Proceedings of the 2010 Federal Geospatial Summit on Improving the National Spatial Reference System

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Contents

Author's Preface

Although this is a "proceedings" document, the authors expressly attempted to create a document different than those commonly falling under that name. Too often, the proceedings of a large and important meeting are a non-narrated collection of scientific papers presented at such a meeting. While useful in their own right, such proceedings often fail to capture the discussions and interactions that followed the presentations.

In writing these proceedings, the authors have attempted to capture those critical audience interactions; after all, the entire point of the Summit was for the National Geodetic Survey to receive feedback from its user base and plan a course of action to address that feedback. In essence, therefore, these proceedings will contain not only the material presented, but also how that material was received.

In some cases, the authors have felt it necessary to interject a relevant, clarifying comment in these proceedings. As these comments were not part of the meeting at the time, they have been inserted either as separate text boxes or as footnotes.

Finally, a note on the titles of audience members; because a complete list of the appropriate titles for each audience member (Dr., CAPT, etc.) was not available, we made no attempt to introduce titles for members of the audience.

Acknowledgements

An event the size and scope of the 2010 Federal Geospatial Summit cannot succeed without the hard work and dedication of many people at all levels. I wish to acknowledge and sincerely thank the following people who contributed to the overall success of the Summit.

First, a special thank-you goes to NOAA's CIO Mr. Joe Klimavicz for opening the Summit with his inspirational keynote speech. I am also deeply thankful to two previous NGS directors, Mr. Dave Zilkoski and Dr. John Bossler, for imparting the wisdom of their experience from the country's last datum transition.

To all the NGS speakers and panelists who took the time to prepare and participate, I give sincere thanks and praise. Your contributions were the heart of the NGS message. And I especially wish to thank Mr. Dave Doyle for his excellent work as Master of Ceremonies.

The logistics of the Summit, from planning to execution, were successfully led by the hard work of the Summit Planning Committee, so a big "thank-you" goes to Renee Shields, Knute Berstis, Mark Eckl, Christine Gallagher, Stu Kuper, Zelda Lecoat, Sonita Tiwari, and Jim Tomlin. And I would also like to thank the numerous NGS volunteers who staffed tables, operated the microphones, ran errands, and simply did everything behind the scenes that was needed during the Summit.

Of course, hosting and attending the Summit was hungry work, and I cannot overlook thanking our caterer, Woodside Deli, for the delicious morning snacks and lunches provided. And on that topic, I was very pleased to have had the caterer supported by the sponsorships of The Coast and Geodetic Survey Heritage Society, The American Association for Geodetic Surveying, The Potomac Region Chapter of the American Society for Photogrammetry and Remote Sensing, The National Society of Professional Surveyors, as well as our two corporate sponsors ESRI and TOPCON.

Last, but absolutely not least, I must give my deepest thanks to the attendees of the Federal Geospatial Summit. Thanks go to both the agencies that paid for their employees to travel, as well as the attendees themselves for their input. Because NGS was in "listening mode" for a great part of the Summit, it was due to their engagement and direct feedback that NGS policy will be improved as we move toward the future and an improved National Spatial Reference System.

Dru Smith
Team Lead, 2010 Federal Geospatial Summit Planning Committee

Introduction

For 203 years, the National Geodetic Survey (NGS)—previously the Survey of the Coast, the Coast Survey, and the Coast and Geodetic Survey—has performed the mission of establishing a consistent coordinate frame for the mapping of the Nation. This mission was refined in 2009 to reflect today's terminology:

To define, maintain, and provide access to the National Spatial Reference System to meet our Nation's economic, social, and environmental needs

While the name of the agency and the terminology of the mission have changed over the span of two centuries, one element of performing the mission has not changed dramatically until the last two decades: the distribution of geodetic control through fixed coordinates on pre-surveyed passive geodetic control marks. Surveying and measurement tools changed in those centuries, but the use of passive marks has remained the primary method to access consistent coordinates for mapmaking in the United States, in a system known as the National Spatial Reference System (NSRS). Two elements of the NSRS, known historically as the horizontal datum (North American Datum of 1983 [or NAD 83]) for determining latitude and longitude, and the vertical datum (North American Vertical Datum of 1988 [or NAVD 88]) for determining elevation, are still primarily accessed through passive control using traditional survey methods, though space-based positioning such as the Global Positioning System (GPS), has been challenging this methodology since its inception.

For a variety of reasons, especially the dynamic movements of the Earth's crust and the existence of GPS, the NSRS contains systematic errors. In 2008, NGS issued a Ten-Year Plan announcing the intent to remove these systematic errors and change the style of performing its mission from one relying on passive marks to one relying on GPS. However, implementation of the Ten-Year Plan requires that NGS work collaboratively with the users of the NSRS, and on May 11 and 12, 2010, NGS hosted a Federal Geospatial Summit on Improving the National Spatial Reference System. Invitations were sent to more than 700 individuals in the Federal, state, tribal, and municipal governments, as well as members of academia and private industry. Over 200 participants attended in person, with another 200 participating via a webcast teleconference.

Prior to the Summit, a 12-page white paper entitled "Improving the National Spatial Reference System" was distributed to registrants and online. It contained detailed information on both the nature and causes of the systematic errors and deficiencies in the current datums of the NSRS. The white paper builds upon the NGS Ten-Year Plan, but with significantly more detail, and with a strong emphasis on definitively answering the question "Why replace NAD 83 and NAVD 88?" The paper can be found in **Appendix A.**

The first day of the Summit began with presentations by NGS, followed by panel sessions to respond to audience questions. On the second day, users were invited to present their own information and concerns, and a final panel session attempted to address them. The agenda is reproduced in **Appendix B.**

Throughout the Summit, the Master of Ceremonies was Mr. Dave Doyle, Chief Geodetic Surveyor of NGS, who handled with professional aplomb the task of introducing speakers, moderating, and maintaining the smooth flow of the Summit program.

List of Abbreviations

AAGS	American Association for Geodetic Surveying
ACSM	American Congress on Surveying and Mapping
BLM	Bureau of Land Management
C&GS	Coast & Geodetic Survey
CO-OPS	Center for Operational Oceanographic Products and Services
CORS	Continuously Operating Reference Station
DORIS	Doppler Orbitography & Radiopositioning Integrated by Satellite
ECEF	Earth-Centered Earth-Fixed
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FGCS	Federal Geodetic Control Subcommittee
FIRM	Flood Insurance Rate Map
GIS	Geographic Information Systems
GLHCC	Great Lakes Hydrographic Coordinating Committee
GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite Systems
GOCE	Gravity field and steady-state Ocean Circulation Explorer
GPS	Global Positioning System
GRACE	Gravity Recovery And Climate Experiment
GRAV-D	Gravity for the Redefinition of the American Vertical Datum
HARN	High Accuracy Reference Network
IAG	International Association of Geodesy
ICAO	International Civil Aviation Organization

IERS	International Earth Rotation and Reference Frame Service
IGLD85	International Great Lakes Datum of 1985
IGS	International GNSS Service
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
LIDAR	Light Detection and Ranging
LOCUS	Leveling Online Computational User Service
NAD 27	North American Datum of 1927
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NGA	National Geospatial-Intelligence Agency
NGS	National Geodetic Survey
NGVD 29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCAN	Natural Resources Canada
NSRS	National Weather Service
OPUS	Online Positioning User Service
RADM	Rear Admiral
RTN	Real Time Network
SLR	Satellite Laser Ranging
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
VLBI	Very Long Baseline Interferometry
VOR	VHF Omnidirectional Range
WGS 84	World Geodetic System of 1984

Day 1: May 11, 2010

Overview

The first day of the Summit was broken down into four primary sections. The first half of the morning was set aside entirely for presentations, setting a historical context of NGS and the NSRS as a whole; the second half of the morning was composed of presentations on the problems with NAD 83 and NAVD 88 and what plans NGS has proposed to fix them. The early afternoon was filled with a panel session to concentrate on answering questions from the audience, based on what had been presented, but specifically surrounding the geometric reference frame which will replace the (historically called) horizontal datum, NAD 83. Finally, the late afternoon had a similar panel session, but dealing with the geopotential reference frame that will replace NAVD 88.

Day 1, Early Morning: "Historical Context"

1. Keynote: Mr. Joe Klimavicz, CIO of NOAA

After some administrative details, Mr. Dave Doyle introduced the keynote speaker, Mr. Joe Klimavicz, Chief Information Officer of NOAA. Mr. Klimavicz spoke of the rich history of NGS, beginning with its roots as the first civilian scientific agency (established by President Thomas Jefferson in 1807) under the moniker Survey of the Coast. He went on to praise the work done leading to today's modern NGS and also pointed out the pitfalls of relying entirely on passive geodetic marks when more modern technological methods exist. To quote Mr. Klimavicz:

"A perpetual coordinate, computed from a single survey, on a mark set into the ground of this very dynamic Earth is no longer as reliable as we once thought."

He went on to recognize the impeccable work done by NGS in managing the CORS network, which is the cornerstone of modern NAD 83 access. He further acknowledge the foresight in the GRAV-D project, which is critical to replacing NAVD 88. Mr. Klimavicz finished by quoting a recent study of the economic benefits of both CORS and GRAV-D which showed that the NSRS provides more than $2.4 billion in potential annual benefits to the U.S. economy.

Mr. Klimavicz's entire speech is reproduced in **Appendix C.**

2. Welcome: Ms. Juliana Blackwell, NGS Director

Ms. Blackwell began by thanking the keynote speaker, and then officially welcoming everyone. She went on to explain that the purpose

of the two-day Summit was to enable *two-way communication* between NGS and the NSRS user community. She emphasized a key point from the white paper (see Appendix A)—specifically that NGS serves the dual masters of "scientific accuracy" and "customer service." This means that any improvements NGS makes in the NSRS to increase accuracy must be balanced against their impact in the user community.

Ms. Blackwell reminded the audience that the improvements to the NSRS being discussed at the Summit had already been planned for two years prior, in the NGS Ten-Year Plan (2008-2018). She reiterated that science and technology were driving these planned improvements, and that there have been significant changes in positioning technologies over 20 years since the last datum change. She again stressed the need to *balance good science with good customer service.*

She reminded the audience that much could be learned about transitioning to the new datums by examining the previous datum transitions. Ms. Blackwell introduced the next two speakers, both former directors of NGS, who also during their careers, served as the original project managers in transitioning from the 1920's datums to the 1980's datums.

3. Lessons Learned from NAD 83: RADM (ret.) John Bossler, Ph.D, Former NGS Director

Dr. Bossler presented a thorough overview of various problems encountered and overcome when replacing NAD 27 with NAD 83. These problems fell into three major categories: *financial, technical, and user.*

Beginning with the financial aspect, Dr. Bossler indicated that the amount of money available for the transition to NAD 83 was inadequate. He was advised to *brief the assistant administrator of NOAA* on the plans, and through this briefing and subsequent briefings, he found that more and more money was being made available. Additionally, he found that one idea (of using convicts as a form of contracted labor) was difficult at first, but proved to be a successful venture when a successful screening process was used.

Moving on to the technical problems, Dr. Bossler related the difficulty of solving an observation equation with approximately one million unknowns.[1] Computer space was also named as a significant

1 *Thankfully, because the replacement for NAD 83 will not be through angles and distances measured between hundreds of thousands of passive marks, but instead will be entirely CORS-based, this exact problem will not crop up.*

challenge. Furthermore, the stability of least squares needed to be established, so resources were assigned to research this problem.

Because astronomic observations needed to be corrected for the deflection of the vertical, study of the gravity field and the geoid was also an inherent part of NAD 83. The geoid was "pretty bad at that time" according to Dr. Bossler, so *a team was built to shore up the geoid* as best as data at the time would allow. Although humorously stated, the solution to this was that many team members were backing up data by taking copies of it home.

Finally, Dr. Bossler mentioned some user problems, the first of which was general lack of caring or understanding by most surveyors as to why the NAD 27 datum wasn't good enough. The mentality was "it works fine in my local community," and *surveyors often didn't think about the country-wide issues of the datum as a whole.* He mentioned resistance by other federal agencies to the change, but this resistance was reduced through cooperation and compromise.

Dr. Bossler went on to tell a cautionary tale about how NAVD 88 money came from other parts of C&GS, and how this led to some in-house enmity. Finally, continuing the financial theme, he mentioned that the recent socio-economic report [Leveson, 2009] stating that the NSRS is worth billions of dollars to the Nation should be leveraged for gaining funding support.

Dr. Bossler concluded with a few summary remarks. First, he cautioned that *users dislike multiple coordinates* on a point. Second he felt GRAV-D was "superb" and finally, the concept of replacing NAD 83 with CORS and giving epoch based coordinates and velocities to users was "the neatest thing" he had seen in his entire career.

The slides used by Dr. Bossler are reproduced in **Appendix D.**

The lessons learned from this presentation which seem directly relevant to today are as follows:

1. **Engage senior leadership of NOAA in these plans.**
2. **Consider a variety of sources of labor when a huge, but temporary, task needs to be done.**
3. **Assign appropriate research to solving the science problems that impede progress.**
4. **Make sure you have enough computational power, space, and secure backups.**
5. **Remember that NGS has a responsibility to the national correctness of the datum, even if**

user feedback indicates that on a local basis "everything seems ok."

6. **Identify the roadblocks which other federal agencies will have in adopting the new datum, and address them long before the transition.**
7. **Be cautious about, but not afraid of, changing coordinates when such a change is warranted.**

4. Lessons Learned from NAVD 88: Mr. David Zilkoski, Former NGS Director

Mr. Zilkoski began by mentioning that he was able to learn from the NAD 83 process, as NAVD 88 followed it by a few years. He continued with cautionary notes that, despite giving advance notice, *there will always be users who felt insufficient notice was given.* He emphasized keeping users informed and involved. He stressed that multiple avenues for user feedback exist and that NGS should exploit them all, including *professional societies, private industry,* state and local governments, and academia.

Mr. Zilkoski echoed Dr. Bossler's sentiments that users were generally resistant to datum change, either because there wasn't a well-understood reason for the change or because there was a simple dislike of change in general. He argued that, by engaging more people early on in the process, some of the difficulty would be alleviated. And while he believed FEMA's early adoption of NAVD 88 was a success, he felt the regional offices of FEMA did not understand the order being issued by FEMA headquarters.

He continued by calling for the early creation of models and tools long before the datum change. However, he cautioned the NSRS users that, unless they speak up with their requirements, NGS will build what models and tools they think are needed, not necessarily ones that are truly needed.

His next cautionary note was for NGS to ensure the datum change is planned and staffed from beginning to end, so the implementation is not forgotten after the scientific work is complete. However, he added that the responsibility for successful adoption of the new datum was not solely NGS's, but was shared by the NSRS user community. He pressed for the *user community to provide information to NGS* as to how the proposed datum change would impact them and to work with NGS to minimize disruptions.

The lessons learned from this presentation which seem directly relevant to today are as follows:

1. **Engage with professional societies, private industry, state governments, local governments, and Universities.**
2. **When engaging with FEMA and other federal agencies with de-centralized working offices, engage with those regional offices.**
3. **Ask the NSRS users what models and tools they need for a successful datum transition.**
4. **Build fully-staffed teams in NGS to handle all aspects of the datum transition, from beginning to end, including implementation.**
5. **Request information from the user community regularly and persistently until it is provided, and then make use of that information.**

Day 1, Late Morning: "Plans to Modernize"

5. Overview of the NGS Ten-Year Plan: Dr. Dru Smith, Chief Geodesist of NGS

Dr. Smith began by reminding the audience of the unique situation in which NGS finds itself; specifically NGS creates the NSRS, but is not the primary user of it. He presumed most of the audience had read the Ten-Year Plan, as it had been in the public domain since 2008, but wished to at least establish some key points from the plan. He began by outlining the laws and mandates that give NGS the role and authority to provide the NSRS to the Nation by quoting relevant portions of the Coast and Geodetic Survey Act and the Office of Management and Budget's Circular A-16.

However, he went on to mention that, despite the mandate given to NGS regarding the NSRS, changes to the NSRS have always been agreed to through the Federal Geodetic Control Committee/Subcommittee. As such, the changes proposed in the Ten-Year Plan and discussed at the Summit will ultimately need to be agreed upon by the FGCS.

Dr. Smith returned to a theme mentioned by Juliana Blackwell, that NGS has the dual responsibility of scientific accuracy and customer desire for constancy of coordinates. In order to properly hold to both of these responsibilities, NGS is leaning toward the adoption of a "semi-dynamic datum," a datum where coordinates can be fixed at an epoch, but whose velocities are known and available to the community,

and where distortions in the network are fixed intermittently. As an example, the rotation of the North American Plate can be modeled and removed so that latitude and longitude are kept constant in portions of "stable" North America. As further example, he referenced the rapidly changing heights in the Gulf of Mexico coastline and proposed that these heights should never be fixed, but rather have their velocities reported as part of the point's metadata. He cited this choice as a way of supporting safety of life and property.

Dr. Smith closed with an analogy between the proposed datum transition and the transition to digital TV that occurred in 2009. That transition was based upon a great idea, but was poorly planned, poorly announced, and poorly understood. At its core, he noted that it failed, because the public did not perceive any need for the change. He called it "a classic example of a solution *to a problem that people didn't know existed.*" He suggested that the Summit was NGS's attempt to instruct the NSRS user community of the actual need for the change, and avoid the pitfalls seen in the digital TV transition.

Dr. Smith closed with solemn words that he felt the power entrusted to NGS to create the NSRS must not overshadow the responsibility to the users of the NSRS.

6. Replacing NAVD 88: Dr. Dan Roman, Geodesist, NGS

Dr. Roman began with an overview of what a vertical datum actually is, and he distinguished between the ideal definition (being a surface of zero height) to its actual realization (being a point cloud of published heights on passive bench marks). He noted that NAVD 88 and its predecessor NGVD 29 both fall into this categorization.

Dr. Roman then went on to explain the current known deficiencies with NAVD 88. Among these deficiencies were two primary ones:

NAVD 88 suffers from use of bench marks that:

- Are almost never re-checked for movement
- Disappear by the thousands every year
- Are not funded for replacement
- Are not necessarily in convenient places
- Don't exist in most of Alaska
- Weren't adopted in Canada
- Were determined by leveling from a single point, allowing cross-country error build-up

NAVD 88 suffers from a zero height surface that:

- Has been proven to be ~50 cm biased from the latest, best geoid models (GRACE satellite)
- Has been proven to be ~ 1 meter tilted across CONUS (again, based on the independently computed geoid from the GRACE satellite)

Dr. Roman was clear that NAVD 88 is the current vertical datum in the NSRS and there are both short- and long-term fixes to these problems. As a short-term fix, he noted NGS strongly supports "Height Modernization Surveys." These surveys are performed with GPS, holding NAVD 88 bench marks fixed, to disseminate NAVD 88 heights throughout a survey via the NGS 59 (Zilkoski et al, 2008) guidelines, rather than traditional leveling. In some regions, some leveling must still be used to validate or populate enough vertical control for NGS 59 methods to be effective.

Dr. Roman went on to discuss long-term fixes, indicating that re-leveling the NAVD 88 network was a poor choice both financially and scientifically. As an alternative, he advocated the path outlined in the NGS Ten-Year Plan. That plan calls for replacing NAVD 88 with a new vertical datum that is defined by a gravimetric geoid model and accessed through GNSS and that geoid model. Further details on the improvement to data and theory necessary to create such an accurate gravimetric geoid are found in the GRAV-D plan. The targeted absolute accuracy achievable at any given point would be approximately 2 centimeters (from a mix of GNSS and geoid errors), but this was an improvement over the current cross-country systematic error build-up of NAVD 88. Furthermore, the idea behind this type of vertical datum would be to establish starting points with GNSS, but to use geodetic leveling in a local region to disseminate heights from those starting points.

Dr. Roman pointed out that Canada is the only other the North American government making efforts to convert to a GNSS/geoid-based vertical datum. He reported that, though Canada plans to convert to their new datum within the next few years, NGS is negotiating with Canada on the specific details of how they can define a common datum for both countries. Other governments could benefit, as the planned geoid model will cover the entire North American continent and surrounding regions, including the Caribbean, Central America, Hawaii, and portions of Greenland and South America.

Dr. Roman proceeded to discuss how the access to the new datum would differ from previous methods of access. He highlighted that the primary access would be through a user's GNSS receiver and an

NGS-provided gravimetric geoid model. The perpetuation of long-out-of-date published heights on passive marks would no longer be the norm. However, new tools will be developed which allow users to share their newly-established heights on passive marks. In addition, attempts to show growing errors over time, and estimate velocities on those points, will also be provided. Furthermore, NGS will get out of the business of endorsing the use of pre-published heights on passive marks as a method of control. Such information will be treated as "secondary access" to the new datum.

Dr. Roman concluded with a few examples of such access, promoting the use of a single GNSS receiver, NGS-provided positioning tools, and an NGS-provided geoid model as the way to determine an orthometric height anywhere, at any time, to better than 2 centimeters of accuracy wherever possible.

7. Replacing NAD 83: Dr. Richard Snay, Chief (ret.) Spatial Reference System Division, NGS

Dr. Snay began with an overview of Earth-Centered, Earth-Fixed (ECEF) reference frames. He reiterated that while much work is done in Cartesian (XYZ) coordinates, it is generally easier for people to visualize latitude, longitude, and height.

He went on to discuss various ECEF frames, beginning with NAD 83, and noted that both NGS in the United States and the Geodetic Survey Division (of NRCAN) in Canada are the responsible agencies for defining and providing access to NAD 83. He went over the history of NAD 83, from its original inception as a primarily terrestrial-based network—now called NAD 83(1986)—to one based on state-by-state GPS surveys, usually referenced as High Accuracy Reference Networks (HARN) and typically designated by the year the GPS observations had been performed (e.g. NAD 83(1995)), until finally the CORS network grew and the realization was NAD 83(CORS96), with CORS as the primary method of access to NAD 83, rather than the passive marks. Eventually, all of the HARNs were adjusted together (using GPS data on approximately 70,000 passive marks) and made as closely compatible as possible with NAD 83(CORS96), and this realization of NAD 83 became known as NAD 83(NSRS2007).

Dr. Snay also emphasized that the focus of NAD 83 was originally much more on relative accuracy between points than it was on absolute accuracy, but the focus changed as GPS and CORS became more prevalent. Furthermore, as the IGS orbits improved, so did the ability to position using GPS.

Dr. Snay took some time to clarify terminology. He began by explaining that the term "horizontal datum" is being superseded more frequently with "geometric reference system." This "reference system" is a theoretical construct, but is only realized, that is, actually made accessible, through the "reference frame." As such, NAD 83 is a reference system, while adding a "datum tag", like NAD 83(NSRS2007) makes it a reference frame. He went on to discuss another reference system, WGS 84, again explaining that parenthetical datum tags (in this case, the GPS week) yield different realizations of WGS 84, each one forming a different reference frame.

The ITRS was the next topic, where each realization is an ITRF, such as ITRF96. Dr. Snay indicated that this is the frame sanctioned by IAG and created by the IERS, and that the combination of four space geodesy techniques by multiple analysis centers assures that there is great rigor in the adopted frame.

Dr. Snay addressed the issue of moving plates as they relate to a reference frame. He first mentioned that the question of picking a "reference plate" is avoided in ITRF by instead choosing to force a "no net rotation" condition on the solution, so that the average rotation of all the reference points is zero globally. He showed that the effect of this is to allow significant (a few centimeters per year) motions of points on the North American plate. Finally, he mentioned the choice by NGS to define NAD 83(CORS96) through a direct 7 parameter Helmert transformation with ITRF96.

The topic of replacing NAD 83 then was tackled. Dr. Snay noted that while ITRF is a globally-used reference frame, there is the significant disadvantage to surveyors and other geospatial professionals concerning the perpetual velocities on latitude and longitude. He mentioned the concept of fixing the replacement of NAD 83 with a plate-fixed frame, but this also has the disadvantage of not removing all horizontal motions, specifically at transition zones between plates. Furthermore, a significant portion of Southern California does not lie on the North American Plate and would not see significant advantage to a frame fixed to the North American Plate.

By way of analogy, Dr. Snay presented a comparison with the time systems currently in use. The scientific world is comfortable with two time systems, local time and UTC, with a simple conversion between the two. Should NGS replace NAD 83 with a dual-system? And even if that were done, the rotations would only transform in the horizontal. Dr. Snay pointed out the further complication that ellipsoid heights change by a much more complicated and locally independent method.

No "fixed plate" solution would solve the chaotic nature of vertical crustal motion.

Day 1, Early Afternoon: "Panel Session on the Geometric Reference Frame"

8. Replacing NAD 83: Panel Session Focused on Geometric Issues

Following the lunch break, a panel was assembled to address issues on the Geometric Reference Frame; replacing NAD 83. The panel consisted of NGS employees and a representative from the Geodetic Survey Division, Natural Resources Canada. The members were chosen for their ability to address technical and policy-oriented issues mentioned in the morning session, as well as to field questions from the audience. Note that **members of the audience are in bold** in the following text.

The Panel consisted of the following persons:
Ms. Juliana Blackwell, Director, NGS
Dr. Richard Snay, Chief (ret.), Spatial Reference System Division, NGS
Dr. Mike Craymer, Geodetic Survey Division, NRCAN
Dr. Giovanni Sella, CORS Program Manager, NGS
Dr. Gerry Mader, Chief, Geosciences Research Division, NGS
Ms. Marti Ikehara, California Geodetic Advisor, NGS

Ms. Blackwell opened, explaining that the panel would begin by immediately taking questions from the audience.

The first audience comments came from **Qassim Abdullah,** Chief Scientist of Fugro EarthData. Initially he expressed the difficulty Fugro had in dealing with the NGS roll-out of NAD 83(NSRS2007) without a transformation grid, calling it a "disaster." Secondly, he endorsed a geocentric reference system, and in fact to simply jump to ITRF.

Ms. Blackwell acknowledged the missteps NGS made during the roll-out of NAD 83(NSRS2007), and reiterated the thinking behind the decision to not pursue a transformation grid. On the direct jump to ITRF as the replacement for NAD 83 (as opposed to adopting a plate-fixed replacement), she took an ad-hoc vote of audience members.[2] Dr. Snay clarified NGS has long been a "dual system" agency, where CORS and tools such as OPUS have been reporting both NAD 83 and ITRF coordinates since 1995. Ms. Ikehara explained that law in California states velocities must be used in surveying and mapping, though it was resisted at first. She indicated that a similar situation could likely occur in the rest of the United States. Dr. Mader added

2 *Surprisingly, the results were overwhelmingly in favor of a direct leap to ITRF! This must be taken with caution, as participants were asked to speak freely and may not have had the authority or information necessary to provide an answer that represents their entire organization.*

that the adoption of an international standard seems the right way to go, considering the near-future expectation of centimeter level real time positioning.

