REPORT

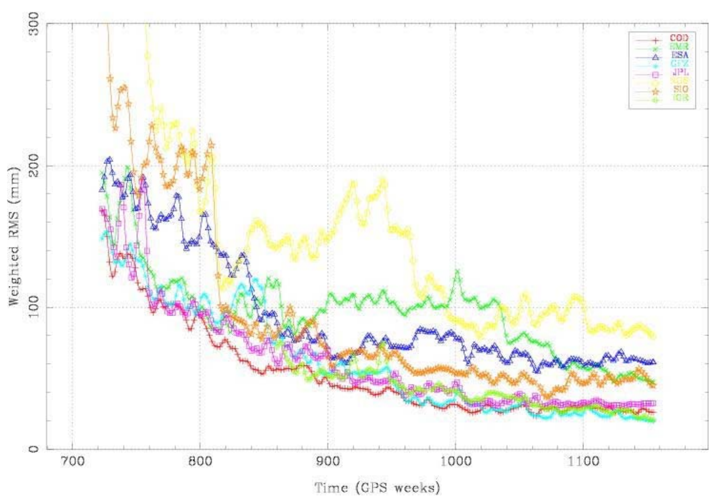
OF

THE NOAA SCIENCE ADVISORY BOARD'S

PANEL ON ASSESSING GEODESY RESEARCH

IN

THE NATIONAL OCEAN SERVICE



Level of performance of the GPS Orbit improvements of the top eight analysis centers of the International GPS Service since 1994..NGS performance is in yellow. (Provided by Ms. R. Neilon, JPL)

by

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9-11 July 2002, Boulder, Colorado

PREFACE

The National Oceanic and Atmospheric and Administration's (NOAA) mission is to predict and assess changes in the Earth's environment, and conserve and wisely manage the Nation's coastal and marine resources. Dr. D. James Baker, past NOAA Administrator, noting the need for an evaluation of the Nation's geodetic needs, requested that an External Review Panel (ERP) be formed under the auspices of the NOAA SAB, to assess the status of NOAA's capacity to meet those needs. The formal request for the assessment and charge to the expert external panel came to the NOAA SAB from the National Ocean Service. The NOAA Science Advisory Board (SAB) recognizing the importance of NOAA's role in geodesy research and development and technology transfer in the public's interest endorsed the assessment opportunity and process.

Following the review of this report by the NOAA SAB, the considered response of the SAB will be communicated to the ERP. The Panel will then respond back to the SAB with a Report for its further consideration of acceptance of the Report. The Report will then be forwarded to NOAA Administrator, Vice Admiral Conrad C. Lautenbacher.

As Chair of the Panel, I would like to express my sincere appreciation to the leadership (Mr. Charles Challstrom, Director of NGS and Dr. Dennis Milbert, Chief Geodesist of NGS) and the staff of the National Geodetic Survey for providing the necessary information and support during the hearings. Further I would like to thank the Panel members who took considerable time from their very busy schedules to produce the Panel's Report. Following acceptance of the Report by the NOAA SAB, the External Review Panel will be disbanded.

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9 July, 2002

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I. EXECUTIVE SUMMARY

The National Geodetic Survey is responsible for to facilitate, broker and provide the scientific and technical expertise and facilities required for the conduct of geodetic research and for the transfer of that technology to under-gird the National Spatial Reference System (NSRS) needs of the United States**.** The NSRS is a national coordinate system that specifies latitude, longitude, height, scale, gravity and orientation throughout the Nation. Thus it provides the Nation's framework for position, direction and shoreline location and is the cornerstone for transportation on land in the air and at sea, communication, state boundaries, land boundaries and records, maps and charts, construction projects, in-place movement of structures, and defense related needs.

The National Continuously Operating Reference System (CORS) provides the Global Positioning System (GPS) user community with a link to the National Spatial Reference System for position determination, and to monitor the stability of CORS positions to a high degree of accuracy. NGS is developing the national CORS network to meet a goal of providing full nationwide access. GPS data collected by NGS through this network is distributed to users via the Internet. Working with partners, NGS expects to extend the network from its present size of less than 200 sites to about 300 sites, enabling every location in the U.S. to be within 200 kilometers of a national CORS site. However, for complete national coverage, 500 stations are required. Moreover, there are important contributions that the CORS can make to other intra-agency activities that are key to NOAA's mission. For example, tropospheric error sources which hinder geodetic use of GPS are valuable for weather forecasting and climate change research. This is a research area that is completely aligned with the NOAA mission. The GPS contribution to numerical weather prediction is valuable in tracking precipitation in real-time and for assessing and tracking severe storms and unstable atmospheric conditions. Homeland Security is also critically dependent on GPS and advanced kinematic digital technology.

While the NGS has been responsible for the existing spatial referencing national capacity of the Nation, there are now important needs and challenges that are not being properly addressed. There are too few people for the number of research topics to be addressed and it is difficult to bring a critical mass to bear on a single topic. These same problems are shared by other components of NGS. NGS management is constrained both financially and in terms of how funds can be spent such as hiring restrictions

Moreover, the value of established reliable standards with regard to spatial reference is in the cost to be borne by society without them. Thus the need for laws requires standards and these can only be established via credible, reliable scientific studies and advances in geodesy.

The ERP supports the basic mission of the NGS as being in the national interest. Lacking the investments and capabilities of the NGS, the Nation would be unable to keep pace with increasing demands for accurate and precise positioning information that influences people's everyday lives, as well as commercial activities, public works, environmental protection, and national security. To continue to provide these services, especially in view of the advances in the state of technology, the NGS must be adequately funded and staffed with support for a robust and credible research effort that underpins scientific and technical advancement. The ERP makes the following recommendations.

II. PANEL RECOMMENDATIONS

Recommendation # 1: NGS must not only retain, but also enhance its research enterprise.

The observed trend over the past 5-7 years has shown a decline in GRD allocated resources with the group becoming increasingly devoted to operational activities managing the daily analysis and production of products from the CORS network. While this has a very significant and recognized value, it falls well short of the necessity to keep pace with and drive innovations for improved processes for the NSRS. Many organizations face decreasing budgets with increasing demands to keep current or advance the technology. Noted advancements in GPS geodesy have been facilitated through the International GPS Service, which brings together the global GPS experts and provides a truly international cooperative forum. NGS, once very active in the IGS, has had decreasing involvement in the past few years, a mutually detrimental situation. NGS GRD personnel should be enabled to participate externally both domestically and internationally as part of a broader R&D effort.

Recommended specific areas of research are:

- geoid research, including support staff for gravity database update and maintenance
- vertical motion modeling ,
- standards to be used in the application of high-quality satellite geodesy to meet user requirements,
- improvement of mathematical models for orbits, clocks, propagation, deformation, and ocean loading to be applied to satellite geodetic techniques
- improvement of the network communications and processing required to treat future real-time satellite geodetic data
- GPS antenna calibration.

Recommendation #2: Develop and implement a management of science planning process.

The means by which the NGS research agenda is defined, supported, and reported needs to be attended to. The sections of the NGS internal assessment that deal with this issue are “Reporting and Feedback Processes” and “Goal Setting.” The NGS research enterprise can be strengthened with the implementation of a more systematic and rigorous planning process.

The NGS internal assessment describes several facets of the current goal setting and execution process for research. As portrayed in the internal assessment, the NGS research agenda appears to result from a number of ad hoc activities. These activities do not necessarily describe a complete, logical, and systematic process, one that enables all interested parties to understand why, how, and when to be involved.

The process of setting the goals for NGS research should be both strategic and tactical. NGS should articulate program goals and activities, identify existing and potential collaborators and users, specify the utility of NGS research to the user base, evaluate strategies to secure funds, and incorporate performance standards, a timetable, and budget.

Recommendation # 3: Develop interaction with GIS community both at the national and international levels.

The "GIS community" was mentioned several times as being an important user. The NGS should develop an approach for formal interaction with this community to ensure that research topics relevant to this large constituency are addressed in the NGS research plan.

This interaction should occur at both the national and international levels and include agencies that provide high quality GIS products. As a corollary, NGS should provide travel support to NGS researchers to accomplish these interactions via conference and workshop attendance and site visits.

Recommendation # 4: Facilitate a National Integrated, Seamless CORS Network, Consolidate CORS activities and Advance the Next Generation CORS.

The CORS national network has needs for densification and standards but must be created with an architecture that allows for easy access to serve the needs of multiple users. The various activities related to CORS apparently are being conducted by staff from several different NGS units. NGS should evaluate the advantages and disadvantages of bringing together all the CORS activities under one organizational unit.

