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2017 Geospatial Summit:

Modernizing the National Spatial Reference System

Silver Spring, MD

April 24-25, 2017

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AUTHOR'S PREFACE

This report represents a snapshot of the presentations and discussions from the National Geodetic Survey's (NGS) 2017 Geospatial Summit. It is not an official transcript or a formal proceedings document. The entire event was video recorded, and the recording can be viewed for a more thorough analysis. The following web page contains detailed information on the summit, including links to presentations and the video recordings from the event: https://www.ngs.noaa.gov/geospatial-summit/index.shtml

Author's note: The terms "we" and "our" are used in the body of the report to denote the activities or points of view of the presenter's organization; otherwise, "we" and "our" refer to those of NOAA's National Geodetic Survey.

ACKNOWLEDGEMENTS

NGS wishes to acknowledge and thank those who contributed to the success of the Summit.

We thank Dr. Russell Callender, Assistant Administrator of NOAA's National Ocean Service. Dr. Callender's opening remarks highlighted the importance of the National Spatial Reference System (NSRS) as the foundation for accurate and reliable coordinate information needed for an increasing multitude of scientific and commercial activities nationwide. We thank all the NGS and invited speakers who effectively captured the challenges and opportunities inherent in an undertaking of this magnitude. We sincerely thank the agencies and individuals who participated in the summit for investing their time and provided their feedback, which is critically important for the continued success of this endeavor.

We acknowledge and greatly appreciate the dedicated efforts of the summit planning and logistics team: Christine Gallagher, project manager, Sonja Bowen, Tatiana Bowie, Brett Howe, Simon Monroe, Frank Mowry, Erika Little, Sonita Tiwari, and Steve Vogel. We also thank the many NGS volunteers who staffed tables, ran errands, and did everything necessary to help make the summit a success.

INTRODUCTION

Throughout its history, NOAA's National Geodetic Survey (NGS)—along with its predecessor agencies—has been responsible for establishing a consistent nationwide coordinate reference system for safe navigation, and a host of scientific, engineering, and commercial activities. Its current mission is:

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

In 2008, NGS issued a Ten-Year Plan announcing its intent to modernize the NSRS by replacing two key elements of the NSRS, 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 heights.

In 2010, NGS published a white paper titled, “Improving the National Spatial Reference System,” detailing the nature and causes of systematic errors and deficiencies in the current datums comprising the NSRS. In 2010, NGS also hosted a Federal Geospatial Summit describing the shortcomings of NAD 83 and NAVD 88 and how NGS proposed to improve those. NGS also used the event as an opportunity to answer questions about the reference frames planned to replace the current datums.

In 2015, NGS hosted a follow-up Geospatial Summit to share updates on the planned replacement of NAD 83 and NAVD 88 with other federal agencies and the broader mapping community. It was the first such event since 2010, and it allowed those attending to voice their comments, questions, and concerns about replacing the datums.

The 2017 Geospatial Summit provided an opportunity for NGS to share updates on modernizing the NSRS with organizations and individuals who depend on precise coordinate information. Capturing and addressing stakeholders’ concerns about the modernization effort was a primary goal for the summit, which featured live polling of both the in-room and webinar audiences, post-session feedback opportunities, and presentations by those who will be affected by the project.

DAY ONE: APRIL 24, 2017

Welcome, overview, and keynote address

Juliana Blackwell, Director, National Geodetic Survey, welcomed the attendees to the Geospatial Summit and introduced NOAA’s Assistant Administrator for the National Ocean Service (NOS), Dr. Russell Callender. Dr. Callender’s opening remarks highlighted the importance of the NSRS to provide the foundational information that communities and decision makers rely upon daily. The NSRS also aligns critical observations, models, and products, and underlies the three NOS priorities: 1) safe and efficient transportation; 2) preparedness and risk reduction; and 3) stewardship, recreation, and tourism.

Modernizing the NSRS is a significant undertaking, and a critical related project is Gravity for the Redefinition of the American Vertical Datum (GRAV-D). Upon completion, GRAV-D's airborne gravity data will be used to develop a new geopotential datum in 2022. The current vertical datum contains elevation errors ranging from 16 inches to 6 feet relative to sea level. GRAV-D will allow surveyors, scientists, and others to use GPS to determine more precise and accurate elevations than currently possible, in less time and with less effort. More than 50 percent of the gravity data planned for the GRAV-D project have been collected. Foundation CORS is another critical project. These permanent reference stations are needed to better connect the NSRS to the global reference frame, the International Terrestrial Reference Frame.

NGS is also modernizing its tools to improve access to the NSRS, and to make them easier to use and maintain. You can test this updated toolkit on our beta website and give us feedback. The most frequently requested tool is one to transform data from historical datums to more modern ones. NGS is

publishing annual experimental geoids that include GRAV-D gravity data in order to approximate the replacement for the current vertical datum.

The new geopotential datum will improve height information, critical for the resilience of our coastal communities, and locations having flood risk. GRAV-D provides an estimated $522 million in annual economic benefits, with approximately $240 million being saved from improved floodplain mapping alone (Leveson, 2009). Together, these benefits combine to bring into reality the NGS vision statement:

> "Everyone accurately knows where they are and where other things are anytime, anyplace."

NGS will continue to work with its federal partners that have mapping responsibilities and rely on the NSRS to accomplish their program goals. The Federal Geodetic Control Subcommittee (FGCS), chaired by the NGS Director, is a formal venue for such federal coordination. Adopting the new terrestrial reference frames and geopotential datum will take careful planning. New data collections will need to be coordinated across agencies. Georeferenced data will need to be transformed to the new terrestrial reference frames and geopotential datum in a few years, and NGS will work with its federal partners to make sure this happens. Some states may want to revisit relevant legislation that specifically references the current horizontal datum, NAD 83. Working in partnership with the National Society of Professional Surveyors (NSPS), states can adopt legislation or policies to ensure smooth transition to the new terrestrial reference frames and geopotential datum. Similar updates may need to be made in contracts and statements of work.

