Geospatial Tools for Addressing Disaster Management, Coastal Settlements, and Climate Change Issues

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Key words: Coastal Zone Management, Deformation Measurement, GPS, Positioning, Risk Management, Spatial Planning

SUMMARY

According to the International Panel on Climate Change (IPCC) "Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003. The rate was faster over 1993 to 2003, about 3.1 [2.4 to 3.8] mm per year."(IPCC 2007) Mid-line projections for sea level rise over the next century range from 2.8 to 4.3 mm/yr for the 5 scenarios presented by the IPCC report. The impacts of the melting of ice sheets in Greenland and Antarctica are not fully addressed by the IPCC models "because a basis in published literature is lacking" (IPCC 2007). Whatever the overall global sea level rise rate turns out to be, it will be experienced differently by coastal communities around the world depending on the motion of the land upon which the communities are built. The impact of rising waters can be compounded dramatically if the coastal zone is subsiding. Clearly, high accuracy measurements of these relative motions will aid in the assessment of possible impacts, mitigations, and adaptation strategies to climate change and associated sea level rise in coastal settlements.

U.S. agencies, such as the U.S. Agency for International Development and the Millennium Challenge Corporation (MCC), are supporting the development of positioning infrastructure in countries that are dealing with issues such as land tenure determination and transportation development. Beyond these fundamental activities, this paper will highlight the cascading benefits of accurate positioning infrastructure to disaster management, habitat restoration, and coastal zone decision making. These additional benefits should be considered by countries seeking to justify support in the development of positioning infrastructure and regional spatial reference frames.

To address the policy issues of FIG Working Group 8.6: Coastal Settlements and Climate Change (Commission 8), this paper will discuss how NOAA's geospatial tools and infrastructure are being used to measure and monitor the relative heights of land and water levels in the coastal zones of the United States. In particular, this paper will focus on the work of NOAA's National Ocean Service in producing accurate measurements of heights and models of the dynamic motion of coastal land as a foundation for the development of decision making tools for the coastal zone. This data on land movement, when combined with accurate local water levels, provide critical information for emergency planning and sustainable development in the coastal zone. The paper will review ongoing NOAA efforts to support commerce and sustainable development around the globe through establishment of geospatial infrastructure and building local capacity for accurate positioning.

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1. INTRODUCTION

According to the International Panel on Climate Change (IPCC) "Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003. The rate was faster over 1993 to 2003, about 3.1 [2.4 to 3.8] mm per year."(IPCC 2007) Mid-line projections for sea level rise over the next century range from 2.8 to 4.3 mm/yr for the 5 scenarios presented by the IPCC report. The impacts of the melting of ice sheets in Greenland and Antarctica are not fully addressed by the IPCC models "because a basis in published literature is lacking" (IPCC 2007). Whatever the overall global sea level rise rate turns out to be, it will be experienced differently by coastal communities around the world depending on the motion of the land upon which the communities are built. The impact of rising waters can be compounded dramatically if the coastal zone is subsiding. Clearly, high accuracy measurements of these relative motions will aid in the assessment of possible impacts, mitigations, and adaptation strategies to climate change and associated sea level rise in coastal settlements.

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This paper will describe the geospatial infrastructure that NOAA and its predecessor agencies have developed to support safe, efficient navigation in the name of commerce, and how that infrastructure is now supplying data for tools that support a variety of coastal management applications. The paper will conclude with a review of ongoing NOAA efforts to support commerce and sustainable development around the globe through establishment of geospatial infrastructure and building local capacity for accurate positioning.

2. BACKGROUND

Within the United States' National Oceanic and Atmospheric Administration (NOAA), the National Ocean Service's (NOS) National Geodetic Survey (NGS) has the responsibility to define, maintain and provide access to the U.S. National Spatial Reference System to meet the nation's economic, social and environmental needs. NGS strives to be a world leader in geospatial activities, including the development and promotion of standards, specifications, and guidelines. Over the past few years, NGS has been working with another NOS office, the Center for Operational Oceanographic Products and Services (CO-OPS), to provide integrated data on the land-water interface. CO-OPS provides the national infrastructure, science, and technical expertise to monitor, assess, and distribute tide, current, water level, and other coastal oceanographic products and services. Together, NGS and CO-OPS are now applying scientific expertise that traditionally served NOAA's navigation requirements to other coastal issues such as habitat restoration, storm surge modeling, and hazard preparedness and response. The result is integrated land elevations and water level data that provide information to decision makers in the appropriate context, for example along coastal evacuation routes. Understanding the magnitude of local land movement and water level changes can inform development policy, permitting processes, and coastal restoration activities which, in turn, can increase the resilience of coastal communities in the face of coastal hazards.