It is not too early to be considering the next generation CORS given possible advances in GPS that would alter present network assumptions. NGS should be conducting a bench marking exercise to examine original and present day concepts and goals of the nationwide CORS, the validation of existing and future user needs and performance requirements, and the development of strategic partnerships with states and identification of key research questions to be addressed. Investments in solutions for completion of the existing plan and for the future infrastructure should be considered.

Recommendation # 5: Distinguish among research, development and operational activities.

NGS needs to better define the distinction among *research*, *development* and *operational* activities. This would help to better allocate staff time that is already in short supply, and would allow research staff to concentrate on research activities. The focus within NGS appears to be heavily weighted towards operations without the appropriate and necessary emphasis on the research and development parts of the end to end process from targeted research to delivery to users.

Recommendation # 6: Emphasize hydrographic surveys.

NGS should increase emphasis on kinematic GPS assisted hydrographic surveys, thereby conducting research that has immediate relevance to a mission critical element of NOS, NGS's parent organization. The Nation's increased needs for Homeland Security and for extremely accurate positioning and navigation (the NOS Promote Safe Navigation program) necessitate the use of advanced kinematic technology. The capabilities are especially important under conditions up reduced visibility. The Federal Aviation Authority has gone digital and NGS must facilitate the same capabilities in the Nation's Ports, such as automated docking and ship avoidance.

This capability would also be in support of the Nation's needs for higher resolution coastal maps and charts and for the advanced flood modeling in coastal areas.

Recommendation #7: Represent geodetic user community to GPS management.

NGS should take a leadership role in representing the applied geodetic user community to GPS management, and ensure that sufficient resources be made available to enable the necessary research to accomplish this role. The Nation's needs for spatial referencing are such that the advances in the state of the science and subsequent technology transfer cannot be compromised.

Recommendation # 8: Transfer Absolute "g" responsibility and facility.

NGS should transfer development, maintenance and operation of its absolute gravimetry program to the National Institute for Standards and Technology. The role of absolute gravimetry is primarily for geophysical studies where it is used as a means of measuring the gravimetric signal associated with height changes. This type of measurement is independent of GPS and other height change measurement systems and as such is potentially a very powerful tool for understanding height changes, but this potential has not yet been realized.

If absolute gravimetry is be continued at the NGS, then there should be a concerted effort to make available the data that are being collected so that many investigators can access and interpret the results. If this is not possible, then it seems that the funds being used for absolute gravimetry are not leading to answers of scientific problems and should be transferred.

III. INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) has within its extensive environmental portfolio, the responsibility to provide and oversee the scientific and technical expertise and facilities required for the conduct of geodetic research, development of advanced technology and for the transfer of that technology in support of the spatial reference needs of the United States.

In 2001, NOAA/NOS conducted an internal assessment of its' program in Geodesy Research. The Executive Summary of that assessment reads as follows: " As part of the overall assessment of science activities in NOAA, an Internal Assessment of geodesy research in the National Ocean service was carried out during the Spring, 2001 by a team of selected employees of the National Geodetic Survey. The picture that emerged is one of a shrinking activity. Although there are 19 employees of the Geosciences Research Division (GRD), only a handful serves as researchers. While significant research results have been obtained in the past, there are now important questions that are not being addressed. There are too few people for the number of research topics to be addressed, so that it is difficult to bring a critical mass to bear on a single topic. These same problems are shared by other components of NGS. NGS management is constrained both financially and in terms of how funds can be spent (e.g. hiring restrictions). Tracking and goal setting processes instituted at the beginning of FY01 have provided NGS management with improved focus on research. The document goes on to say that: "the bulk of currently assigned personnel are not engaged in geodetic research…and….the research (head) count is but 7 in total".

In Spring 2001, an External Review Panel (ERP) was created and charged with assessing the overall science portfolio of Geodesy research within the National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA). The ERP was to evaluate and assess the conduct of geodesy research within NOAA, specifically the National Geodetic Survey (NGS) and to report the panel's findings, including recommendations to the NOAA Science Advisory Board* for its consideration.

From 5-7 June, 2001, hearings and executive session discussions were held to effect the external evaluation of geodesy research conducted within NOS. The meeting was convened and conducted by a NOAA SAB and NOAA NOS jointly selected panel of external experts consisting of academics, federal agency users of the NGS technology, and industry stakeholders. An SAB member chaired the panel. The hearing and review was held in the NOAA facilities housed in building SSMC-3, Conference Room 8836 at 1315 East-West Highway in Silver Springs, MD.

*To obtain independent advice on the quality and relevance of its science, NOAA established a Science Advisory Board in 1997. The responsibility of the SAB is to advise the Undersecretary of Commerce for Oceans and Atmosphere on short and long-range strategies for research and application of science to NOAA's environmental stewardship and prediction mission. The SAB is an official Federal Advisory Committee and its operations comply with the Federal Advisory Committee Act (FACA).

a) Charge to the External Review Panel

NOAA requested that the SAB assist in a review of the quality, relevance and use of science in support of NOAA's mission. The specific objectives of the SAB reviews are to include considerations of eight themes: science quality, credibility and utility; timeliness and scale of the scientific enterprise; science/policy connections; capacity building; education; efficiency, synergy, and maximization of resources; social science integration; and diversity. The overall goal of the review process is intended to lead to improvements in the quality and application of science in NOAA and as such should identify information and gaps and ensure that science accomplishments are communicated to stakeholders.

b) Membership of the External Review Panel

The NOAA SAB NGS External Review Panel (ERP) consisted of nine members including external technical experts, agency partners, agency customers, and a NOAA SAB representative. The membership included:

Mr. Dean Gesch, Federal government use of geodetic products and technology
Dr. Thomas A. Herring, Geodesy research
Dr. Dennis McCarthy, Geodesy and time systems research and use
Captain David MacFarland, NOAA Coast Survey use of geodetic products and technology
Ms. Ruth Neilan, Geodesy research and international use of geodesy
Dr. Jeffrey Payne, NOS use of geodetic products, services and technology
Dr. Leonard J. Pietrafesa, NOAA Science Advisory Board, ERP Chair
Mr. Michael Shaw, Federal use of geodetic products, services and technology
Mr. James Stowell, Private industry use of geodetic products, services and technology

The list of members and their institutional and organizational affiliations of the panel members is presented in Appendix A.

c) Review Support

Dr. Dennis Milbert, Chief Geodesist provided and coordinated all logistics associated with the review. Dr. Milbert also provided all materials necessary for the conduct of the review and was always available to facilitate the review process. Mr. Charles Challstrom, Director of NGS provided an overview of the organization. The structure of the NGS is provided in Appendix B and the list of Geodesy research personnel is in Appendix C. A copy of Dr. Challstrom's presentation is given in Appendix D.

Dr. Gerry Mader, Chief, GRD, made a presentation on geodetic research in general, and Dr. Daniel Roman, Research Geodesist, presented an overview of the state of the science of geoid modeling. Finally, Drs. Milbert and Mader participated in a thorough question and answer period on the second day of the review. A copy of Dr. Roman's presentation is provided in Appendix E. The NGS Work and Research Plans presented and discussed by Drs. Milbert and Mader are presented in Appendices F and G, respective

The summary and recommendations of the External Review Panel's assessment are the subject of this report. This report will be delivered to the NOAA SAB at its 9-11 July,2002. The SAB will respond in writing regarding the findings of the ERP.

The report includes discussions of the role of NGS in the national interest and includes:
- a description of that role and the importance of science in that role;
- identification of the science drivers in that role;
- an overall assessment of the NGS capacity to meet its mission;
- recommendations from the ERP.
- appendices are also provided, by way of example and status, to elucidate NGS structure, personnel, annual operating, and work and research plans.

The ERP intended to:
- assess progress and quality of ongoing and completed scientific activities;
- assess the contributions, responsiveness, relevance, and scientific achievements produced by the activities;
- identify problem areas and recommend corrective actions;
- identify any new science directions that could enhance the quality and relevance of NOS/NGS/GRD programs.

The ERP will report findings and recommendations to the head of the reviewed organization, the NOS Assistant Administrator, and the NOS Chief Scientist. However, the SAB member on the panel will first report the Panel's findings to the Science Advisory Board at a full SAB Meeting. The SAB may then choose to accept the Panel's full report, accept a portion of the report, or decline to endorse the report, forwarding their recommendation to NOAA Administrator, Vice Admiral C. Lautenbacher.