NGS will also work with the private sector. Since the NSRS is foundational data, it will be integrated into other products and services. The value added by the private sector can be of tremendous benefit to the broader surveying and mapping community. However, for a smooth transition, there needs to be coordination and open communication. Find where you fit in and can contribute to this effort. Engage with NOAA and NGS through summits like this one and other opportunities NGS provides. Engage with professional societies such as NSPS and MAPPS. These societies have a tremendous national and local reach, and NGS will meet with them consistently to leverage their communication networks. With your support and engagement, I know we'll succeed.

Introduction to modernizing the National Spatial Reference System

Why is NGS replacing NAD 83 and NAVD 88

Joe Evjen, Geodetic Standards and Applications Branch Chief, Spatial Reference System Division (SRSD), NGS, detailed the reasons for replacing NAD 83 AND NAVD 88, and provided updates on NGS' progress in this significant undertaking. Mr. Evjen listed the many vertical datums in use today that will be replaced by a single datum extending from the pole to the equator. Global Navigation Satellite Systems (GNSS) are improving access to—and the accuracy of—our spatial reference system. GNSS equipment is relatively cheap and fast. While we can continue to leverage this technology to maintain the old datums, it makes sense to align GRAV-D results to modern global standards.

A large portion of the geodetic control markers in the United States were installed from the 1930s through the 1960s. Even small instabilities for these markers translate to significant inaccuracies when viewed over several decades, and systematic errors of several meters have been identified across the United States. Using space-based systems to define the NSRS is immune to the instabilities of relying on passive control marks and aligns with the efforts of Canada, Mexico, and other nations to develop global standards for coordinate reference frames.

Mr. Evjen showed graphics detailing the anticipated positional changes from NAD 83 (2011) to IGS08 terrestrial reference frame, epoch 2022.00, for the North American, Caribbean, Mariana, and Pacific plates. He indicated that if the NAD 83 datum were truly "plate fixed," an 8-year epoch change would not yield the systematic plate rotation that is evidenced by comparing NAD 83 (2011) data with that from NAD 83 (NSRS2007). He indicated the NSRS in 2022: will comprise four semi-dynamic reference frames; the vertical datum will be based on GPS and an improved geoid; all component data will be time tagged; and all coordinates will be derived from GNSS surveys. He also indicated that the epoch designation 2022.00 does not represent a policy choice at this time.

Recap of previous geospatial summits and customer concerns

Mr. Evjen summarized the results of the previous geospatial summits by recapping the reference frame changes that were proposed and described in those two summits. He summarized prominent stakeholders' comments and concerns NGS has received as it proceeds through the modernization project, and directed audience members to NGS' centralized information resource for NSRS modernization: https://geodesy.noaa.gov/datums/newdatums/. He showed the *NSRS Modernization News,* which provides brief, regular updates on the NSRS modernization project, and showed how anyone may subscribe to email notifications about the release of new NGS products, updates to existing services, and free training and educational opportunities from NGS.

Recent decisions: naming conventions, managing velocities, and white papers

Dru Smith, NSRS Modernization Manager, NGS, introduced the audience to various parts of the planning and decision process for modernizing the NSRS. Since 2008, NGS has published two "10-year plans," with each containing broad goals, such as, "Replace NAD 83," but without containing certain details, such as, "What will be the name of the replacement?" Many of those details were decided in 2016. The replacement for the three NAD 83 reference frames will be four terrestrial reference frames designated "NATRF2022," "PATRF2022", "CATRF2022" and "MATRF2022" (named, respectively, for the North American, Pacific, Caribbean, and Mariana tectonic plates). [1] The new geopotential datum will be designated, "NAPGD2022," representing, "North American-Pacific Geopotential Datum of 2022."

[1] The acronyms PTRF2022, CTRF2022 and MTRF2022 were introduced at the Summit. However, feedback from the summit indicated that users preferred the acronyms PATRF2022, CATRF2022 and MATRF2022. In May of 2017, NGS officially changed the acronyms to these latter versions.

NGS decisions for the scientific aspects of the modernization project will be summarized in the "Blueprint for 2022" documents. The first of these blueprint documents, corresponding to the geometric aspects of the NSRS, was distributed at the summit. NGS will publish the remaining blueprint documents, corresponding to the geopotential aspects of the NSRS and the procedures for replacing bluebooking, in the next several months.

The time-dependent coordinates from the four new reference frames mentioned above will be identical to those from the International GNSS Service (IGS)—at an epoch to be determined—and will remove the long-standing non-geocentricity of the current NAD 83 frames. These time-dependent coordinates will differ from IGS coordinates only in terms of a 3-parameter transformation, based on a model of each plate's rotation. Each reference frame will have three parameters associated with it: Euler Pole latitude, Euler Pole longitude, and rotation rate (in radians/year). These parameters will be used to compute time-dependent 2022 terrestrial reference frame coordinates from time-dependent IGS coordinates.

The time-dependent Cartesian coordinates in these reference frames will be plate fixed, and the blueprint document describing geometric coordinates specifies what "plate fixed" means. These coordinates will be stable in areas of the continent where tectonic plate motion is completely described by plate rotation. All remaining velocities will be described by an Intra-Frame Velocity Model (IFVM, one for each frame), which will allow users to compare time-dependent coordinates in any of the four terrestrial reference frames, across years. Using the IFVMs will allow NGS to provide time-dependent coordinates at the highest levels of accuracy as a primary service, in addition to comparing those time-dependent coordinates across time at lower levels of accuracy as a secondary service.