Measuring changes in coastal ecosystems due to sea level rise requires observations of spatial patterns and how they change with time. Through geodetic surveys, NOAA is helping to tie vertically dependent ecosystem observation systems, such as water level gages and surface elevation tables (SETs), to a spatially and temporally precise national vertical datum, the North American Vertical Datum of 1988 (NAVD88). Tying all observations to a common reference such as NAVD88, is the only way the observations can be accurately compared. NGS is also conducting research to identify improved surveying methodologies to enable higher precision and accuracy in measuring and monitoring the dynamics of the land-water interface. By conducting this research and providing guidelines for producing high accuracy data in the coastal zone, NGS is positioned to support the global community in planning for the impacts that localized land movement and changes in sea level may bring.

3. NOAA'S GEOSPATIAL INFRASTRUCTURE FOR COMMERCE & TRANSPORTATION

3.1. NOAA'S Mission and Multiple Uses of Infrastructure

NOAA's Mission is "To understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs." To achieve this mission, NOAA focuses on four Mission Goals and a Mission Support Goal:

- Protect, Restore, and Manage the Use of Coastal and Ocean Resources through an Ecosystem Approach to Management
- Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond
- Serve Society's Needs for Weather and Water Information
- Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation
- Provide critical support for NOAA's Mission

The U.S. economy relies upon an intermodal transportation network of ship, rail, highway, and air transport to move people, cargo and commerce to, from and across the nation. This movement is heavily dependent upon the services that NOAA provides – weather and ice forecasts, real-time and forecast water level conditions and obstruction surveys, nautical charts for safe navigation, hazardous spill response, Satellite Search and Rescue. NOAA delivers information to move America, helping maintain the efficient flow of transportation and commerce.

NOAA seeks to protect lives, economic investment and environmental integrity by providing critical tools for the Nation's intermodal transportation network. Funding for navigation products such as Electronic Navigational Charts and accurate tides and currents data supports the safe, efficient, and environmentally sound transport of goods. NOAA is now finding added value in the infrastructure investments made for commerce and transportation in terms of applications to other Mission goals. Knowing exact water depths can allow a ship to load valuable extra cargo - just one inch of additional draft can increase revenues up to $50,000 or more. Knowing exact elevations of hurricane evacuation routes in conjunction with accurate local water levels allows emergency management officials to make critical decisions about when to issue evacuation orders. The same infrastructure that provides those land elevations and water levels is now being used by coastal scientists and mangers to understand critical structural components of the ecosystems they work in.

3.2. Foundations for Accurate Positioning

As the provider of the National Spatial Reference System (NSRS), NGS lays the foundation for all geospatial activities in the US. The NSRS is a consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the United States, as well as how those values change with time. The NSRS comprises a consistent, accurate, and up-to-date national shoreline; a network of Global Positioning System (GPS) Continuously Operating Reference Stations (CORS) which supports 3-dimensional positioning activities; a network of permanently marked points; and a set of accurate models describing dynamic, geophysical processes that affect spatial measurements. In addition, NGS provides standards, specifications, and guidelines that, when followed appropriately, enable users to precisely and accurately measure the earth's surface. NGS has traditionally served the surveying, engineering, and construction fields, providing geodetic control that has allows roads, rails, and ports to connect seamlessly. This contribution to the Nation's transportation infrastructure is fundamental to the flow of goods and people around the country that drive our economy.

NOAA is responsible for surveying 95,000 miles of the Nation's coasts to provide an accurate, consistent, up-to-date national shoreline. The shoreline depicted on NOAA's nautical charts approximates the line where the average high tide, known as Mean High Water (MHW), intersects the coast. NOAA shoreline mapping also provides the line where Mean Lower Low Water (MLLW) intersects the coast. This information is critical for navigation safety and is now also being used to help manage and restore coastal habitats that serve as buffers for coastal communities.

Figure 1 - Illustration of the need for an accurate spatial reference frame.