Within one year following receipt of the Final Report of the Panel, NOS will provide a written report to the NOAA Administrator (and the NOAA SAB if the SAB endorsed the original report) describing the nature and effectiveness of any actions taken to address the recommendations expressed in the report.

IV. THE ROLE OF THE NGS IN THE NATIONAL INTEREST

The National Geodetic Survey (NGS) has a rich and extensive history in service to the Nation. NGS activities provide uniform public benefits, especially through the National Spatial Reference System. The mission of the NGS is to deliver and evolve the nation's foundation of reference for latitude, longitude, height, velocity, shoreline, and gravity throughout the U.S. with consistency, accuracy, timeliness, and easy access. This mission is in support of public safety, economic prosperity, and environmental well being. The strategic goals of the NGS are to deliver and evolve the National Spatial Reference System (NSRS); optimize relationships with customers and partners to meet changing needs and requirements; and achieve world class leadership in innovative techniques and application of geodetic science, related remote sensing technology and tools, and precise positioning.

The NSRS is intended to be a consistent national coordinate system that specifies latitude, longitude, height, scale, gravity and orientation throughout the Nation, as well as how these parameters change with absolute time. Thus it provides the Nation's framework for position, direction and shoreline location and is the cornerstone for transportation, communication, state boundaries, land boundaries and records, maps and charts, construction projects, in-place movement of structures, and defense related needs.

The NGS conducts research to improve and ensure the accuracy and accessibility of the National Spatial Reference System. Research goals include providing real-time positioning capability accurate to 1 cm in three dimensions throughout the U.S. by 2005; providing orthometric heights accurate to 2 cm through improved accuracy of a gravimetric geoid; and developing new techniques and applications of the Global Positioning System (GPS) for geodetic, navigation, and remote sensing challenges/problems. For example, mathematical and computational methods are being developed by NGS researchers for geoid modeling, leading to improved accuracies for U.S. surveying. NGS is also working to better estimate the behavior of the ionosphere, to provide for GPS satellite and receiver antenna calibrations vital to GPS solutions, and to refine the measurement of the Newtonian gravitational constant.

Research conducted by the NGS is focused primarily on the operational mission, but NGS researchers also engage in work that helps to advance the state of knowledge. Both kinds of research are needed to have a healthy science enterprise, one that promotes the constant introduction of new ideas to benefit practical applications, as well as challenges the staff to produce outstanding results. Nontheless, all NGS research is related to and focused on mission and responsibility.

The science advisory panel supports the basic mission of the NGS as being in the national interest. Lacking the investments and capabilities of the NGS, the Nation would be unable to keep pace with increasing demands for accurate and precise positioning information that influences people's everyday lives, as well as commercial activities, public works, environmental protection, and national security. To continue to provide these services, especially in view of the advances in the state of technology, the NGS must be adequately funded and staffed, including for a robust and credible research effort that underpins scientific and technical advancement.

V. SCIENCE DRIVERS

The support and future development of the National Spatial Reference System (NSRS) infrastructure requires investments in the science that supports these activities. In the sections below, those area where investment in research and development should lead to improved efficiencies in the use of the national reference system are discussed.

A. Real time sub-centimeter systems

Most engineering and surveying projects, such as land boundary surveys, require position determination and boundary delineation with accuracy of order 10 mm [Dr. D. Roman, on NGS standards, Appendix B]. In current practice this accuracy is achieved by referencing new survey work to existing ground control points (physical monuments in the ground) whose coordinates are known. One control point can define the position of the new work, and with conventional theodolite and distance measurement systems, at least one other control point is needed to define the orientation of the new work. Historically, one of the prime functions of the NGS, in collaboration with other state and local survey organizations, was to determine of the coordinates of the control points and to maintain the descriptions of these points. NGS is responsible of the national scale primary control network while local agencies have densified these networks to a scale accessible to the local surveying community. The typical spacing of the points in the primary network is several hundred kilometers while local surveyors would like points within a few kilometers of their work sites.

The development of GPS has dramatically changed the way that conventional surveys can be carried out and in the future is poised to have an even greater impact. Implicit with GPS is knowledge of the orientation of new survey work and thus the adoption of GPS allows a single control point to be used to position the new survey work. The development that would allow the complete elimination of the use of control points is the ability to make absolute position measurements with 10mm level accuracy in real-time. Over distances of tens of kilometers, real-time positioning with 10mm level of accuracy is currently possible with differential GPS techniques provided the coordinates of the fixed station in the differential system are known. With current technology, base stations would need to be established with a spacing of about 10 km to allow real-time positioning with the required accuracy. To cover the country with this spacing of stations would require over 100,000 stations.

If real-time kinematic positioning were possible with separations from base stations of 200 km, then the number of base stations would reduce to about 500. Deployment of this number of Continuously Operating Reference Stations (CORS) is possible with current technology. Real-time transmissions of carrier phase data and algorithms built into receivers that would allow ambiguity resolutions with just a few seconds of data over these distances would revolutionize the methods of precise surveying. Development of algorithms and software that will allow real-time positioning with 10-mm level accuracy over distances of 200 km is currently a research problem whose solution would significantly enhance the use of GPS for cadastral and engineering surveys.

B. Standards

Standards are "principles, rules and measures by which we can make or have made critical judgments." In NGS parlance, principles and rules are based on measures. Thus, the national law that states that "citizens in the United States shall act according to established Standards for Surveying and the establishment of Control for Boundary, and property definition as defined by the NGS" has a basis in fact. While maintaining accepted standards is not a difficult task, adjusting established standards to take advantage of new technology has presented unique challenges to the NGS. The principle motivations for standardization are needs to reduce costs throughout all sectors requiring geodetic information, to increase interpretability, to create accepted property lines, and to improve safety, to name several. Without reliable, dependable geodetic information, our every day lives would become chaotic and confrontational very quickly.

Arguably, everything we see and touch in with the boundaries of the United States was built or designed within a set of Standards. Standards are the homogeneous infrastructure that we employ, the basis of the language that we use to communicate and the unit of currency for boundaries and property lines. The establishment and maintenance of these standards resides within the NGS.

However, reliable as present standards may be, our society must take advantage of the evolution of those standards given new, technological advances. Space based technologies are viewed as the future of maintaining and advancing our current national spatial infrastructure just as the Internet was to the information super-highway. This evolution must be planned for and assumes that there is an agency that can broker and facilitate the testing and adaptation to the new technology and standards. Historically this expertise has resided within the science group in NGS. This group has accepted the responsibility to identify and test the new technology, determine its application value, and then validate and establish the standardized use of the new technology. The systematic approach to adopting and managing these new technologies is the responsibility of NGS. Failure to maintain this traditional activity will most certainly impact associated laws in the Nation, if not the World.

Areas of research related to the testing, implementation and adoption of new technology involve studies of: atmospheric signal transmission; satellite orbit determinations; measurements of plate motions of the earth's crust and other motions due to earthquakes, volcanoes, and landslides; geodesy; high density, capacity data, information and sound and video transmission; and land and marine GIS spatial and emerging temporal architectures.

Fields of application for new technological advances include GIS; mapping and mapmaking; classes of GPS measurement and types of acceptable benchmark monumentation ,surveying; construction stakeout; engineering and deformation studies; high precision monitoring; the monitoring of the structural integrity of bridges, large buildings and dams; the movement of railways and highways; surveying subsidence of dams and other structures; mining; machine guidance and control; navigation; hydrology; civil engineering; natural disaster emergency response; safety issues; transportation by car, train, ship and airplane; agriculture; commerce; mitigation against natural hazards such as coastal and inland floods; and coastal erosion.
Some of the technologies mentioned are necessary to build the type of infrastructure necessary to support the information technology environment of the future. Items such as high speed networks, operating systems, enterprise technology management, and relational databases are key building blocks for emerging technologies which will improve the services provided by the NGS to the citizenry of the country.

In summary, the value of established reliable standards with regard to spatial reference is in the cost to be borne by society without them. Thus the need for laws requires standards and these can only be established via credible, reliable scientific studies and advances in geodesy.

C. Geoid Modeling

Geoid modeling is a fundamental research topic in geodesy. A high-resolution, high-accuracy geoid model is needed for reliable conversion of GPS ellipsoidal heights to orthometric heights. While investigation of techniques to improve computation of the geoid is an area of active research, the end product of such research, a quality geoid model, has immediate relevance for the operational user community. Heights measured by GPS relative to the ellipsoid can be converted by use of the proper geoid model to an orthometric height reference frame, which is commonly employed by the GIS community and topographic map users.