The "Blueprint for 2022" document describing decisions for updating the geopotential datum will indicate this geopotential datum will be based on a global, three-dimensional geopotential model (GGM), which will contain all GRAV-D data and can produce any physical (gravity based) value on or above the Earth's surface. For the updated geopotential datum, NGS will produce a high-resolution geoid, deflection-of-the-vertical and surface-gravity products that will be consistent with the GGM. To address the time-dependent aspects of the geopotential datum, NGS will provide a geoid-monitoring service and allow for the effects of deglaciation, sea-level rise, earthquakes, and other significant changes.

Project updates related to NSRS modernization

Modernizing the geometric reference frame

Dan Roman (acting Chief Geodesist, NGS), Steve Hilla (Geosciences Research Division (GRD) Chief, NGS) and Kevin Choi (CORS Branch Chief, NGS), indicated the key elements in modernizing the NSRS mentioned here are drawn from the forthcoming "Blueprint for 2022." The NSRS will comprise four reference frames, each frame will rotate about an Euler pole, and an OPUS tool will provide access to the reference frames. As mentioned earlier, these frames will be designated North America, Pacific, Caribbean, and Mariana. The modernized NSRS will be tied to the International Terrestrial Reference Frame (ITRF) at an epoch date that has yet to be determined, but will likely be 2020. At that epoch date, the four frames will be identical to the ITRF.

The NATRF2022 frame will be rigid and fixed to a rigid part of the North American plate. Euler poles account for most of the horizontal velocity within a frame. The remaining signal is currently modeled by HTDP (Horizontal Time-Dependent Positioning software). HTDP software is complicated to maintain and accounts only for horizontal motions. A velocity model is needed to account for both horizontal and vertical motions, and to distinguish non-Eulerian Velocity (NEV) from Intra-Frame Velocity (IFV).

The simplest solution is to grid CORS velocities. Residual horizontal velocities in the eastern continental United States from a gridded-CORS approach will largely be resolved, while the western continental United States has some anomalies. Assuming the CORS spacing is sufficient, a gridded-CORS approach produces a horizontal and a vertical signal, which is important for determining orthometric heights.

NGS will investigate the sufficiency of gridded CORS. Our concern is in (both horizontally and vertically) dynamic areas. We are not sure a gridded-CORS approach will be sufficient in Alaska. We will look at other models and evaluate the costs and benefits of what we can support in-house versus the increased complexity of outside models. Alternatively, users could model velocities on their own.

NAD 83 forcibly combined data spanning many years—using HTDP with no vertical modeling—to compute and find one height at one epoch. NATRF2022 will compute coordinates at a single survey epoch to show actual motion. Even gridding surrounding CORS provides better subsidence information than we have today.

The coordinate conversion software tool NADCON 5.0 will soon be available for testing on NGS' beta website. This tool will allow users to convert geographic coordinates to or from any input dataset of latitude/longitude/height, state plane coordinates, Universal Transverse Mercator, XYZ, or U.S. National Grid values, in addition to designating output values from among several different datums. This conversion tool incorporates the capabilities of several NGS computer programs, which originally were stand-alone products.

Modernizing the geopotential, or vertical, datum

Monica Youngman, (Survey Section B Branch Chief and GRAV-D Project Manager, Observations and Analysis Division (OAD), NGS), Dru Smith (NSRS Modernization Manager, NGS), and Derek van Westrum (Research Geodesist, Survey Section B, OAD, NGS), explained the new geopotential datum, NAPGD2022, will not be called a "vertical datum" because it will contain more than height information. The term "geopotential" refers to the gravitational potential energy field surrounding the Earth. Modernizing the geopotential datum begins with a global three-dimensional geopotential model, followed by creating derivative products, such as geoid and deflection-of-the-vertical models (GEOID2022; DEFLEC2022). GEOID2022 will have time dependencies and will be supported by a geoid monitoring service, and the geoid model will be tested for achievable accuracy via geoid slope validation surveys.

NGS' GRAV-D (Gravity for the Redefinition of the American Vertical Datum) project, an airborne gravity survey of the entire nation and its possessions, is the foundation for building the global geopotential model. GRAV-D's goal is to create a gravimetric geoid accurate to 1 cm—where possible—to support 2-cm-accuracy orthometric heights using a GNSS receiver and a geoid model. GRAV-D also includes long-term monitoring of geoid change. The GRAV-D project area covers the contiguous United States, Alaska, Hawaii, Guam, and American Samoa, approximately 15.6 million square kilometers.

Alaska—where the datum is in greatest need of repair—has been the priority area for the project. Next in priority have been the coastal regions of the United States and the Great Lakes, followed by the Hawaiian and Pacific Islands, the Aleutians, and the interior continental United States. To date, approximately 60 percent of the target areas have been surveyed.

Beginning in 2014, NGS has been publishing annual experimental gravimetric geoid models that incorporate all available gravity sources, including new satellite gravity models and all airborne gravity collected from the GRAV-D project to that point. These annual experimental geoid models compute the geoid using present-day satellite gravity models and airborne gravity data to prepare NGS for the final geoid model in 2022, and to provide an improving view of what the final geoid model will look like as it replaces NAVD 88 in 2022. Orthometric height changes computed from different geoid models are also published. When the NSRS modernization project is completed in 2022, height changes in the continental United States are expected to range from -30 to 130 cm, and in Alaska from -20 to -220 cm, compared to the current hybrid geoid, GEOID12B.

The NGS presenters also described recent and ongoing geoid slope validation surveys (GSVS), undertaken to test the accuracy of differential geoid undulations between points (geoid slopes) from NGS' gravimetric geoid models, and to address the actual achievable accuracy of a gravimetric geoid model. These surveys use high-precision, high-resolution (~ 1.5-km spacing), ground-based survey techniques to determine the shape of the geoid along a large (~300km) distance. NGS performed the first of these GSVS surveys in 2011 in south Texas, an area with low topography and geoid variation, and confirmed regional 1-cm differential geoid accuracy from airborne gravimetry (Smith, 2013). This was

followed by a second survey in 2014 in Iowa, an area with low topography and high geoid variation, and had similar results. The third and final survey is being conducted in 2017 in Colorado, an area with high topography and geoid variation.