3.3. Height Modernization and the Coastal Zone

A critical aspect of the NSRS for hazard mitigation and disaster management is the vertical datum by which heights are defined and related to local water levels. Planning coastal settlements and preparing for potential disasters in the coastal zone requires a detailed understanding the topography of the land; specifically where water will go in the event of flooding. For settlements on low lying coastal plains, surrounding coastal habitats may provide some protection and even small height variations can be the difference between flooding or not. The recently completed 2006 Coastal Resource Management Customer Survey by NOAA's Coastal Services Center documents widespread recognition of the importance of topography and water level data sets and their use by coastal managers around the country.

Height Modernization is an NOAA program that combines recent advances in Global Navigation Satellite System (GNSS) technology, particularly GPS technology, with traditional surveying techniques to update the vertical component of the NSRS. Height Modernization is important for vessel under-keel and bridge clearance; storm surge modeling; flood plain mapping; crustal motion monitoring; as well as coastal habitat restoration. NOAA conducts ongoing Height Modernization efforts throughout the country to improve coastal and inland elevations and provide essential infrastructure that supports commerce and enhances community resilience. One of the important uses of height modernization is to measure rates of subsidence, or land sinking which, in coastal areas, influences local rates of relative sea level rise. In many areas, the only way to escape an incoming hurricane is to follow specific hurricane evacuation routes. If state and local officials do not have accurate elevation information for the roads in relation to local water levels, residents trying to leave during an emergency might get trapped in fast-rising water. NOAA research into monitoring elevations of coastal ecosystems that serve as natural barriers will provide critical information to preserve these ecosystems and in turn protect coastal communities facing an increase in local sea level.

As part of the Height Modernization program, NGS has begun a research effort to identify best practices for gathering height data in different habitat types of the inter-tidal zone. Several technologies and methodologies are being investigated for their effectiveness and efficiency in collecting this data. These technologies produce measurements with varying accuracies and spatial coverage. Ongoing work at NGS is providing information on sources and limits of vertical error associated with the use of these technologies in the difficult environmental conditions of the coastal zone.

3.3.1. Guidelines for Surface Elevation Tables

Surface Elevation Tables (SET) can measure changes in the surface of a coastal wetland or mangrove with accuracy in the 3 to 5 millimeter range[1], but individual SET devices only measure discrete points within 1.5 m^2 plots on the surface and taking the measurements can be quite time consuming. This technology is based on deep rod benchmarks driven to refusal in unconsolidated coastal sediments. SET devices measure the relative change in elevation between the sediment surface and the base of the benchmark. The elevation dynamics of surface sediments recorded by SETs are not included in the calculation of tidal datums because these changes are taking place above the base of the benchmarks used as the frame of reference to calculate the datums. Therefore, SETs can complement data from nearby tide stations to give a more complete picture of the local relative sea level rise experienced by the coastal habitat. In addition, the deep rod foundations of SETs function as permanently monumented survey control stations, providing a reference to measure crustal motion and for more synoptic topographic surveys.

NGS is currently working on a suite of guidelines for SETs including using GPS to tie SETs to the NSRS and to local tidal datums, identifying and quantifying error sources, and reviewing statistical techniques for data analysis. By themselves, SET benchmarks will not record the relationship between coastal land elevation and sea level. This is only achievable by relating SET benchmarks and nearby tidal benchmarks to a common vertical reference frame. NGS is refining techniques for adapting GPS antennas to the major variations of SET devices to put absolute elevations on the SET foundations. In addition, a statistical framework is being developed within which researchers can develop and apply the most efficient statistical models, based on an understanding of spatial components of variance. Patterns in spatial variance provide information on the scale of processes acting on surface elevation. Included in this work is an exploration of temporal variance and its implications for minimum length of time series analyses. While coastal ecologists and geologists have been using various iterations of SET technology for over a decade, the NGS focus on producing robust standards, specifications, and guidelines for connecting to the official National Vertical

[1] Cite Cahoon paper

Datum will provide the confidence in the measurements necessary to ensure that coastal scientists and managers will trust and use the data for planning and decision making.