Other federal agencies, universities, and international organizations are actively working on improved global geoid modeling, whereas NGS has a primary goal of producing the best possible model of the geoid for the United States for use by surveyors and spatial data users. The ultimate goal is to produce, and provide regular updates to, a geoid model derived solely from gravity data. Until enough suitable gravity measurements exist, and computational techniques and error characterization advance further, hybrid geoid models incorporating leveled benchmark data will need to be produced. However, research into improved geoid modeling should proceed on two fronts: improving current data processing approaches and input data for hybrid models, and also research on new, innovative methods for calculation of a purely gravimetric geoid model.

D. Models

Applied geodesy research within the NGS is emphasized here to underscore the need for enhancing the development and refinement of models. Fulfilling the mandate of the NSRS requires the de-facto requisite operational elements which would be difficult, if not imprudent, to separate from the research activities. A balance of resources must be achieved so that operational demands do not diminish the research effort. Deriving positions from GPS signals is generally straightforward for lower accuracy applications. There are remarkable results at the few meter level for the handsets and car navigation and the like, but as requirements demand very precise levels of positioning, at the centimeter and millimeter levels, a number of error sources must be accounted for to determine accurate and precise position and time. These error sources include propagation effects, orbit determination, clock modeling for satellite and receiver clocks, ocean loading, etc. These must be understood and modeled correctly to achieve targeted levels of accuracy.

The dramatic improvement of the utility of application of GPS over the past decade stem mostly from improvements in: models and estimation techniques in the software analysis packages;
ground based receiver instrumentation hardware and in-receiver software upgrades; and technological improvement to and stabilization of the GPS constellation.

1) Propagation Models

The GPS signal experiences various propagation effects as it travels from the satellite to the observing receiver due to the ionosphere, atmosphere or any medium it must pass through. We consider the influences of both the ionosphere and the troposphere.

a) The Ionosphere

The ionosphere can produce a significant effect on the observed signals due to the frequency dependent nature of propagation through the ionosphere. This is why geodetic applications require dual-frequency receivers so that the effect can be calibrated and removed (effect is inversely proportionate to the square of the frequencies). While this can largely be removed, higher order terms may remain introducing errors in the results. Such higher-order ionospheric effects are not benign during periods of high solar maximum. We are just past the peak of the solar cycle and the effects in data analysis can still be seen.

Solar activity can cause ionospheric activity even during normally quiet periods. The equatorial and polar regions are locations on the Earth where the ionosphere can cause problems in signal tracking due to a generally higher total electron content or scintillations, which can even cause receivers to lose lock on the phase signal. Current models fail to fully characterize the time and spatial variability of the ionosphere. This is an area where GPS can be used to further ionospheric research, and near-real time monitoring of the ionosphere can be used to provide ionospheric calibrations. Users of single frequency receivers can apply these calibrations. A practical application is to provide corrections for aviation where airplanes carry single frequency (L1) receivers. The FAA’s developing Wide Area Augmentation System (WAAS) will employ such a strategy.

b) The Troposphere

The troposphere, the lower section of the atmosphere that contains water vapor, causes a delay in the transmitted signal and is a variable effect due to changing water content of the air or precipitable water vapor (PWV). The effects of this can not be removed with the dual frequency approach applicable to the ionosphere, but can be minimized with ancillary measurements such temperature and pressure and proper modeling. As GPS accuracy has improved, water vapor continues to be a source of error at the level of approximately a few mm. Modeling which can compute and remove the delay due to PWV is an area of great interest, particularly as a “data” observation source thus serving as a benefit to atmospheric science and meteorlology.

These tropospheric error sources which hinder geodetic use of GPS are increasing in value for meteorological research, weather forecasting, and climate change research. This is a research area that should be completely aligned with the NOAA mission. For atmospheric scientists to utilize these observations appropriately, strategic partnerships with the 'expert users' in GPS geodetic research would seem an optimal approach. The GPS contribution to numerical weather prediction is most valuable in tracking the variability of PWV in real- to near-real time, a high value input for assessing and tracking severe storms and unstable conditions. This hints at the great potential to utilize the CORS network in a real-time analysis mode.

c) Multi-path

Multi-path occurs when the GPS signals are reflected from objects prior to being recorded by the GPS receiver causing errors in observations. A general multi-path model is very difficult to characterize, as this effect is specific to the site conditions surrounding each GPS ground antenna. As multi-path is so site dependent, great care in placing antennas becomes extremely important for geodetic use of the stations. One of the key drawbacks for truly precise use of the CORS is the poor siting of the antennas, the RF characteristics of the selected antenna and monument/site stability.

d) Antenna Effects - Phase Center Models

Selecting a geodetic antenna depends on a number of factors and is an area where continued research could provide great benefit – in accuracy, cost and efficiency. Geodetic research within the NGS has been involved in antenna testing for a number of years and provides critical measurements required to determine the phase center locations and patterns of many GPS antennas. Careful measurements of the GPS phase center must be available to relate the observations to the physical geodetic control point on the ground. The phase centers are not completely fixed, and their geometric position changes based on the radiation of the antenna by the signal. Attempts have been made to model this effect but this area remains a needed research effort. The antenna must have good symmetrical pattern with multi-path rejection at low elevation angles to minimize reflected signal from local ground objects. Conventional GPS geodesy uses a 'choke' ring back-plane for the antenna, which further reduces multi-path. The standard antenna in use today chosen for phase center stability (a Dorne Margolin with choke ring) is costly, often difficult to obtain, and has few options. NGS is encouraged to continue these measurements as new antenna and antenna back-planes become available.

GRD is increasingly involved in measuring the GPS satellite's antenna phase centers prior to launch. This is highly commended and strongly encouraged to continue as a top priority. This facilitates the measurement of the satellite transmit phased array and its relation to the center of mass of the satellite, which is critical information for precise orbit determination.

e) Radome Effects

An antenna radome protects the antenna from weather conditions, animals (e.g., nesting birds) and makes it less conspicuous to 'curious' people. The material of the radome affects the signal, and measurements taken at the same point with and then without a radome produce different results, mostly in the vertical, but this is an issue of the height modernization effort. There is no single accepted standard for a radome despite a great deal of design effort invested by the southern California Integrated GPS Network (SCIGN) group, which could be evaluated for broader use.

2) Orbit Models

Precise orbit determination of the GPS satellites is essential to producing highly accurate geodetic measurements. When GPS was being evaluated for civilian use in the mid-80's, the NGS was active in research for precise orbit determination (POD). The NGS led the Coordinated GPS Network within the auspices of the International Association of Geodesy. This was the first attempt to collect data from a sparse yet globally distributed GPS network to provide data for GPS satellite orbit determination. To perform POD requires expertise in fundamental orbital mechanics, and technical depth in dealing with the perturbing forces such as gravity, radiation pressure, drag, eclipsing effects, etc. Models are continually being improved in these and other areas. Incorporation of space geodetic techniques into the conventional geodetic systems requires an active applied research section within the NGS.

Figure 1 shows the level of performance improvement of the top analysis centers of the International GPS Service. The NGS is one of the centers producing precise GPS orbits for more than a decade. Reviewing recent performance shows the NGS daily orbits at the 10cm level 3d-wrms – the best analysis centers are capable of consistently producing 3-5 cm orbits and satellite/station clocks at the 0.2 ns level. The NGS currently does not participate in the sub-daily orbit determination and prediction, nor in the rapid satellite and station clock estimation, there is a sense that much of the GRD resources are devoted to sustaining a growing GPS network operations and product generation. Additional resources and talent, or partnerships with other US organizations could enhance NGS performance. Improvements could be realized if resources for research were available,

To achieve a real-time positioning system, the NGS must either develop the in-house capability for generating sub-daily orbits (even hourly or real-time orbits) and clocks or develop partnerships with other organizations with demonstrated expertise in developing such systems (e.g., NASA/JPL). In any case, no system is close to being a "black-box". A number of international agencies with mandates similar to NGS are joining together to establish a real-time global network to support their real-time national activities. For example, both Canada and NGS, among others, have real-time national infrastructures, but to achieve real-time precise positioning requires a global network and some significant development for real-time system processing.

