10 to 19
- 20 to 49
- 50 or more
- Mobile Home
- Boat, RV, Van, etc.
- 1 to 4 subtotal
- Multi-family – 5 or more

Total Housing Units

Units in Structure for Vacant Housing Units

- 1, detached
- 1, attached
- 2
- 3 or 4
- 5 to 9
- 10 to 19
- 20 to 49
- 50 or more
- Mobile Home
- Boat, RV, Van, etc.
- 1 to 4 subtotal
- Multi-family – 5 or more

Vacant Housing Units

Tenure by Units in Structure

- 1, detached
- 1, attached
- 2
- 3 or 4
- 5 to 9
- 10 to 19
- 20 to 49
- 50 or more
- Mobile Home
- Boat, RV, Van, etc.
- 1 to 4 subtotal
- Multi-family – 5 or more

Owner Occupied

- 1, detached
- 1, attached
- 2
- 3 or 4
- 5 to 9
- 10 to 19
- 20 to 49
- 50 or more
- Mobile Home
- Boat, RV, Van, etc.
- 1 to 4 subtotal
- Multi-family – 5 or more

Renter Occupied

- 1, detached
- 1, attached
- 2
- 3 or 4
- 5 to 9
- 10 to 19
- 20 to 49
- 50 or more
- Mobile Home
- Boat, RV, Van, etc.
- 1 to 4 subtotal
- Multi-family – 5 or more

Total Occupied Housing Units

Median Year Structure Built

- Median Year Structure Built
- Median House Age

Gross Rent

- Less than $100
- $100 to $149
- $150 to $199
- $200 to $249
- $250 to $299
- $300 to $349
- $350 to $399
- $400 to $449
- $450 to $499
- $500 to $549
- $550 to $599
- $600 to $649
- $650 to $699
- $700 to $749
- $750 to $799
- $800 to $899
- $900 to $999
- $1,000 to $1,249
- $1,250 to $1,499
- $1,500 to $1,999
- $2,000 or more
- No cash rent

Median Gross Rent (dollars)

Value for all Owner-Occupied Housing Units

- Less than $10,000
- $10,000 to $14,999
- $15,000 to $19,999
- $20,000 to $24,999
- $25,000 to $29,999
- $30,000 to $34,999
- $35,000 to $39,999
- $40,000 to $49,999
- $50,000 to $59,999
- $60,000 to $69,999
- $70,000 to $79,999
- $80,000 to $89,999
- $90,000 to $99,999
- $100,000 to $124,999
- $125,000 to $149,999
- $150,000 to $174,999
- $175,000 to $199,999
- $200,000 to $249,999
- $250,000 to $299,999
- $300,000 to $399,999
- $400,000 to $499,999
- $500,000 to 749,999
- $750,000 to $999,999
- $1,000,000 or more

Median Value (dollars) for All Owner-Occupied Housing Units

2.2. Definitions

The following defines the variables as described by the Census Bureau[51]:

Housing Unit: A house, an apartment, a mobile home or trailer, a group of rooms, or a single room occupied as separate living quarters, or if vacant, intended for occupancy as separate living quarters. Separate living quarters are those in which the occupants live separately from any other individuals in the building and which have direct access from outside the building or through a common hall. For vacant units, the criteria of separateness and direct access are applied to the intended occupants whenever possible. In terms of this calculation, housing unit includes owner-occupied housing unit, renter-occupied housing unit, and vacant unit.

Household: A household includes all the people who occupy a housing unit as their usual place of residence. In terms of this calculation, housing unit includes owner-occupied housing unit, and renter-occupied housing unit.

Owner-Occupied Housing Unit: A housing unit is owner occupied if the owner or co-owner lives in the unit even if it is mortgaged or not fully paid for.

Renter-Occupied Housing Unit: All occupied units which are not owner occupied, whether they are rented for cash rent or occupied without payment of cash rent, are classified as renter-occupied.

Vacant Housing Unit: A housing unit is vacant if no one is living in it at the time of enumeration, unless its occupants are only temporarily absent. Units temporarily occupied at the time of enumeration entirely by people who have a usual residence elsewhere are also classified as vacant.

Housing Unit in Single-Unit Structures: Housing units in multi-unit structures are units in both single attached-structure and single detached-structure. Excluded from this category are multi-unit structures, mobile homes, and occupied living quarters that do not fit in the previous categories, such as houseboats, railroad cars, campers, and vans.

Housing Unit in Multi-Unit Structures: Housing units in multi-unit structures are units in structures containing 2 or more housing units. Some tabulation further categorized them as units in structures with 2, 3 or 4, 5 to 9, 10 to 19, 20 to 49, and 50 or more units. Excluded from this category are single-family homes, mobile homes, and occupied living quarters that do not fit in the previous categories, such as houseboats, railroad cars, campers, and vans.