3.3.2. Other Elevation Collection Methods for the Coastal Zone

The vegetation cover, wetness, and unconsolidated soils of the coastal zone make collecting precise and accurate elevation data difficult at best. As mentioned in the next section, NGS has issued Draft Guidelines for Establishing GPS-derived Orthometric Heights (Standards: 2 cm and 5 cm), and will release guidelines for using Real Time Kinematic GPS in the near future. NGS now has projects underway to define best practices for using GPS and remote sensing to make vertical measurements under difficult environmental conditions. NGS research on Light Detection And Ranging (LiDAR) and Synthetic Aperture Radar (SAR) for shoreline delineation and subsidence detection is now being updated and expanded to include applications for coastal science and management. It is clear that the spatial coverage of these remote sensing technologies is required to attain the synoptic view needed to address any coast-wide management issues. However, with this expanded coverage area comes a reduction in the accuracy of the vertical measurements being made. NGS is currently focused on higher accuracy ground based measurements using GPS.

Laser levels and kinematic GPS are currently used to capture precise elevation data in marsh environments. These technologies, used separately, produce elevation models with varying accuracies in the horizontal and vertical positions. Kinematic GPS can produce precise latitude and longitude positions however it requires long occupation times to achieve vertical accuracies in the range of +/- 2 cm, which effectively reduces the density of data points that can be collected over the marsh surface and increases that amount of interpolation needed to produce a representative surface. Laser levels can achieve a higher degree of vertical accuracy, however they must be used along previously established and mapped transects in order to correlate vertical elevations with specific horizontal (lat / lon) positions. The NOAA Height Modernization program is supporting research into the integration of these technologies to promote the collection and use of accurate height information.

NGS is now evaluating the industry's first integrated laser level and Real-Time Kinematic GPS, the Laser Zone Millimeter GPS System. This system, designed for use in engineering and construction, combines the strengths of these two technologies to produce highly accurate vertical measurements and associate them with specific horizontal positions. This new system reduces the level of effort required to read and record elevation data by using a fixed laser receiver rather that requiring the surveyor to manually manipulate the equipment for each reading. This improvement has the potential to dramatically increase efficiency with which elevation data can be captured as well as increasing the utility of the resulting data by integrating it automatically with accurate horizontal positions. NGS is evaluating this new system in a variety of coastal habitats and environmental conditions and plans to publish guidelines for the use of this tool for measuring and monitoring the land / water interface.

3.4. Myriad Applications for Water Levels

NOS' Center for Operational Oceanographic Products and Services (CO-OPS) collects and distributes observations and predictions of water levels and currents to ensure safe, efficient and environmentally sound maritime commerce. CO-OPS establishes standards for the collection and processing of water level and current data and manages the National Water Level Observation Network (NWLON). The NWLON is a network of 175 long-term, continuously operating water-level stations throughout the USA. These stations provide routine real-time automated and event-driven data acquisition, using the a satellite link to upload the data to offices in Silver Spring, MD, for quality control and distribution of the internet. The NWLON data-collection platforms are now capable of measuring other oceanographic parameters in addition to water levels, including meteorological parameters. Sensors are calibrated and vertically referenced to nearby networks of benchmarks. The data continuity, the vertical stability and careful referencing of NWLON stations have enabled the data to be used to estimate relative sea-level trends for the Nation, as described in the NOAA Technical Report NOS CO-OPS 36.

NWLON stations are the backbone of a national network of Physical Oceanographic Real-Time Systems (PORTS) in major U.S. harbors. PORTS® is a decision support tool that improves the safety and efficiency of maritime commerce and coastal resource management through the integration of real-time environmental observations, forecasts and other geospatial information. PORTS® measures and disseminates observations and predictions of water levels, currents, salinity, and meteorological parameters (e.g., winds, atmospheric pressure, air and water temperatures) that mariners need to navigate safely.

For several years CO-OPS has been building partnership to take advantage of the usefulness of their water level data for non-navigational applications. Many active partnerships now exist to apply NOAA water level data to include beneficial uses of dredged material, coastal planning, monitoring coastal wetland loss and marsh restoration, storm-surge monitoring, evacuation route planning, emergency preparedness, and HAZMAT response. For example, three categories of water level analyses are generated for marsh restoration efforts: (1) local tidal datums are computed; (2) long-term sea-level change is assessed; and (3) the frequency and duration of inundation are analyzed. CO-OPS efforts in seeking out novel applications for their existing capacities is a model that the rest of NOAA is beginning to follow, and will serve developing nations well in terms of making the most out of development assistance focused on port infrastructure for commerce.