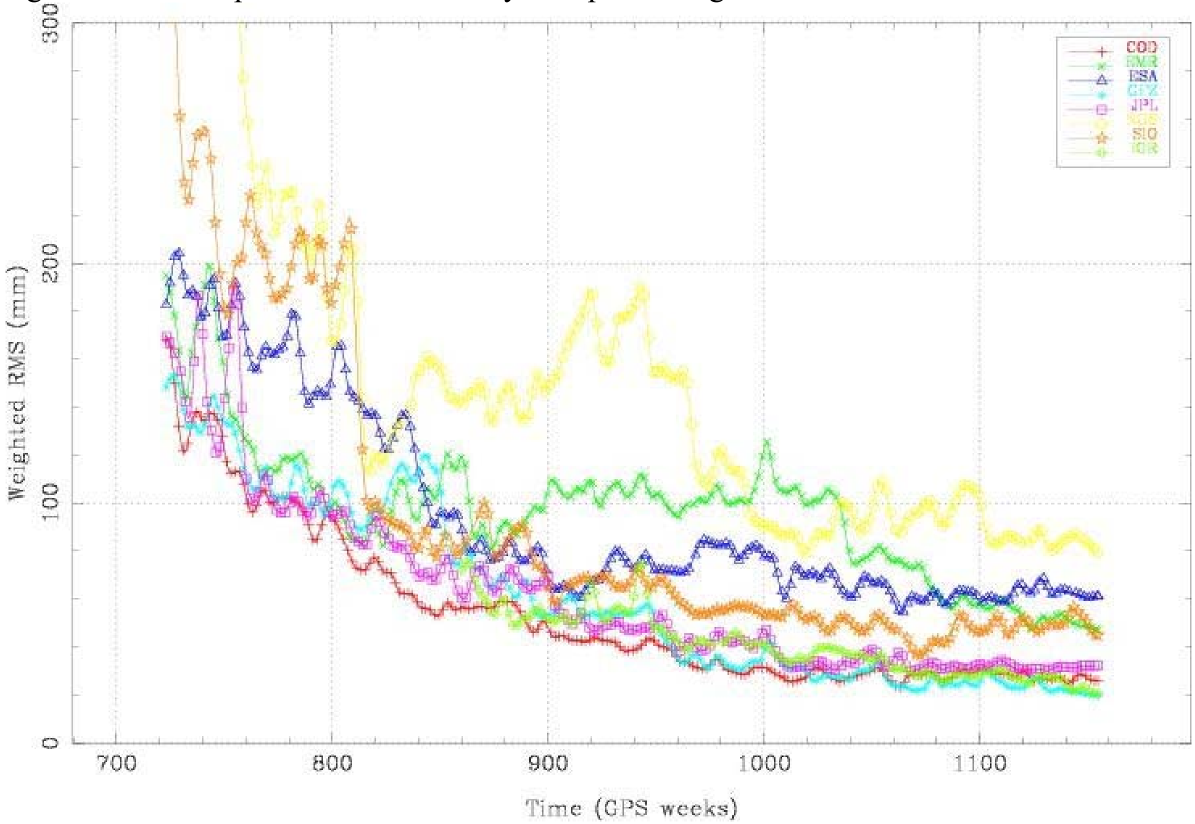

Figure 1. Level of performance of the GPS Orbit improvements of the top 8 analysis centers of the International GPS Service since 1994. NGS is at ~8cm vs. ~2-5cm for others.

3) Clock Models

A key component of real-time positioning using GPS is accurate modeling of the satellite clocks. Errors in clock characterization are the dominant source of error in real-time positioning. Models that are capable of predicting short-term clock behavior need to be developed to a level that is consistent with the errors in orbit modeling. While there have been significant developments in improved orbits, the area of clock models has received little attention. This work requires significant research and can be carried out in cooperation with other national and international institutions. Researchers must be prepared to adapt models to clocks employed in the most recent satellites as well as in future systems.

4) Ocean Loading Models

The effects of ocean tidal loading can change by centimeters over 100 km and the existing models can be inaccurate in coastal regions. As an example of the magnitude of the effects of ocean tidal loading, Figure 2 shows the maximum amplitudes of the semi-diurnal, diurnal and long period tides for two latitude bands. Amplitudes can be up to 30 mm near the coast. For accurate height measurements, especially with short duration measurements, accurate values for ocean tidal loading are required. These amplitudes could also change with time as coastal waterways are changed and continued studies of ocean tidal loading effects are required to ensure accurate modeling of this effect.

The effects of ocean tidal loading on horizontal position determination are not shown in Figure 2. The horizontal amplitudes are typically 5 to 10 times less than the radial amplitudes, and need to be accounted for, for the most accurate positioning. For most NGS applications, the errors in the horizontal ocean tidal loading are likely to be small given current horizontal accuracy requirements. Figure 2 shows the maximum amplitudes in semidiurnal, diurnal, long-period tidal bands as a function of longitude for two latitudes (42^{o} N, about the latitude of Boston, and 30^{o} N, about the latitude of Houston). Errors in the ocean tidal loading models are likely to be proportional to values in the figure. The rapid gradients tend to coincide with crossing the coastline. For short GPS occupations (measurements made in only a few minutes), the height coordinate could be in error by these amounts if ocean tidal loading is not accounted for.

E. Deformation

Modeling of vertical crustal motion (deformation) is an emerging area of research that has direct relevance for many members of the NGS user community. As precise measurement of heights using GPS and airborne LIDAR survey methods have become more commonplace, surveyors and spatial data producers and users have increasing requirements for vertical reference frame transformations. Ideally, vertical motion models would be incorporated into robust vertical transformation tools, similar to that which has been done for horizontal motion. The characteristics of vertical motion vary widely, including the magnitude, the spatial extent, and the physical mechanism causing the motion. Numerous agencies and research groups are measuring and monitoring vertical motion (often referred to as deformation), so a systematic effort at improving vertical modeling for geodetic applications would necessarily have to develop a means for incorporating data from diverse, but related vertical motion activities.

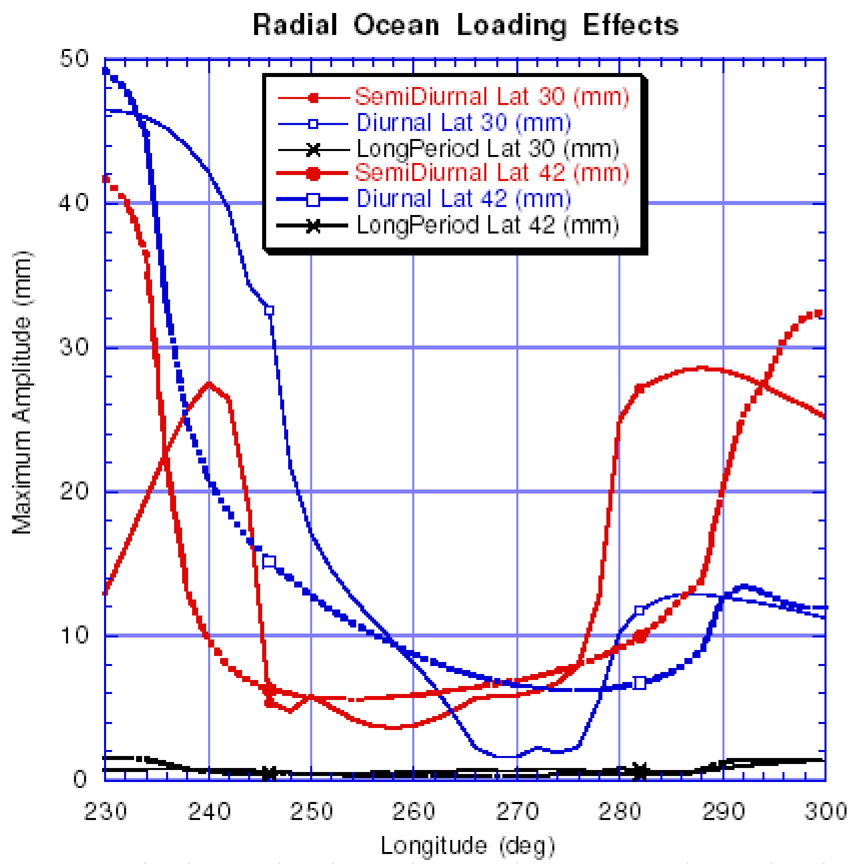

Figure 2: Magnitude of the ocean tidal loading contributions to radial position errors.

F. Absolute Gravimetry

The role of absolute gravimetry is primarily for geophysical studies where it is used as a means of measuring the gravimetric signal associated with height changes. This type of measurement is independent of GPS and other height change measurement systems and as such is potentially a very powerful tool for understanding height changes. Specially, it should be possible to separate height changes from post-glacial rebound (associated with upper mass flow) from height changes due to elastic rebound from recent ice melting. An example of absolute gravimetry results are shown in Figure 3 below.