Median Value of Specified Owner-Occupied Housing Units: Value is the respondent's estimate of how much the property (house and lot) would sell for if it were for sale. This tabulation includes only specified owner-occupied housing units--one-family houses on less than 10 acres without a business or medical office on the property. These data exclude mobile homes, houses with a business or medical office, houses on 10 or more acres, and housing units in multi-unit structures.

Vacancy Status: Unoccupied housing units are considered vacant. Vacancy status is determined by the terms under which the unit may be occupied, e.g., for rent, for sale, or for seasonal use only.

[51] Source: U.S. Bureau of the Census, 2000 Census of Population and Housing, Profiles of General Demographic Characteristics. It is updated every 10 years. http://factfinder.census.gov/home/en/epss/glossary_h.html

2.3. Calculations

Baldwin County, Alabama, is used to illustrate how the residential property values were calculated at the county level. Table 70 displays the total number of owner-occupied, renter-occupied and vacant housing unit structures for the county totaling of 74,285 housing units.

Table 70. Total Number of Housing Unit Structures in Baldwin County, AL

Housing Unit = 74,285

Owner Occupied = 44,036			Renter Occupied = 11,300			Total Occupied Housing Units = 55,336
For Migrant Workers	Other Vacant	For Rent	Rented or Sold, Not Occupied	For Sale Only	For Seasonal, Recreational, or Occasional Use	Total Vacant Housing Units =18,949

Of the total housing structures in the county, 63,090 consisted of 4 or less units while 11,195 consisted of multi-family units of 5 or more (Table 71).

Table 71. Housing Unit Structures in Baldwin County, AL

Units in Structure = Total Housing Unit = 74,285

1, attached = 1,451
1, detached = 44,984
2 = 1,006
3 or 4 = 1,834
(1 to 4 subtotal = 49,275)
5 to 9 = 1,998
10 to 19 = 1,315
20 to 49 = 2,741
50 or more = 5,141
(Multi-family-5 or more = 11,195)
Boat, RV, Van, etc. = 688
Mobile home = 13,127

Table 72 reports the number of units for each value range of the owner-occupied housing unit structures in Baldwin County, while Table 73 shows the number of housing unit structures by rental price, and Table 74 indicates the number of vacant housing units by type.

Table 72. Owner-occupied Housing Unit Structure in Baldwin County, AL

Range Value of Owner-Occupied Housing Units	The Median Housing Value	Value (units)
Less than $10,000	10,000	1,159
$10,000 to $14,999	12,500	670
$15,000 to $19,999	17,500	706
$20,000 to $24,999	22,500	759
$25,000 to $29,999	27,500	876
$30,000 to $34,999	32,500	958
$35,000 to $39,999	37,500	867
$40,000 to $49,999	45,000	1,777
$50,000 to $59,999	55,000	1,957

Range Value of Owner-Occupied Housing Units	The Median Housing Value	Value (units)
$60,000 to $69,999	65,000	2,336
$70,000 to $79,999	75,000	2,503
$80,000 to $89,999	85,000	3,154
$90,000 to $99,999	95,000	3,137
$100,000 to $124,999	112,500	5,487
$125,000 to $149,999	137,500	4,519
$150,000 to $174,999	162,500	3,432
$175,000 to $199,999	187,500	2,037
$200,000 to $249,999	225,000	2,377
$250,000 to $299,999	275,000	1,889
$300,000 to $399,999	350,000	1,678
$400,000 to $499,999	450,000	702
$500,000 to 749,999	625,000	532
$750,000 to $999,999	875,000	270
$1,000,000 or more	1,000,000	254

Table 73. Renter-occupied Housing Unit Structure in Baldwin County, AL

Range Value of Rent Price of Renter Occupied Housing Units	The Median Rent Price	Value (units)
Less than $100	100	114
$100 to $149	125	173
$150 to $199	175	238
$200 to $249	225	257
$250 to $299	275	284
$300 to $349	325	519
$350 to $399	375	745
$400 to $449	425	801
$450 to $499	475	644
$500 to $549	525	857
$550 to $599	575	914
$600 to $649	625	619
$650 to $699	675	674
$700 to $749	725	643
$750 to $799	775	528
$800 to $899	850	645
$900 to $999	950	434
$1,000 to $1,249	1,125	463
$1,250 to $1,499	1,375	121
$1,500 to $1,999	1,750	120
$2,000 or more	2,000	64
No cash rent	0	1,208

Table 74. Vacant Housing Unit Structure in Baldwin County, AL

Vacant Housing Units = 18,949		
1, attached = 427	Single Units = 7,150	
1, detached = 6,723		
2 = 375	Multi-units = 8,983	
3 or 4 = 354		
5 to 9 = 724		
10 to 19 = 866		
20 to 49 = 2,246		
50 or more = 4,418		
Boat, RV, Van, etc. = 304		
Mobile home = 2,512		

Residential property values were calculated at the census tract level for owner-occupied housing units, renter-occupied housing units and vacant housing units. The following outlines their respective calculations:

Owner-Occupied Housing Unit Value

Owner-occupied housing unit value is the sum of the median housing value of owner occupied housing unit by range value multiplied by the number of housing units in that range value.