The next audience member to address the panel was **Kevin Kelly** of ESRI. He began by stating that ESRI had a similar difficulty with the lack of an NAD 83 (NSRS2007) transformation. He asked for guidance on how to serve customers who are asking for the transformation.

Mr. Doyle fielded the question first, explaining that the positional differences cross-country were in the sub-3 centimeter range, which was significantly lower than any of the previous transformation grids (NAD27 to NAD 83(86) and NAD 83(86) to NAD 83(HARN)). Furthermore, these two previous transformations were both two-dimensional only. He further emphasized an accepted rule: that a survey based on old passive mark coordinates cannot maintain its internal precision simply by applying a transformation grid to the computed coordinates of the survey. Rather, one should return to the original survey data, take the new passive mark coordinates, and re-compute the surveyed marks to get their new coordinates in the new frame.

Next up was **Lew Lapine,** Director of the South Carolina Geodetic Survey and former director of the National Geodetic Survey. He emphasized that, as a state agency, he endorsed a plate-fixed coordinate frame. He also endorsed the use of state plane coordinates as part of the new reference frame. He continued to endorse the replacement of NAVD 88, particularly stressing the need for FEMA and USACE to be involved. His next point was to stress the importance of passive marks in boundary surveying. He went on to claim that OPUS is not used at all in South Carolina since the statewide RTN yields 1-cm realizations of NAD 83 statewide in under 60 seconds, and wondered about the role of real-time in the replacement of NAD 83. Lastly, he brought up construction and precision agriculture as the primary users of the RTN, and urged NGS to "get away from surveyors and mappers" when considering their customer base.

Dr. Sella was first to address some of these points, stating if users want centimeters of accuracy, they must be prepared to go back to raw data and re-process it, rather than relying on simple transformations. He also highlighted the fact that NGS had a Federal mandate, and could not consider the needs of only one state. He agreed that real time was a component of the access to the frame, but that NGS was not leading the way with running real time networks.

Lew Lapine further clarified that he felt his users needed centimeters of *relative* accuracy, and did not care how their coordinates fit into a *global* frame.

Bill Henning, NGS real-time team lead, rose from the audience to address this. He pointed out the difference between *boundary* markers (passive marks whose physical location, rather than coordinate, defines the boundary) and *control* markers (which could be passive or active).

The next comments came from **George Sempeles** of the FAA. He mentioned that adopting ITRF would put the United States in compliance with ICAO recommendations. He went on to state that adoption of a global reference frame would solve many international aviation issues. His wished to learn what level of magnitude to expect in coordinate shifts when the new reference frame is adopted.

Dr. Snay stated that approximately 2.2 meters of 3-dimensional (latitude, longitude, and ellipsoid height) shift would be expected.

George Sempeles clarified that 2.2 meters will affect tens of thousands of charts and urged for a careful roll-out.

Dr. Craymer then added a Canadian perspective. Canada is not planning on moving away from NAD 83 immediately. Due to legal restrictions, this will be difficult to change. He felt that the United States adopting a new frame would give strength to the argument for Canada also moving to a more geocentric frame.

Dr. Mader reverted to a previous comment, asking Lew Lapine the source of the South Carolina reference stations serving as base stations in the RTN.

Lew Lapine clarified that OPUS was used to seed the network. He went on to claim that there is "too much error" in the NGS CORS coordinates for them to be "held" for users to get "1 centimeter relative accuracy" (where he pointed out that he calls a coordinate comparison "accuracy" and not "precision.") He indicated that South Carolina is therefore running an independent reference system. When asked (by Dr. Mader) how he ensures his system is in the NSRS, Lew indicated that the RTN is regularly compared against the published coordinates of passive control marks, including bench marks.[3]

Audience member **Dave Zilkoski,** retired Director of NGS spoke next. In addition to endorsing the continued cooperation between states and federal agencies, he asked whether there was some plan to research the ability to get GPS-derived ellipsoid heights to sub-centimeter accuracy.

3 *Consistency between the SC RTN and passive control marks ensures consistency with the passive component of the NSRS, but not the active component. The NGS Ten-Year Plan states clearly that the active component of the new geometric reference frame will be the 'primary method of access' to the NSRS, while passive control will become 'secondary.' As such, users are urged to seek consistency between RTN's and the CORS, and not with passive marks as a method of testing the actual compliance with the NSRS of the future.*

Dr. Mader felt less than optimistic, due to multi-path issues, particularly when the environment is unknown or changing often, such as with a roving GPS receiver. Dr. Sella further confirmed this.

Dr. Mader returned again to comments from Lew Lapine, stating that NGS wishes to engage with RTNs by being the provider of base station coordinates.

Dr. Snay referred back to Dave Zilkoski's question, stating he was more optimistic, considering NGS is moving toward GLONASS and Galileo data, as well as using the 3rd GPS frequency, L5.

Mike Londe from the BLM then addressed the panel. He expressed BLM's concern that transformations be in place to move from one reference frame to another and that serious consideration of the implementation be made.

Ms. Blackwell emphatically stated that NGS intended to abide by this request to provide tools. She explained the best way for NGS to know what tools to build will be through pilot projects between NGS and other agencies.

Mike Londe added that the new BLM manual on cadastral surveys now allows coordinates to be used as collateral information on boundary points, requiring even more care when changing coordinates.

Various statements from audience members participating via webinar came in. They were, "**BLM** wants plate fixed." Then, from **Earl Burkholder,** "I vote for ITRF only." **Tony Williams,** Ohio DOT, indicated most states will require a plate-fixed system, needing repeatability. From **Anonymous**, a comment that states without an RTN, we may not see the issues Lew saw in South Carolina regarding NGS coordinates.

Qassim Abdullah, echoed previous comments that the user should be given a choice on their reference frame.[4] He further stated that 3 centimeters of change is important to his user base. He offered up a criticism of HTDP that, despite being scientifically accurate, it is written in FORTRAN and is not terribly user friendly. He recommended NGS offer up a better, more user-friendly transformation tool. He again requested that a transformation from NAD 83(HARN) to NAD 83(NSRS2007) be provided.

4 *As mentioned in Dru Smith's and Richard Snay's morning speeches, the likely path will be a semi-dynamic datum, where ITRF is provided and velocities are modeled and users will be allowed to pick certain "fixed" coordinates in time as they need, but be able to transform through time to ITRF coordinates.*

Ms. Blackwell acknowledged NGS needs updated tools. Mr. Doyle reiterated the reasoning for no NAD 83(NSRS2007) transformation tool, but did agree that NGS could use better, user-friendly tools.

Marc Cheves, editor of *American Surveyor Magazine,* commented that surveyors should stop complaining about changing coordinates, as their job is to understand these changes and apply them appropriately. He also commented that State Plane, while in regular use, is only good to 1:10,000.

Mr. Doyle provided background on the 1:10,000 number, indicating this is somewhat of a common misunderstanding, and that the real issue is about education of the user base, not the projection tool used. He specifically urged the agencies in attendance to educate NGS as to the tools that are needed.

Kevin Kelly, ESRI, recommended that, if NGS is having difficulty finding resources to make "sexy tools," NGS could simply provide information to the private sector and let them create such tools, with new, up-to-date software and interfaces.

Ms. Blackwell implied that NGS does have more work than resources and, therefore, does endorse partnerships and user-contributed software. She indicated that much of the data is already available, and she urged vendors to seek out useful data for making a tool.

Yogendra Singh, EINFOWAYS, offered advice to the audience, based on his own success, to work collaboratively with NGS on all geodetic work.

Day 1, Late Afternoon: "Panel Session on the Geopotential Reference Frame"

9. Replacing NAVD 88: Panel Session Focused on Geopotential Issues

Following break, a new panel was convened to address issues on the Geopotential Reference Frame; on replacing NAVD 88. The panel consisted of NGS employees and a representative from the Geodetic Survey Division, Natural Resources Canada. The members were chosen for their ability to address technical and policy-oriented issues mentioned in the morning, as well as to field questions from the audience. Note that **members of the audience are in bold** in the following text.

The Panel consisted of the following persons:
Ms. Juliana Blackwell, Director, NGS
Dr. Vicki Childers, GRAV-D Project Manager, NGS
Dr. Dru Smith, Chief Geodesist, NGS
Dr. Dan Roman, Research Geodesist, NGS

Mr. Dan Martin, Vermont Geodetic Advisor, NGS
Mr. Marc Véronneau, Geodetic Survey Division, NRCAN

Ms. Blackwell opened, re-iterating the need for NGS to receive feedback, particularly with regard to the changing paradigm for the vertical datum.

Jim Slater, NGA, had a few questions. His first was whether Canada or other countries were on board with the "new North American datum."

Dr. Smith clarified that NGS is proposing the replacement of NAVD 88 in the United States, but that this is not a replacement for NAVD 88 for all countries. Mr. Véronneau backed this up, indicating that Canada and the United States are working together to produce a common replacement for NAVD 88 in both countries. He explained the historical reasons why NAVD 88 was not adopted in Canada, and further, the concern for using a geoid-based datum when geoid models have varied significantly in the last decades, but mentioned that geoid modeling has stabilized with GRACE and GOCE data.

Jim Slater's next question was whether new reference frames will be developed in the context of GNSS or only GPS?

Dr. Smith answered "GNSS," but cautioned that proper weighting and consideration of all technical aspects must be used to blend the multiple constellations together.

Jim Garster, USACE, explained that USACE is attempting to tie all projects to "the NSRS" (and not just "NAVD 88"). He pointed out that passive marks are "extremely important" as a height-monitoring tool for the USACE. He expected documentation on how to transform from NAVD 88 to the new geoid based datum, as well as any future changes to the geoid model.

Ms. Blackwell began with a reminder of why bench marks were the way of business for vertical datums in the past. She acknowledged that users still rely on this method of starting on a point for a height, but that NGS would no longer be setting such monuments. She emphasized their use as a monitoring tool. Dr. Smith agreed, but stated that "passive marks will have a critical role in the future different than the role they have had for centuries." He went on to express his desire that the changing nature of heights on passive marks be embraced, and the idea of a single height on a mark, standing for eternity, be disavowed.

From the Internet, a set of questions came in. The first was whether deflections of the vertical would be discussed. The second question was whether NGS will address "errors in orthometric height in the CORS"

data in Ohio. The third question was a general complaint regarding issues in the height of CORS data that are not being addressed.

Dr. Roman indicated that deflections of the vertical will be a natural byproduct of modeling the geoid, necessary for creation of the new datum.

Dr. Smith indicated that unaddressed issues would be addressed post-Summit, but was unclear about the nature of the question asked, as orthometric heights on CORS implies either true knowledge of the geoid or leveling (to get NAVD 88 heights) on some physical mark.[5]

Manoj Sumant, NOAA CO-OPS, asked if LOCUS (Leveling Online Computation User Service) would get the same look and feel as OPUS.

Mr. Martin answered that there were issues with treating LOCUS like OPUS. First is the very non-automated way leveling data is processed, which is very different than the simple hands-off way of processing GPS in OPUS. This also is why the "sharing" option, such as OPUS-DB, is not easily attached to LOCUS.

Kevin Knuuti, Chief Engineer, Sacramento, USACE agreed with Jim Garster's earlier comment about the criticality of passive marks. His concern was that, if NGS is not maintaining a national passive mark network, local, vertical datums will crop up, disconnected from one another. Furthermore, he stated that the USACE would accept a transformation for NAD 83(NSRS2007) with the error bars.[6] His final question was how the new geopotential reference frame would affect their current work in dynamic heights.

Dr. Smith first addressed the issue of error bars, indicating that NGS has plans for all their tools to have consistent sensible error bars on both coordinates and velocities. Dr. Roman went on to explain that the geoid and its changes will also have error bars. He continued by saying that dynamic heights will no longer be directly obtained from geopotential numbers published on passive control, but will come from the GNSS/geoid-based orthometric height which will then be converted to a geopotential number using surface gravity data (coming from GRAV-D) and then into dynamic heights. Mr. Martin further emphasized the need for new procedures in surveying so that access to the new datum is consistent, if appropriate procedures are followed.

5 *Post-Summit, this issue was discussed and an explanation provided to ODOT. The issue centered on changes to OPUS output in Ohio which occurred as the Ohio CORS were densified. This investigation helped NGS see a weakness in OPUS which NGS is researching and correcting.*

6 *This feedback is critical, as it removes one of the major hurdles which caused NGS to decide to not publish the transformation.*

Dave Zilkoski clarified some details but specifically mentioned that he saw the future of LOCUS being a tool mixed with OPUS, where starting heights come from OPUS with local leveling being processed with LOCUS.

Paul Rooney, National Flood Insurance Program, FEMA, offered a few comments. First, he mentioned that thousands of surveys and millions of insurance policies all trace back to point surveys tied to NAVD 88 bench marks. He mentioned that survey costs and unchecked bench marks are a significant concern and that a geoid/GNSS-based vertical datum may go a long way toward solving some of these problems. He further noted that tens of thousands of local ordinances refer to FEMA FIRMs tied to NAVD 88, all of which need to be updated. He also noted that FEMA still deals with incorrect NGVD 29 to NAVD 88 conversions. He said these are difficult issues in need of being addressed to successfully embrace a GNSS/geoid based vertical datum.

Nikos Pavlis, NGA, asked "how accurate is the new geoid going to be?" and "how will you verify this?"

Dr. Roman stated the goal is "1 centimeter wherever possible". As for ways to validate the accuracy, he indicated a mix of methods, including matching to the sea surface at tide gages where good sea surface topography models are available, as well as deflection of the vertical surveys.

Mike Londe, BLM, offered some concerns. First was the concern NGS is "abandoning the passive control network," mentioning that many boundary marks reference elevation.

Dr. Roman reiterated the need for passive marks to monitor crustal-surface height changes. Dr. Smith restated his previous comments that orthometric heights on passive marks should come from the user, using GNSS, and not from a permanently-fixed height from the NGS database.

Tim Blak, Dewberry, wondered about getting onto the new vertical datum now, rather than waiting eight years for the geoid to be done.

Dr. Smith explained that, just recently, the OPUS "extended output" is already providing "prototype orthometric heights" using the gravimetric geoid such as it exists. He cautioned this also means that, as GRAV-D proceeds, the gravimetric geoid model will change, and so these prototype heights may change. Although the geoid will be improved regionally over time, he stated that NGS policy is to not replace the vertical datum until the entire geoid has been updated nationwide. Ms. Blackwell finished up by mentioning that even eight years is optimistic, given the current level of funding of GRAV-D.

Lew Lapine, Director of the South Carolina Geodetic Survey, commented that advocacy for the NGS budget should be pursued to speed up GRAV-D's completion. However, he followed up by wondering why a prototype new Geometric Reference Frame couldn't also be provided, using new CORS coordinates.

Dr. Giovanni Sella, CORS Program Manager, elaborated that, in fact, NGS will be finishing a multi-year CORS reprocessing and switching to ITRF2008. But he also warned that even the idea of producing velocities for points was difficult, due to the non-linear behavior of many CORS stations.

Dr. Smith closed by referring back to the question about validating geoid accuracy. He stated that a co-located GPS, leveling, gravity and astro-geodetic deflection of the vertical survey, performed over a line longer than the Nyquist wavelength of GOCE, would allow for a geoid slope validation.

Day 2: May 12, 2010

Overview

The second day of the Summit was set aside for NGS to listen to the concerns of its guests, respond with immediate feedback when possible, and record concerns to address at a later date. Although the agenda allowed for a full day, the number of "minute sessions" was less than expected, so the agenda was modified. The early morning was therefore committed to minute sessions and the late morning to a panel session. As a result, the Summit ended at lunch on the second day.

Day 2, Early Morning: "Minute Sessions"

1. Lew Lapine, Director of South Carolina Geodetic Survey

Lew Lapine, a former director of NGS, expressed his belief that RTNs will only become more accurate, and that the success of the South Carolina RTN is due to their ability to "tune our RTN to" passive control, and he stressed the importance of passive control to users of the NSRS in South Carolina. He advocated for a dual system, both ITRF and plate fixed. He mentioned that in South Carolina the magnitude of changes from NAVD 88 to the proposed new vertical datum appear to be similar to those separating NGVD 29 from NAVD 88. Lew said he'll have to tell people we're "going back to 29."[7] He went on to advise NGS to "stop talking about horizontal and

7 *This is an unfortunate coincidence in magnitude, likely to occur in coastal regions where subsidence has not had a significant impact in the last 80 years. NGS does not advocate stating 'going back to 29,' nor any other way of calling the new datum a step backwards, or comparing it to a datum based on traditional leveling.*

vertical" as separate, but rather to talk about a singular reference frame. Lew (mistakenly) stated that NGS was getting involved in running an RTN, and gave advice on running one.[8]

2. George Sempeles, Federal Aviation Administration

George Sempeles began by advocating for *annual* Summits. He brought the "next generation air transport system" of "NextGen" to our attention. One aspect in particular is very important—moving away from ground-based NavAids (radar, communications) to space-based GNSS-enabled Navigation; no more "VOR-to-VOR" flight patterns. As such, he felt accurate geodetic data would be a "critical enabler" of NextGen.

He explained that the effects on FAA of the datum change are numerous. Thousands of instrument approaches still depend on accurate geodetic information. En-route charts and waypoints depend on elevation and position. Hundreds of thousands of manmade obstructions and millions of natural obstructions surveyed on thousands of airport surveys with accurate latitude, longitude, and elevation in NAD 83 and NAVD 88 will need to be considered. In short, millions of points describe the national airspace system in NAD 83 and NAVD 88. FAA needs a plan for rolling out this transition: will it be all at once, piece by piece? For this reason, he is advocating caution and frequent Summits.

3. Rick Koehler, Instruction Hydrologist, National Weather Service

Mr. Koehler reminded us that NWS forecasts river flood statements, and not just weather. NWS is not a high-accuracy horizontal user, but does rely on very accurate vertical data. The NWS requires 1 inch local accuracy for river levels and related structures. If that could be accomplished predominantly through GNSS and the geoid, it would be a huge boon to the NWS. Additionally, the NWS is using more LIDAR data, and therefore, with a gravimetric geoid-based vertical datum, their LIDAR could move right into creating orthometric heights.

Furthermore, the NWS performs ground water surveys and would find the absolute gravity work of collaborative interest. Finally, he mentioned that NWS works closely with USGS and FEMA (and especially on the upcoming Community Hydrologic Prediction System), and therefore, if those agencies switch to the new datum, so would NWS.

8 *NGS has no plans to run a real time positioning network.*

4. Qassim Abdullah, Chief Scientist, Fugro EarthData

Qassim Abdullah recommended "making a leap" and "making a sacrifice" to move to ITRF. He mentioned how fast technology is moving and challenged the audience to wonder who could predict where the geospatial community will be in 10-15 years?

5. Karl Brown, Vegetation Mapping Program, National Park Service

Karl Brown thanked everyone for the chance to speak. He stressed the importance of tying the Summit to the FGCS meeting to be held the next day and making the most of opportunities for federal agencies, who are more alike than different, to cooperate and collaborate with each other, now and in the future. He also noted private industry was represented in the audience and encouraged working with that community.

He noted the diversity and millions of acres of NPS holdings, and how positioning within them is very important. He mentioned they also have an international component, such as the international peace park w/ Canada, and a common datum between countries, or access to an international datum, is part of making sure these international assets are properly mapped.

He reiterated the thoughts of many others: passive control matters. The earliest NPS surveys are tied to old control, and transformations between passive realizations of the datum are like a "Rosetta stone" to connect older surveys to the future.[9] He noted that large scale maps are detailed enough, and the growing accuracy of handheld GPS equipment implies that 2 meters of change "matters" to the NPS. He also called for the announcement of future Summits at least "six months in advance."

6. Alan Jones, Federal Aviation Administration

Alan Jones opened with a reminder of how the nature of the dynamic Earth has become better known over time. "Our coordinate system must move with the Earth". He continued, stressing that knowledge of Earth's dynamics is such that the reference frame must reflect this.[10]

9 NGS is not denying the importance of passive control, but with the future datums, passive control will not be installed and monitored by NGS, and therefore will be a secondary method of access, behind active control.

10 NGS agrees with this endorsement of including dynamics into the new NSRS, but recognizes there are users who prefer their coordinates locked to the plate and unchanging as the plate rotates.

7. Mike Londe, Geodesist, Bureau of Land Management

Mike Londe stated BLM sees the need for a good geoid, as bench marks are harder to find, and a GNSS/geoid based vertical datum will help. However, he questioned the motivation for moving to a geocentric datum, stating that "no convincing arguments"[11] had been made, and that more information and transparency was needed as NGS moves forward. He wondered whether conversion tools would be available on release of the new datum and not simply promised later. He expressed concern that when BLM switched to NAD 83 there was no budget, personnel, or resources to change datums. As such, he felt BLM may not switch to the new datum, if they can only be provided with a tool to move from NAD 83 to a new system.[12]

The slides used by Mike Londe are reproduced in **Appendix I.**

8. Larry Moore, National Geospatial Program, United States Geological Survey

Larry Moore reminded the audience that USGS completed the topographic quadrangle mapping series in 1992, and therefore the United States has no map series on a modern datum. Mark DeMulder's recent goal at USGS has been to revive the Topographic mapping program, converting it into a digital GeoPDF service with a three-year refresh rate, however he indicated a 2 meter horizontal shift was not large enough to be significant at the 1:24,000 scale. He urged NGS to excel at metadata and urged transparency as we move forward.

9. Jim Garster, United States Army Corps of Engineers

Jim Garster noted it has been a challenge for USACE to fully embrace and understand datums and for the agency as a whole to use the correct datum in their projects. He was thankful for a recent USACE policy (March 2009) to "Relate all projects to NSRS." In order for this policy to be effective, USACE needs the connections between water level datums and the terrestrial vertical datum, which means connections between tidal bench marks and geodetic bench marks. However, the USACE does not endorse change for the sake of changing.

OPUS-DB is an "essential" tool for USACE, and OPUS-Projects highly desired for multi-levee projects. However, USACE still ties all projects to a "primary project control point," so passive control has a

11 NGS feels the white paper "Improving the NSRS" makes a convincing argument for this change.

12 This approach would be akin to staying with NAD 27 and relying on NADCON to get to NAD 83. While possible in the broad sense, it does not properly account for individual coordinate changes, and therefore is not an appropriate form of geodetic control.

role there. He went on to state how "critical" it was for NGS to provide good uncertainty assessments in their positioning tools, but also how strong a need there is for good specifications and procedures to meet certain accuracy goals. That is, the USACE wants "performance-based standards" contractors can follow.

He expressed hope that a vertical time-dependent positioning tool (VTDP), akin to HTDP, be developed. Finally, he expressed concern that, in the future, RTNs, and even less cumbersome methods of handheld positioning, will yield "centimeter access" to the NSRS, so that "everyone thinks they're a surveyor." As such, he endorsed the idea of an "RTN certification" process to ensure their alignment to the NSRS. Finally, he stressed the importance to USACE of education on the topics of datums and accuracy.

The slides used by Jim Garster are reproduced in **Appendix J.**

10. Paul Rooney, Federal Emergency Management Agency

Paul Rooney began by summarizing the FEMA role of "identifying levels of flood risk". While that allows for a fairly large error budget (about 0.1 foot), the use of GNSS to perform the task would be a huge boon to FEMA. This impacts both communities who have to adopt the flood maps to cover existing structures, as well as the specifications for new construction.

He educated the audience on the huge inventory of maps with a few dozen spot elevations, each in NAVD 88, and what a huge challenge it will be to switch to the new datum. He felt FEMA was still struggling with the conversion from NGVD 29 to NAVD 88. There is currently a five-year review cycle for flood maps, but the maps are only updated if there are significant changes, such as in subsidence areas.

Day 2, Late Morning: "Panel Session Responding to Minute Sessions"

Following break, a panel was brought to the stage to address, as possible, the various concerns raised during the "minute sessions" of the morning. The panel was made up of NGS employees, and the members were chosen for their ability to address technical and policy-oriented issues mentioned in the morning, as well as to field questions from the audience. Note that **members of the audience are in bold** in the following text.

The Panel consisted of the following persons:
Ms. Juliana Blackwell, Director, NGS
Dr. Dru Smith, Chief Geodesist, NGS

Dr. Gerry Mader, Chief, Geosciences Research Division, NGS
Mr. Bill Henning, Real Time Networks Specialist, NGS
Dr. Richard Snay, Chief (ret.), Spatial Reference System Division, NGS
Ms. Renee Shields, Height Modernization Program Manager, NGS
Mr. Mark Howard, FAA Liaison, NGS

Dr. Smith opened by explaining that each person on the panel would speak, addressing issues from the minute sessions, and then any remaining questions from the audience would be addressed, and the Summit would adjourn at lunch.

Dr. Smith began by addressing the question of "need for convincing arguments to move to a new datum." He emphasized that the "white paper" (see Appendix A) which was the work of many people in NGS over many months has been presented to the audience in advance of the Summit. He felt no stronger arguments for needing the datum could be presented. However, he further noted that, in time, the FGCS will vote to change to the new datum and that NGS will eventually cease to support the old datums. He welcomed further conversation, but felt the white paper was convincing as is.

He continued on the topic of "a-priori tools and transformations." He agreed that such tools are critical and reminded the audience that the OPUS extended output already has a prototype service, yielding "orthometric heights" based on the current best gravimetric geoid.

He closed by stating that "pilot projects" between NGS and other agencies must occur over the next 10 years, so NGS can learn how the users actually make use of the NSRS and understand how changes to the NSRS will affect users' operational procedures. Doing so will allow for the creation of new operational procedures to be implemented when the new datum is in place.

Mr. Howard spoke next, discussing that the FAA and NGS have been, and will continue to be, talking on all the issues of concern to the FAA.

Dr. Mader reminded the audience OPUS is already an epoch-based service, where the dynamic nature of the Earth is accounted for, and reference stations are moved through time to the point of the survey. He also indicated our commitment to OPUS-Projects, and that it was "coming soon".

Mr. Henning spoke next, reminding everyone that NGS is aware of other users besides surveyors. He expressed his belief that by the time the switch of datums occurs, the primary access to the NSRS will be RTNs, so one of our critical tasks will be to assure alignment between

RTNs and the NSRS. He also mentioned NGS plans to install a "Foundation CORS" network.[13]

Ms. Shields took the microphone next and explained to the audience that the success in South Carolina which Lew Lapine quoted took lots of Height Modernization money over many years and that this isn't a viable option for most of the rest of the country. In reference to Rick Koehler's concerns, she noted that NGS is already working to unify the USGS stream data and water level data to one single datum. She also mentioned the concerns heard from several people concerning resources that would be needed for the conversion, and that more products would be digital in the future and hence easier to update. She finished by stating that the Height Modernization Program would assume the role of bridging the present and future needs of the user community, through support for enhancing tools and infrastructure and for education and capacity building.