3.5. Spatial Foundations for Integrated Observing System Data

Cross-cutting the agency's efforts and essential in supporting its mission goals, NOAA is working hard at integrating a vast array of global environmental observations and effectively managing terra-bytes of data. In order to ensure interoperability of geospatial observations, a common spatial reference frame is required, as is a common set of standards and protocols for data management and communication. To address these needs, NOAA is participating in the design and implementation of the Global Environmental Observations System of Systems

(GEOSS), an international effort to bring together the hardware and software of a vast array of earth observing systems so that the data can be made available in a meaningful way to people around the world. As part of GEOSS, NOAA has a prime responsibility for the Integrated Ocean Observing System (IOOS). To fulfill this responsibility, NOAA is working to make data from different ocean observing platforms, from satellites to ships, and from buoys to tide stations, interoperable and accessible. Effectively combining these data streams enables new information to be synthesized and used to address human health and safety, disaster management, environmental protection and sustainable development.

Figure 2 - Illustration of Integrated Ocean Observing Systems

3.6. From Commerce and Transportation to Disaster Management and Climate Change

Through the collaborative mechanism of the COASTAL program, NOAA is bringing together expertise from several offices and adding value to existing capacities and infrastructure by applying them in novel ways. The Height Modernization program's research on high-accuracy surveys of coastal habitats and CO-OPS' water level analysis are enabling the land / water interface to be described more accurately than ever before. With the National Spatial Reference System as a framework, environmental observations are being integrated and made more useful to a wider array of applications supporting NOAA's broad missions. Geospatial tools, for environmental and community planning, are being developed based on this flood of available data. Beyond the technical capacity-building that NOAA seeks to provide to the world, it is this leveraging of infrastructure for multiple applications, expanding benefits of investments in commerce to disaster management and adaptation to climate change that may prove most valuable.

4. CASE STUDY: NEW ORLEANS & THE NORTHERN COAST OF THE GULF OF MEXICO

The tragedy that unfolded along the coasts of the Gulf of Mexico from Florida to Texas in the aftermath of Hurricanes Katrina, Rita & Wilma was a clarion call in the United States, to focus all existing capabilities on improving community resilience in the face of coastal hazards. NOAA's existing geospatial infrastructure was updated and evaluated to find new ways for it to serve this new national imperative. Surveys of high water marks on homes and debris piles were performed using GPS. New elevation models were created using Light Detection and Ranging (LiDAR). More tide stations were deployed and new tidal models were created for the affected areas. These efforts were combined with other information to document the spatial patterns of destruction caused by this unprecedented series of coastal storms. Looking forward, it is critical that these geospatial tools be used to improve planning and response, and their capabilities made more widely available around the world.

Figure 3 - Flooding of civic infrastructure by hurricane Katrina and evidence of local subsidence

In 2006 the Interagency Performance Evaluation Task Force issued a draft report on the levee system around New Orleans. The report, the work of many organizations including NOAA's NGS and CO-OPS, identified several locations in southeast Louisiana where additional CORS and NWLON instrumentation are needed. It also cited the need for additional supporting infrastructure to define and monitor changes in geodetic and water surface elevations datums. This report was the impetus for Federal Emergency Management Agency (FEMA) to support the 2006 Louisiana Height Modernization Survey to provide updated heights on approximately 320 benchmarks in southern Louisiana. This project was a partnership between NOAA, FEMA, and the Louisiana Spatial Reference Center at Louisiana State University. The project included the establishment of many new CORS and new tide stations designed to withstand severe storm and storm-surge conditions along the Gulf Coast as well as airborne gravity measurements to update the geoid model for the area. Given the high rates of subsidence that are compounding the local effects of sea level rise in the Gulf Coast, NGS is working with many partners to develop a plan to engage the population in a long range effort to develop and maintain an accurate height system as they rebuild their communities.