= ∑ (the median housing value of owner occupied by range value × no. of housing units in that range value)

Example (Table 72) = Sum of product (the median housing value, value) = $6,188,942,500

Renter-Occupied Housing Unit Value

A capitalization rate approach is applied to value of the rental property because the Census data provide only monthly gross rental price.

The capitalization rate or Cap Rate is a ratio used to estimate the value of income-producing properties. It is the net operating income divided by the sales price or value of a property expressed as a percentage. Investors, lenders and appraisers use the Cap Rate to estimate the purchase price for different types of income producing properties. The Cap Rate calculation incorporates a property's selling price, gross rents, non rental income, vacancy amount and operating expenses.

Since the net income by tract is not provided, the gross rental income is estimated and adjusted to reflect an estimated net rental income per unit. Estimated monthly expenses (expressed as a percent of gross rental income) are deducted from the gross monthly rental income. Then, the resulting estimated monthly net rental income is annualized and divided by a capitalization rate.

Estimated rental property value = (Net rental operating income) / Capitalization Rate

= ∑ (no. of housing units in that range value x ((100-monthly expense)% × the median rent price of renter occupied by range value) × 12) / capitalization rate

Example (Table 71) = {Sum of product (no. of housing units X ((100-20)% × the median rent price) × 12}/7.5% = $765,881,600

Capitalization Rate

Based on the explanation from http://www.answers.com/topic/capitalization, the capitalization rate is defined as following:

In finance, the Capitalization Rate method is a process whereby anticipated future income is converted to one lump sum capital value. A Capitalization Rate is divided into the expected periodic income to derive a capital value for the expected income (net income).

In this report, the capitalization rate is used to calculate property value of renter-occupied housing units and multiple-unit structures. This capitalization rate is basically used in real estate business. It changes every year, and varies by state. However, for this analysis, a national capitalization rate of 7.5% is assumed (http://www.crowncommercialfinance.com/subpage.html).

Monthly Expense Portion

The estimated monthly rental expenses are expressed as a proportion of the gross rental income. It represents owner expenses such as real estate taxes, advertisement, repair, etc. In this analysis, it is assumed that the monthly rental expense portion is 20% of gross monthly rental income. This 20% accounts for a 5% vacancy factor, 5% for repairs, and 10% for property taxes (Source: Personal communication with Travis Bard, Windermere Commercial Real Estate, Chino Valley, Arizona, November 2006).

Vacant Unit Value

Vacant unit value is comprised of four subcategories: Single-Unit Structure Value, Multiple-Unit Structure Value, Mobile Home Value, and Van, Boat, etc. Value.

Single-Unit Structure Value (only single attached-unit and single detached-unit)

Single-unit structure value is the total number of single attached-unit and the number of single detached-unit, multiplied by the median value of owner occupied housing units

= (no. of vacant single detached units + no. of vacant single attached units) × the median value of owner occupied housing units

Example = 7,150 × $122,500 = $875,875,000

The Median Value of Owner Occupied Housing Units

Median value of owner occupied housing unit is from http://www.census.gov/prod/cen2000/index.html

To be conservative, the median value of owner occupied housing units was used in the calculation instead of the weighted average value of owner-occupied housing unit.

Multiple-Unit Structure Value (units in structures containing two or more housing units only)

Multiple-unit structure value is calculated in a similar manner as the renter-occupied housing units were calculated. The number of vacant multi-units were multiplied by the derived rental property value (described above):

= (no. of vacant multi-units × ((100-monthly expense%) × median value of gross rental rate × 12)) / capitalization rate

Example = {8,983 × (564.44 × (100-20)% × 12)}/7.5% = $741,653,248

Average median value of gross rental rate = {sum of product (median gross rent, tenure renter occupied housing units)}/renter-occupied housing unit = $564.44

Mobile Home Value (number of mobile home units multiplied by average mobile home value).

$$= \text{no. of mobile home units} \times \text{average mobile home value}$$

Example = 2,512 × $40,000 = $100,480,000

Average Mobile Home Value

The range price of mobile home value is very large depending on location, type, year, size, facilities, and so on. Nonetheless, based on values found on the Internet, an average mobile home value of $40,000 is used.

Van, RV, Boat, etc. Value

Van, boat, etc. value is the number of van, boat, etc. units multiplied by average van and boat value.

$$= \text{no. of van, boat, etc. units} \times \text{average van, boat value}$$

Example = 304 × {($40,000 + $60,000) / 2} = $15,200,000

Average Van, RV, and Boat Value

The average van and boat value is the average value of the average van value and the average boat value. The range price of van and boat value is very large depending on type, year, size, facilities, and so on. Nonetheless, based on values found on the Internet, an average value of $40,000 and $60,000 is assumed for vans/RVs and boats, respectively.