Dr. Snay gave an overview of the recent "multi-year CORS processing" project at NGS. This presentation is available in **Appendix K.**

At this point, questions from the audience were taken.

Jeff Oyler, CO-OPS, asked how the change to the gravimetric geoid-based vertical datum aligned with the update to the Great Lakes datum, IGLD85.

Dr. Smith explained that the priority of GRAV-D to fly the Great Lakes was moved up from what the GRAV-D plan originally stated. He indicated this was necessary for the IGLD85 update to make use of the new airborne data. Marc Véronneau also spoke about Canada's desire to move to a geoid-based datum in the next one to two years (which would possibly precede the IGLD85 update). [Author's Note: The method of accessing dynamic heights with the new datum will differ from NAVD 88. Rather than beginning with leveling-based geopotential numbers, a user will now begin with a GNSS/geoid-based orthometric height, convert (via new GRAV-D data) into geopotential numbers, and then into dynamic heights.] Dave Zilkoski urged NGS to attend the GLHCC meetings, noting how important it was for the adoption of IGLD85 and its identity with NAVD 88. He then urged NGS to provide more information concerning the datum changes on NGS' website.

Dr. Smith answered by saying the plans for the new datums were still forming, and he acknowledged the website needs work. Ms. Shields said regular Height Modernization telecons occur and NGS has a new

13 The plan for these sites is being finalized, but essentially they are NGS-owned or operated sites, hoped to be ITRF and IGS reference stations.

Stakeholder Feedback Plan. Dr. Smith mentioned the NGS Director is expected to find one or two persons in the next year to be the project managers for the datum transitions. Dr. Giovanni Sella also mentioned that the Multi-Year CORS re-processing results have been available from the beginning and that feedback is good. He also stated that the monthly meetings have been held regularly for two years and are open to the public.

Dave Zilkoski urged for a simple "new datums" portion of the NGS website.

Dr. Smith agreed. He also stated that FGCS meetings should be open to the public, and only closed if government-specific information, such as budgets, was being discussed. Furthermore, he pledged that FGCS will announce meetings at least six months in advance to encourage preparation and attendance.

Some comments came in from the webcast audience. The first was a request for a conversion tool from the current datums to the new datums. The second was for NGS to put all future revisions out for public comment. Finally, a request was made for a standard list-serve to be used to announce such things.

Dr. Smith answered these by stating that transformations will exist, and that NGS has recently set up a list-serve, but has not yet fully activated it for use. Mr. Doyle reminded the audience that NGS regularly uses the ACSM and AAGS as methods for vetting NGS plans.

More webcast audience comments continued. The first was that NGS set a specific date for future revisions and announce it with enough lead time for users to get software and legislature changed to adopt it. Furthermore, it was requested that NGS go to absolute antenna calibrations.

Dr. Smith gave the date of "8 to 12 years" for the datum switch.

Dr. Mader answered that the absolute antenna calibration program being stood up at NGS would be ready "within the next few weeks".

Further webcast comments: "We need more of this discussion in the GIS community." Mr. Doyle agreed, stressing the growing involvement NGS has had with the GIS community over the last few years.

George Sempeles asked what geodetic surveying efforts were occurring in Alaska. Dr. Smith reiterated the lack of good control in general, and that Alaska was the number one priority of the GRAV-D program. Mr. Howard followed up saying many airport surveys are being done, but tying them to NAD 83 and NAVD 88, as per the standards for airport surveys, is a challenge in Alaska which has such poor control.

Dr. Smith further emphasized that while GEOID06 was put out in Alaska statewide, it was really only a useful tool along the limited leveling lines in Alaska. Dr. Snay mentioned that 20 new CORS had been added to Alaska.

Mike Londe asked for the NGS website to be more user-friendly and secondly for the list-serve to be a way to reach a wider audience.

Qassim Abdullah added a comment, thanking NGS for the openness of the process. He wondered if a book covering all of the topics NGS engages in could be produced either in NGS or through collaboration. He brainstormed about a Yahoo group "friends of NGS" and praised the use of webinars. He finished by stating that a proceedings of the Summit be published, with "customer wants" listed, and that this be publicly available.[14]

From the Internet, **Ray Williams** (USACE) asked that VDatum be modified so a distinction between "rising sea level" and "falling land" can be made in the software, based on statements (clarified by Dr. Smith as his opinion only) that the "geoid should rise as sea level rises"). Dr. Smith indicated that his opinion was that the geoid should change as sea level changes, but that this was a point of negotiation with Canada. Marc Véronneau agreed these finer points yet needed to be ironed out, and that NGS and Canada will work within the IAG, as well to finalize a plan.

Ms. Blackwell then made the closing statements for the Summit. She first stated she had taken extensive notes and was planning to use them to help NGS set priorities. She reminded the audience that, in addition to providing customer service, NGS must also serve the agency in which it is housed, NOAA. This has meant sometimes conflicting, sometimes aligning, priorities between NOAA and the broader NGS customer base. Second, she endorsed partnerships with other countries and stated NGS would continue to reach out to international partners as we move forward with the NSRS improvements. She went on to thank the federal agencies and asked them to hold NGS accountable for a steady, well-informed pace toward the new datums. She reiterated her opening statements, that NGS must perpetually seek a balance between the best science and providing service to customers. She called for increased participation in FGCS and stated that future events, such as FGCS meetings or the next Summit will be planned well in advance so folks can plan to attend. She encouraged all federal agencies affected by the change to the NSRS to begin building transition time and resources into their planning and budgeting cycles.

14 This is collected in the following chapter.

Ms. Blackwell thanked everyone for coming and closed the Summit.

Lessons Learned and Future Plans

Overall, NGS found the participation in the 2010 Federal Geospatial Summit on Improving the NSRS to be outstanding. With over 200 attendees in person, and another 200 on the webcast, NGS felt that both the "word got out" and also that NGS received some much needed feedback. However, the Summit was only an early step in the long road to replacing NAD 83 and NAVD 88.

Throughout the course of two days, the attendees of the Summit heard of lessons learned from past datum changes. In addition, NGS learned of user concerns and received multiple requests to take certain actions. Of significance, NGS heard one generally overarching message from the Summit attendees, which might be summed up as follows:

The NSRS user community* supports *NGS's plan to improve the NSRS, but urges caution, communication, and cooperation due to the scope of impact this will have.

There were obviously a variety of concerns raised, but an overwhelming majority supported the datum change. In order for NGS to stay on track with the issues raised by the Summit attendees, the next section contains action items that are being used by NGS to plan for the next few years.

Actionable Items for the next two years:

The following checklist represents a mix of those requests heard from customers at the Summit, as well as actions to take that can be inferred from the overall concerns. In addition, actions already planned by NGS prior to the Summit, which line up with the feedback from the Summit are listed. It is NGS's intention to use the following list as a guide for setting priorities for the near term. Not every action is listed here, but the most critical and time-sensitive are, for if they are not addressed, there is little reason to address other, long-term actions. What follows are the seven most critical actions NGS should undertake before Summer of 2011, in order to maintain the momentum gained at the 2010 Summit.

Action 1: Budget for the datum changes.

This action speaks to the lessons learned from NAD 83 and NAVD 88, as well as the need for appropriate funds for the two largest initiatives necessary for the success of the datum transition: GRAV-D and

Foundation CORS. Together, these will require millions of allocated dollars every year over the next decade.

Current status: NGS continues to advocate for its modernization plans by providing briefings to appropriate NOAA and OMB personnel, as well as others as called upon (Congressional staff, the National Research Council). NGS will continue to seek the appropriate funds to perform this modernization while using already available funds. Realignment of personnel is also taking place and is expected to save costs by assigning existing employees and contractors to new work supporting the transition.

Action 2: Name the project manager or managers to lead the transitions.

Much of the planning for the datum transition has been done by NGS leadership as a whole. However, from this point forward, it is clear team leaders within NGS must be put in place to spearhead the transition from NAD 83 and NAVD 88.

Current status: The NGS Director and Deputy Director have been debating the best method for filling these positions for much of 2010. They are expected to name the project managers before the end of calendar 2010.

Action 3: After naming project managers (see above), immediately have them write a comprehensive staffing plan, and re-align NGS resources to that plan.

A majority of NGS personnel perform tasks necessary to the upkeep of the current datums in the NSRS. It is impossible for NGS to completely staff both the upkeep of the current datums, as well as the creation of the new datums. Many personnel must be moved from current work to new jobs in NGS that support the creation of the new datums. This will also represent some cost savings to NGS, but it will not be a simple change. New training must take place, and NGS leadership is cognizant of general human resistance to change. Nonetheless, fear of backlash is no excuse for failing to move the organization toward a more modern way of performing its mission.

Current status: In 2010, the first steps toward this re-alignment occurred. While the project managers will write the ultimate plan, the overall direction is already known, and some steps have been taken: consolidation of most of the NAVD 88 replacement work will take place in the Observation and Analysis Division, and most of the NAD 83 replacement work will take place in the Spatial Reference System Division. Furthermore, consolidation of outreach and

education into the Geodetic Services Division has begun. The complete re-alignment of resources to support the transition is expected to have taken place before the end of 2011.

Action 4: Make a policy decision on whether to keep taking in GNSS and leveling data from outside of NGS and what NGS will do with it if it continues.

As reported three years ago in the NGS Ten-Year Plan, NGS needs very little in the way of passive control to perform its mission in the future. However, NGS has relied for decades upon the passive control surveys of outside users, and this situation is not easily resolved, for the NSRS user community has come to think of their surveys as something NGS not only needs, but will forever keep and use. One advantage NSRS users have come to see from the current situation is the ability for users to share passive control with one another, through the intermediary of the NGS Integrated Database.

However, NGS can provide access to the NSRS entirely through GNSS, and therefore must make a decision as to what role the NSRS user community's passive control surveys will play in the NGS future.

Current Status: NGS receives GPS surveys in two forms (OPUS and Bluebooking), and stores them in two databases (OPUS-DB and IDB). This is a horrible situation for NGS, straining its resources. In 2010, the NGS Executive Steering Committee formed Process Action Team Number 24 (PAT 24) to discuss the situation and provide policy guidance to the ESC. The members of PAT 24 will hold meetings internally and with external users. Such a meeting, not formally part of PAT 24, took place in September 2010 between some RTN operators and the Multi-Year CORS reprocessing team.

The schedule for PAT 24 is to provide its report to the ESC by mid-2011.

Action 5: Create a Web page of the datum changes, and assign a person to keep the information on it updated.

NGS will use many methods of communicating with the outside world about the datum change. However, the NGS Web page will be the heart of that, holding all information and providing a long record of communications, decisions, meetings, technical information, etc.

Current Status: NGS has not yet created this page. A simple page, containing information to date, will be created before the end of 2010. Once the project managers are named (see above), a permanent

Web staffer will be assigned to support them and keep the Web page up to date.

Action 6: Perform at least one pilot project in the next two years with another federal agency to study and understand the impacts of the datum changes.

Because the change in datums will affect all users of the datums, NGS must fully understand the impacts of the changes they will be implementing. As the NSRS is mandated for use by federal agencies by OMB Circular A-16, NGS must first address those users. Other NSRS users, such as state and municipal governments, may benefit from the knowledge gained between NGS and other federal agencies, but if not, work with the states may also need to occur.

Current Status: NGS has met with FEMA in North Carolina in August 2010 and proposed a pilot project to take place in 2010-2011.

Action 7: Name the time and place of the next Summit at least one year prior to its occurrence.

While the need for frequent communication with the user community was raised, upon reflection, the idea of holding Summits annually seems premature to NGS leadership. It is felt that a year of work doing outreach and setting up pilot projects (see above) will make the next Summit significantly more informative. As such, the plans for the next Summit are for it to take place sometime in mid-2012. Although the location is not fixed, there is an overall feeling the next meeting will not be in the Washington D.C. region, nor even on the East Coast of the United States. Further details will be clarified, and a formal announcement will be made no later than early 2011.

Current Status: The 2010 Federal Geospatial Summit planning committee has created a list of potential dates and locales for the next Summit. The plan is for this list to be posted as a survey online, concurrent with these proceedings being posted online, with a request for feedback. The announcement of the next (likely 2012) Summit will take place in early 2011.

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Appendix A

White Paper entitled "Improving the NSRS" which was distributed prior to the Summit

Improving the National Spatial Reference System

Introduction

The future of positioning is GNSS[1]. The underlying reference frames for all GNSS systems are geocentric. The International Terrestrial Reference Frame (ITRF), used for globally consistent scientific applications such as the determination of sea level change, has gotten progressively more geocentric over the last ten years, so that now the origin of the ITRF coincides with Earth's center to about 1 centimeter of accuracy. Furthermore, countries are increasingly choosing GNSS as their primary tool to access a vertical datum, minimizing their reliance upon unmonitored passive control.

In the United States, the official geometric, historically called "horizontal", datum, NAD 83[2], has a known non-geocentricity of over two meters and the official vertical datum, NAVD 88[3], is accessed through a set of passive control that is fragile, inaccurate and rapidly deteriorating. The National Geodetic Survey (NGS) is working to define and adopt a geocentric reference datum for the United States to replace NAD 83 and is working to compute an accurate geoid model which will serve as the defining surface of a new vertical datum that is accessed through GNSS technology and which replaces NAVD 88. These two changes are dependent upon one another in a variety of ways and are currently planned to occur simultaneously.

The decision to proceed with these changes was both obvious and difficult because NGS is cognizant of two important, but conflicting needs in the user community: **accuracy** and **constancy**. To fulfill its mandate to provide the geodetic reference frame for all United States geospatial activities, NGS must strive to be as scientifically accurate as possible. After much internal discussion, NGS has determined that it must address serious issues of inaccuracy in the current realizations of NAD 83 and NAVD 88. At the same time NGS recognizes that significant user resources have been invested in the current realizations of these datums.

In order to continue improving accuracy while minimizing the impact of new reference frame paradigms, NGS is working to implement this transition over the next 10 years. This will allow time for the user community to voice concerns, for NGS to address them, and to ensure that the transition will go as smoothly as possible.

For this reason, on May 11-12, 2010 NGS will convene the first in a series of Federal Geospatial Summits to address these proposed improvements to the National Spatial Reference System. The intent of these summits is to solicit user input and to provide documented solutions to address all concerns.

This white paper defines the issues as currently understood by NGS and is to serve as the catalyst for soliciting user comments, questions and concerns.

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[1] Global Navigation Satellite Systems – All constellations of positioning satellites including GPS, Galileo (Europe), GLONASS (Russia) and Compass (China)
[2] The North American Datum of 1983
[3] The North American Vertical Datum of 1988

Part 1: Replacing the North American Vertical Datum of 1988 as the official U.S. Vertical Datum

Background

Significant changes to the science and methodology of geodetic leveling occurred during the mid-20th century. A widespread multi-agency effort to collect terrestrial gravity measurements, development of new corrections to leveling and a deeper understanding of the differences between local mean sea level (LMSL) at disparate tide gages all called into question the accuracy and reliability of the National Geodetic Vertical Datum of 1929 (NGVD 29). These improvements in scientific knowledge, and the new 625,000 kilometers of leveling (including 81,500 kilometers of 1st order re-leveling) performed post-NGVD 29 were used to create the North American Vertical Datum of 1988 (NAVD 88).

NAVD 88 was a major improvement over NGVD 29, however no nationwide effort to re-adjust NAVD 88 has been made since its inception. Some localized leveling has allowed for original heights to be superseded, and in some cases (e.g. Louisiana) a number of questionable heights have been removed in favor of updated leveling and GPS-based heights. Without an active maintenance plan, current regional distortions in the network are already impacting its value and effectiveness.

Because of known problems in the original realization of NAVD 88, and ongoing problems in the very nature of a passive-mark based system of vertical geodetic control, NGS proposed in their 10 year plan (NGS, 2008) that "a new geopotential datum…is defined and realized through the combination of GNSS technology and gravity field modeling". There are six major issues with NAVD 88 which warrant its replacement:

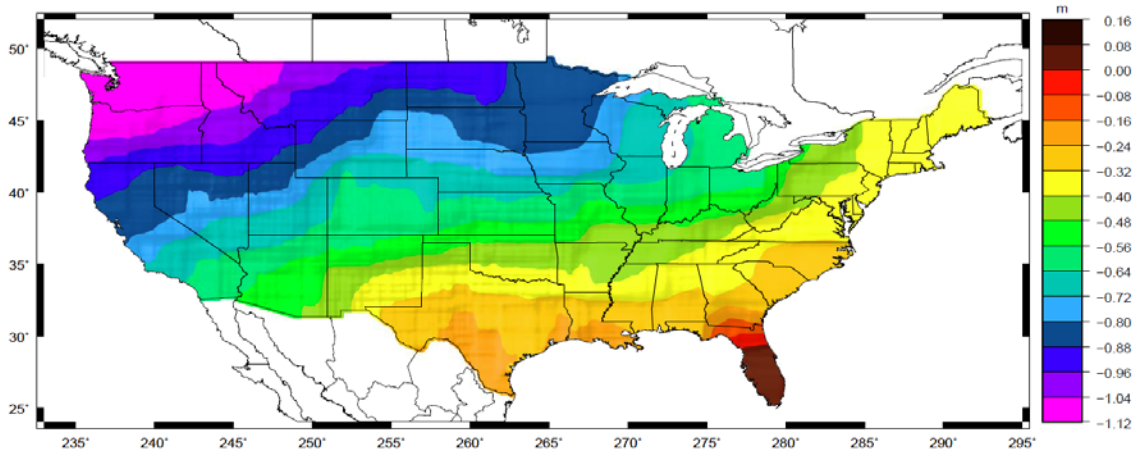
1) Cross-country accumulation of errors from geodetic leveling
2) Fragility and location of passive marks
3) Bias in the NAVD 88 H=0 reference surface as compared to the geoid
4) Subsidence, uplift, and other crustal motions
5) Sea level change
6) Changes to Earth's gravity field

Cross-country Accumulation of Errors from Geodetic Leveling

NAVD 88 is realized through the publication of geopotential numbers (and orthometric heights) at hundreds of thousands of passive geodetic control marks across the North American continent. These geopotential numbers were computed through an adjustment of geodetic leveling, holding a single point, Father Point/Rimouski, fixed. While this method removed the existent warping in NGVD 29 caused by holding multiple tide gages fixed, it introduced the potential for an accumulation of systematic errors across the country as leveling spread out from Father Point. As a most optimistic prediction of these errors, one can simply propagate the best estimate of 1st Order, Class II leveling ( ) over the 4000 km from Father Point to Los Angeles and the predicted error accumulation would only be 4.4 cm. However, this equation only accounts

for random observational errors, and fails to consider any theoretical errors, such as the formulae used to convert leveled height differences into geopotential numbers in mountainous terrain. As will be seen, it is possible that serious theoretical issues may exist. However, for the sake of simplicity, the combination of observational and theoretical errors will henceforth be simply called "leveling errors". Independent tests (Zilkoski, et al, 1992), performed immediately after NAVD 88 (using VLBI[4] and GEOID90), showed a more pessimistic estimate than 4.4 cm. In those tests, discrepancies (which must be interpreted as a combination of leveling, geoid modeling and VLBI errors) were seen in the -105 to +76 cm range at various locations around the USA. It is difficult, in such early tests, to separate how much of those discrepancies are due to leveling alone.

A significantly more reliable estimate of error accumulation from leveling alone was performed in 2004 (Wang, et al, 2004)using published NAVD 88 heights, co-located with GPS-derived ellipsoid heights and a long-wavelength geoid model, derived entirely from the GRACE[5] satellite mission. Spatial filtering of the leveling and GPS data to the wavelengths accessible from GRACE removed localized issues and allowed for a continent-wide view of these discrepancies. Because the accuracy of the GPS data and the GRACE data is in the 1-3 cm range in an absolute sense, any significant discrepancies can justifiably be identified as cross-country error in NAVD 88. The differences are shown in the figure below, and range from about 16 cm in Florida to -112 cm in the Pacific Northwest. The figure below is an update to one that first appeared in Wang, et al, 2004. The average value is non-zero due partially to the bias in the choice of the NAVD 88 H=0 constraint, to be discussed later. Note that the errors do not correlate with radial distance from Father Point, indicating the complex nature of the issue, and difficulty with expecting the standard error model of geodetic leveling to yield true error estimates cross-continent.



[4] VLBI: Very Long Baseline Interferometry – A measurement technique capable of determining geometric vectors between widely separated points, based on the observation of quasars by radioastrometry antennas at each point
[5] GRACE: Gravity Recovery and Climate Experiment

Fragility and Location of Passive Marks

From evidence submitted by users of NAVD 88, NGS has determined that thousands of bench marks are lost or displaced every year. Because the method of accessing the datum is through direct contact with a passive mark, this fragility in the vertical control network is of no small consequence. A significant portion of bench marks are located along roads and railways. This has the obvious advantage of providing ease of access and long flat stretches for leveling. But any construction project (road widening, railway removal, etc) along those corridors can result in the simultaneous removal of a huge number of bench marks. Another disadvantage of using transportation corridors to build the vertical control network is the non-homogenous geographic distribution of the NAVD 88 bench marks. Users who do not work near level lines are at a financial disadvantage relative to those who do.

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Bias in the NAVD 88 H=0 Reference Surface from the Geoid

When performing the minimally constrained adjustment which led to NAVD 88, the choice to hold the LMSL height as "fixed" at Father Point/Rimouski was made. And, while NAVD 88 ostensibly was to disseminate orthometric heights (heights above the geoid), the choice to fix NAVD 88 to LMSL at Father Point/Rimouski was not made because of a particular closeness of LMSL to the geoid at that point. Rather, the selection was made "to minimize the effects on National Mapping Products as requested by users…". That is, because National Mapping Products relative to NGVD 29 existed in paper form, choosing a new datum that aligned well with NGVD 29 eliminated significant map recompilation efforts. The final bias between the Father Point/Rimouski LMSL and the actual geoid remained something of an indeterminate quantity due to the lack of good geoid modeling at the time. Attempts to quantify this bias have been made at NGS since GEOID96. The most recent estimate of the bias in the NAVD 88 reference surface, using a GRACE-based geoid model, is approximately 50 cm. That is, the difference between a true orthometric height and an NAVD 88 height, anywhere in the continent, is, on average, about a half-meter.

Subsidence, Uplift and Other Crustal Motions

Of all the banes of passive vertical geodetic control marks, subsidence is amongst the worst. As the purpose of geodetic control is to provide an accurate starting height for surveying and mapping, the unrecorded movement of a passive mark set in a subsiding crust compromises the intention of the mark. Even worse, decisions made based on marks set in a subsiding crust may yield unintentional harm to life or property. For example, decisions about building homes in flood prone areas, or declaring roads to be high enough to serve as evacuation routes, must be based on accurate heights or the results can be devastating.

While subsidence, or its inverse, uplift, does not affect NAVD 88 everywhere in the country, it does have the greatest impact in coastal low-lying areas such as the Gulf of Mexico coast, Chesapeake Bay, and California agricultural regions. Accepting the perpetuation of known, but unmeasured errors in these NAVD 88 bench marks is possibly more damaging than not having any geodetic control at all.

Sea Level Change

It was the intent of NAVD 88 to provide orthometric heights to users, accepting that some bias in the network was unavoidable for national map consistency. And while orthometric heights have been colloquially called "heights above mean sea level", they are actually scientifically defined as heights (measured along the plumb line) above the geoid. The important distinction is that "sea level" does not exist anywhere but the sea, while the geoid is that surface of equal gravity potential energy that best fits but is not exactly the same as global mean sea level and therefore it extends globally, even under the continents. What is critical in the preceding statements is the question of how the geoid changes as sea level changes. It is well known that sea level is rising globally at a few millimeters per year, and with the internationally accepted definition of the geoid tied to global mean sea level, this change must also be taken into account. Even though NAVD 88 is tied to LMSL at Father Point/Rimouski, no attempt to update NAVD 88 based on a changing LMSL at that point has ever been made.

As NGS updates the geoid model so that it continually fits a changing sea level, users will eventually notice that even in areas where subsidence is not occurring, their orthometric heights will change. This reflects the reality that the vertical distance separating a given location and the global mean sea level is decreasing, which is information that should be properly conveyed to the public, particularly in coastal regions.

Changes to Earth's Gravity Field

Similar to the sea level issue, is the fact that Earth's masses are in a constant state of flux, which affects the gravity field and subsequently the geoid; however, luckily, very few mass changes are large enough to change the shape of the geoid in a measurable way over decadal time spans. An example of one significant exception is in the vicinity of Hudson Bay where the post-glacial rebound of the crust is linked with a related inflow of deep mantle masses below the crust. This gain in mass below that region of Canada causes a change to the geoid on the order of a few millimeters per year in the center of the region, with a decreasing magnitude of change radiating outward from there. Based on the definition of orthometric height, geoid changes should result in corresponding orthometric height changes, however, this is not accounted for in NAVD 88.

On the possibility of re-leveling NAVD 88

A variety of solutions to the problems listed above have been discussed, including the re-leveling of NAVD 88 itself. However, NGS would need to rely on contracted personnel, at a cost falling somewhere above $200M. Yet even this would only replicate NAVD 88 and all of the issues with it. Instead, NGS has chosen to embrace a paradigm shift, fully utilizing the strengths of GNSS and our own expertise with geoid modeling. The resultant plan is known as GRAV-D (Gravity for the Redefinition of the American Vertical Datum) and is expected to take about ten years and approximately $40M to complete, after which an accurate and temporally tracked geoid model will be available to serve as the vertical datum for the nation. As further evidence supporting this paradigm shift, a 2009 socio-economic study [Leveson, 2009] estimated that the value of current NOAA modernization efforts to replace NAVD 88 would be $4.8 billion over 15 years, including $2.2 billion in savings from improved floodplain management.