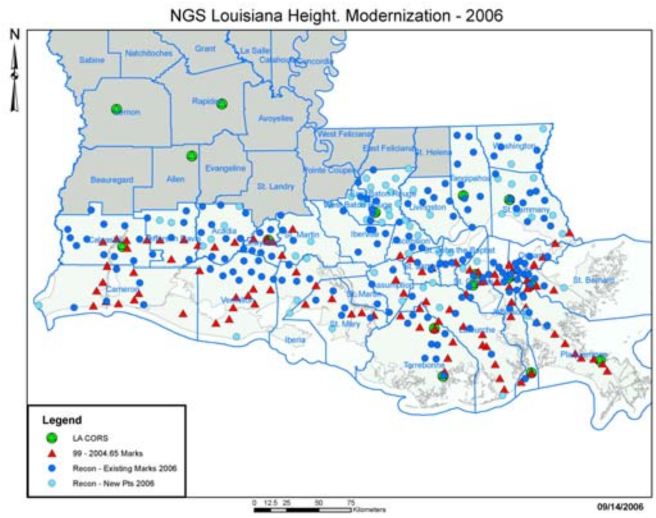

Figure 4 - Map of the 325 known elevations in southern Louisiana

5. GEOSPATIAL TOOLS FOR THE FUTURE OF THE COASTAL ZONE

5.1. Online Positioning User Service (OPUS)

OPUS provides GPS users, such as scientists, engineers, and professional surveyors, the ability to obtain highly accurate positioning coordinates for the purposes of transportation, construction, navigation, surveying, and other activities. OPUS allows GPS users to submit their GPS data files via the Internet to NOAA, where the data are processed using data from nearby CORS to determine a position, and the results are emailed back to the user. OPUS has proven to be a boon to construction, transportation, and mapping industries by reducing surveying time and costs to a fraction of those previously reported. Usage of OPUS has grown from around 1,000 data submissions per month in 2002, to over 13,000 per month in 2006.

Use of CORS/OPUS dramatically reduces survey project time and cost. Before the advent of GPS, it could take up to six months of field work to complete a project involving the establishment of 30 survey marks including setting the marks, positioing them, and publishing the data. Today, the time has been reduced to less than one month. This has reduced the average estimated cost of establishing a survey mark to approximately $800 today as opposed to almost $15,000 in 1984. Each OPUS solution is estimated to save the user $600 over traditional positioning methods. Over 450,000 OPUS solutions have been processed since the service began operating just four years ago, realizing over $270 million in cost savings by public users of GPS. OPUS is completely automatic and requires only a minimal amount of information from the user. For the last five years, this tool has allowed anyone with a single geodetic quality GPS receiver to position themselves in the National Spatial Reference System to an accuracy of two centimeters with just 2 hours of data. The latest version called OPUS-RS for OPUS Rapid Static, was released in January 2007, and produces similar results with only 20 minutes of data. The number of OPUS solutions has grown from about 1,000 per month in FY 2002 to over 13,000 per month in FY 2006. Growth in the use of this free tool is expected to increase dramatically as GPS receivers come down in price and as the network of CORS expands around the world.

OPUS solutions are based on data gathered from CORS. The CORS Web site is http://www.ngs.noaa.gov/CORS/. CORS comprises a nationwide network of permanently operating GPS receivers. NOAA provides access to GPS data from this network free of charge via the Internet. The primary objective of CORS and OPUS is to enable GPS users to determine precise positional coordinates relative to the National Spatial Reference System. These services allow OPUS users to achieve centimeter-level accuracy.

The CORS network, which provides the data that OPUS solutions are based on, includes sites operated by more than 175 organizations, including other Federal agencies, state and local governments, universities, the private sector, foreign governments, and others who share the goal of making more accurate positioning available worldwide. CORS User Forums and Workshops are held across the country on a regular basis. Installation of CORS, workshops and training for tech transfer, and making OPUS available in developing countries is the primary way NGS participates in foreign assistance programs. NGS actively seeks opportunities to work with developing nations to go beyond the positioning infrastructure and provide models and tools and build local capacity for accurate positioning.

5.2. Vertical Datum Transformation Tool (VDatum)

The coastal land-water interface depends on how water levels change in both space and time. To combine or compare coastal elevations (heights on land and depths of water) from diverse sources (such as from NOAA Nautical Charts and U.S. Geologic Survey topographic quad sheets), they must be referenced to the ***same*** vertical datum to serve as a common framework. Using inconsistent datums can cause mismatches in the data that become acutely problematic when producing maps at the accuracy that is critically needed by Federal, state, and local authorities to make informed decisions (Parker, 2001, 2003).