Getting prepared for NSRS modernization

How to update state legislation to reference new terrestrial reference frames and geopotential datum

Dave Doyle, National Society of Professional Surveyors (NSPS), addressed the summit participants on steps they may take to prepare for the new reference frames. He urged everyone to participate in state and local surveying and mapping societies and events, and to encourage their colleagues to do the same.

As background, Mr. Doyle previously indicated that forty-eight states have a state-specific coordinate system law tied to NAD 83. California legislation also references NAVD 88. NGS, NSPS, and AAGS (the American Association for Geodetic Surveying) believe it would benefit professional land surveyors and mapping professionals for laws or regulations to reflect the latest federal geodetic infrastructure.

As a result, these groups formed an advisory committee to make recommendations regarding NSRS Legislation. In 2016, the committee drafted and unanimously approved a template legislation as a framework for states to craft their own individual state laws to replace existing laws that rely heavily on NAD 83. The template is brief and generic in its language; yet accurate. It provides a great deal of flexibility for the states to add their own state-specific information, and should not need to be modified in the future, even if components of the NSRS change after 2022. NSPS and its state affiliates will assist with this effort to update legislation in advance of 2022.

Day Two: April 25, 2017

COLLECTING GEODETIC CONTROL DATA IN THE FUTURE

Leveling after 2022

Dan Gillins (PhD Geodesist, Project Analysis Branch, OAD, NGS) and Kendall Fancher (Instrument and Methodologies Branch Chief, Geodetic Services Division (GSD), NGS), summarized the procedures, challenges, and limitations of relying on NAVD 88 and conventional leveling surveys to determine precise heights. Among the challenges, control marks: are assumed not to have moved; may not be in convenient locations or near a project area; are often destroyed and rarely replaced; and represent heights derived from a single point, allowing error to build up across the country.

The North American-Pacific Geopotential Datum of 2022 (NAPGD2022) will replace NAVD 88. NAPGD2022 will not be realized by leveling between passive marks, and will be accessed by GNSS observations referenced to NATRF2022 and a high-accuracy gravimetric geoid model (GEOID2022). Advantages from using the new geopotential datum include: it will be easily accessed via GNSS observations, vertical control may be established in convenient locations, and orthometric heights on control marks may be derived or monitored when a survey is conducted.

The results of the geoid slope validation survey of 2011 were shown to demonstrate the actual achievable accuracies of using GNSS observations and a gravimetric geoid model to determine precise heights. For the NSRS modernization in 2022, GNSS observations and a high-accuracy geoid model will connect survey networks to NAPGD2022. Leveling improves the accuracy of height differences between marks, and adding leveling observations to GNSS observations increases the overall redundancy in a survey network.

NGS will develop models to combine and adjust GNSS-derived heights and/or observations with leveling observations and will conduct more tests using projects combining GNSS and leveling observations. NGS will also provide guidance for the necessary spacing of vertical control from GNSS; update FGCS specifications for leveling; add a relevant section to NOS NGS Manual 3, *Geodetic Leveling;* and develop necessary software applications and tools to determine precise heights using the new geopotential datum.

Monitoring changes in the geoid

Theresa Damiani (PhD Geodesist, Geosciences Research Division (GRD), NGS), outlined the major components of a long-term geoid monitoring plan. The primary steps to establish a new geopotential datum in 2022 are: an airborne gravity survey of the entire United States and its holdings (GRAV-D); yearly experimental geoid models created with all available data; a model of geoid change over time; long-term monitoring of geoid change over time for North America and U.S. possessions; and defining a static gravimetric geoid, having 1-cm accuracy where possible.

Dr. Damiani outlined the gravity change signals we should monitor in order to maintain geoid accuracy at the 1-cm level over the next several decades, the characteristics of these signals that are important to monitor, and the geophysical phenomena that are responsible for geoid change. Some of these geophysical phenomena are sudden or episodic, such as earthquakes and volcanic activity. Some are continuous, with effects observable in less than a decade, such as ice-mass loss and glacial isostatic adjustment, and some are observable only over several decades, such as the effects of groundwater withdrawal and climate variability. She also outlined the steps for monitoring geoid changes, most of which can be estimated from satellite gravity measurements, which describe total geoid change regardless of the source.

Small gravity signals the satellites can't detect—but do affect the geoid—may be added to these estimates from data or models. From these signals, a combined gravity model of change over time and an estimate of the geoid change over time may be created. NGS has experts at merging gravity data and

making geoid models, and only a small portion of the monitoring relies on models or data created outside NGS.

In 2022, NGS will release static and dynamic geoid models. The static (S) model will be a typical geoid model, aimed to capture the 1 cm-accurate model at an epoch to be determined. The dynamic (D) model will capture the rate of change of the geoid at all places. Both models will be integrated into OPUS, and will be mostly transparent to users. Orthometric heights provided by OPUS will be time sensitive, representing a combination of the static geoid model plus the geoid rate of change indicated by the dynamic model. NGS will provide separate tools to directly access both the "S" and "D" models and will re-evaluate the "S" and "D" models periodically to determine whether they maintain accuracy and meet users' needs.

The Geoid Monitoring Service is a new project since January 2017, planned to be operational and produce NGS' first dynamic geoid by 2022. NGS will likely work with satellite gravity experts to build in-house NGS expertise and to create the geoid change model. We are currently doing research to determine which signals need to be added to the satellite gravity models and how best to estimate or measure those, using either models or data. NGS acknowledges the need to create a realistic plan for geoid emergency response, for example, in the aftermath of cataclysmic earthquakes or volcanic eruptions. Although all of North America will be monitored, most of these changes occur in Alaska, the volcanic areas of the western United States, and Canada.