Part 2: Replacing the North American Datum of 1983 as the official U.S. Horizontal Datum

Background

As exemplified earlier, NGS has always been an early adopter of new and emerging technologies in mapping, charting and geodesy. In the case of horizontal datums, the use of Electronic Distance Measuring equipment in the 1950's helped NGS discover and quantify local and regional distortions in the North American Datum of 1927 (NAD 27) and ultimately led to the replacement of NAD 27 with NAD 83. As the new datum was coming into realization, modern space geodetic techniques such as VLBI, SLR[6], and GPS were introduced. Within just a few short years, NGS once again found itself in the position of acknowledging and attempting to fix the various local and regional distortions in the realization of the newly adopted datum. State-by-state GPS surveys, commonly referred to as the High Accuracy Reference Networks (HARNs), were conducted, first to improve latitude and longitude accuracy on passive control, followed by a second round for the determination of accurate ellipsoid heights, because height determination methods had improved post-HARNs. Eventually all of this data went into a massive re-adjustment, NSRS2007, with the goal of improving nationwide consistency and accuracy by removing state-to-state coordinate inaccuracies. While that readjustment was generally successful, yielding a median formal standard deviation of 1 cm in the horizontal and 2 cm in ellipsoid height, it did not resolve every problem with NAD 83 (including the non-geocentricity), and was only applicable to about 70,000 passive marks in North America.

The only space geodetic data widely available at the time of the first realization of NAD 83 were Transit Doppler observations. These observations had an expected uncertainty of about one meter. Latitudes and longitudes for the original realization of NAD 83 were geodetic (ellipsoidal) although lacking the necessary extraterrestrial measurement techniques to rigorously determine the geocenter of the Earth.

As GPS and SLR data became more available, and ultimately combined with other space geodetic techniques into creating the International Terrestrial Reference Frame of 1988 (ITRF88), knowledge of Earth's geocenter to the sub-decimeter level materialized. And when ITRF88 and NAD 83 3-dimensional coordinates were compared, it was seen that NAD 83 had a non-geocentricity of over two meters. Ultimately, an official transformation between NAD 83 and ITRF96 (a later realization of ITRF) was adopted by both the NGS and Geomatics Canada (now Geodetic Survey Division, Natural Resources Canada), defining the official origin offset between the two frames at 2.209 meters (Craymer, et al, 2000). All future transformations between new versions of ITRF and new realizations of NAD 83 would always return to this base non-geocentricity as the defining connection between the two.

A two meter non-geocentricity, which will manifest itself as latitude, longitude and ellipsoid height errors of ± 2 meters (globally), in a world where sub-meter instantaneous positioning will

[6] SLR: Satellite Laser Ranging – A measurement technique measuring the round trip time of lasers from the Earth to satellites orbiting the Earth, useful for determining both the center of mass of the Earth around which the satellites orbit as well as variations of the Earth's gravity field which perturb those satellite orbits

be in most handheld devices, will be a glaring error to general users. Specifically, this non-geocentricity in NAD 83 already manifests itself as a roadblock of improving accuracy by:

1) Causing inconsistency between national mapping products and GNSS orbits and positioning
2) Forcing a biased and tilted inconsistency in national geoid products (undulations and vertical deflections), necessitating the continued use of "hybrid" versus "gravimetric" geoid models until this is solved.
3) Causing confusion and inconsistency by mixing height systems when measuring sea level change, and
4) Causing an inconsistency between our national coordinate frame and that of other countries

In addition to the problems manifested by using a non-geocentric reference frame, two other problematic issues with NAD 83 need to be addressed. They are:

5) Inconsistency between coordinates of the Continuously Operating Reference Station (CORS) network and passive marks
6) Lack of velocities on passive control used to realize the datum

Inconsistency Between Mapping Products and GNSS

As stated earlier, the future of positioning is GNSS. That technology is changing so fast that soon stand-alone GNSS users will have access to inexpensive multi-constellation positioning devices that can achieve sub-meter accuracy. As this happens, a horizontal discrepancy in the national datum up to two meters will cause a variety of difficulties. For example, maps of roads in the USA may have NAD 83 coordinates, but personal navigation units work in WGS 84[7] (whose origin is geocentric to within a few centimeters). Personal navigation units are expected to eventually yield sub-meter accuracies and provide "in the lane" driving directions. Under such a scenario, comparing WGS 84 coordinates of the car to NAD 83 coordinates of the mapped roads will mean up to 2 meters of error that could cause incorrect lane determinations.

It is impractical to assume that the appropriate datum transformation would be coded accurately in every personal handheld positioning device to correct for this. The datum transformation between WGS 84 and NAD 83 was historically a concern only to geodesists, and is often coded incorrectly in commercial software, if it is coded at all. Even today there persists software which treats WGS 84 as equivalent to NAD 83. Rather than risk life and property to such misunderstandings, NGS feels that a geocentric datum is the best approach.

A Biased and Tilted Inconsistency in National Geoid Products

While ± 2 meter errors in horizontal coordinates are certainly worrisome for some applications, as discussed above, the ± 2 meter vertical error is much more problematic. Consider one of the

[7] World Geodetic System of 1984 – Defined and maintained by the Department of Defense, and in which frame the broadcast positions of GPS are provided

most fundamental height equations of geodesy, which converts the ellipsoid heights (h) as derived from GPS into orthometric heights (H), as used on topographic maps, through a model of geoid undulations (N):

$$H = h - N$$

Currently, in the official datums of the USA, this equation is incorrect at the level of a few meters. This is partly due to measurable systematic errors in the orthometric heights, addressed earlier, but partly due to a tilted set of systematic errors in NAD 83 ellipsoid heights. This error ranges from about 1.5 meters in Florida to 0.3 meters in the Pacific Northwest, just to use the Conterminous USA example, due to the non-geocentricity of NAD 83. In order to "close" the above equation, NGS produces a "hybrid geoid" model (N*) so that the modified equation reads:

$$[H + \text{systematic errors in NAVD 88}] = [h + \text{systematic errors in NAD 83}] - N^*$$

NGS is addressing this issue by replacing both NAD 83 and NAVD 88, so that the original equation will close using newly defined official datums for the NSRS.

Confusion and Inconsistency when Measuring Sea Level Change

As both a program office of NOAA, and a provider of scientific positioning services to the United States, NGS is engaged in many activities that seek to quantify sea level change, which is a global phenomenon and one that is studied best without bias from national height systems. Satellite altimeters that orbit around the center of mass of the Earth and measure sea level change in the open ocean are making measurements relative to a geocentric ellipsoid, not NAD 83. But, the official ellipsoid height system of the USA remains NAD 83, and so GPS surveys performed at tide gages in the United States, a source of local sea level change detection, would tend to use NAD 83 ellipsoid heights. This sort of inconsistency must be accounted for all the time when national and global studies are compared. The sea level community should have one set of ellipsoid heights that are consistent, globally and locally.

Inconsistency between coordinate frames of U.S. and other countries

NGS works closely with many countries, and on issues of national datum definition NGS has always worked with our closest neighbors. While Canada and the United States are currently in the NAD 83 system, Mexico has adopted the geocentric ITRF system for use in their country. By moving toward a geocentric reference frame, the USA and Mexico may find more consistency in cross-border geospatial work. NGS is also in active discussions with Canada about plans to move away from NAD 83, but the final decision of the Canadian government toward replacing NAD 83 is not yet clear. For the same reasons stated in this paper, many other countries have moved to a geocentric reference frame including New Zealand (NZGD2000), Australia (GDA94) and Malaysia (GDM2000).

Inconsistent Coordinates, CORS to Passive Marks

The earth is dynamic, and as a result all geodetic control is in motion and coordinates are not static. In the past this was not a problem because the measurement errors far exceeded the magnitude of the motion. So, historically, a passive mark with a "known" coordinate was the way to provide geodetic control to a surveyor or mapmaker.

Today, the proliferation of continuous GPS sites and Real Time Networks, yielding differential accuracies of a few centimeters, make relying on a long-outdated "known" coordinate on a passive mark unnecessary. Doing so can cause inconsistencies between maps and coordinates computed using active GPS control.

The most recent example of this is a re-adjustment of all available GPS data observed on passive marks in the USA. That re-adjustment, called NSRS2007, was designed to reconcile GPS vectors through a 15 year time span to a common epoch, using the Horizontal Time Dependent Positioning (HTDP) tool. Unfortunately, a variety of issues have prevented full consistency between CORS and NSRS2007. For example, no accounting of the vertical motion of passive marks was made.

There have been many proposals to address this inconsistency, including a new realization of NAD 83 where the velocities of the passive marks would be estimated, rather than solving for a coordinate set fixed in time. Alternatively, if a three dimensional crustal motion model were available, another readjustment of the passive marks could be done to gain consistency with CORS.

Both of the above approaches treat passive and active control as equally important methods of accessing the geometric reference frame. There is another alternative, which is to purposefully define the active control as the only direct access to the geometric reference frame. In this way, passive control becomes a secondary form of access, and only viable if the passive control coordinates are established through a GNSS survey using active control. The installation, surveying and maintenance of passive control would then pass on to users whose work relies on that control, where NGS would provide the tools[8] necessary to connect that passive control to the active control. In this way, passive control becomes "tied to" the NSRS, rather than "part of" the NSRS.

This is the approach which NGS outlined in their ten year plan (NGS, 2008). Because it is a new way of providing access to the NSRS, effectively removing most elements of passive control from the auspices of NGS responsibility, this new approach would best coincide with a new geometric reference frame. That way, when the new frame becomes active, coordinates in the new frame will only exist at active control. NGS would still provide a "mapping grade" conversion between NAD 83 and the new frame, much like NADCON was provided as a conversion from NAD 27 to NAD 83, but would not consider the converted coordinates on passive marks as part of the NSRS. As users perform GNSS surveys on passive control, they would be given tools to compute coordinates and velocities in the new frame, and tools for

[8] Some of these tools are already in public use, such as OPUS and OPUS-RS

sharing that information, but NGS would not endorse the use of that passive control as the primary method of accessing the NSRS.

Lack of Velocities on Passive Control Used to Realize the Datum

The NAD 83, like most geodetic control, must provide a framework for multiple users to arrive at consistent maps and other geospatial data. By having coordinates "frozen to an epoch", as was done with NSRS2007, this consistency is provided. On the other hand, coordinate changes are useful information and attempts to provide "the definitive coordinate" for a point, while ignoring its motion fails to provide users with the sort of information that would be beneficial to protecting life and property. Currently, the passive control included in the NSRS2007 adjustment have a coordinate set (latitude, longitude and ellipsoid height) but no estimated velocities, even if that mark was surveyed repeatedly over the 15 years preceding the readjustment.

NGS could re-adjust the GPS surveys in the NSRS2007 adjustment and solve for velocities, though success would be limited, considering that most points were not observed more than once over 15 years. Furthermore, NGS does not have the resources to engage in a campaign to re-observe all passive marks in a way that allows the regular computation of velocities.

A different approach, aligned with the issue of active/passive inconsistency, will instead be adopted. Specifically, NGS will compute velocities on passive marks where possible – that is, where users have submitted multiple GPS surveys over time on the same mark. In addition, NGS will develop three-dimensional models of Earth's crust which can be used to estimate velocities at particular locations, though such velocities will obviously only be useful if a passive mark is moving as the crust moves.

In order to reconcile the many needs for constancy in coordinates with the reality of a dynamic planet, a semi-dynamic reference frame will be incorporated. In such a scenario, NGS would provide coordinates of control at specific epochs, computed or modeled, and the velocities of those marks, as well as any known episodic motions, such as earthquakes or post-seismic relaxation. Users would then be able to choose whether to adopt a specific epoch for their work, and account for the motion of marks through time. NGS will provide accuracy, but users will have the option to adopt constancy.

Again, because this is an entirely new approach (i.e. estimating and/or computing of velocities on passive marks), this is best done while defining a new datum. Users will know that having velocities on passive marks means they are working in the new datum and not in NAD 83.

Summary

The National Geodetic Survey has embarked on a ten year process of removing inaccuracies in the existing datums of the United States and is seeking to engage the entire geospatial community to make the transition to new datums as seamless as possible.

Many options for addressing these inaccuracies have been proposed. Only a true paradigm shift is capable of addressing all of them. By fully embracing the benefits of GNSS as the positioning tool of today, and of the future, NGS will effectively link the replacements for NAD 83 and NAVD 88 through a geocentric reference frame and gravimetric geoid model. By tracking the dynamic nature of the Earth, and giving users tools to account for it, NGS will provide a new National Spatial Reference System that is semi-dynamic. That is, a full accounting of velocities at active control and in the geoid will be maintained at NGS, but users may choose to adopt a non-dynamic frame by adopting coordinates of choice at particular epochs. Whether users choose to work in a fully dynamic or semi-dynamic frame, NGS will provide the tools for transforming between them.

By setting these targets out ten years, this pace will include time for the user community to voice concerns and for NGS to address them. Hopefully this will ensure as smooth a transition as possible. For this reason, on May 11-12, 2010, NGS will host the first of a series of Federal Geospatial Summits to address proposed improvements to the National Spatial Reference System and to receive feedback from the user community on these proposals.

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Acknowledgements

This paper was prepared by Dr. Dru Smith, Chief Geodesist, National Geodetic Survey, and approved for distribution by the Executive Steering Committee of NGS on April 26, 2010.

Dr. Smith was given significant assistance by many people in NGS while writing this paper, and wishes to thankfully acknowledge them. They are, in alphabetical order: Gordon Adams, Mike Aslaksen, Timothy Blackford, Doug Brown, Mike Cline, Dave Doyle, Mark Eckl, Joe Evjen, Doug Graham, Steve Hilla, Ross Mackay, Dan Martin, Chris Parrish, Dan Roman, Jarir Saleh, Renee Shields, Ajit Singh, Richard Snay, Tomás Soler, Jim Tomlin, Maralyn Vorhauer and Yan Wang.

Appendix B

Agenda of the Summit

NOAA's National Ocean Service, National Geodetic Survey

Federal Geospatial Summit
Replacing North American Datum of 1983 (NAD 83)
and North American Vertical Datum of 1988 (NAVD88)

May 11 - 12, 2010
NOAA Auditorium
1301 East-West Highway
Silver Spring, MD 20910

Agenda Tuesday, May 11

7:30 – 8:30	**Arrival, Registration, and Continental Breakfast**
8:30 – 10:00	**Morning Session I**
8:30 – 8:45	**Kick-off** Mr. Dave Doyle, Chief Geodetic Surveyor, NGS
8:45 – 9:00	**Keynote** Mr. Joe Klimavicz, Chief Information Officer, NOAA
9:00 – 9:10	**Welcome** Ms. Juliana Blackwell, Director, NGS
9:10 – 9:35	**Lessons from Past Re-definitions: NAD 83** RADM (ret.) John Bossler, Ph.D, Former NGS and C&GS Director
9:35 – 10:00	**Lessons from Past Re-definitions: NAVD 88** Mr. Dave Zilkoski, Former NGS Director
10:00 – 10:30	**Break**
10:30 – 12:00	**Morning Session II**
10:30 – 10:45	**Modernizing the NSRS—The NGS Ten-Year Plan** Dr. Dru Smith, Chief Geodesist, NGS
10:45 – 11:15	**Modernizing the Geopotential Datum—Replacing NAVD 88** Dr. Dan Roman, Research Geodesist, NGS
11:15 – 11:45	**Modernizing the Geometric Datum—Replacing NAD 83** Dr. Richard Snay, Former Chief, Spatial Reference System Division, NGS
11:45 – 12:00	**Overview of the Afternoon Session** Mr. Dave Doyle
12:00 – 1:30	**Lunch and Sign-up for "Minute Sessions"**
1:30 – 5:00	**Panel Discussions**
1:30 – 3:00	**Panel Discussion I, Geometric Focus**
3:00 – 3:30	**Break**
3:30 – 5:00	**Panel Discussion II, Geopotential Focus**

NOAA's National Ocean Service, National Geodetic Survey

Federal Geospatial Summit
Replacing North American Datum of 1983 (NAD 83)
and North American Vertical Datum of 1988 (NAVD88)

Wednesday, May 12

7:30 – 8:30	**Arrival, Continental Breakfast, and Last-minute Sign-up for "Minute Sessions"**
8:30 – 12:00	**"Minute Sessions"**
8:30 – 8:45	**Welcome** Mr. Dave Doyle
8:45 – 10:00	**"Minute Session" Presentations** All Attendees Who Signed Up
10:00 – 10:30	**Break**
10:30 – 11:45	**"Minute Session" Presentations** All Attendees Who Signed Up
11:45 – 12:00	**Morning Summary and Introduction to the Afternoon Session** Mr. Dave Doyle
12:00 – 1:30	**Lunch Break**
1:30 – 5:00	**Panel Discussions and Closing**
1:30 – 3:00	**Panel Discussion Responses to "Minute Session"** NGS Staff—Response to Issues Raised in Morning Session
3:00 – 3:30	**Break**
3:30 – 4:45	**Panel Discussion Responses to "Minute Session"** *(continued)* NGS Staff—Response to Issues Raised in Morning Session
4:45 – 5:00	**Closing Remarks** Ms. Juliana Blackwell

Appendix C

Speech by Mr. Joe Klimavicz

Opening Remarks

Joe Klimavicz
Chief Information Officer
National Oceanic and Atmospheric Administration

When you think of NOAA's National Geodetic Survey, (NGS), you probably think of science and surveying. Although the name has changed over the years, NGS was, after all, **our Nation's first civilian scientific agency,** established by President Thomas Jefferson in 1807. There was a very good reason NGS was a priority for Jefferson's Administration.

From the ancient past, to the birth of our Nation, through the present, knowing where people, places, and things are located has been of critical importance. For example, in Jefferson's time, the safety of mariners, ships, cargoes, and the new Nation's fledgling maritime commerce relied upon knowing the precise locations of shoals, reefs, and navigational hazards among which they moved, while carrying the Nation's commerce. Our founding fathers, including George Washington and Thomas Jefferson, were surveyors not out of hobby or idle curiosity, but because of the fundamental necessity of surveying to the growth and defense of our Nation.

Virtually all of today's Federal surveying and mapping programs owe their legacy to Jefferson. In 1804, Thomas Jefferson said, "We shall delineate with correctness the great arteries of this great country… those who come after us…will fill up the canvas we begin."

The vision of Jefferson is reflected today in a great network of over 1,500,000 survey marks, or geodetic points, connected to each other by very exact measurements, with each mark giving an accurately computed latitude, longitude, and height.

The precision of this network takes into account aspects of measurements that many users of our data and the public are not aware, due to NGS doing their job as "geodesists" to make sure that it is done correctly. This includes, for example, measuring variations in gravity and movement of the Earth's crust.

These markers are one component of the NOAA managed and maintained National Spatial Reference System (NSRS), which provides a consistent framework for latitude, longitude, and height information, which supports all spatial activities in the United States. The NSRS provides the foundation and backbone for transportation, mapping and charting, along with a multitude of scientific and engineering

applications. NSRS is a primary element of any system that collects data for prediction, modeling, and analysis, as precise positioning information is an essential component of **any** observing system.

What our predecessors have built and what we continue to expand upon is an invisible, interlocking, and precise positioning foundation. It is the **economic foundation for our country.** In fact, today, you are never more than a few miles from a small brass mark embedded in stone or concrete or, at least a place where such a marker used to be located. Despite Federal law prohibiting their disturbance, **geodetic marks disappear by the hundreds annually,** making them an increasingly fragile part of the NSRS infrastructure.

While geodetic marks have been the way of conducting surveying for centuries, this is changing. In fact, the ***planet*** is changing. We now know that the Earth is so dynamic, that it is difficult to name them all. The sea level is changing; glaciers are melting; the continent is uplifting; tectonic plates are moving and colliding, and sometimes the very soil beneath our feet is subsiding in the range of a few inches every year. **A perpetual coordinate, computed from a single survey, on a mark set into the ground of this very dynamic Earth is no longer as reliable as we once thought.**

Thankfully, we are constantly improving our techniques and accuracies. The use of man-made satellites has proven to be the greatest innovation in the history of positioning and navigation. Today, the Global Positioning System (GPS) technology has ***transformed*** the way we do business. NOAA manages and maintains a network of over 1,400 Continuously Operating Reference Stations, (CORS), which are GPS base stations, whose accuracy and reliability significantly outpaces the old brass disks. By using CORS, NGS provides a positioning service to the country, improving the accuracy of latitude and longitude determination, narrowing it from a range of 5 meters down to a centimeter.

While our positioning methods are changing, they have not changed the economic importance of positioning infrastructure, products, and services. That is why we are here today—to share information as a community, and to ensure that our modernization of the National Spatial Reference System is performed in coordination with you, the users, so you will continue to reap the benefits, without significant disturbance to the performance of your own missions.

A 2009 independent socioeconomic study showed **billions of dollars in benefits to states and communities from NOAA's positioning products and services,** including the fundamental Geospatial

infrastructure for transportation, mapping and charting, along with a multitude of scientific and engineering applications.

Specifically, according to the study:

- The NSRS provides more than $2.4 billion in potential annual benefits to the U.S. economy
- The NOAA CORS network alone provides an estimated $758 million per year in benefits.
- An additional $522 million in annual economic benefits could be generated by the implementation of a new vertical reference system, allowing users to determine more precise elevations, using GPS, with approximately $240 million alone saved from improved floodplain management.

NOAA will lead this modernization effort, but we cannot do it alone. This is why we are pleased to have representatives from our Federal partners in the Geospatial community here today. We also welcome our partners from states, municipalities, industry, and academia. **The NSRS is a critical part of the Nation's infrastructure,** and as we move forward to embrace new technologies and improve the accuracy of our services to you, we hope that you will help us understand how best we can serve you in the future.

Thank you.

Appendix D

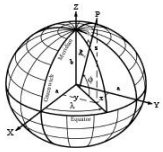
Slides used by Dr. Bossler

Slide 1

FEDERAL GEOSPATIAL SUMMIT

MAY 11, 2010
SILVER SPRING, MARYLAND

PROBLEMS AND SOLUTIONS DURING THE NAD 83 & NAVD 88: LOOKING BACK



JOHN D. BOSSLER
REAR ADMIRAL NOAA (RET.),
PROFESSOR EMERITUS, OHIO STATE UNIVERSITY

Slide 2

IN THE SEQUEL

- FINANCIAL PROBLEMS
- TECHNICAL PROBLEMS
- USER PROBLEMS
- INTERESTING USER EXAMPLE
- BOSSLER ON REDEFINITIONS

Slide 3

FINANCIAL PROBLEMS

P: OVERALL INITIAL BUDGET WAS INADEQUATE
S: BEGGED TOWNSEND and CALIO FOR MORE MONEY

P: COST OVERUNS ON SOFTWARE AND DATA CONVERSION
S: RESULTED IN 50% CONTRACTS AND IN HOUSE

P: KEY *ALL* THE DESCRIPTIONS?
S: USE CONVICTS TO KEY DATA

P = PROBLEMS
S = SOLUTIONS

Slide 4

TECHNICAL PROBLEMS

P: ROUND OFF ERRORS
S: PETER MEISSEL CAME TO NGS FOR A YEAR

P: TOO MANY EQUATIONS
S: REDUCED SPACE NEEDED (R.SNAY)

P: CORRECT WEIGHTING NEEDED
S: VARIANCE COMPONENT STUDY (TEAM OF
B. CARTER, E. MCKAY, ET AL)

Slide 5

TECHNICAL PROBLEMS

P: CORRECT ITERARTION OF EQUATIONS
S: USED “PITFALLS” (A. POPE, J .ISNER)

P: GEOID REFINEMENT AND ENHANCEMENT
S: GATHER NEW DATA, R & D ON METHODS (TEAM OF B. STRANGE, T. SOLER, R. FURY AND C. GOAD)

P: DATA MANGEMENT
S: BACKUP AT HOME, DEVELOPED PROCESS (L.WADE, G. YOUNG, M. VORHAUER)

Slide 6

USER PROBLEMS

P: SURVEYORS DIDN’T UNDERSTAND
S: HELD USER MEETINGS AT NGS, CONFERENCES

P: USGS AND OTHER FEDS SLOW TO ACCEPT
S: COMPUTED ESTIMATED MAP CORNERS

P: C&GS RESISTED
S: CREATED A SCHEDULE CHANGING NAD 29 TO 83

Slide 7

NAVD 88

MANY PROBLEMS WERE SOLVED in NAD 83, DESCRIPTIONS, SOFTWARE, HELMERT BLOCKING, ETC

P: MONEY PROBLEMS EXISTED
S: TOOK FROM C & GS, TOWNSEND

P: TECHNICAL PROBLEMS STILL EXISTED, E.G., ORIGIN
S: SOLVED BY C. WHALEN, D. ZILKOWSKI, G. YOUNG

Slide 8

AN INTERESTING CONSULTING CASE

- SMUGGLERS CROSSED FROM CANADA TO THE STATE OF WASHINGTON. OVER THE BORDER?
- PUBLIC DEFENDER ASSERTED THAT SMUGGLERS WERE 800 FEET INTO CANADA ACCORDING TO GPS
- STUDIED ZENITH TELESCOPES, METHODS, ETC. COULD NOT FIND ERRORS = TO 800 FEET. WENT TO COURT
- BEFORE I TESTIFIED, I USED INTERNET, GOT DEFLECTION FROM NGS. IN THE MERIDIAN PLANE IT WAS 800 FEET

Slide 9

REDEFINITION OR NOT?