VDatum is a vertical datum transformation tool, developed by NOAA to enable elevation or depth information from disparate sources to be combined seamlessly. This tool makes it possible to use different maps referenced to different "zero points" to be used together effectively. VDatum models are compiled for specific geographic areas using local land elevations and local bathymetry data. The land elevations are generally derived from LiDAR, however the bathymetry can be from cutting edge side scan sonar or archive data up to 200 years old. VDatum is now available for several coastal regions in the U.S. The tool is being used for many important applications and technologies, such as: storm surge and coastal inundation models, tsunami research, shoreline mapping, National Shoreline definition, coastline change analysis, sea level rise impacts, nearshore bathymetry standardization, referencing of hydrographic surveys with kinematic GPS, LIDAR data collection, ecosystem resource management, navigation services, and disaster mitigation planning.

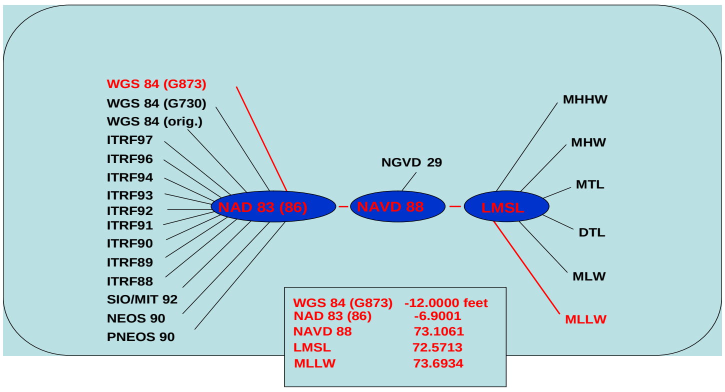

Figure 5 - VDatum The transformation Roadmap

5.3. Hazard Assessment and Hurricane Evacuation Tools

Tools that bring together various data sets in real time to assist in decision making during emergencies can save lives and property. An example of a tool that that brings together critical land and water level data along with weather reports and storm tracks from the NOAA's National Hurricane Center (NHC), is Hurrevac.com. This tool is restricted to government emergency managers to assist them with decision making while under hurricane threat. The tool incorporates local land and water level data sets with information gathered through local hurricane evacuation studies. Again, this tool allows NOAA to leverage critical additional value from data that was originally intended for navigation. It is the accuracy of the geospatial data at the heart of this tool that makes it so effective.

6. NGS CAPACITY BUILDING EFFORTS

6.1. Outside Capacity Building

An accurate, accessible, and reliable spatial reference frame is the foundation upon which geospatial tools are created. To build the models and tools and the outside capacity for accurate positioning necessary to fully use our spatial infrastrucutre, NGS has helped develop a series of Spatial Reference Centers around the country to address regional issues. Through partnerships with the US State Department and the Millennium Challenge Corporation (MCC), NGS is helping countries around the world establish their own spatial reference networks. The MCC focuses on promoting sustainable economic growth that reduces poverty through investments in areas such as agriculture, education, private sector development, and capacity building. The work NGS does in these countries sets the stage for future economic development and lays the foundation for the geospatial tools that will help them address disaster management and climate change issues.

6.2. Land Access and Port Improvements in Benin

In January 2007, NGS staff traveled to Benin, in West Africa, to provide technical assistance to the Institut Géographique National (IGN), in support of their efforts to modernize the country's spatial reference frame. In cooperation with the Millennium Challenge Corporation (MCC), and working with IGN geodesy and photogrammetry technical specialists, NGS staff traveled to six major communities around the country to review sites for the installation of a CORS network. These stations will provide the necessary spatial framework for the efficient use of GPS to support the multi-million dollar MCC-sponsored efforts for access to land and port improvements over the next five years. Data for the CORS will be quality controlled and distributed by NGS until such time as IGN has developed its own capacity to provide this support. These stations will also have a significant positive impact on the activities of GPS users in the various neighboring countries and will contribute to the development of the unified African Reference Frame initiative (AFREF).

6.3. Air Navigation and Hurricane Response in Central America and Caribbean

Starting in 1996, NGS surveyed 19 Caribbean countries as part of an air navigation initiative sponsored by the U.S. Federal Aviation Administration (FAA). This project included airport surveys, installation of geodetic control marks in a High Accuracy Reference Network (HARN), and contributions to regional spatial reference frames. These airport surveys started a process that introduced NGS to many surveying and engineering professionals in the region.