While the comparison on absolute gravity results and GPS measurements should be a powerful technique for understanding the origin of height changes, this potential has not yet been realized. In general, finding results from absolute gravimeter measurements is difficult and their accuracy can be compromised by a lack of modeled ground water variations. An analysis by Larson and van Dam [2000] suggested that GPS provides a much more cost-effective method for studying postglacial rebound. Interestingly, in this paper published less than one year ago, showed only 4 measurements for the gravity changes at Churchill and not the extensive data set above, suggesting that even researchers working closely with absolute gravimeter data cannot obtain all of the results.

If absolute gravimetry is be continued at the NGS, then there should be a concerted effort to make available the data that are being collected so that many investigators can access and interpret the results. If this is not possible, then it seems that the funds being used for absolute gravimetry are not leading to answers of scientific problems.

G. Scope of the National Continuously Operating Reference System Infrastructure.

The national Continuously Operating Reference System (CORS) provides GPS users with a link to the National Spatial Reference System for position determination, and to monitor the stability of CORS positions to a high degree of accuracy. NGS is developing the national CORS network to meet a goal of providing full nationwide access. GPS data collected by NGS through this network is distributed to users via the Internet. Working with partners, NGS expects to extend the network from its present size of less than 200 sites to about 300 sites, enabling every location in the U.S. to be within 200 kilometers of a national CORS site.

In March of 2001, NGS held a CORS user workshop. Findings from this workshop are pertinent to the future CORS system development. Workshop participants characterized CORS as a cooperative model involving national, state, and other interests, and agreed that although the CORS network has a need for densification, current funding is inadequate to achieve significant expansion in a timely fashion. Users also noted that standards and specifications need improvement, and that NGS should seek the seamless integration of national and cooperative CORS stations.

The ERP endorses the concept of a seamless, integrated, and user-friendly CORS network that serves multiple users' needs. NGS's appropriate role is to provide GPS users with a link to the National Spatial Reference System for position determination, and to work cooperatively with state, local, private sector, academic, and other interests to extend the benefits of the federal and other investments. This network must support basic requirements for highly accurate positioning, navigation, and deformation information, while entertaining new uses, such as for flood management, precision farming, and weather prediction.

The ERP believes that NGS should play a strong role in helping to determine the optimum configuration of this infrastructure through national leadership, the management of scientific and technical issues, the transfer of information and technology, and coordination with partners. The role of NGS research should be to reduce uncertainties in deployment strategies by examining the technical means to achieve a desired level of performance (e.g. real-time, centimeter level positioning) for the least cost. Is an expansion of the network through the addition of more stations the only solution? For example, it is not too early to be considering the 'next generation CORS,' and how advances in GPS might alter the network assumptions. Given rapid changes in technology and the expected attributes of the next generation of GPS satellites, NGS should consider undertaking a benchmarking exercise. The activity would include examination of the original concept and goals of a nationwide CORS, the validation of existing and future user needs and performance requirements, including education;

development of a national view of strategic partnerships with states, and identification of key research questions. Finally, the value of investing in solutions for completion of the existing plan and for the future infrastructure should also be addressed. Traditional Geodetic Methods

H. Traditional Geodetic methods

The application of GPS to conventional surveying tasks has become wide spread, but the accuracy of GPS can be severely limited in certain environments. Specifically, in areas of dense overgrowth from trees, it is often not possible to track GPS signals, and in areas with large numbers of buildings, GPS results can be significantly effected by reflected signals from buildings, so called multi-path. For short measurement occupations, the effects of multi-path can produce errors in position estimates of several centimeters. Similarly, GPS signals that propagate through foliage can be significantly corrupted by reflections from the foliage.

A quantitative method for assessing the magnitudes of positions errors in the poor GPS observing conditions does not exist and given the role of NGS in setting standards, research into this area should be a high priority. Also to determine the accuracy of GPS in these conditions requires an independent method of position determination, which is best supplied by traditional measurements methods. NGS should retain survey teams proficient in conventional surveying methods.

I. Network and Data Processing

The U.S. Global Positioning System (GPS) constellation of satellites plays a major role in regional and global studies of Earth. In the face of continued growth and diversification of GPS applications, the worldwide scientific community has made an effort to promote international standards for GPS data acquisition and analysis, and to deploy and operate a common, comprehensive global tracking system. As part of this effort, the International GPS Service (IGS), along with a multinational membership of organizations and agencies, provides GPS orbits, tracking data, and other high-quality GPS data and data products on line in near real time to meet the objectives of a wide range of scientific and engineering applications and studies. The Global Data Centers archive and provide on-line access to tracking data and data products. The online data are employed by the Analysis Centers to create a range of products, which are then transmitted to the Global Data Centers for public use. This web site is part of the IGS Central Bureau Information System (CBIS), providing both IGS member organizations and the public with a gateway to all the IGS global data product holdings, as well as other valuable information.

The IGS global network of permanent tracking stations, each equipped with a GPS receiver, generates raw orbit and tracking data. The Operational Data Centers, which are in direct contact with the tracking sites, collect the raw receiver data and format them according to a common standard, using a data format called Receiver Independent Exchange (RINEX). The formatted data are then forwarded to the Regional or Global Data Centers. To reduce electronic network traffic, the Regional Data Centers are used to collect data from several Operational Data Centers before transmitting them to the Global Data Centers. Data not used for global analyses are archived and available for online access at the Regional Data Centers.

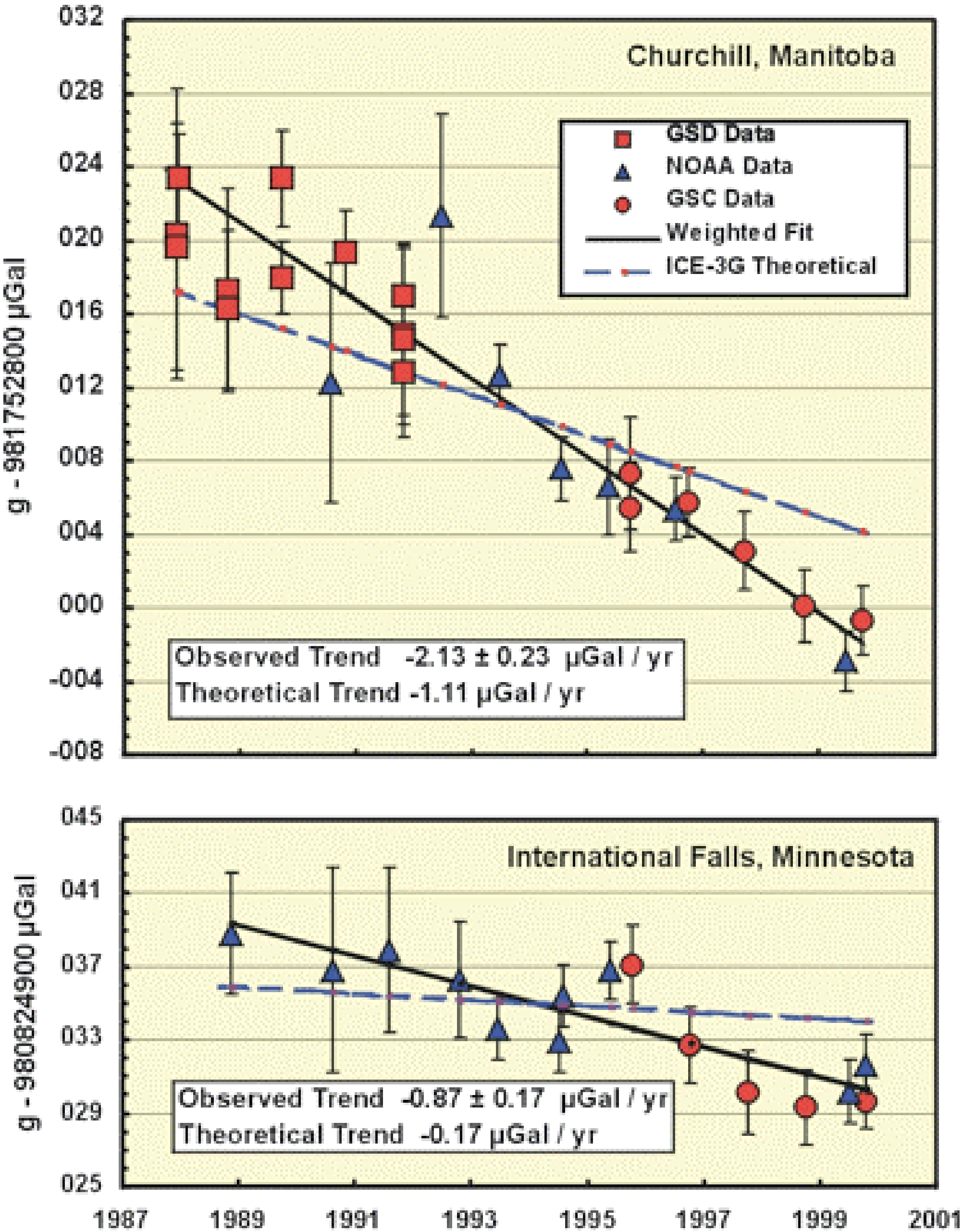

Figure 3: Absolute gravimetry results (results obtained from Natural Resources Canada http://www.pgc.nrcan.gc.ca/geodyn/mid_tilt.htm) showing the effects of post-glacial rebound. The conversion to height rate of change, if the cause is post-glacial rebound is –6.5 mm/□gal [Wahr *et al.,* 1995] suggesting that the height rate for Churchill should be 13.8±1.5 mm/yr. Current GPS estimates from the IGS combined solution 9.8±0.5 mm/yr.