Implications of a dynamic world on traditional passive geodetic control

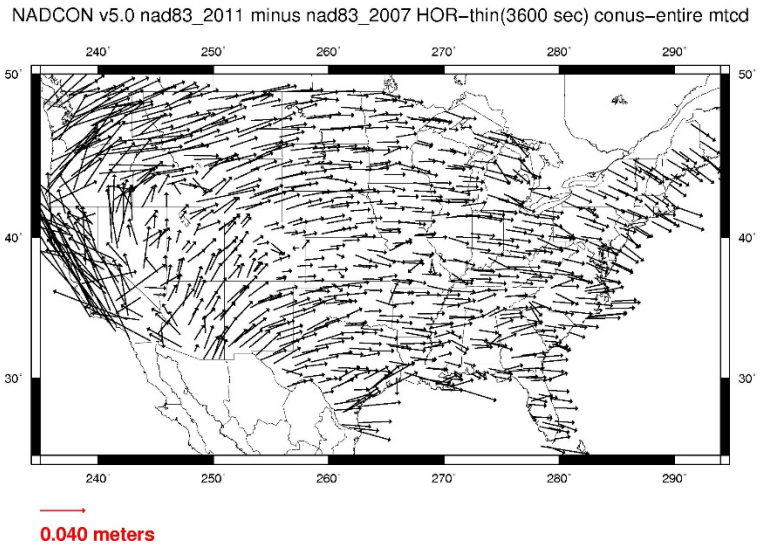
Dru Smith, NSRS Modernization Manager, used a case study of properly determined coordinates for a single geodetic control point in Louisiana to illustrate the consequences of relying on passive geodetic control marks in the context of the dynamic Earth's crust in which they reside. The case study illustrated that the Earth's crust is a dynamic place. As a result, passive control set into that crust will move, and true time dependency is not properly captured in the NGS IDB, nor on the datasheets of passive control.

True time dependency will be properly captured in the NSRS database, and reflected on datasheets of passive control after 2022. It will be modeled and removed in two phases: plate rotation, which affects horizontal coordinates only; and intra-frame velocities, which affects all three coordinates (x,y,z).

The NGS standard operating procedure has been to use survey data from multiple dates and adjust these data to one epoch, using HTDP, which does not include any vertical modeling, except in parts of Alaska. Values are often superseded with new adjustments, but rarely have those adjustments actually been given the epoch of the survey. Using that data sometimes yields erroneous results, such as an observable subsidence rate that is actually aliased into an uplift rate.

Each of the three NAD 83s is, in theory, a plate-fixed frame. Since HTDP was used to remove both tectonic rotation and intra-plate motion for latitude and longitude, NAD 83 coordinates should look fixed over time and would not exhibit systematic plate rotation, as Mr. Evjen presented in comparing NAD 83 (2011) data with that from NAD 83 (NSRS2007).

Dr. Smith showed a graphic of adjusted horizontal coordinate vectors of NAD 83 (2011) minus NAD 83 (2007) for the continental United States (see below).



Within the errors expected in NAD 83, a 2-cm horizontal coordinate difference over 8 years would not normally be considered significant. The graphic showed every point east of the Rocky Mountains between NAD 83 (NSRS2007) epoch 2002.0 and NAD 83 (2011) epoch 2010.0 has the exact same systematic movement, indicating that NAD 83 contains some "residual plate rotation." The NAD 83 frame and the North American Plate have different rotation rates, and therefore, we may conclude that the frame is not "plate fixed." NATRF2022 coordinates will have the plate rotation removed, but still exhibit their time dependency, until the intra-frame velocity model is used to estimate a coordinate at an epoch of convenience.

Dr. Smith concluded with the following points: passive control moves with the Earth's crust; NGS sees value in acknowledging and presenting that movement through both measurements and model; and NGS also sees the value in having semi-static coordinates, for comparisons across years.

Future coordinate products will include: time-dependent IGS coordinates, time-dependent *TRF2022 coordinates (same as above, minus plate rotation), and predicted *TRF2022 coordinates at "epochs of convenience" (same as above using the intra-frame velocity model to predict).

Submitting processing and viewing data in the future

OPUS projects to NGS integrated database

Mark Schenewerk (PhD, Geodesist, OPUS Projects Project Manager, GRD, NGS), described how using OPUS-Projects will replace bluebooking as the means to submit survey project data for inclusion into the

NGS IDB. The NGS Bluebook (Input Formats and Specifications of the National Geodetic Survey Data Base) is a set of strongly structured data formats. While its origins go back to the late 1970s and early 1980s, it has been updated and adapted to changes in technology over the years. The term "bluebooking" refers to formatting surveying results following the NGS Bluebook specifications for submission to the Integrated Database (IDB).

Bluebooking has been the standard for submissions to the IDB for decades. Many NGS software programs are tailored specifically to these formats, many users of geodetic control information are familiar with it, and it has served its purposes very well. Conversely, it uses 1960's technology; its detail and complexity are intimidating; it is time intensive for those submitting the data; and it is difficult, if not impossible, to adapt for the future.

In 2015, NGS began a project called "Deriving a valid path for OPUS-Projects GPS projects to be loaded to the NGS IDB," now more commonly known as OPUS to IDB (OP2IDB). The purpose of this project is to demonstrate that, with minimal changes to its web-based Graphical User Interface (GUI), OPUS-Projects can be extended to prepare complete data submissions to the IDB.