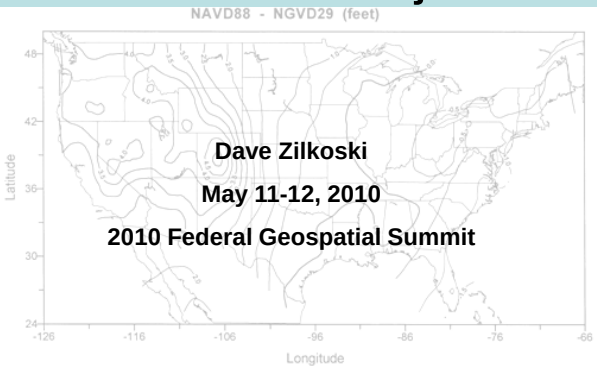
- VERTICAL DATUM MOST IMPORTANT BECAUSE OF GPS AND ACCURATE GEOID. THIS STRATEGY WILL PREVAIL.
- USER CONSTANCY IS PREMIER
- ACCURACY, ESPECIALLY ABSOLUTE POSITIONING, IS SECONDARY.
- NEW NGS PARADIGM (GPS) IS GREAT

Appendix E

Slides used by Mr. Zilkoski

Slide 1

Lessons From the NAVD 88 Project



Dave Zilkoski

May 11-12, 2010

2010 Federal Geospatial Summit

Geospatial Solutions Require an Integrated, Collaborative Environment

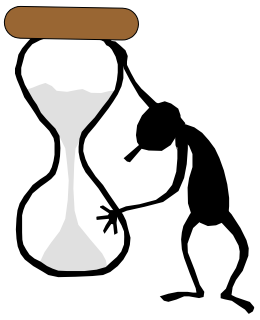
Slide 2

No Matter What You Do

- **Some Users Will Not Worry About A Datum Change Until It Is Officially Published**

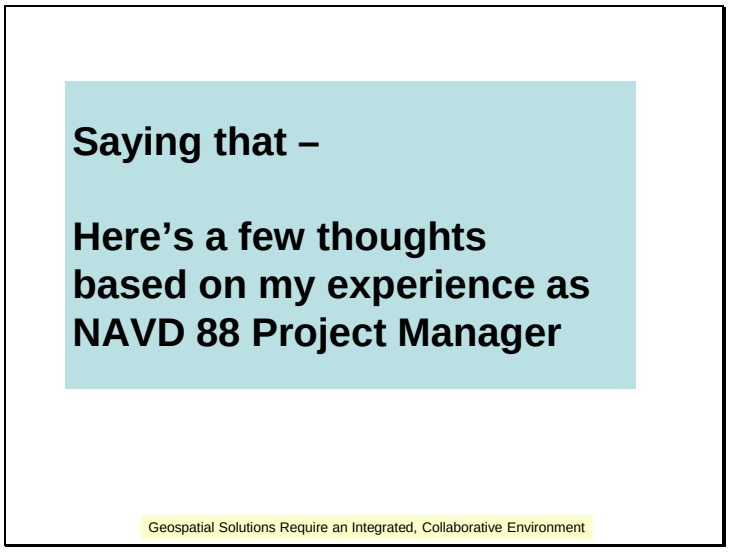
And

- **They Will Then Ask You Why You Didn't Inform Them Earlier About The Change**



Geospatial Solutions Require an Integrated, Collaborative Environment

Slide 3



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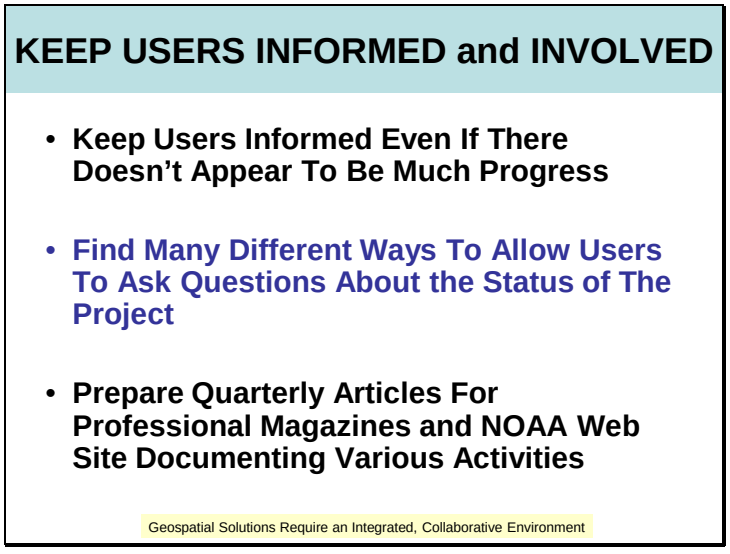


Slide 5

Involve Everyone

- **Involve State and Local Government**
  - **Use NGS Height Modernization Partners and Spatial Reference Centers**
- **Involve Universities**
  - **Research**
- **Involve Professional Societies**
  - **Training/Seminars/Articles**
- **Involve Private Industry**
  - **Data Acquisition and Evaluation of Results**

Geospatial Solutions Require an Integrated, Collaborative Environment

Slide 6

Create an Integrated, Collaborative Environment

- **Involve All Users in the Process and Work With Existing Groups to Get Their Input (ACSM, FGCS, NSGIC, ASPRS, TRB)**
- **Convene Symposiums that Involve All Users of the NSRS and Hold "Short" Non-Technical Interactive Webinars**
- **Prepare a Work Plan With Action Items That Include NGS Collaborating With Other Agencies and Users**
- **Work With Others to Prepare Their Transition Action Plans**

Geospatial Solutions Require an Integrated, Collaborative Environment

Slide 7

Understand Each Other's Requirements

- **Obtain an Understanding of All User Requirements**
- **Have Users Identify Concerns and Assist in Developing Potential Solutions**

- **Develop Models and Tools Prior to the Completion of the Project**

Geospatial Solutions Require an Integrated, Collaborative Environment

Slide 8

Institutionalize the Process

- **Create an Official NGS Team Responsible for the Project Including the IMPLEMENTION Phase**
- **Formalize Agency Decisions and Work Plans**
  [Most Agency Leads Involved in the Project Today Will Not Be in Their Current Role in 2018]
  - **FGCS for Feds**
  - **ACSM for Surveyors and Mappers**
  - **AASHTO (?) for State DOTS**

Geospatial Solutions Require an Integrated, Collaborative Environment

Slide 9

Impacts, Benefits, and Responsibilities

- **Identify and Document Impacts and Benefits Resulting from the New Datums**
- **Assign Responsibilities and Hold NGS/Users Accountable**

Geospatial Solutions Require an Integrated, Collaborative Environment

Slide 10

Example From NAVD 88 Project IMPACT

- **Users Will Have to Retrieve New datasheets because all Published Heights of Bench Marks Will Have Changed**
- **Data Bases containing heights referenced to NGVD 29 will have to be updated to NAVD 88**
- **Maps depicting NGVD 29 Heights will have to be modified for NAVD 88 Heights**

Geospatial Solutions Require an Integrated, Collaborative Environment

Slide 11

Example From NAVD 88 Project BENEFITS

- Surveys between bench marks will often close better
- NAVD 88 will provide a better reference to compute GPS-Derived Orthometric Heights
- 40,000 Additional bench marks of First-Order accuracy will be available on NAVD 88
- Data and NAVD 88 adjusted height values will be readily available and accessible in a convenient format from NGS's web site: http://www.ngs.noaa.gov
- Federal Surveying and Mapping agencies will publish only on NAVD 88

Geospatial Solutions Require an Integrated, Collaborative Environment

Slide 12

Example from NAVD 88 Project NGS' RESPONSIBILITIES

- Data Acquisition, Analyses, and Adjustment
- Perform procedures to officially replace NGVD 29 with NAVD 88
- Compile documentation to brief Congress and State officials on NAVD 88 impacts and benefits to minimize problems with uniformed users
- Estimate conversion (bias) shifts between NGVD 29 and NAVD 88
- Incorporate other data, e.g., COE and/or USGS data, into NAVD 88 (data must be in computer-readable form)

Geospatial Solutions Require an Integrated, Collaborative Environment

Slide 13

Example from NAVD 88 Project
USER'S RESPONSIBILITIES

- **Data Acquisition of Local First- and Second-Order Leveling Data to be Incorporated into NAVD 88 (data must be in computer-readable form)**
- **Provide Kinds Of Data, Reports, Routines, and Training Required To Implement NAVD 88**
- **Relay (In A Timely Manner) To NGS Problems with Implementation Of NAVD 88**

Slide 14

Final Thought

2018 Will Be Here Before You Know It

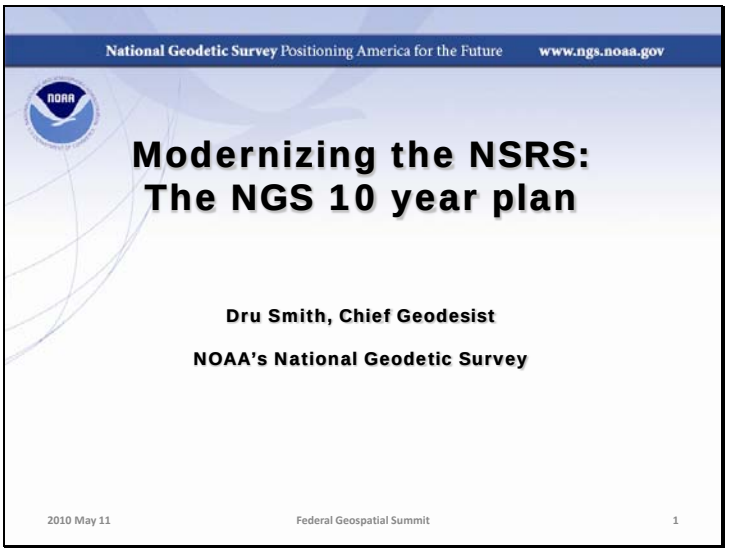
And

Before You're Ready Unless Everyone Collaborates to Achieve a Common Goal

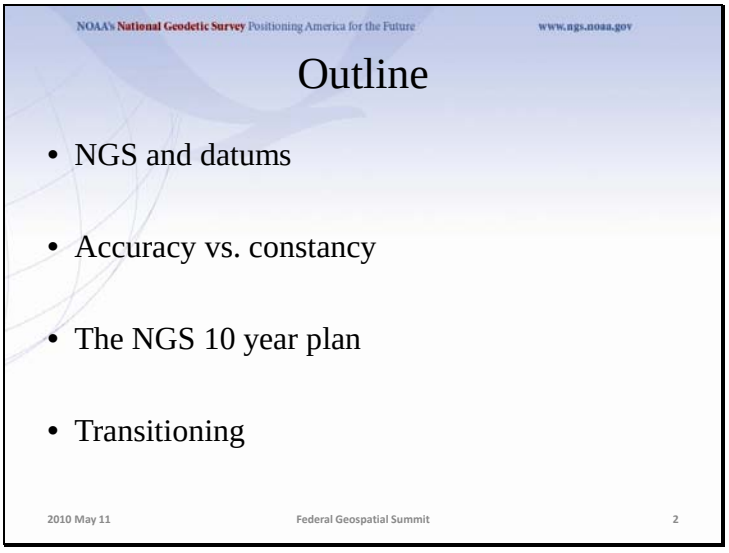
Appendix F

Slides used by Dr. Smith

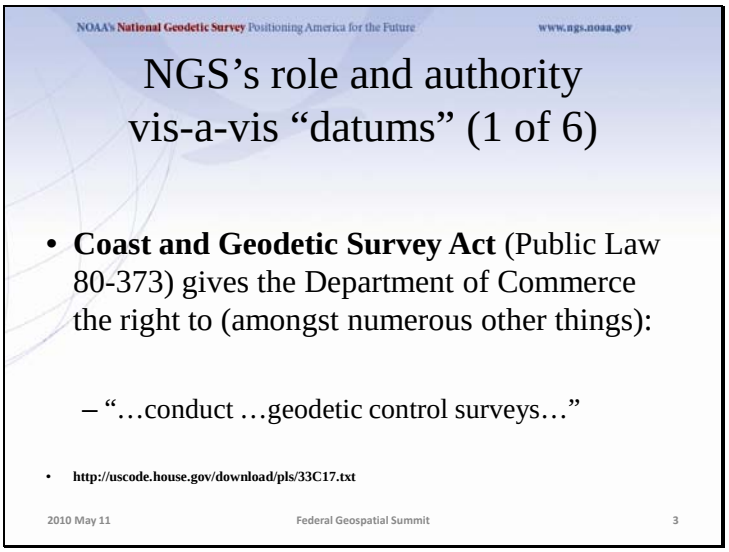
Slide 1



Slide 2

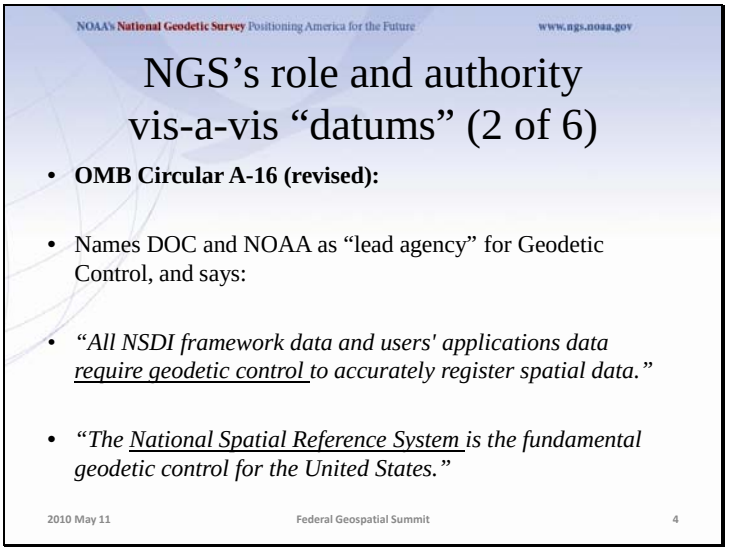


Slide 3



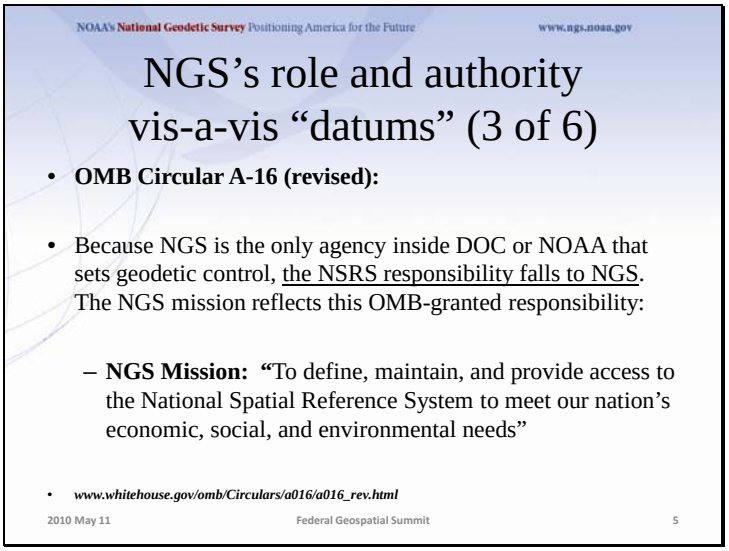
There is no single law that gives NGS its mandate. The mandate is drawn from multiple sources. The same can be said of NOAA itself which has no "organic" bill to give it a singular mandate.

Slide 4



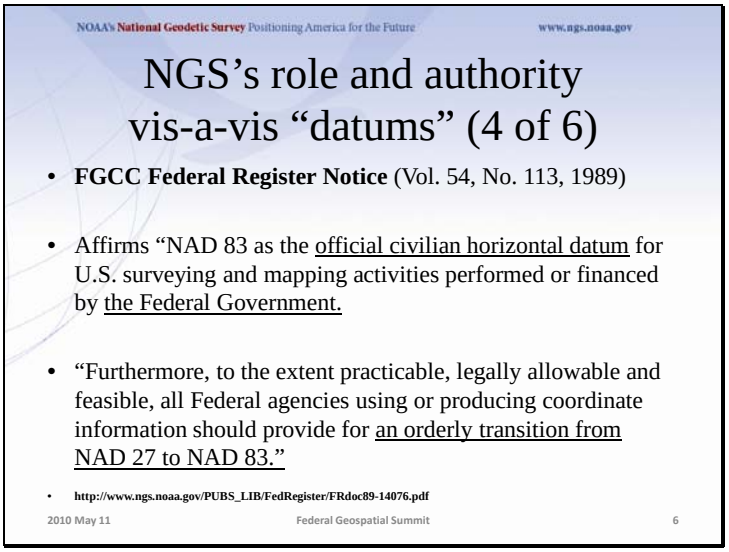
The OMB circular A-16 is one of the clearest documents, outlining the roles of the multiple civilian mapping authorities.

Slide 5



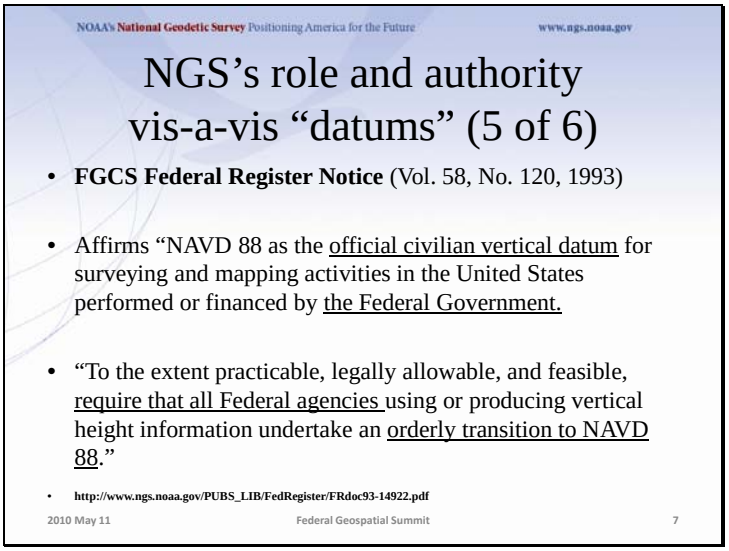
The NSRS is broadly defined by NGS in the 10 year plan to include the horizontal and vertical datums, the national shoreline and a variety of other components.

Slide 6



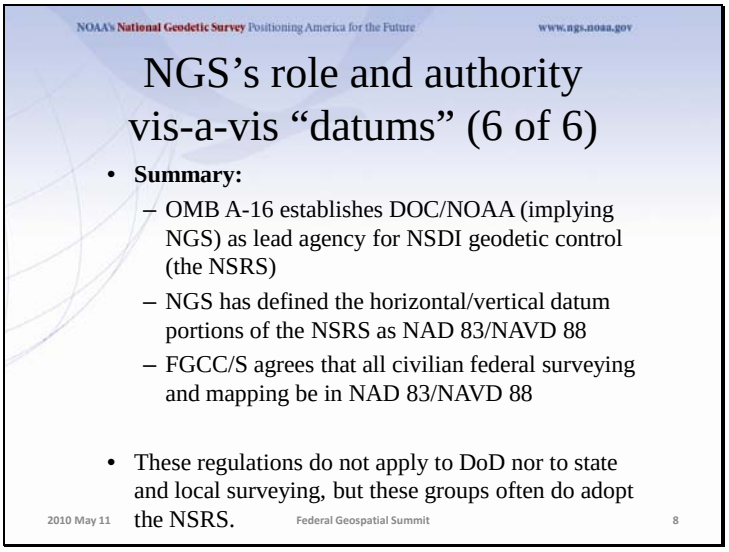
The FGCS (previously FGCC) has members from multiple positioning and mapping agencies. This FRN from the FGCC therefore is a community agreed-upon mandate to themselves that the NGS-defined horizontal datum should be used by every civil mapping authority.

Slide 7

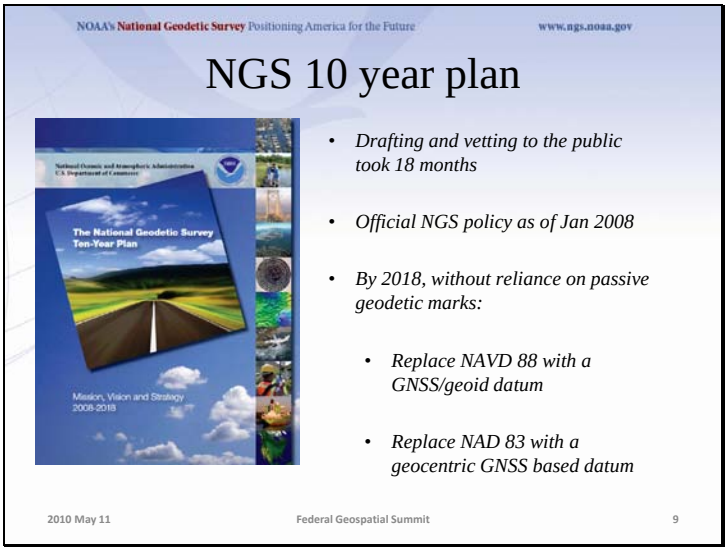


The FGCS has members from multiple positioning and mapping agencies. This FRN from the FGCS therefore is a community agreed-upon mandate to themselves that the NGS-defined vertical datum should be used by every civil mapping authority.

Slide 8

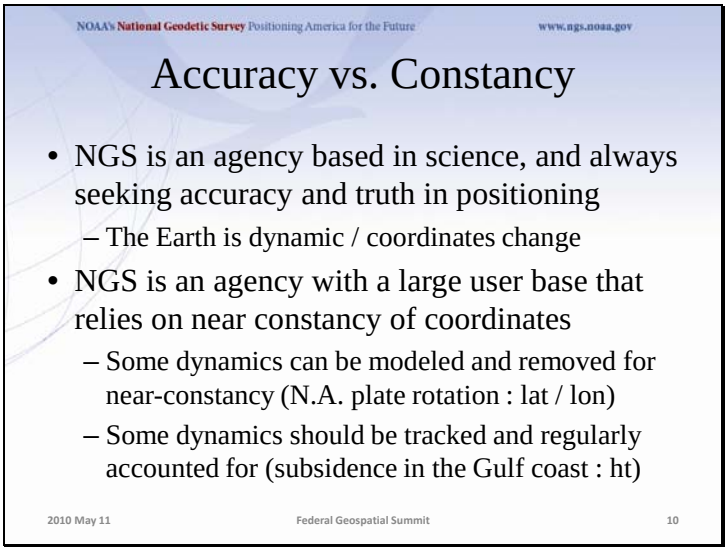


Slide 9

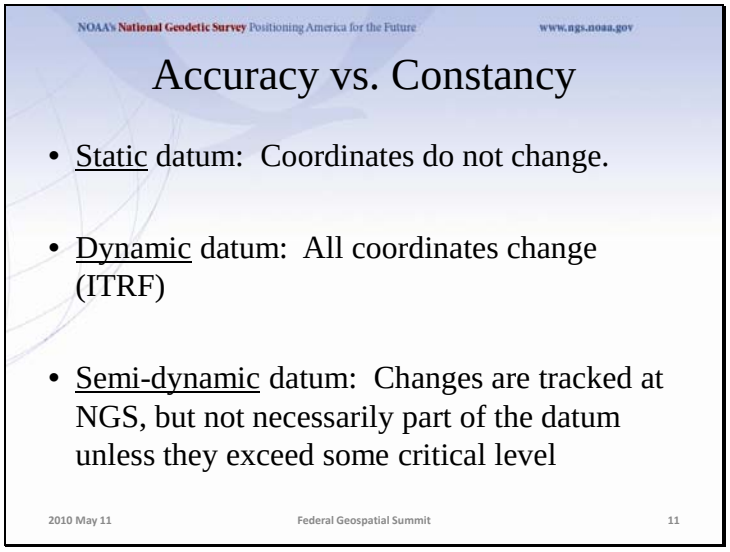


Highlights of the NGS 10 year plan relevant to the Summit

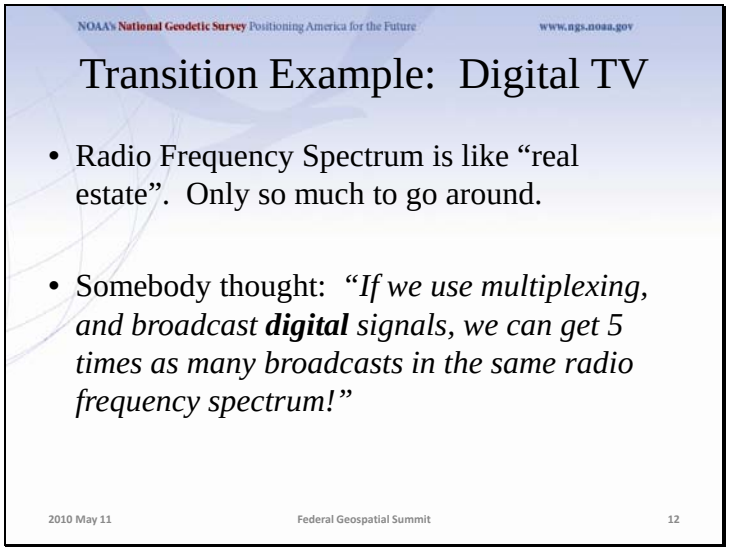
Slide 10



Slide 11



Slide 12



Slide 13

Transition Example: Digital TV

- 1996 Congress:"Transition coming in 2006!"
- 2005: Analog TVs *still* being mass produced
  - Congress: "Um, how does February 2009 sound?"
- 2006: Analog TVs *still* being mass produced
  - Congress: "Hey, we're serious…2009 is coming"
- 2008: FCC finally creates a DTV website
- Feb 2009: Too few people have converters
  - Congress: "How does *June* 2009 sound?"

Slide 14

Transition Example: Digital TV

- At its core, this transition went poorly for many reasons, but one in particular:
  - There wasn't a perceived *need* to convert to digital.
    - TV isn't a *necessity*. (Though…Emergency Readiness?)
  - Nonetheless, available spectrum was running out with all the new technologies and *making efficient use of existing spectrum made a lot of sense*
    - …to those who understood and cared
- A classic example of a solution to *a problem that people didn't know existed.*

Slide 15

A problem that does exist

- The White Paper should explain the problems and raise awareness of them
- The burning question is no longer "why" but "how"
- Moving forward must be done with contemplation, caution and commitment

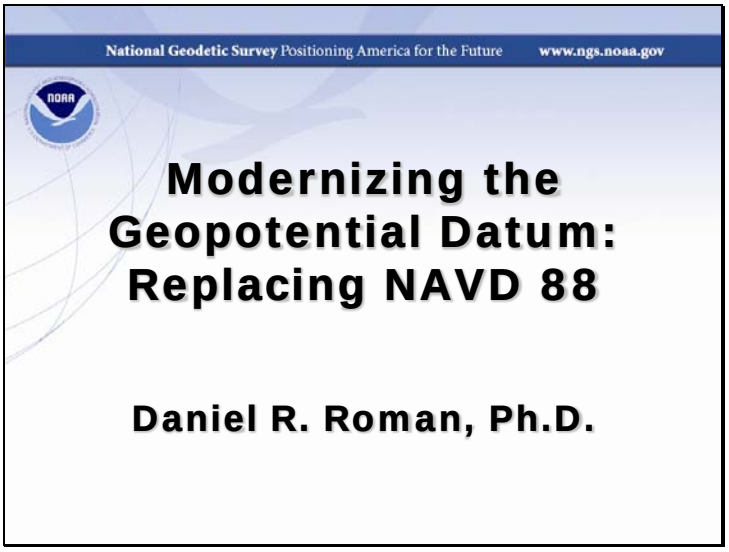
Slide 16

With great power comes great responsibility…

Appendix G

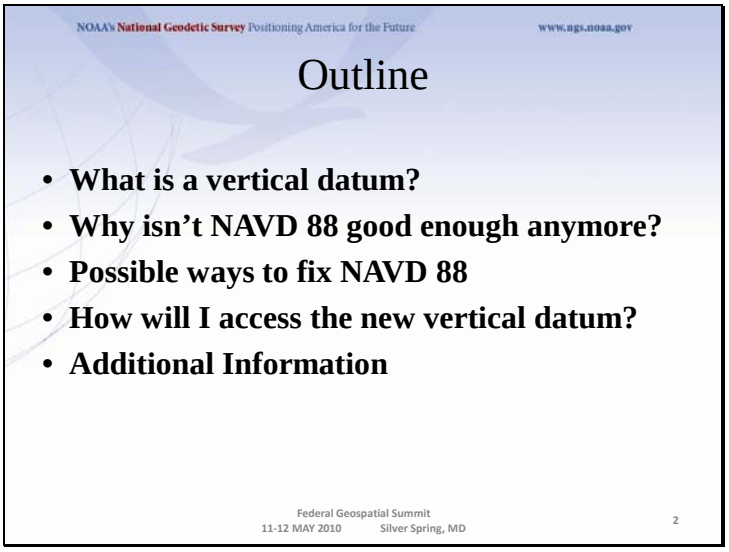
Slides used by Dr. Roman

Slide 1



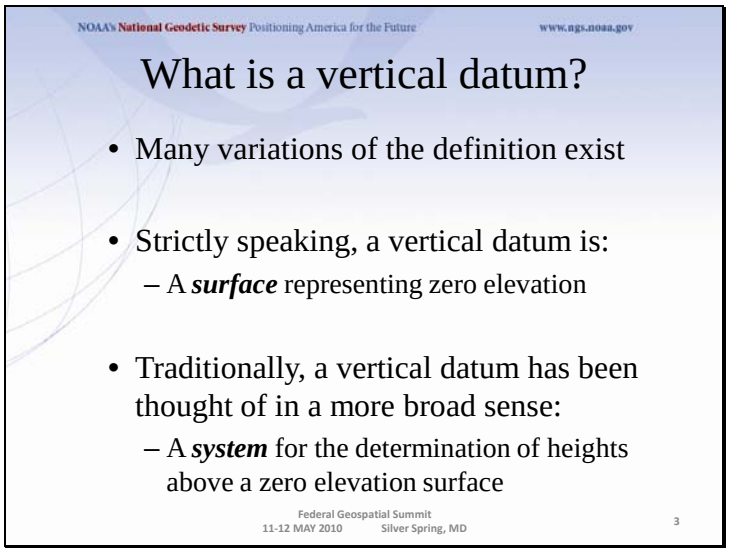
The purpose of this PPT file is to provide a single slideshow about the move toward a new vertical datum, including GRAV-D updates. It is meant to be distributed around NGS for use at a variety of speaking engagements. While the content of the slides should not be modified, the intention is for this to be very "compartmentalized" so that "chapters" of slides can be cut out if they are not important/relevant to the audience.