J. Registration of Remote Sensing Data

Remote sensing data is playing an increasingly large role in providing data about crop status, resource management and infrastructure. Since many of the remote sensing systems are scanning device rather than the traditional optic lens photographic systems, precise registration and distortion characteristics are critical to geographically registering the image data. GPS data can be used to determine the positions of identifiable objects in an image and in turn can be used to determine the coordinates of all points in an image. The ability to register remote sensing data (i.e., convert the natural coordinates of the image to geographic coordinates) would be of benefit to many segments of the US economy and NGS is encouraged to develop a research program in this area.

K. Future Geodetic Systems: Requirements and Utility

The rapidly changing technologies for positioning and spatial imaging demand an evolving research and development effort in order to keep current. The advent of GPS modernization with additional civil frequencies and the design and integration of GPS III strongly suggest that the US National Geodetic Survey should be leading the effort to represent the national interests with respect to precise positioning and act as a two-way conduit for information and technology with the appropriate user community and other US agencies.

NGS should be more actively involved and engaged in these developments. Keeping abreast of the potential other GNSS systems is equally important (i.e., Galileo), the expertise within the NGS should have the ability to asses or understand the potential use of these other systems, either in-house or through expanded partnerships with the university and US research community.

L. Underwater Geodesy

For many geophysical problems, especially those related to deformation monitoring, being able to accurately position (sub-centimeter) objects on the ocean bottom would greatly enhance our knowledge of the differences between oceanic and continental tectonics. The fundamental problem here is that due to the interaction between electromagnetic radiation and water, especially highly conductive seawater, it is not possible for electromagnetic signals to propagate any sizable distance in water. Sound waves are the only signals that can be successfully propagated through water. However, the speed of sound in water is highly dependent on temperature, density and salinity making sound waves difficult to use for precise positioning underwater. Several groups are developing this type of measurement system and at this time it would seem best for these measurements to be continued in a research mode by these groups. If an accurate underwater system can be developed, then NGS should consider implementing such as system for its own research program.

VI. ASSESSMENT OF THE NGS MANAGEMENT OF SCIENCE

The ERP discussed the means by which the NGS research agenda is defined, supported, and reported. The sections of the NGS internal assessment that deal with this issue are "Reporting and Feedback Processes" and "Goal Setting." The ERP believes that the NGS research enterprise can be strengthened with the development and implementation of a more systematic and rigorous science planning process. The objective would be to enhance strategic goal setting, business operating procedures, annual project selection, information gathering and feedback mechanisms, and outreach to users. Through addressing these key areas, the NGS should be better able to document how it makes decisions, ensure that research priorities and projects are relevant to client needs, and gain Administration, Congressional and client support for programs.

The internal assessment describes several facets of the current goal setting and execution process for research. Goal setting involves three potential contributions: higher level direction and mandates; individual researcher initiatives; and external influences. The assessment states that the dominant practice has been to rely on researchers to identify research topics that hopefully will have value, but that this process does not have a formal and consistent mechanism for gaining external input to inform and validate decisions. It is notable that the NGS has recently implemented several changes to improve planning and reporting, including the *Quarterly Report on Research*, and the *NGS Roundtable*. In contrast, the internal assessment also states that there are "…no reporting or feedback channels to NOS or NOAA that are specific to research." The NGS also is seeking to improve the connections between the NGS Research Plan and the overall NGS Work Plan.

As portrayed in the internal assessment, the NGS research agenda appears to result from a number of ad hoc activities. The science panel believes that these activities do not necessarily describe a complete, logical, and systematic process, one that enables all interested parties to understand why, how, and when to be involved. The process of setting the goals for NGS research should be both strategic and tactical. Strategic goal setting should result from an iterative and inclusive process that looks to future conditions, the needs of existing and potential users, and the national interest. It is important to understand and focus on the customer base, or drivers, for NGS research. A fundamental strategic issue would be to determine the appropriate balance among operations-driven research and curiosity-driven research. The long-term strategic view can be used to craft supporting initiatives on different time scales and provide a basis for prioritizing work. In this context, annual decisions can be made about individual research projects based on immediate need, demonstrable impact, mission support, available resources, and other factors.

The current NGS Research Plan provides a start for developing a more robust NGS strategic view of research. However, as noted in the assessment, it appears that higher-level mandates and external input apparently have had little past influence on the process or decision-making. These are important inputs to consider if NGS chooses to revisit the Research Plan. The assessment also indicates that the work items in the current Research

Plan will be harmonized with the overall NGS Work Plan during FY 2001. This seems to suggest a process of "retrofitting" the Research Plan to meet the objectives of the Work Plan, rather than developing an overall NGS strategic view that includes both operational and research perspectives as fundamental inputs, and how they must interrelate.

The overall management of science planning process might be treated as a business process with business objectives and operating procedures. Building a credible and widely shared strategic view is useful for enlisting long-term support and guiding shorter-term tactical decisions. NGS researchers need to be active in soliciting input from users, and users should have an understanding of how to engage with researchers. This extends to communicating clearly the role and scope of NGS research, and the capabilities that users can tap. The NOS Science Council, for example, might serve as a mechanism for facilitating a broader base of potential user interactions with NGS research, including reviews of NGS research activities at the NOS level to help steer the development of future objectives. There must be a real and sufficient "market" for NGS research that continually evolves and adapts to user needs. In taking a more businesslike approach, NGS should articulate program goals and activities, identify existing and potential collaborators and users, specify the utility of NGS research to the user base, evaluate strategies to secure funds, and incorporate performance standards, a timetable, and budget.

The NGS should attempt to standardize and clearly communicate its project or activity selection process, leading to sustainable engagement with both collaborators and users. NGS should be concerned with acquiring the necessary level of information to discriminate user's stated desires for research results versus their actual or proposed use of the results. During project formulation, NGS should work closely with users to ensure the relevance and effectiveness of proposed efforts, and with other NOAA line offices, as appropriate, to focus the broader capabilities of the agency on solutions to problems.

If NGS research projects are selected through both formal and informal mechanisms, this should be stated and made clear to the user. Formal mechanisms for collaborators and users to engage with NGS might include consulting strategic plans, working with peer-review panels, reviewing needs assessments, and accessing guidance on how to propose specific projects. Informal mechanisms might rely upon networking with leaders from business, academic, government, and other communities. In practice, project selection is really a year-round process, and the NGS' senior managers should continually assess opportunities to develop new research activities.

The utility of NGS research should benefit from an approach that identifies, articulates, measures, and is responsive to the needs of users. NGS should consider developing metrics to assess research program processes, outputs, and impacts. Evaluation should be conducted not only to determine the quality of enhancements to scientific and technical expertise, but also for how well users apply information for decision-making. User input can be solicited to refine program emphases, and identify and design research projects through surveys, needs assessments, workshops, evaluations, and direct interactions. NGS outreach activities should serve to educate users about research products and results, and build awareness about value. For example, what client base is the research most intended to target? Are information-gathering mechanisms in place to solicit useful feedback? Can existing data, products, and applications be shared with a broader audience? Is there a group of potential users that currently are not identified, or are emerging? A broad and diverse set of users and collaborators is essential for advocacy and resource stability.