The most significant changes for OP2IDB occur in the setup adjustment form. Five adjustment types are listed and required for a submission:

- Horizontal-free: constrain a single set of horizontal coordinates and a single ellipsoid height coordinate.
- Horizontal-constrained: fix all currently published positions and ellipsoid heights.
- Vertical-free: fix one position and one published orthometric height.
- Vertical-constrained: constrain all previously adjusted orthometric heights and one NAD 83 adjusted position.
- Other: for backwards compatibility, a standard OPUS-Projects adjustment and a b-file are created.

Re-inventing bluebooking means going from creating and interpreting strongly formatted reports to users entering information in much more human-friendly ways, and to NGS receiving that information formatted in much more flexible formats, such as XML. Dr. Schenewerk showed the remaining timeline for the project. Internal and external testing are scheduled for the summer of this year, and a follow-on project will take OP2IDB from beta to production.

Replacing bluebooking

Dave Zenk (Northern Plains Regional Advisor, State Advisor Branch, Geodetic Survey Division, NGS), described how "bluebooking" will be replaced by a process built around the general model of OPUS-Projects (OP)—a browser-based analysis, processing, and submitting tool. OP will be expanded to accept leveling surveys and then other survey types, including traverse, real-time networks (RTN), absolute gravity, and relative gravity, with the ability for data type to flow among tabs. In this way, mixed-method surveys will be processed in a method-by-method build up.

The NGSIDB is not capable of handling time dependencies, or built to handle GPS raw data files. NGS will provide transformations between historic datums and the new reference frames, aimed at helping users manage data that is not in the NSRS DB. NGS considers readjusting actual survey measurements—not coordinate transformations—as best practice. If NGS can make it easier to store measurements in the NSRS DB, then it can provide better access to the new terrestrial reference frames and geopotential datum and better customer service.

NGS is taking a broad view that OP is a capable interface that can be adapted to essentially any type of survey data. A leveling project needs mark descriptions, mark locations, mark photos, and the leveling measurements. OP already has the tools to ingest the first three of these four items. As with leveling, gravity surveys—whether aerial or terrestrial; absolute or relative—need metadata support, but also have special analytical needs. All can be supported within gravity tabs in the OP interface.

Real-Time-Kinematic (RTK) and Real-Time-Network RTK (RTN) surveys efficiently produce accurate positions that may be of value in improving or validating other surveys. Therefore, NGS could provide an RTK/RTN tab in OP to capture these valuable positions. RTK/RTN positions must be traceable to the NSRS. RTK/RTN surveyors would prove that calibration to NSRS was performed using an approved combination of active and passive techniques, which might include: published passive marks, national CORS, and OPUS static.

To support future needs, the new NSRS database must be: spatially-enabled, velocity-capable, handle all current data types and allow for new future data types, fast, nimble, and reliable. We regard the future role of passive geodetic control as: control for projects, monitoring sites for crustal motion, and used for calibrating RTNs. Depending on accuracy needs, new coordinates should be freshly determined, rather than relying on published coordinates based on old surveys.

The primary means of accessing the new terrestrial reference frames and geopotential datum will be GNSS technology. At a minimum, access will be via: CORS positions, velocities and discontinuities in the latest IGS reference frame; OPUS-S (static), OPUS-RS (rapid static), and variants; an RTN validation service; quantifying agreement with the NSRS; and a spatial and temporal relationship between the IGS reference frame and the new geometric reference frame. While passive control will continue to be used as a secondary method to access the NSRS, such control will be ‘tied to,’ and not a ‘part of,’ the NSRS.” GPS surveys on marks after 2022 can be “bluebooked” and submitted to NGS. This could mean a complete overhaul for bluebooking, database storage, and time dependencies.

Geospatial visualizations

Brian Shaw (GIS Specialist, State Advisor Branch, GSD, NGS), Jason Woolard (Cartographer/remote sensing specialist, Systems and Quality Assurance Branch, Remote Sensing Division (RSD), NGS), and Jon Sellars (Cartographer/remote sensing specialist, Systems and Quality Assurance Branch, RSD, NGS), made the following points:

- The realms of geodesy and geographic information systems (GIS) continue to converge.
- Use the tools of your time.
- Graphics convey more than words.

IMPACTS OF NEW TERRESTRIAL REFERENCE FRAMES AND GEOPOTENTIAL DATUM ON PROGRAMS AND PARTNERS

NGS Coastal Mapping Program and VDatum

Mike Aslaksen (Remote Sensing Division Chief, NGS), and Stephen White (Cartographer/remote sensing specialist, and VDatum Program Manager, Systems and Quality Assurance Branch, Remote Sensing Division, (RSD) NGS), presented information on NGS' Coastal Mapping Program (CMP) and the free software tool, VDatum. NOAA has a Congressional mandate to conduct remote-sensing surveys of the coastal regions of the United States and its possessions for delineating the nation's legal coastline. The goal of the CMP is to provide the nation with consistent up-to-date shoreline information and to acquire accurate nearshore elevation data. NOAA uses digital cameras, Lidar, and high-resolution satellite imagery to collect this information.

On the operational side, implementing the new reference frames will affect proprietary sensor software used to process the data, as well as geo-referencing base stations and control points, critical to obtaining consistent data. With regard to the impact on NOAA's shoreline product, tidal datums are not expected to be affected, and minimal effects are expected for charting applications.

The National Tidal Datum Epoch (NTDE) is a product of NOAA's Center for Operational Oceanographic Products and Services (CO-OPS). An NTDE update is expected around 2020, which will compound the impact of NSRS modernization to shorelines. The effects of this update need to be detailed, and education efforts about this change are important. Horizontal transformations to shoreline will be needed if nautical charts are not updated to the latest reference frames, metadata, and statements of work.

With regard to IOCM (Integrated Ocean and Coastal Mapping) products: new products will need to be tied to the latest reference frames, old products will need to be transformed by delivery mechanism, or remote-sensing/GIS software will need transformation capabilities. Outreach and education will be needed to avoid confusion regarding different reference frames and to ensure consistency in the resulting data.