Source: The average values for mobile home, vans, RVs and boats are determined by multiple sources http://www.boats.com, http://www.usedboats.com/, http://www.cars.com, http://www.home-listings-usa.com/, http://www.mobilehome.net/, http://www.rv.net/rvs/

3. Commercial Property Valuation

The Census Bureau does not obtain commercial property value. Therefore, to capture the full economic impact of tropical cyclone damage to property, commercial property values were estimated. The following assumptions were made for the estimation:

- Aggregate county-level commercial property value increases as population density rises.
- The economic value of commercial property increases with the intensity/density of its use.
- There is a multiplicative relationship between residential property and commercial property.
- As a geographic area moves from rural to metropolitan to super metropolitan, the scarcity factor of land, intensity of use (more populated areas allow and demand higher intensity uses), and population densities increase the ratio of commercial property to residential property.

These assumptions were used as the foundation of the calculations of the commercial property value. Each county was classified by MSA category, a multiplier or ratio of commercial to residential property value was assumed for each MSA category, and the commercial property value for each county was estimated based on its MSA classification and the assumed multiplier. Details are in the following sections.

3.1. MSA Categorization

The United States Office of Management and Budget (OMB) defines metropolitan and micropolitan statistical areas according to published standards that are applied to Census Bureau data. The general concept of a metropolitan or micropolitan statistical area is that of a core area containing a substantial population nucleus, together with adjacent communities having a high degree of economic and social integration with that core.

Micropolitan area—A core based statistical area associated with at least one urban area that has a population of at least 10,000 but less than 50,000. The micropolitan area comprises the central county or counties containing the core, plus adjacent outlying counties having a high degree of social and economic integration with the central county as measured through commuting.

Metropolitan area—A collective term, established by OMB and used for the first time in 1990, to refer to metropolitan statistical areas, consolidated metropolitan statistical areas, and primary metropolitan statistical areas. Also, a core-based statistical area associated with at least one urban area that has a population of 50,000 or more; the metropolitan area comprises the central county or counties containing the core, plus adjacent outlying counties having a high degree of social and economic integration with the central county as measured through commuting.

Metropolitan division—A county or group of counties within a core based statistical area that contains a core with a population of at least 2.5 million. A metropolitan division consists of one or more main counties that represent an employment center or centers, plus adjacent counties associated with the main county or counties through commuting ties.

Metropolitan statistical area—A geographic entity, defined by OMB for statistical purposes, containing a large population nucleus and adjacent communities having a high degree of social and economic integration with that nucleus. Under the 1990 metropolitan area standards, qualification of an MSA required a city with 50,000 population or more, or an urbanized area of 50,000 population or more and a total population of at least 100,000 (75,000 in New England). MSAs are composed of entire counties, except in New England where the components are cities and towns.

Combined area (CSA)—A geographic entity consisting of two or more adjacent core based statistical areas (CBSAs) with employment interchange rates of at least 15. CBSAs with employment interchange rates of at least 25 combine automatically. CBSAs with employment interchange rates of at least 15 but less than 25 may combine if local opinion in both areas favors combination.

Core—A densely settled concentration of population, comprising either an urbanized area (of 50,000 or more population) or an urban cluster (of 10,000 to 49,999 population) defined by the Census Bureau, around which a core based statistical area is defined.

Core based statistical area (CBSA)—A statistical geographic entity consisting of the county or counties associated with at least one core (urbanized area or urban cluster) of at least 10,000 population, plus adjacent counties having a high degree of social and economic integration with the core as measured through commuting ties with the counties containing the core. Metropolitan and micropolitan areas are two categories of core based statistical areas.

3.2. MSA Level

The counties in the database were assigned to one of four MSA categories, based on their estimated 2005 population (Table 75).

Table 75. MSA Categorization

Level	MSA Categorization	No. of Population
1	Rural area	Less than 10,000
2	Micropolitan area	10,000 – 49,000
3	Metropolitan area	50,000 – 2,499,999
4	Metropolitan division	More than 2,500,000

Source: http://www.whitehouse.gov/omb/inforeg/metro2000.pdf

3.3. Commercial Property Calculation

The following multipliers were assumed for each MSA category, and the commercial property values were calculated in the following manner.

If MSA =1, Commercial Property Value = 3 x residential value

If MSA =2, Commercial Property Value = 3 x residential value

If MSA =3, Commercial Property Value = 4 x residential value

If MSA =4, Commercial Property Value = 5 x residential value

Commercial property value multiplies were obtained in an interview with Travis Bard, a commercial property broker.