Slide 2

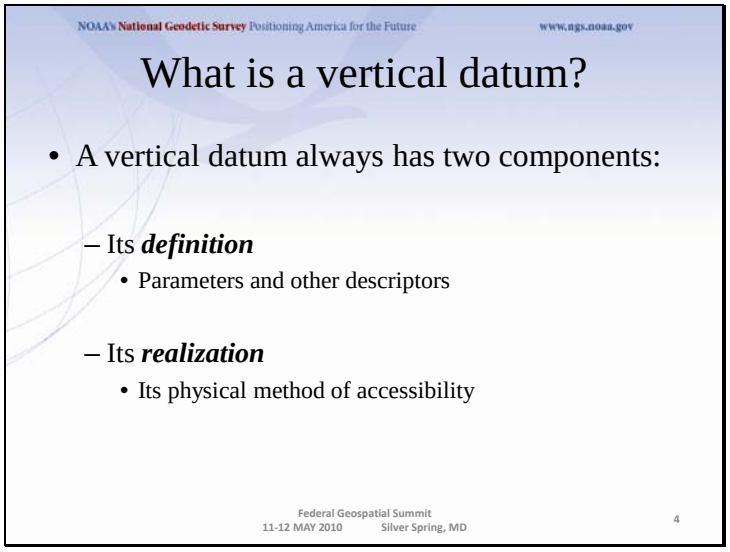


This is a listing of the parts of subject matters to be covered. Cut out entire chapters if they are unimportant to your audience.

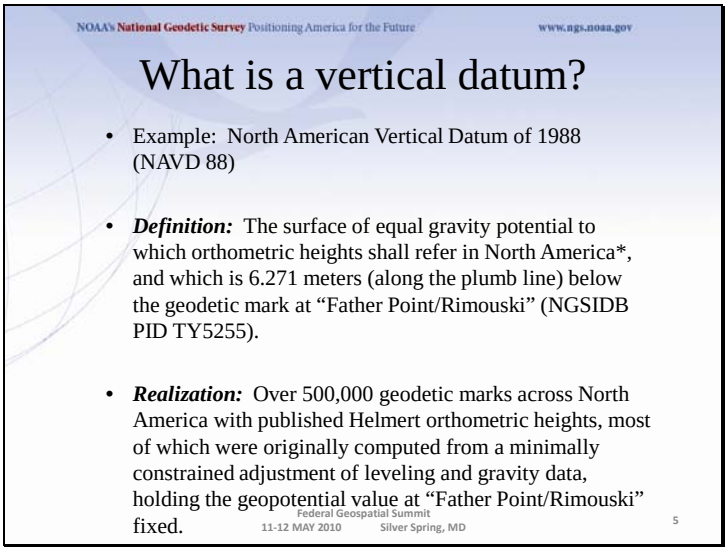
Slide 3



Slide 4



Slide 5

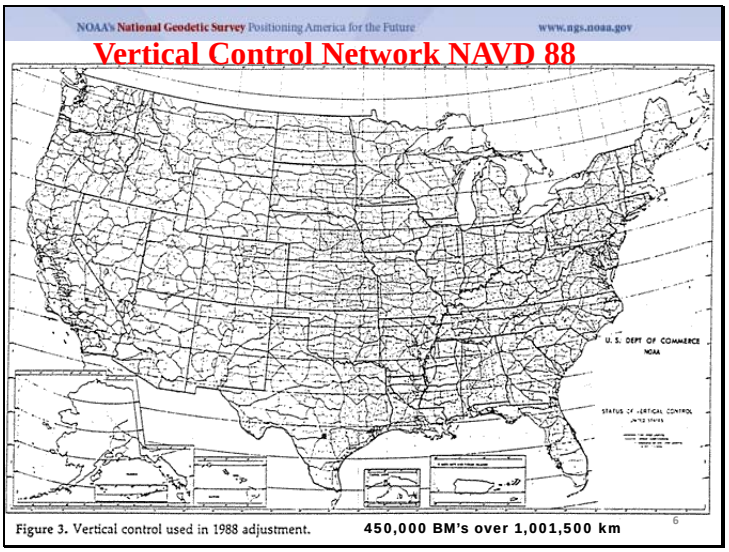


By fixing the geopotential value at the origin point, it was possible to ensure that the origins of IGLD 85 and NAVD 88 aligned.

*It should be pointed out that while the datum was defined in such a way as to be usable on the North American continent, it was never actually adopted in Canada. It can be used there, but it's not their official civilian datum.

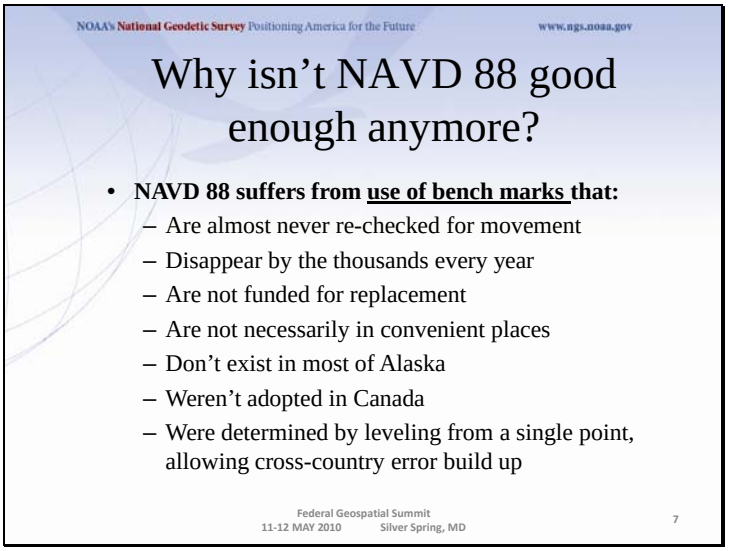
Note that the designation of the vertical control point at Father Point is "1250 G=NAVD 88 DATUM POINT" for PID# TY5255 and is not available from the publicly accessible NGSIDB.

Slide 6



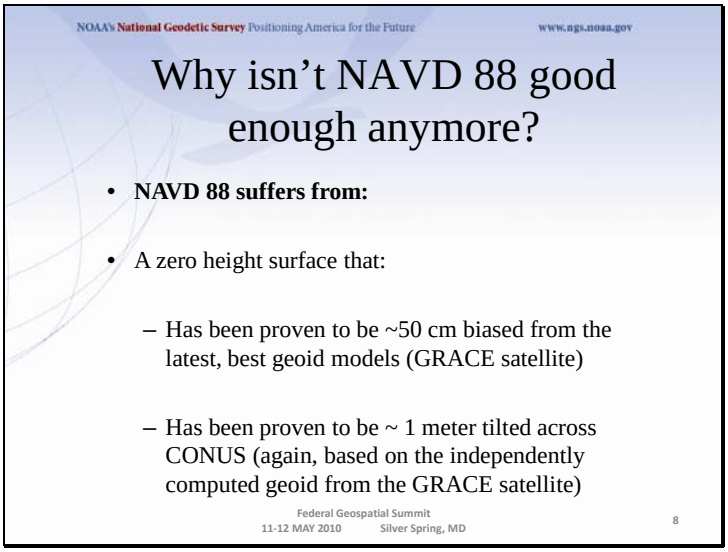
Levels and only the one connection to tide gage included in NAVD88.

Slide 7

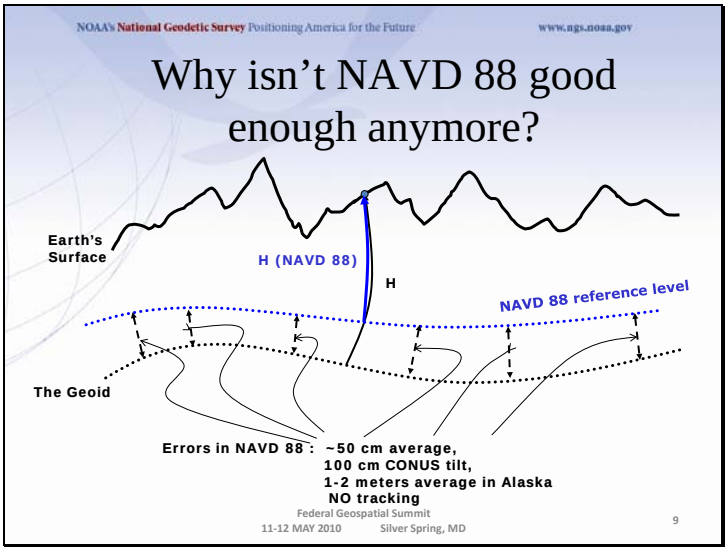


Clarification on the word "convenient" – this is used to mean "there isn't always a bench mark around when you need one – sometimes you have to find one far away and level from it to your site of interest"

Slide 8

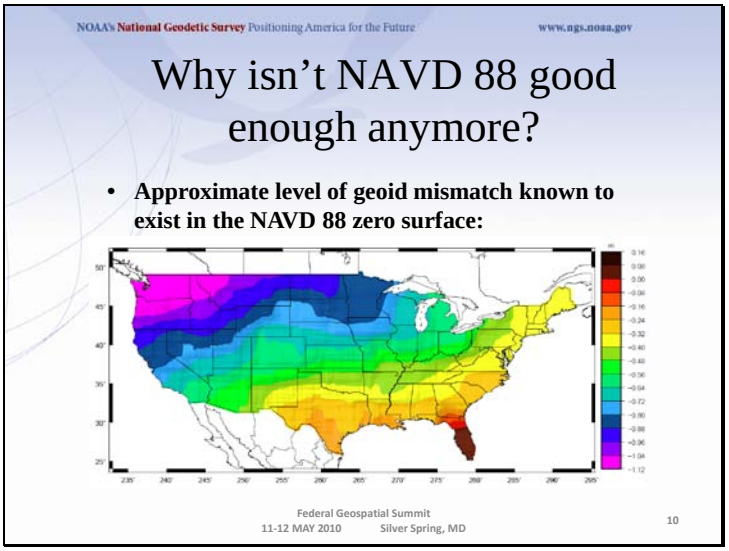


Slide 9



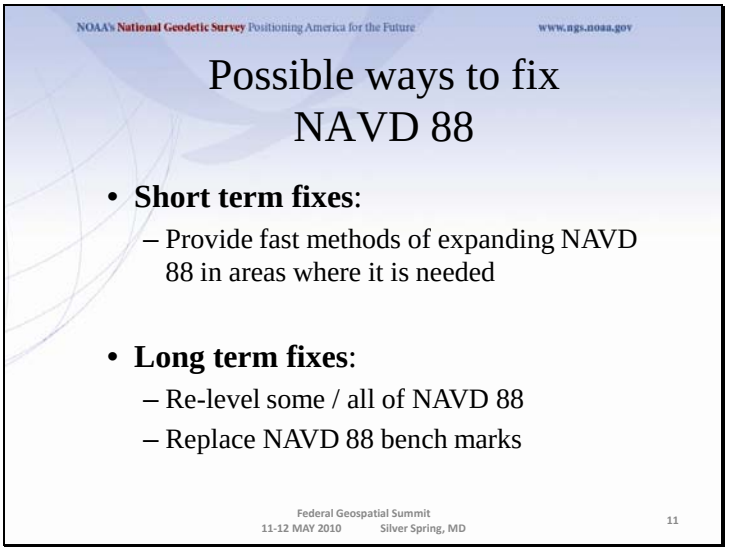
This slide shows what NGS now knows about the error in NAVD 88 itself. Using a continental geoid computed from the GRACE satellite, a bias and tilt in NAVD 88 has been computed using GPS derived ellipsoid heights on NAVD 88 bench marks. These are now known errors that exist in all NAVD 88 bench marks. This datum realization error, relative to the geoid, is over and above the errors from marks moving.

Slide 10

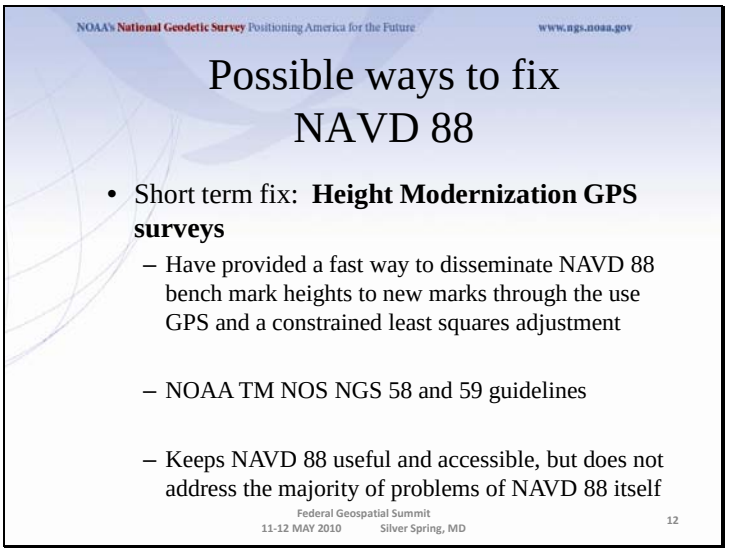


This map reflects the sort of height changes that users could expect if NAVD 88 were replaced with a geoid-based vertical datum. This is only a large scale approximation and should not be used as an absolute guide.

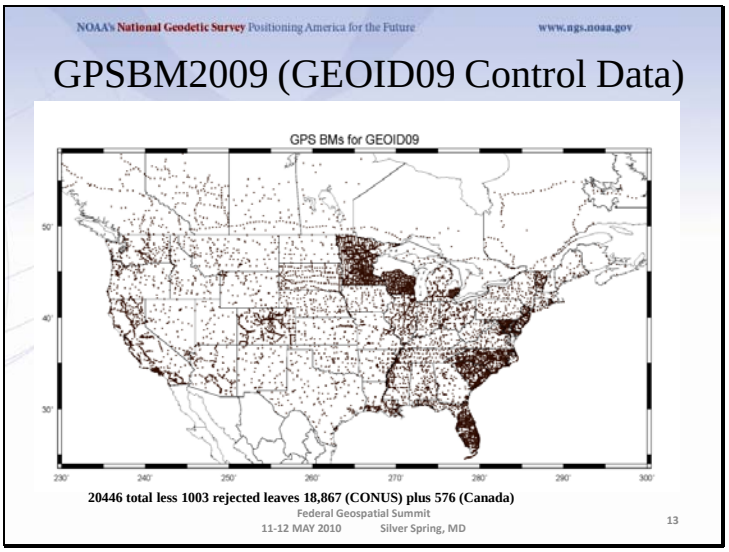
Slide 11



Slide 12

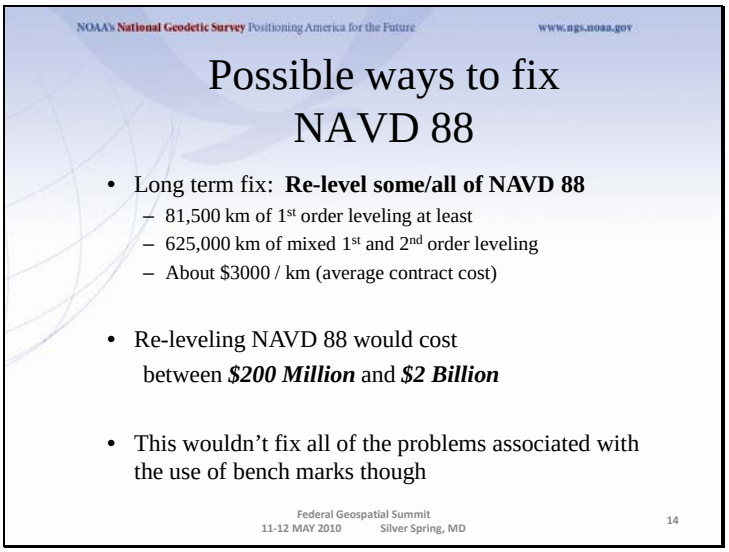


Slide 13



Height Modernization is limited by the quality of the GEOIDxx model available at the time.
In turn, the GEOIDxx model is limited by the quality and distribution of control points where both an ellipsoidal height and orthometric height are known.
Of the nearly 500,000 bench marks, only about 20,000 have ellipsoidal heights – are these are very poorly distributed.

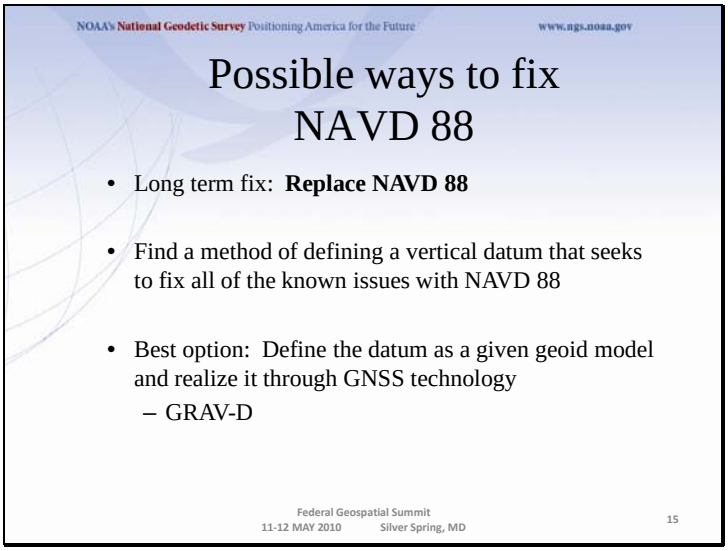
Slide 14



Re-leveling NAVD 88 won't fix:

- Sparseness of the bench marks
- Continued subsidence or uplift of bench marks
- Destruction of bench marks
- Canada's decision not to adopt NAVD 88
- Whatever errors caused a continent-wide 1 meter build up in the leveling the first time around

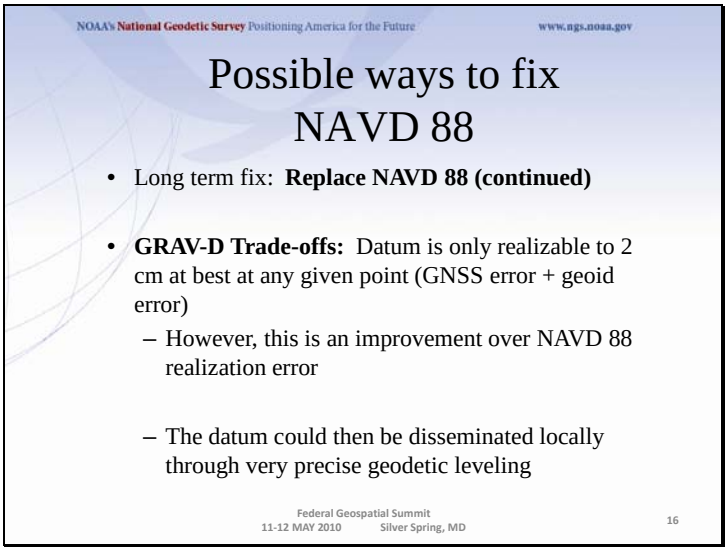
Slide 15



Why is this the best option? Because it addresses:

- Different datums existing for CONUS, Hawaii, PR/VI (and, theoretically, Canada, Mexico, and the Caribbean and Central American countries)
- Sparseness of bench marks
- Error build up as one gets far from an origin point
- Financial and personnel realities
- Fragility of bench mark network

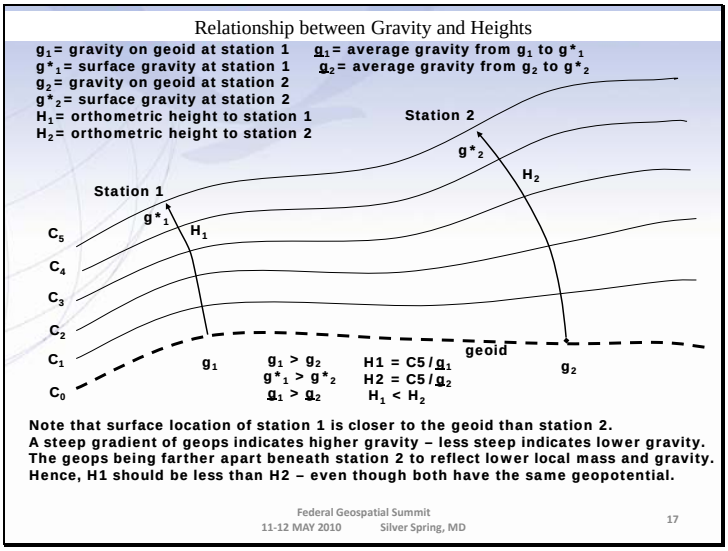
Slide 16



Although the idea of a GNSS/geoid vertical datum will mean realization errors generally no better than 2 cm at any given location, this is better than NAVD 88 which has leveling error build up away from Father point. Additionally, the ability to know the datum through a single GNSS receiver at any point of convenience will mean that leveling from existing bench marks to “bring in” the datum will no longer be necessary.

Nothing currently can replace geodetic leveling for precise local differential height dissemination. GRAV-D is not meant to replace leveling of that sort, but instead to provide immediate 2 cm access to the datum anywhere, so that (if necessary) leveling can then be performed very precisely off of that starting point to locations of interest.

Slide 17



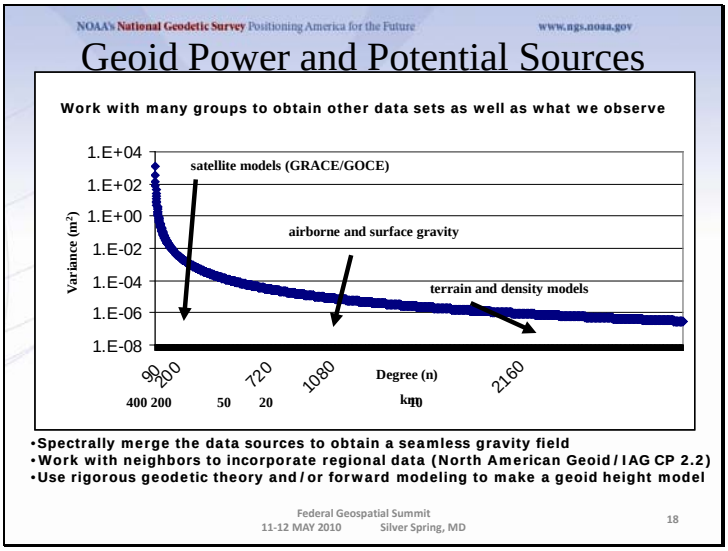
-Heights, gravity and the geoid are all related.

-As see here, both stations have different heights but the same geopotential. Since there is not geopotential difference, water will not flow even though one point is “higher” than the other. This is why dynamic heights are favored over orthometric heights in local areas dealing with hydrographic issues.

-However, you can’t see the geoid. The ocean surfaces are close, but ocean currents and weather disturb the ocean surface from what it would be … and you definitely can’t “see” it under the land.

-Hence, another means must be found to define this surface – possibly in relation to one already established.