Anticipated positional changes resulting from changing to the new reference frame were illustrated on aerial images of the port facilities at Seattle, WA; Long Beach, CA; and Charleston, SC. Images were also shown to depict the effects of applying the new geoid incorrectly at different coastal communities.

Mr. White explained current developments and applications of the VDatum (Vertical Datum Transformation) software tool. VDatum is a free software tool under development jointly by NGS, CO-OPS and NOAA's Office of Coast Survey (OCS). VDatum is designed to vertically transform geospatial data among a variety of tidal, orthometric, and ellipsoidal vertical datums, allowing users to convert data from different vertical references to a common system, and enabling the fusion of diverse geospatial data onto a preferred vertical datum. More information on this software tool is available at https://vdatum.noaa.gov/.

NGS anticipates the release of the next NTDE in the 2022-2023-time frame, computed on the period of 2002-2020. This is the official time period of tidal observations used for primary datum calculations, and is based on the time it takes the Earth, Moon, and Sun to complete an epoch tidal cycle. The NTDE averages out seasonal fluctuations and provides a nationally consistent tidal datum network by accounting for seasonal and apparent environmental trends in sea level that affect the accuracy of tidal datums. The current NTDE covers the period 1983-2001, and includes the longest-period tidal variations, an 18.6-year node cycle.

You can help our efforts to modernize the NSRS by collecting GPS observations on bench marks, alerting us to problems in our models or software tools, and letting us know what enhancements to our existing models or tools would benefit you.

IMPACTS OF THE NEW TERRESTRIAL REFERENCE FRAMES AND GEOPOTENTIAL DATUM ON NGS PARTNERS

The following presentations were offered by NGS partner agencies, who were asked to address a specific set of NSRS modernization issues. Generally, these issues followed the form:

- We are looking forward to NSRS modernization because:
- We are concerned about NSRS modernization because:
- The tools, products, or services we need most from NGS or others are:
- The outreach products or services we need most from NGS or others are:
- Our preparations to date for the new reference frames include:

Several common themes or concerns emerged among the agencies represented, notably,

- Agencies are looking forward to NSRS modernization because: the new terrestrial reference frames and geopotential datum will align more closely with global reference systems, the new terrestrial reference frames and geopotential datum will provide a more accurate representation of our physical world for numerous georeferenced data products, and the new terrestrial reference frames and geopotential datum represent significant progress toward a

common global geodetic reference frame for all geospatial data, reducing confusion for many surveying applications.

- Agencies are concerned about NSRS modernization because: they anticipate technical and resource challenges integrating legacy data with data referenced to the new terrestrial reference frames and geopotential datum; changing the datum on maps requires administrative actions by communities; boundaries and elevations are administratively fixed and enforced by federal, state, and local laws; and there will be a high demand for user education and easy-to-use tools to transform coordinates.

- The tools, products, or services agencies need most from NGS or others are: tools to convert coordinates among datums and datum realizations (online and open-source tools on a modern code base are preferred); GPS and GIS vendors should update their software to incorporate the new geometric and geopotential datums and GNSS data sets from foundation CORS; and well-documented practices to guide users in processing observations to bring their control up to date in the current epoch.

- The outreach products or services agencies need most from NGS or others are: continued NGS geospatial summits and monthly training webinars; updates on the schedule for implementing the new terrestrial reference frames and geopotential datum; educating GIS and other professionals who work with geospatial data, but have limited geodetic knowledge; and collaborating with NSPS to update legislation that references datums.

- Our preparations to date for the new reference frames: varied according to individual agency's program responsibilities.

Federal Emergency Management Agency (FEMA)

Ms. Kimberly Pettit, representing FEMA, indicated a major product that will be affected by modernizing the NSRS will be National Flood Insurance Program (NFIP) Flood Maps. NFIP insures about $1.3 trillion in property in high-risk areas. FEMA publishes flood maps that define the boundaries of the high-risk area (horizontal), and the elevations to which buildings must be built in the high-risk area (vertical). To date, we have been working on the transition from NAD83 (1986) to NAD83 (2011), developing dynamic digital data delivery requirements, and expanding legal compliancy standards for digital data.

We are looking forward to the new reference frames because: new construction permits, real estate transactions, and flood insurance require flood-risk status determinations and minimum building elevation; and NSRS improvements could reduce surveying costs for thousands of precise horizontal and vertical measurements referenced to NSRS. The reference-frame name change will bring clarity to all map products, currently all referred to as NAD 83.

Changing the datum on maps requires administrative actions by communities. Once the boundaries and elevations are published by FEMA they are fixed administratively and enforced by federal, state and local laws. Legal issues arise when conversions introduce small shifts in relative positions. The dynamic

nature of the Earth and corresponding dynamic datums make future legal considerations and procedures difficult with integrated datasets.

The tools, products, or services we need most are: the ability to convert between datums, and datum realizations for all data types, especially rasters and polygon vectors. Commercial vendors—such as Esri and FME—using the new NGS tools to create an integrated conversion toolkit may be a good solution. The outreach products we need most include guidance documents, quantitative conversion analyses, and conversion tools. Most NFIP end users are unlikely to benefit from training.

U.S. Geological Survey (USGS)

Ms. Kari Craun, representing USGS, introduced a number of USGS products and services that will be affected by the new terrestrial reference frames and geopotential datum. She polled scientists from across USGS to understand from their perspective the impacts of changing horizontal and vertical datums. Most do not believe the change in datums is a problem, and many understand it will provide significant benefits. Overall, however, the integration with legacy data referenced to older datums will need to be addressed. Ensuring we have adequate conversion tools that have been tested by an authoritative source, such as NGS, will be very important.