VII. NGS REVIEW IN CONTEXT OF NOAA SAB SCIENTIFIC THEMES

NOAA SAB criteria consist of eight themes. The ERP assessment of geodetic research in the context of those themes reached the following conclusions

1) Scientific Merit (*SAB theme of quality and credibility*): The degree to which the program and its components will advance the state of the science, discipline, or understanding through the use of state-of-the-art methods.

That degree is compromised presently. The needs are great, the opportunities enormous and the challenges can be addressed in an efficient and timely manner. However, the staffing is below critical to address current and future research topics. The existing NGS Research Plan establishes a number for research staffing, but this number is insufficient to address existing research issues let alone take on new initiatives. Further the existing and even planned staffing is insufficient to allow for intra-agency linkages from NGS to NOS, NWS, OAR and NESDIS, all necessary for NOAA to meet its' mission.

Albeit, NGS and its partners from the University, other agency both national and international and private industry could achieve the level of science and technology needed and possible but NGS must develop and implement a planning and management of science process.

2) Relevance of Science and Science-based products and services (*SAB themes of timeliness and scale and science/policy connections*): The degree to which the organization seeks constituent input in the selection, design, implementation, and evaluation of science projects and programs, and/or, the degree to which the science endeavors satisfy legislative mandates.

This is an area where the value of what NGS does and could, should do is of fundamental and foundational importance to the Nation.

Standards are "principles, rules and measures by which we can make or have made critical judgments." And, in NGS parlance, principles and rules are based on measures. Thus, the national law that states that "citizens in the United States shall act according to established Standards for Surveying and the establishment of Control for Boundary, and property definition as defined by the NGS" has a basis in fact. While maintaining accepted standards is not a difficult task, adjusting established standards to take advantage of new technology has presented unique challenges to the NGS. The principle motivations for standardization are needs to reduce costs throughout all sectors requiring geodetic information, to increase interpretability, to create accepted property lines, and to improve safety, to name several. Without reliable, dependable geodetic information, our every day lives would become chaotic and confrontational very quickly.

3) Delivery of Science-Based Information**:** The degree to which program results and findings are transferred to NOS and external constituent programs, and the changes in client practices resulting from the delivery of such findings.

NGS needs to revisit its' communication network and build a more interactive process by which user workshops are held within NOS, across NOAA, with other interested agencies and with user groups. These partners and constituents are expected to articulate their use of NGS R&D, their needs and the architecture that would work best to facilitate the transfer of NGS technology.

4) Innovation: The degree to which new approaches to solving problems are employed and the degree to which the program focuses on new types of coastal science issues.

The present NGS staff has done a credible job at being innovative to address research issues. However, the lack of sufficient numbers of research staff and the lack of resource support for this staff has undermined the capacity of the NGS R&D staff to be truly innovative. This condition holds across the scientific enterprise of geodesy within the NGS/NOS.

5) Impediments to Progress: The degree to which impediments to progress are overcome through creative problem-solving, partnerships, and perseverance.

NOS/NGS management should assess what is being done and what needs to be done that is not being done and then request the necessary staffing and resources to address those issues. There appears to have been a serious atrophying in the in house capabilities of the NGS of involvement of NGS of a decade or two ago and that which exists presently. The present strategy of relying on retirements to provide the research staff needed may not be the best resource management plan and should be reconsidered. Several examples are given below to show that NGS has lost capacity.

Precise orbit determination of the GPS satellites is essential to producing highly accurate geodetic measurements. When GPS was being evaluated for civilian use in the mid-1980's, the NGS was active in research for precise orbit determination (POD). The NGS led the Coordinated GPS Network (CIGNET) within the auspices of the International Association of Geodesy. This was the first attempt to collect data from a sparse yet globally distributed GPS network to provide data for GPS satellite orbit determination. Incorporation of space geodetic techniques into the conventional geodetic systems requires an active applied research section within the NGS and NGS personnel have not been able to participate at the national and international level for lack of numbers and resources.

The NGS has one of the centers producing precise GPS orbits for more than a decade. Reviewing recent performance shows the NGS daily orbits at the 8cm level 3d-wrms – the best analysis centers are capable of consistently producing 2-4 cm orbits and satellite/station clocks at the 0.2 ns level. The NGS currently does not participate in the sub-daily orbit determination and prediction, nor in the rapid satellite and station clock estimation, there is a sense that much of the GRD resources are devoted to sustaining a growing GPS network operations and product generation. Here again, additional resources and talent, or partnerships with other US organizations could enhance NGS performance. Improvements could be realized if resources for research were available,

To achieve a real-time positioning system, the NGS must either develop the in-house capability for generating sub-daily orbits (even hourly or real-time orbits) and clocks or develop partnerships with other organizations with demonstrated expertise in developing such systems (e.g., NASA/JPL). In any case, no system is close to being a "black-box". A number of international agencies with mandates similar to NGS are joining together to establish a real-time global network to support their real-time national activities. For example, both Canada and NGS, among others, have real-time national infrastructures, but to achieve real-time precise positioning requires a global network and some significant development for real-time system processing.

A key component of real-time positioning using GPS is accurate modeling of the satellite clocks. Errors in clock characterization are the dominant source of error in real-time positioning. Models that are capable of predicting short-term clock behavior need to be developed to a level that is consistent with the errors in orbit modeling. While there have been significant developments in improved orbits, the area of clock models has received little attention. This work requires significant research and can be carried out in cooperation with other national and international institutions. Researchers must be prepared to adapt models to clocks employed in the most recent satellites as well as in future systems. NGS must become engaged.

Modeling of vertical crustal motion (deformation) is an emerging area of research that has direct relevance for many members of the NGS user community. As precise measurement of heights using GPS and airborne LIDAR survey methods have become more commonplace, surveyors and spatial data producers and users have increasing requirements for vertical reference frame transformations. Numerous agencies and research groups are measuring and monitoring vertical motion. Here again a systematic plan and approach within NGS and between its partners must be developed for the issues to be properly addressed and resolved. The problem? People and resources.

5) Inclusion of education and social science components (*SAB education and social science themes)*: The degree to which science projects and programs include social science components and an educational element to enhance public and constituent awareness and application of the scientific results and findings.

NGS does not have truly organized social science or public education components but the value of its R&D is such that a modicum of effort would be of great value to the organization. The products derived from its' science is of such fundamental importance to the Nation that the lack of a coordinated, orchestrated effort in this area is a missed opportunity for building constituent and public support. Moreover, K-12 children would benefit from appropriately packaged learning modules on the value and utility of NGS products and services.

7) Partnerships and leveraging: The degree to which connections are made to existing or planned national and international efforts; partnerships with other NOAA Line Offices, other federal agencies, and non-governmental organizations.

The opportunities are present. Leveraging opportunities are enormous both nationally and internationally. The will exists within the geodesy group but the capacity is lacking. See # 4 above on Impediments to Progress.

8) Diversity.

NGS has traditionally fostered a diverse workforce. The geodesy program consisting of 19 staff total is ~ 3/4ths male and1/4th female. There are two Asians and one Hispanic on the staff. While this is not representative of national demographics the nature of geophysical sciences in general and geodesy in particular has been challenged nationally by a lack of engagement of traditionally underrepresented groups. Nonetheless, the NGS and GRD appears to have made and professes that it will make every effort to be inclusive and supportive of opportunities for underrepresented groups. The NOAA Minority Serving Institution Initiative presents an opportunity for NGS/GRD to expand its scientific workforce and thus build internal capacity.

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IX. ACRONYMS (in order of appearance in text)

NOAA National Oceanic and Atmospheric Administration
NOS National Ocean Service
NGS National Geodetic Survey
SAB Science Advisory Board
ERP External Review Panel
NSRS National Spatial Reference System
CORS Continuously Operating Reference System
GPS Global Positioning System
GRD Geosciences Research Division
FACA Federal Advisory Committee Act
GPS Global Positioning System

GIS Global Information System
FAA Federal Aviation Authority
WAAS Wide area Augmentation System
PWV Precipitable Water Vapor
RF Radio Frequency
POD Precise Orbit Determination
SCIGN Southern California Integrated GPS Network
NASA National Aeronautics and Space Administration
JPL Jet Propulsion Laboratory
IGS International GPS Service
CBIS Central Bureau Information System
RINEX Receiver Independent Exchange
FY Fiscal Year
R&D Research and Development
CIGNET Coordinated International GPS Network
g Gravitational Acceleration
IAG International Association of Geodesy
LIDAR Light Detection And Ranging

X. APPENDICES

Appendix A. Science Advisory Panel External Review Team Members

Mr. Dean Gesch
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