Slide 18


NOAA's National Geodetic Survey Positioning America for the Future
www.ngs.noaa.gov
Geoid Power and Potential Sources
Work with many groups to obtain other data sets as well as what we observe
1.E+04
1.E+02
1.E+00
1.E-02
1.E-04
1.E-06
1.E-08
Variance (m²)
satellite models (GRACE/GOCE)
airborne and surface gravity
terrain and density models
90
200
720
1080
2160
Degree (n)
400 200
50
20
km
•Spectrally merge the data sources to obtain a seamless gravity field
•Work with neighbors to incorporate regional data (North American Geoid / IAG CP 2.2)
•Use rigorous geodetic theory and / or forward modeling to make a geoid height model
Federal Geospatial Summit
11-12 MAY 2010
Silver Spring, MD
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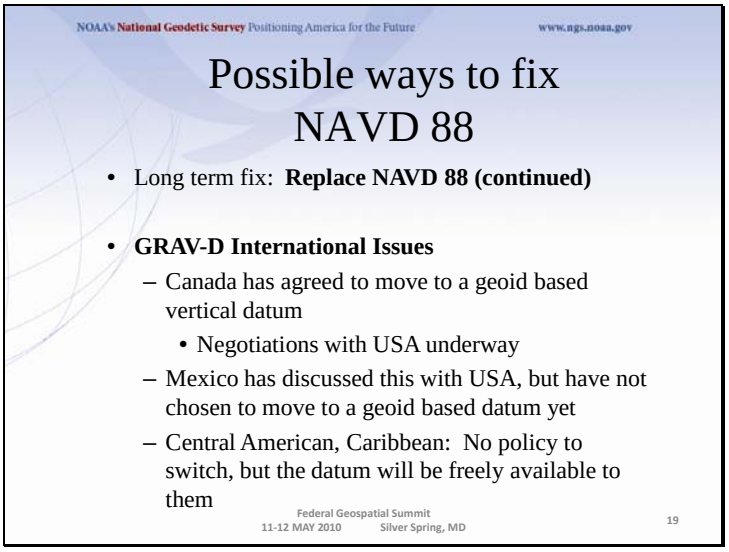
Slide 19



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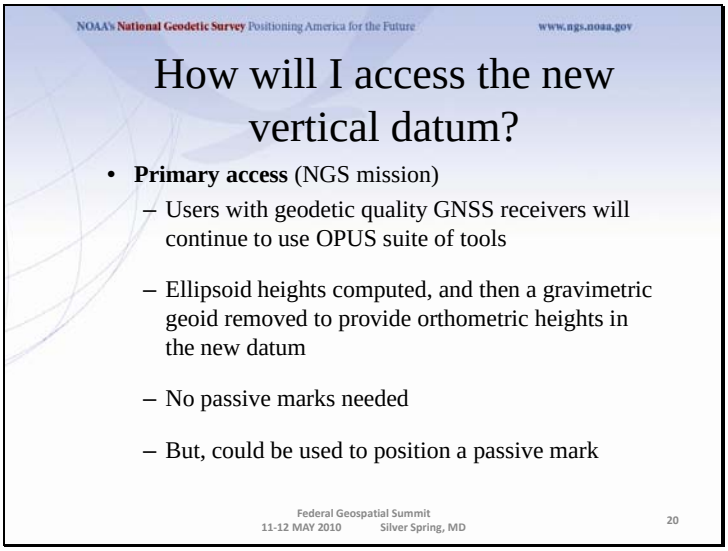
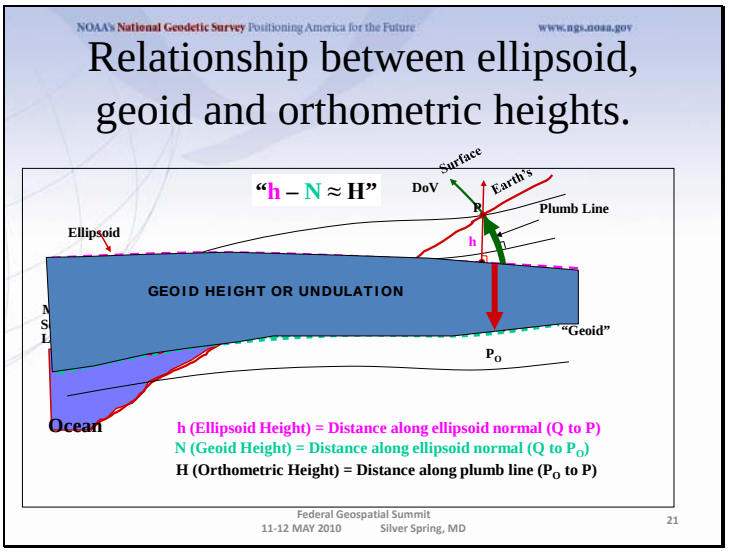
Slide 20



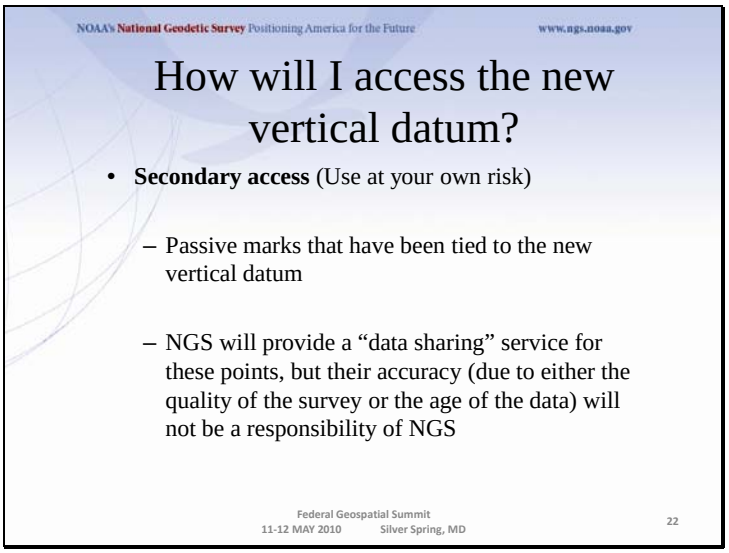
Multiple questions come up about using the new vertical datum. Two examples are given in the next few slides. The first is the example of how the new datum will address subsidence, say for floodplain mapping. The second example is about how the datum will be accessable when there aren't bench marks in the immediate region of interest. Both examples rely on this simple formula:

- Get an ellipsoid height (h) from GNSS in the latest geometric datum (the replacement for NAD 83)
- Remove the NGS provided geoid model (N)
- The orthometric height in the new datum (H) is just H=h-N

Slide 21

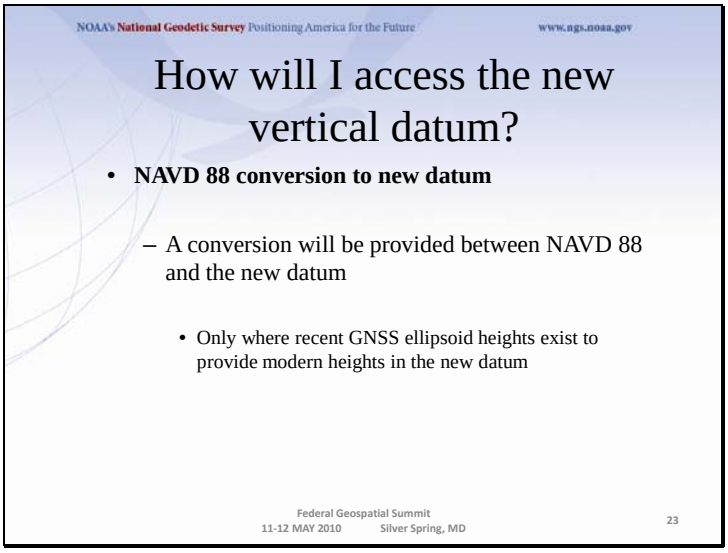


Slide 22



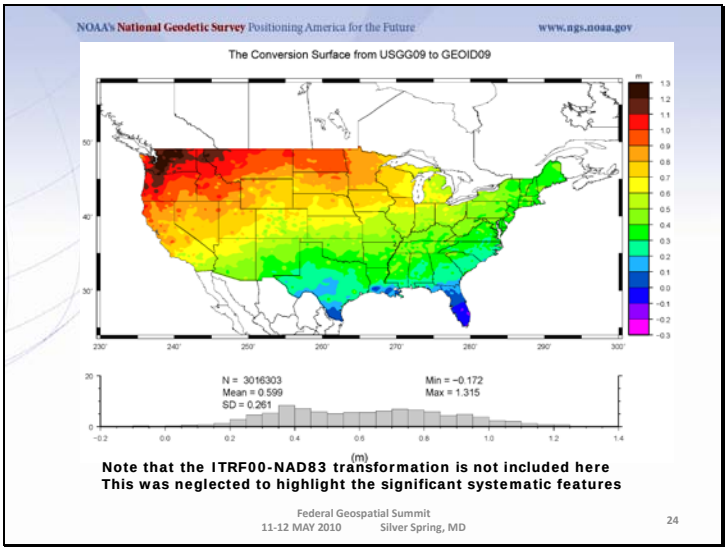
NGS will eventually stop making the claim that we "know" the heights of bench marks as the method of providing access to the vertical datum. What NGS will do is provide the orthometric height to a user on the day of their survey (and with the disclaimer that this height should not be taken as "known" for very long, due to the dynamic nature of the Earth).

Slide 23

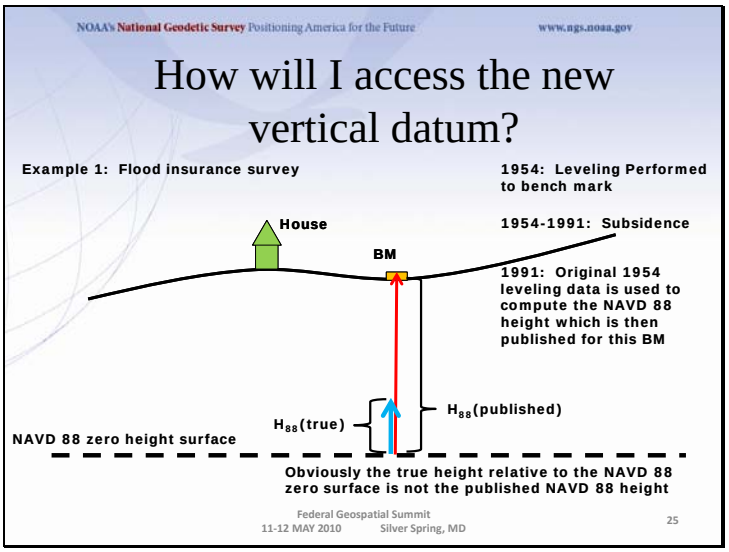


In areas where a brand new (relatively speaking) GNSS based ellipsoid height has been determined at an NAVD 88 bench mark, that data will allow for NGS to convert to the new datum. The more of these points that can be determined right near the time of the new datum's release, the better will be the conversion.

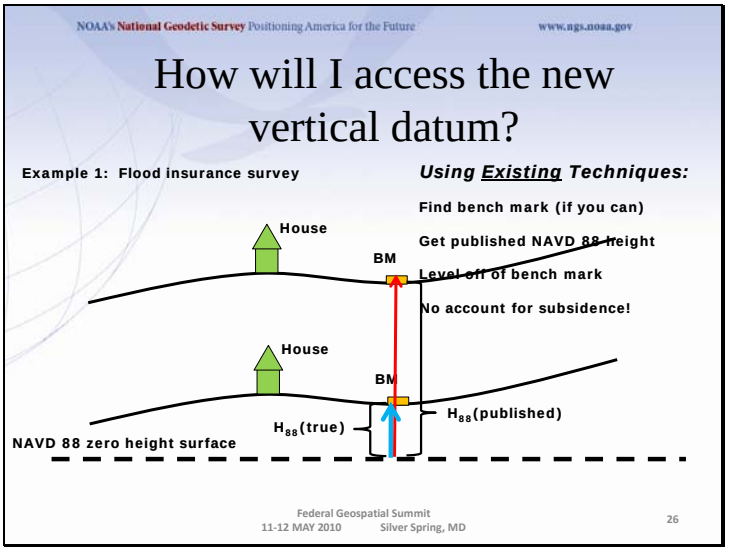
Slide 24



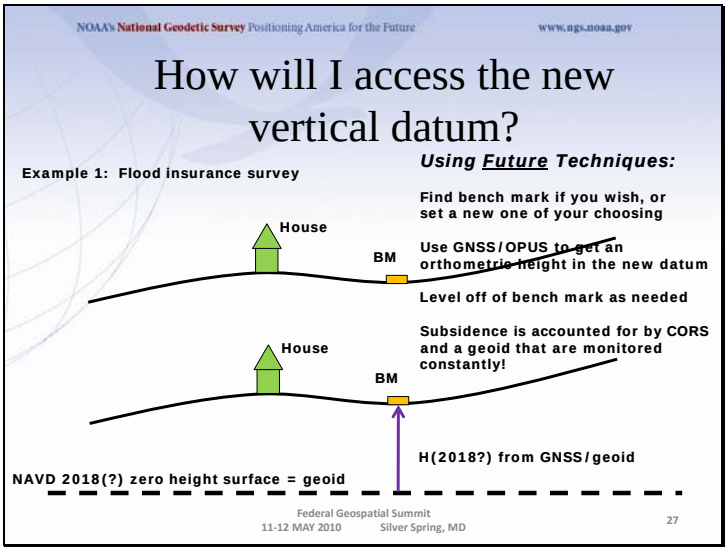
Slide 25



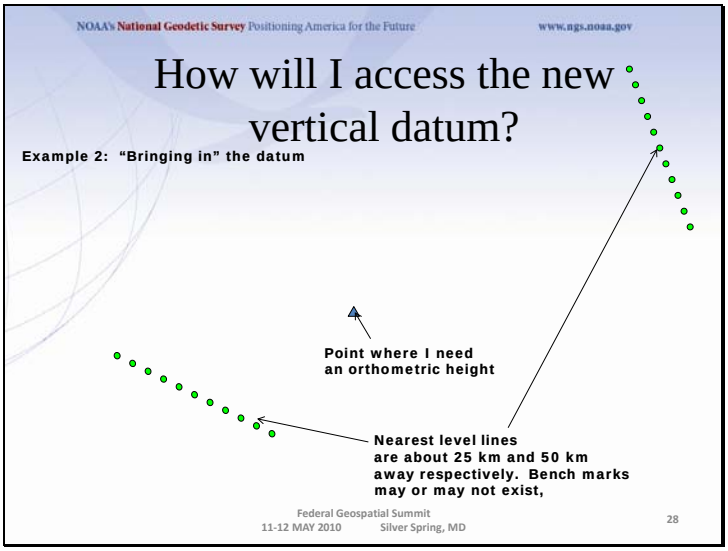
Slide 26



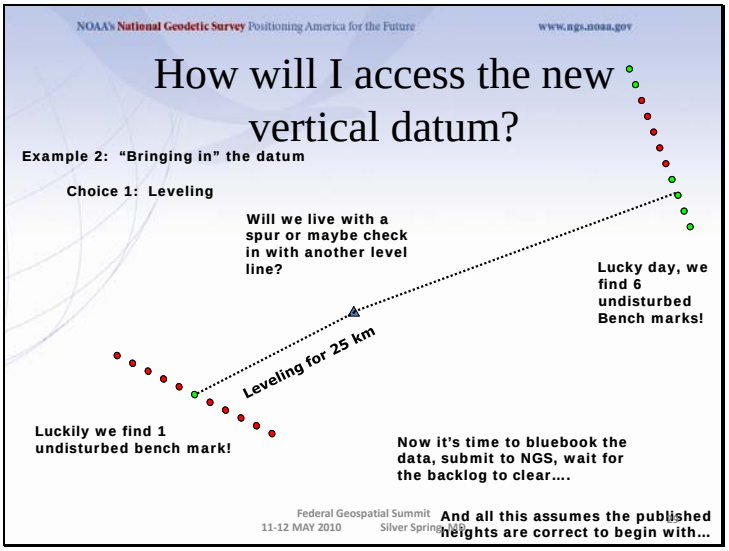
Slide 27



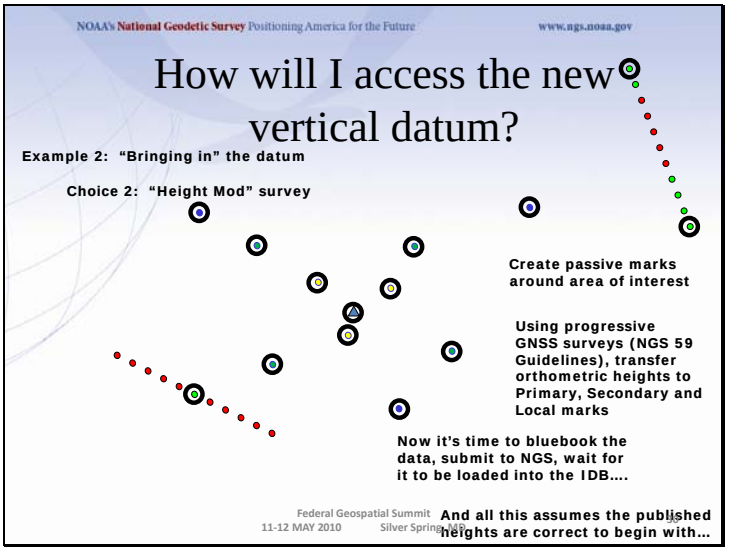
Slide 28



Slide 29

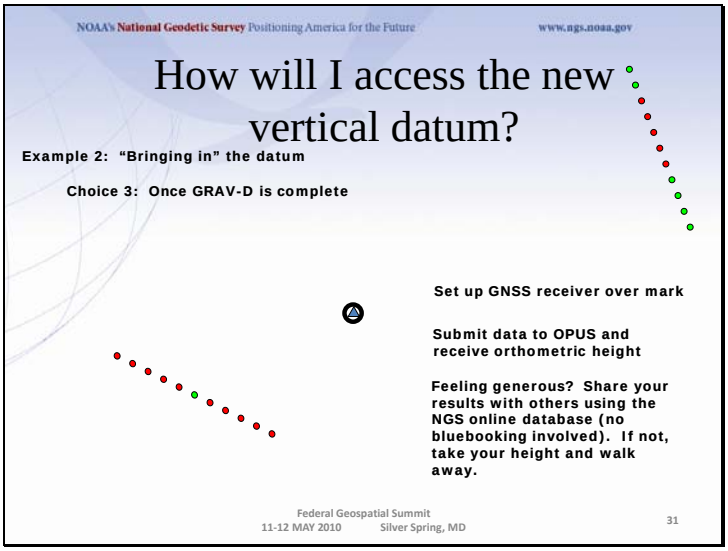


Slide 30

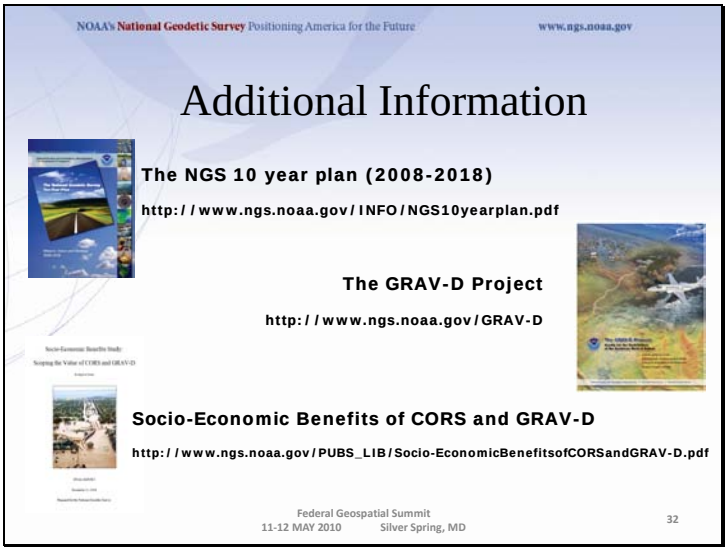


Note that even if this goes off as planned, there may still need to be leveling involved to check existing bench marks or possibly check the GPS results on these new points.

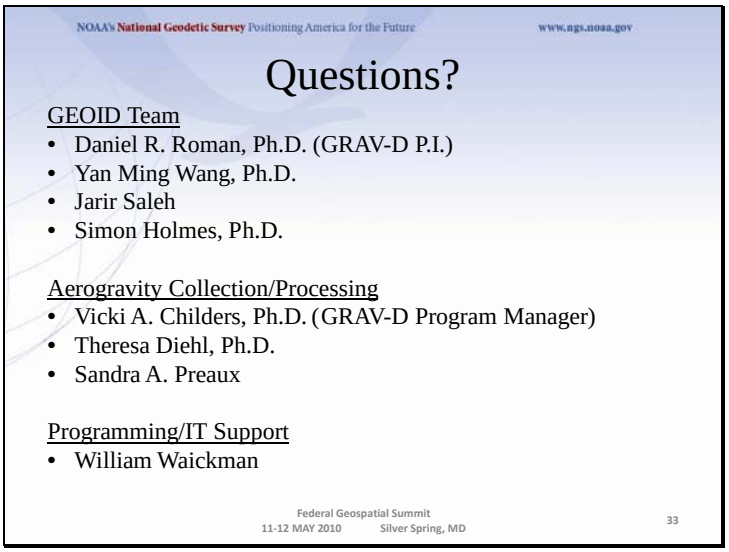
Slide 31



Slide 32



Slide 33


NOAA's National Geodetic Survey Positioning America for the Future
www.ngs.noaa.gov
Questions?
GEOID Team
• Daniel R. Roman, Ph.D. (GRAV-D P.I.)
• Yan Ming Wang, Ph.D.
• Jarir Saleh
• Simon Holmes, Ph.D.
Aerogravity Collection/Processing
• Vicki A. Childers, Ph.D. (GRAV-D Program Manager)
• Theresa Diehl, Ph.D.
• Sandra A. Preaux
Programming/IT Support
• William Waickman
Federal Geospatial Summit
11-12 MAY 2010 Silver Spring, MD
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Appendix H

Slides used by Dr. Snay

Slide 1

Modernizing the Geometric Reference System

Replacing NAD 83

Richard Snay
NOAA (retired)

Federal Geospatial Summit
Silver Spring, MD
May 11, 2010

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
National Ocean Service
National Geodetic Survey

Positioning America for the Future

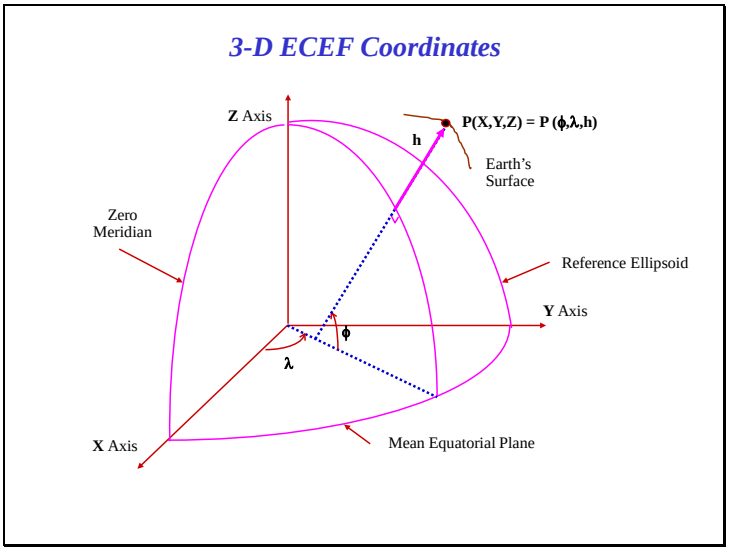
Slide 2

Defining a ECEF Reference System

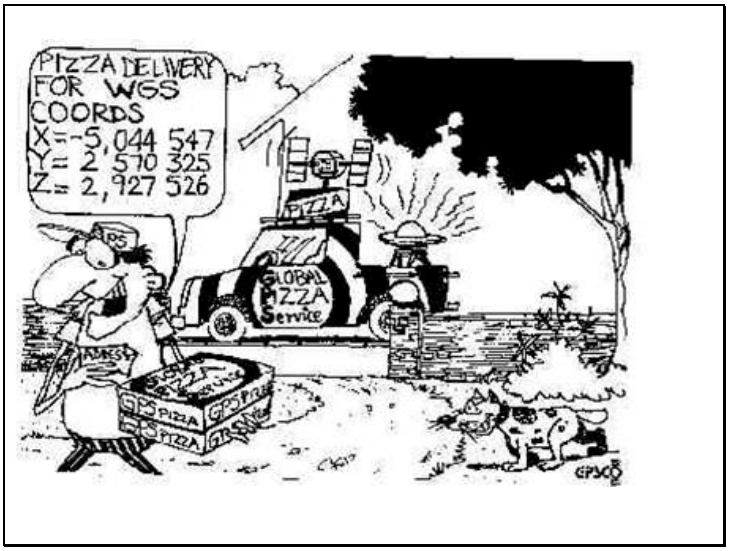
* ECEF = Earth centered, Earth fixed
* Z-axis = Earth's pole of rotation
* X-axis = Intersection of equator and prime meridian
* Y-axis = Forms right-handed system with X- and Z-axes
* Scale = meter or distance that light travels in a vacuum during 1/299,792,458 seconds
* Ellipsoid = needed to define latitude and ellipsoidal height
* Complications arise from Earth's dynamics

(Polar motion, plate tectonics, earthquakes, subsidence, etc.)

Slide 3



Slide 4



Slide 5

North American Datum of 1983 (NAD 83)

* Legal reference system in the United States

* National Geodetic Survey is responsible agency in U.S.

* First realized in 1986, revised for HARN,
  revised again for CORS

* Originally, NAD 83 was mostly a horizontal reference
  system

* Evolved to a 3-dimensional reference system,
  thanks to GPS

Slide 6

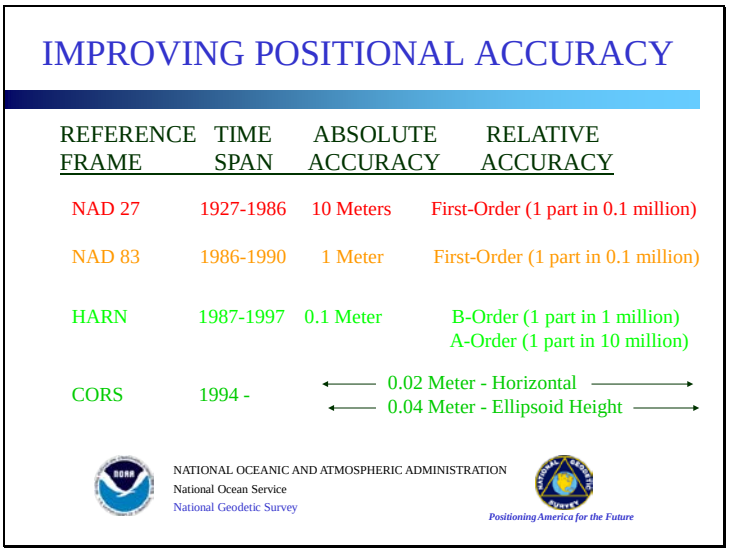
NAD 83 (continued)

* Origin is located about 2 meters from Earth's center

•Redefined to be "mathematically equivalent" to ITRF96 in the late 1990's. That is, the U.S. and Canada jointly adopted a 14-parameter transformation from ITRF96 to NAD 83 such that if a person knows the ITRF96 coordinates of a point, then he/she can compute the corresponding NAD 83 coordinates and vice versa.

• Points located in "stable" North America should experience no significant horizontal motion relative to NAD 83.