Since then, NGS has become involved in the MesoAmerican-Caribbean Sea Hydrographic Commission (MACHC) of the International Hydrographic Organization (IHO). MACHC serves in an advisory, scientific, and technical capacity to assist institutions responsible for hydrography and navigation within the Member countries. Working with MACHC, NGS has expanded the HARN to include CORS, in the British Virgin Islands, Jamaica, Barbados, Surinam, and the Cayman Islands. CORS data from these countries are now available thru the NGS CORS website, and nearly all have agreements to allow OPUS to calculate positions within their boundaries. As part of the Gulf of Honduras Initiative, NGS is helping to address a full range of issues, including accurate nautical charts and territorial limits. Cooperative efforts are now focused on the infrastructure for vertical measurements, installing CORS, doing absolute gravity measurements for a better geoid model, and building local capacity through workshops and technical assistance. To help developing countries achieve the additional benefits of geospatial infrastructure described in this paper, NGS pledges to be diligent for the long term, committing to a mission of international leadership in geospatial activities, and building capacity around the world to develop and use geospatial tools to address disaster management and climate change issues.

7. CONCLUSION

Over two hundred years ago, when Lewis and Clark returned from their expedition, Thomas Jefferson recognized the critical need for maps and charts for the Nation’s development, and founded the US Survey of the Coast. Later called the US Coast and Geodetic Survey, this institution laid the foundation for safe and efficient transportation for years to come by providing information needed to conduct commerce. In recent years, the advent of GPS, Geographic Information Systems (GIS), and various remote sensing techniques have revolutionized our ability to provide data for accurate maps. Today, NOAA is aggressively investigating new technologies to provide more accurate data, more quickly to support global commerce and transportation. This flood of new technology increases the quantity and type of information available and enables us to model the earth's dynamic processes with finer and finer spatial resolution.

While these advances in technology have been driven by requirements to provide information for safe navigation, they have implications for society far beyond their original intent. New applications of accurate positioning in coastal regions are leading to a better understanding of potential impacts of hazards, and strategies to mitigate them. High accuracy digital elevation models with merged bathymetry, topography, and water level data can improve our storm surge and coastal flooding modeling capabilities. A better understanding of coastal elevation dynamics, especially subsidence in the face of sea level rise, allows us to provide information on evacuation routes to emergency managers, and to provide information critical to infrastructure improvements based on elevation trajectories over time.

In addition to the direct benefits to communities facing coastal hazards, these emerging technologies have much to contribute to ecosystem management and habitat science. How often and for how long coastal habitats are covered by the tides is a driving force behind species distribution within coastal ecosystems. Land elevation in relation to local water levels is a critical structural element of several coastal habitat types including tidal salt marshes, oyster reefs and submerged aquatic vegetation. Advances in geodesy and accurate positioning are giving us the power to make measurements at a spatial scale that can assist us in tracking gradual changes in coastal ecosystems as the effects of climate change and sea level rise take hold. These same advances are improving our ability to restore or reconstruct coastal habitats that are damaged or that are built as mitigation for habitat destruction elsewhere. Using these new technologies to monitor changes in the land/water interface can serve as an early warning system for coastal ecosystem health and give coastal resource managers time to respond. Given the myriad social, economic and environmental benefits derived from these coastal ecosystems as well as the direct contributions to resiliency of coastal communities, it is incumbent upon us to take advantage of the full range of applications presented by technological advancements driven by the navigation needs of global commerce.

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BIOGRAPHICAL NOTES

David B. Zilkoski received a B.S. degree in Forest Engineering from the College of Environmental Science and Forestry at Syracuse University in 1974 and a M.S. degree in geodetic science from The Ohio State University in 1979. He has been employed by National Oceanic and Atmospheric Administration (NOAA) since 1974. In February 2000, he was selected as Deputy Director of the National Geodetic Survey and was named Director in February 2006. Under his leadership, NGS has the developed and transferred new positioning technologies such as the Shallow Water Positioning System (SWaPS) for monitoring underwater features, GPS-equipped buoys, the incorporation of geodetic data and procedures into restoration projects for determining accurate elevation models, and the use of new geodetic and remote sensing technology such as GPS, LIDAR, and IFSAR to generate shoreline and other coastal information for managers.

He has authored a number of publications on coastal subsidence, surveying, and vertical datum including a chapter in *The DEM Users Manual* (2001, The American Society for Photogrammetry and Remote Sensing, Bethesda, MD, David F. Maune, ed.). He is also a guest lecturer at the University of California at Riverside.

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