Slide 7



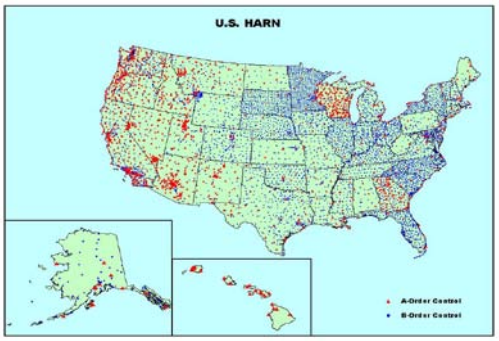
NAD27: 2-dimensional
- 24,000 to 25,000 points
- Referenced to a point at Meade Ranch Kan.
- Not Earth Centered

NAD83: 2-dimensional
- Earth Centered
- 1.8 Million point
- Some Space Observations
- Single Simultaneous Adjustment

HARN: 3-dimensional
- Earth Centered
- GPS Observations

Slide 8

HIGH ACCURACY REFERENCE NETWORKS (HARN)



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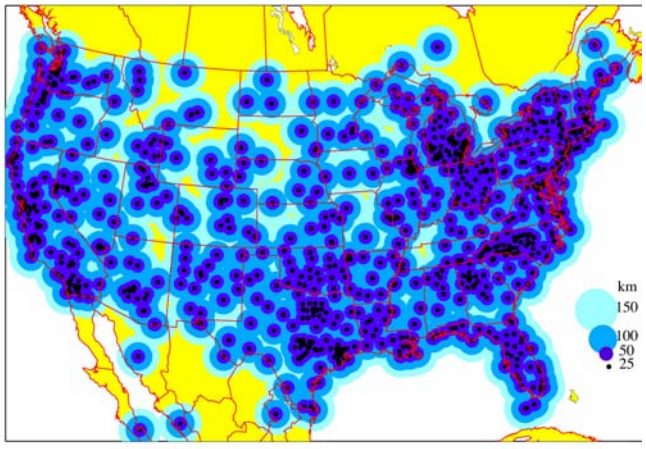
Continuously Operating Reference Stations (CORS)



Slide 10

NAD 83 NAMING CONVENTIONS

- NAD 83 (UVWXYZ) – the part within parentheses is called the "Datum Tag"
- Original realization called NAD 83 (1986), because the adjustment was completed in 1986. This realization of NAD 83 was based mainly on triangulation, trilateration and doppler data.

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NAD 83 NAMING CONVENTIONS

- The HARN realizations are named NAD 83 (1987), NAD 83 (1988), …, NAD 83 (2004) where the number in parentheses usually identifies the year when the GPS observations were performed.
- The CORS realization is called NAD 83 (CORS96) where 96 identifies that this realization was defined in terms of a transformation from ITRF96.
- NAD 83 (NSRS2007) was created for passive reference stations. It is designed to be consistent with NAD 83 (CORS96).

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NAD 83 READJUSTMENT of 2007

FIRST SURVEYS OF HARN COMPLETED BETWEEN 1987 AND 1997

GPS HEIGHT MODERNIZATION SURVEYS OF HARN
COMPLETED BETWEEN 1997 AND 2005

3-D ADJUSTMENT OF ALL HARN SURVEYS AND
OTHER SELECTED GPS SURVEYS COMPLETED IN 2007

ADJUSTMENT USED CORS COORDINATES REFERRED TO NAD 83 (CORS96)
FOR CONTROL TO REMOVE SMALL REGIONAL DISTORTIONS
(3 - 6 CM)

RESULTING REFERENCE FRAME CALLED NAD 83 (NSRS 2007)

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Definitions

- A Geometric Reference System is a set of rules for assigning positional coordinates (and velocities) to points on or near the Earth.
- A Geometric Reference Frame is a realization of a Geometric Reference System that is obtained by assigning specific positional coordinates (and velocities) to a set of identifiable points.
- NAD 83 is a geometric reference system.
- NAD 83 (xxxx) is a geometric reference frame.

Slide 14

World Geodetic System of 1984 (WGS 84)

* GPS broadcast orbits give satellite positions in WGS 84

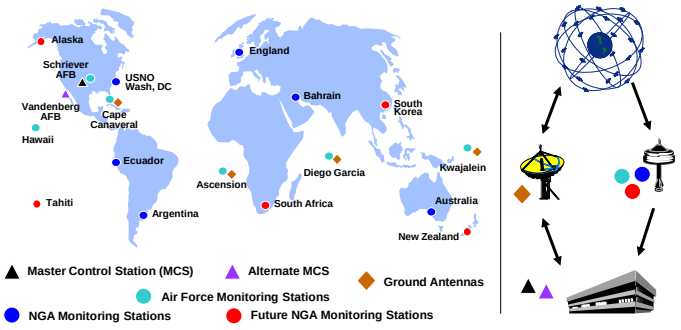
* Department of Defense is the responsible agency

* System originally agreed with NAD 83

* Revised to agree with International Terrestrial Reference Frame (ITRF) in early 1990's

Slide 15

GPS Tracking Network Defining WGS 84



Slide 16

WGS 84 Naming Conventions

- WGS 84 (transit) – this is the original realization of WGS 84 which is based on transit doppler satellite data
- WGS 84(G730), WGS 84(G873), WGS 84(G1150) – these realizations are based on GPS data, the number in parentheses identifies the GPS week that the military adopted the version.
- WGS 84 is a reference system.
- WGS 84 (xxxx) is a reference frame.

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International Terrestrial Reference System (ITRS)

* Supports accurate 3-dimensional positioning

* International Earth Rotation and Reference Frame Service is responsible organization

* Defines international standard for origin, orientation, and scale

* Provides positions and velocities for several hundred sites worldwide

Slide 18

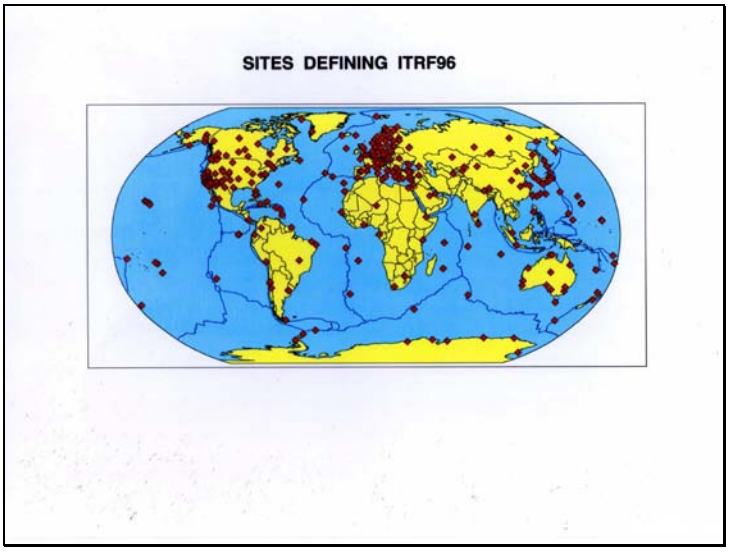
International Terrestrial Reference System (ITRS) - (continued)

* Postions and velocities revised every few years, producing the following International Terrestrial Reference Frames:
ITRF88, ITRF89, …, ITRF2000, ITRF2005, ITRF2008

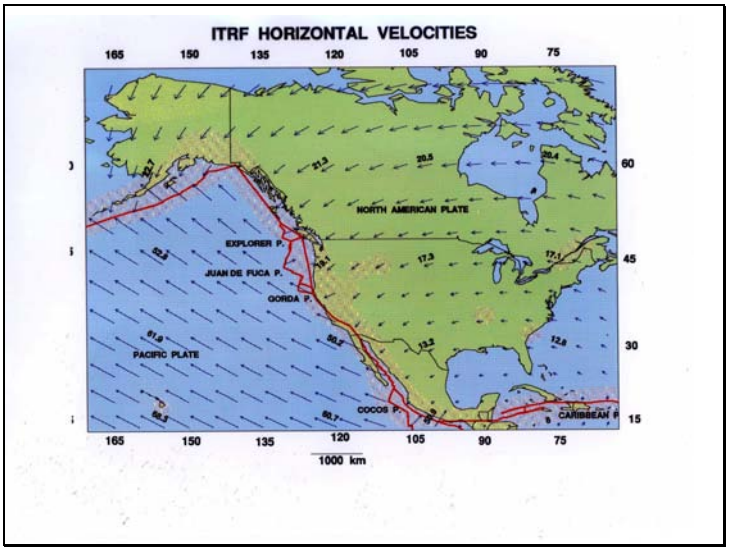
* Integrates results from various observing techniques:
- Global Positioning System (GPS)
- Very Long Baseline Interferometry (VLBI)
- Satellite Lase Ranging (SLR)
- Doppler Orbitography & Radiopositioning Integrated by Satellite (DORIS)

* Combination of several solutions, each performed independently by an analysis center

Slide 19



Slide 20



Slide 21

7-Parameter Helmert Similarity Transformation (preserves shape)

(The following equations represent an approximation based on the assumption that the rotation angles are small.)

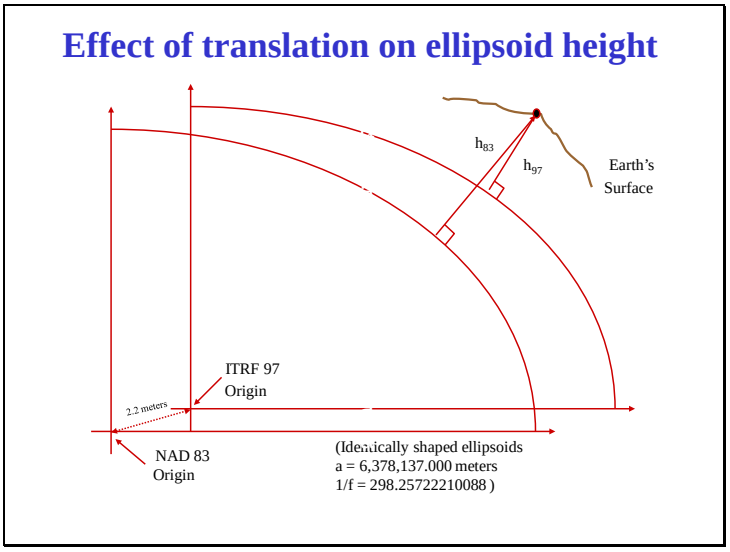
$$x_{NAD} = T_x + (1+S)\ x_{ITRF} + R_z\ y_{ITRF} - R_y\ z_{ITRF}$$

$$y_{NAD} = T_y - R_z\ x_{ITRF} + (1 + S)\ y_{ITRF} + R_x\ z_{ITRF}$$

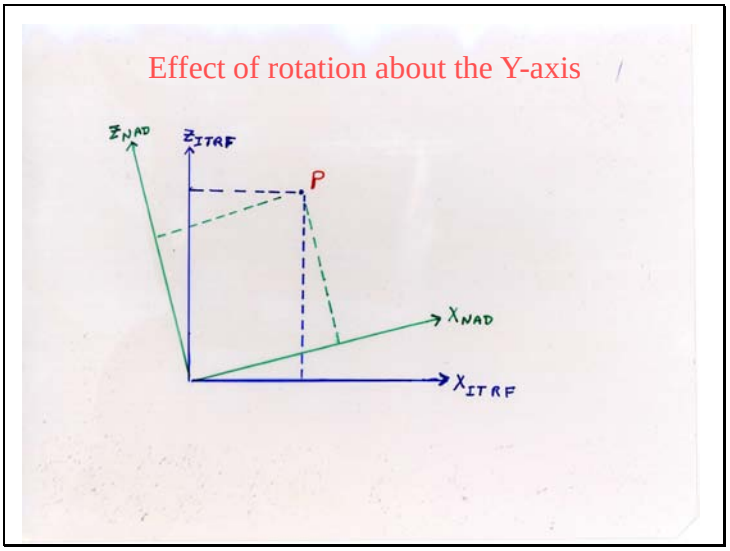
$$z_{NAD} = T_z + R_y\ x_{ITRF} - R_x\ y_{ITRF} + (1 + S)\ z_{ITRF}$$

3 translations (T_X, T_Y, T_Z)
3 rotations (R_X, R_Y, R_Z)
One differential scale (S)

Slide 22



Slide 23



Slide 24

Transformation Parameters
ITRF96 --> NAD_83(CORS96)

Translations: T_x = 0.9910 meters
T_y = -1.9072 meters
T_z = -0.5129 meters

Rotations: R_x = [25.79 + 0.0532 (t - 1997.0)] k radians
R_y = [9.65 - 0.7423 (t - 1997.0)] k radians
R_z = [11.66 - 0.0316 (t - 1997.0)] k radians

Scale change: S = 0.0 (unitless)

where t = date in years (eg., 1999.3096 = 23 APR 1999)
and k = 4.84813681 (10**-9)

Slide 25

Transitive Property

(ITRF2000 → NAD83)

= (ITRF2000 → ITRF96) + (ITRF96 → NAD83)

(A → D) = (A → B) + (B→C) + (C → D)

Reflective Property

(B →A) = - (A→ B)

Again, these properties are based on a small angle assumption.

Slide 26

Horizontal Time-Dependent Positioning (HTDP)

- HTDP allows users to transform positional coordinates across time and between different ECEF reference frames.
- HTDP incorporates adopted 14-parameter transformations.

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Replacing NAD 83

- Want the new reference system to be more geocentric
- Option 1: Adopt ITRF20xx
- Option 2: Adopt reference frame that agrees with ITRF20xx at some instant of time, but does not move relative to “stable” North America.

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Option 1: Adopting ITRF20xx

- Advantage: Ideally there would be just one reference frame for everyone in the world. (Note: The current WGS84 realization is essentially equivalent to ITRF2000 and its next realization will be essentially equivalent to ITRF2008.)
- Disadvantage: All points in North America would have significant horizontal velocities
  - In central & eastern CONUS, between 1 and 2 cm/yr
  - In California, western Oregon, western Washington, Alaska and Canada, more than 2 cm/yr

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Option 2: Frame fixed to North American plate

- Advantage: Points in "stable" North America would experience no significant horizontal motion.
- Disadvantage: Each tectonic plate would need its own reference frame. Hawaii is located on the Pacific plate, Puerto Rico on the Caribbean plate, and Guam on the Mariana plate. Also, points located near plate boundaries would still be moving significantly (eg., California, Oregon, Washington, southern Alaska).

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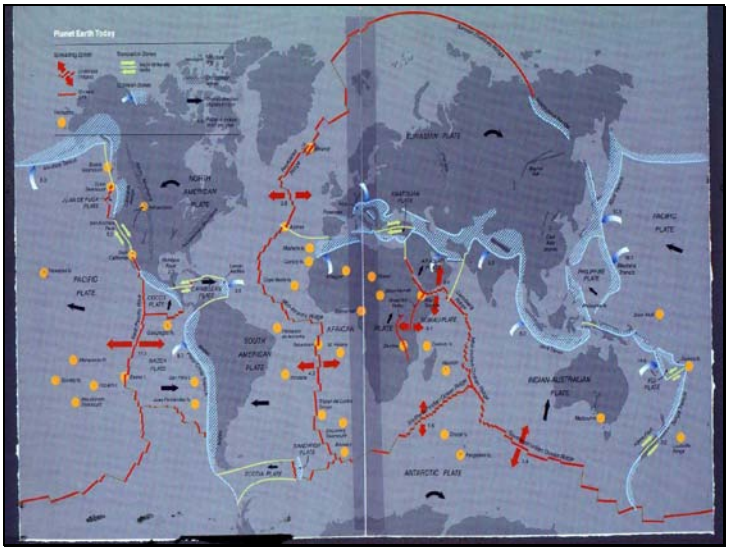
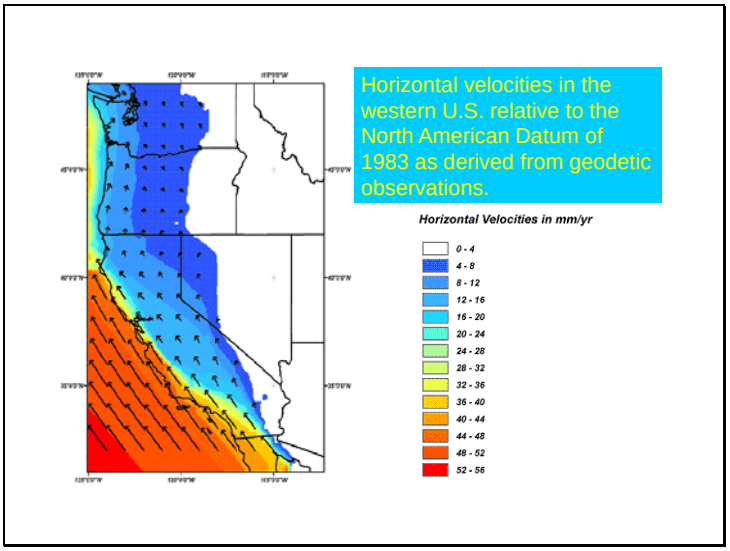


Slide 31



Slide 32

Analogy with time systems

The world has adopted essentially two time systems:

* Universal Coordinated Time (UTC) for global applications

* Local time for applications within a single “time zone”

The conversion between the two time systems is simply a matter of adding or subtracting an integral number of hours.

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Can the geospatial community deal with two geometric reference systems?

- ITRF20xx for interplate applications
- Plate-specific reference frames for intraplate applications
- A conversion between two given frames would simply involve applying a set of 3 rotation rates.

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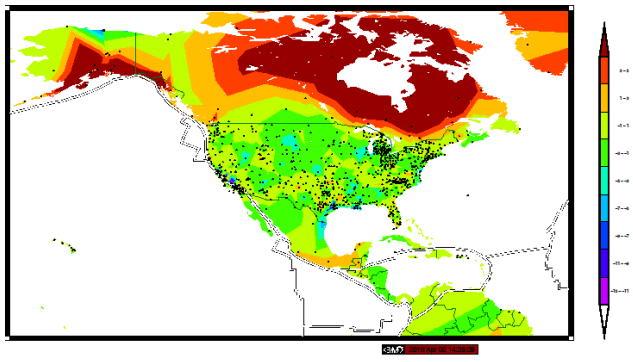
Slide 34

What about vertical velocities?



Appendix I

Slides used by Mike Londe (BLM) during Minute Sessions

Slide 1

BLM Issues

Michael D. Londe, Ph.D.
Geodesist, DOI - BLM

Slide 2

Recognition

- We can see the need for development of a 3-D datum that will support modern positioning technologies.
- We recognize the need for improvements in the geoid to support the use of GNSS in height transfer. BLM projects that require accurate elevations have difficulty in finding existent and consistent BMs close to projects.

Slide 3

Concerns

- Is there truly a need to define a totally new datum or is this a chance to do neat science? What would the conversion to a geocentric datum gain us? We have not seen convincing arguments on this.
- BLM has the need to tie past, present, and future surveys and mapping projects together.
- Will the tools be developed and available in a timely fashion to transform between datums? It will not do us any good to have a datum with transformation tools promised for later.

Slide 4

Concerns

- New coordinates will be introduced for the CORS this year. Is this the first of many changes by 2018?
- Datum creep. What are the magnitudes of the changes in the CORS positions. We have not received clear answers on this. How well can we relate surveys tied to NAD 83 (CORS96) to control based on the new coordinates?

Slide 5

Concerns

- It took more than a decade for the BLM to convert GIS data to NAD 83.
- There was not a budget, personnel, or resources for that conversion. If anything the situation will be worse this time around.
- If the magnitude of the proposed changes are approximately 2 meters we heard yesterday it might not make sense to transform.

Slide 6

Requirements

- We need a stable horizontal and vertical datum referenced to a specific epoch (s) where practical.
- We need the transformation tools to move positions between the realizations of NAD 83, WGS 84, ITRF, and the various vertical datums. It is not practical to store raw observations and recompute.

Slide 7

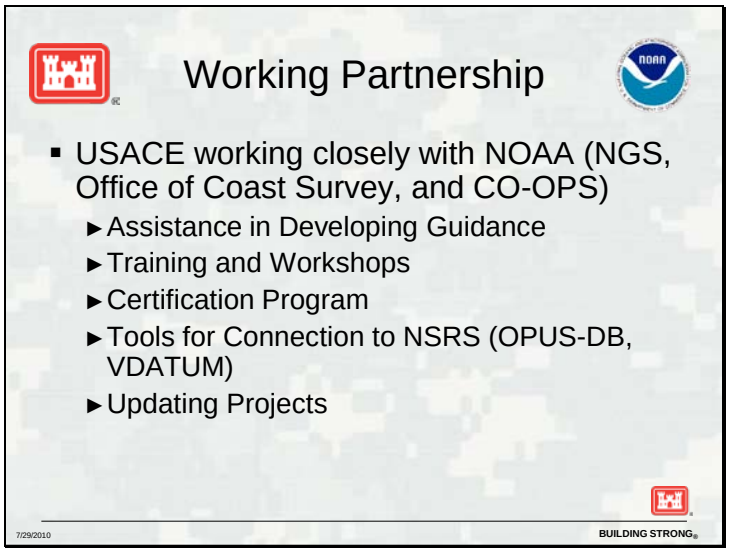
Requirements

- Transformation tools need to be available at the time of release of the datum and not at a promised future date.
- Better explanations and more transparency on proposed changes.

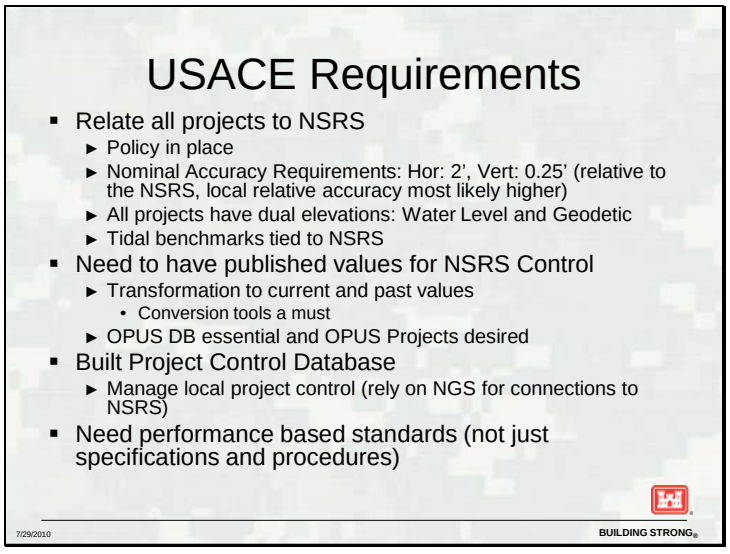
Appendix J

Slides used by Jim Garster (USACE) during Minute Sessions

Slide 1



Slide 2



Slide 3

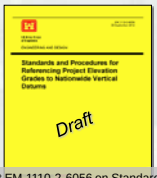
Continued Challenges

- Areas of Subsidence and Uplift
  - ► Vertical time dependent positioning???
- Implementing standards
  - ► Establishing Geodetic and Water Level references
- Education
  - ► Critical to making sure datums are understood
- Tidal areas (new datum related to tidal gages)
- Real Time Networks (connected to NSRS)

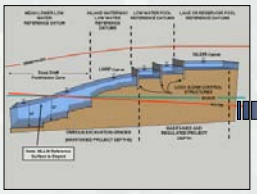
Slide 4

Guidance Development

Developed EC 1110-2-6065/70 (Jul 07) to provide interim guidance on evaluating project datums.



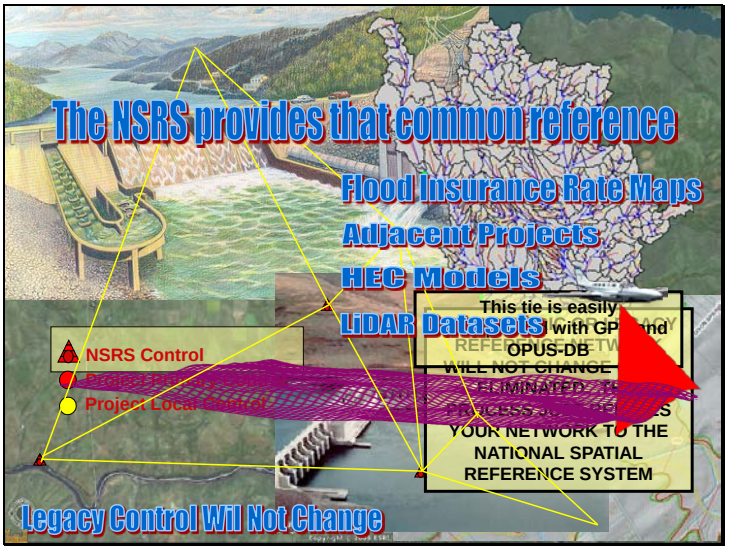
Draft EM 1110-2-6056 on Standards and procedures for referencing project elevation grades to nationwide vertical datums



Relate all to a Single Nationwide Reference System (i.e. NSRS)

Developed ER 1110-2-8160 on Policy for referencing project elevation grades to nationwide vertical datums

Slide 5



Why then are we so worried abut where the dam's height is referenced?

How does the structure and the level of the reservoir relate to the floodplain downstream, FEMA's flood maps, HEC models, homes, etc
Click
Your dam has its local control with a very high relative accuracy between the points
Click
This control is what should be tied to the NSRS. This will provide the common reference to other projects etc…
Click
Your project can then be referenced to the NSRS where its relationship to other projects, home, floodplain models, etc can be developed.
Click
FEMA flood maps, other civil works projects, hydrologic models, etc… are currently tied to the NSRS – This provides a common reference used to determine relationships

Appendix K

Slides used by Dr. Snay during Panel responding to Minute Sessions

Slide 1

IGS Reanalysis

- Several IGS Analysis Centers (including NGS) have each reprocessed all IGS data observed since 1994.
- NGS has also reprocessed all CORS data observed since 1994.
- This analysis included new calibration results for both GPS satellite transmission antennas and GPS receiver antennas.
- NGS will use results from this reanalysis to produce ITRF2008-compatible positions and velocities for stations in the CORS network.

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Slide 2

NAD 83 (CORS96a)

- NGS will use new ITRF2008 coordinates and velocities for CORS to produce a new realization of NAD 83 to be called NAD 83 (CORS96a)
- NAD 83 (CORS96a) will be defined so that the 14-parameter transformation between it and NAD 83 (CORS96) will be the identity function.
- Hence, NAD 83 (CORS96a) coordinates should be consistent with NAD 83 (NSRS2007) coordinates and with the use of GEOID09 to convert NAD 83 (CORS96a) ellipsoid heights to NAVD 88 orthometric heights.

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Slide 3

NAD 83 (CORS96a) - continued

- NAD 83 (CORS96a) coordinates will, nevertheless, differ from NAD 83 (CORS96) coordinates because they are being derived using
  - More GPS data
  - More rigorous computational procedures
  - More accurate models for systematic errors
- NAD 83 (CORS96a) should become available in the fall of 2010.
- CORS coordinates were last revised, in a wholesale manner, in 2002. Hence, current CORS coordinates are less accurate than desired.

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