Our major products and services which will be affected by the new terrestrial reference frames and geopotential datum include:

- National Map databases (base geospatial information)
- 3D Elevation Program (3DEP) data, products, services
- USGS Topographic Maps
- ISO 19111 geographic information – spatial referencing by coordinates
- Geomagnetic observatory time-series data
- Landslide hazard assessments, digital spatial data
- USGS earthquake program
- USGS water information (stream gages, water quality data, etc…)

Our preparations to date include: awareness and education on the possible impacts, and preparing a justification for revising ISO 19111.

Conversions of large national spatially referenced datasets, such as 3DEP products (high-resolution, high-accuracy elevation data), will be a challenge. These data, including national seamless elevation layers at multiple resolutions, will have to be converted. Metadata will also need to be updated. We will need to decide whether to convert lidar point-cloud data and digital-surface models. If we do not convert these to the new terrestrial reference frames and geopotential datum, we will need to make it clear to users what the differences will be in the datums of legacy products and new products; and that if they use them together, they will need to do a datum conversion. This is only one specific example of a legacy dataset that will have to be adequately labeled with regard to the old and new spatial reference system.

We are excited because new data, collected using sensors such as lidar, IFSAR, other remote sensing data, will be associated with the new terrestrial reference frames and geopotential datum, and thus, adoption of these datums into software will be critical. The new terrestrial reference frames and geopotential datum will provide: closer alignment with global reference systems, improved locations for magnetic observatory reference points, and more accurate representation of the physical world in our elevation, and other geo-referenced products.

We are concerned about datum modernization because: there will be challenges with integrating legacy data associated with NAVD 88 and NAD 83 with data referenced to the new terrestrial reference frames and geopotential datum; it will be important for metadata associated with legacy data to have correct datum references; and converting existing 3DEP products will be a large effort. Metadata will also have to be updated. Some legacy data will be on old datums while new data will be on the new terrestrial reference frames and geopotential datum; this may result in user confusion.

The tools, products, or services we need most, from NGS or others, are: official transformation models between the old and new terrestrial reference frames and geopotential datum; release of conversion software as open-source software from NGS; and we need NGS to potentially work with major commercial GIS and geo-processing software vendors to test their conversion software.

The outreach we need most, from NGS or others, is: for NGS to actively participate in revising ISO 19111, updates on the schedule for implementing the new terrestrial reference frames and geopotential datum, and for NGS to continue to provide training in the form of webinars and video training.

We want to make sure we are using conversion tools and software that has been verified and certified by NGS to the extent possible. We rely on commercial and open-source software, so we are hoping NGS can work with both of these communities to make sure they are using verified algorithms and information in their software.

U.S Army Corps of Engineers (USACE)

Mr. Jim Garster, representing USACE, indicated that their major products and services affected by the new terrestrial reference frames and geopotential datum will be existing project maps, designs, and studies, as well as project Operations and Maintenance (O&M) manuals. Our preparations to date for the new reference frame include: policy and guidance documents, workshops, webinars, and newsletters; and MART (USACE Survey Monument Archival & Retrieval Tool), which keeps track of project control and ties to NSRS/NWLON.

The advantages of the new terrestrial reference frames and geopotential datum we anticipate are: consistency of datums across the country, specifically vertical; better relationship between geodetic and hydrologic datums; and improved accuracy for GPS-derived elevations (via geoid models).

The challenges we anticipate from modernizing the datums are: the relationship between existing and older datums and new terrestrial reference frames and geopotential datum; the relationship between new vertical datums and tidal datums; the impact to state plane coordinate projections; small

[coordinate] changes might get ignored; potential dynamic datum; constantly changing coordinates; how often will it change; and conversion tools will be more complex.

The tools, products, or services we need most, from NGS or others, are: transformation routines and tools, including statements of accuracy; user-defined epoch for output datasheets; incorporating transformations in GIS tools (from ESRI, and others); superseded values need to be documented on datasheets; OPUS Projects; and connections to the NSRS.

The outreach we need most, from NGS or others, includes: on-line tutorials on datums and the importance of datum transformations, and a publication describing and documenting the differences between NAD 83/NAVD 88 and the new terrestrial reference frames and geopotential datum.

National Geospatial Intelligence Agency (NGA)

Mr. Stephen Malys, NGA Senior Scientist for Geodesy and Geophysics, indicated the major products and services for his agency that will be affected by the datum updates are: The Homeland Security Infrastructure Program, the Homeland Infrastructure Foundation-Level Data (HIFLD), and collaboration among NGA, Department of Homeland Security, and USGS. Geodetic surveys on weapons test ranges in the continental United States will continue to use WGS 84 (Gxxxx) and EGM 2008 (the Earth Gravitational Model 2008).

The advantages of the new terrestrial reference frames and geopotential datum that NGA anticipates are: the replacement to NAD 83 will be closely aligned with the ITRF, and therefore closely aligned with the current (and future, 2022) realizations of WGS 84; and the replacement to NAVD 88 will be more closely aligned with our best global geoid: EGM 2008. These NGS efforts represent significant milestones toward a common global geodetic reference frame for all geospatial data, a major goal of geodesy for many decades, and will reduce confusion for most practical surveying applications.

The concerns we have about the new terrestrial reference frames and geopotential datum are: there will likely be small differences between NAD xx and WGS 84 (Gxxxx), and differences at the 1- to 10-mm level is a topic of scientific interest. Will the community accept these small differences as statistically insignificant, or of no practical interest?

The tools, products, or services we need most are: GPS and other GNSS data sets from foundation CORS, and tools to facilitate direct comparison with the WGS 84 reference frame. The outreach we need most includes: continued collaboration among NGA, NOAA, and NASA; support to maintain the health of the geodesy discipline within the U.S. Government; and interagency collaboration and communication to the surveying community on the U.S. Government policy regarding use of foreign GNSS, since multi-GNSS surveying receivers will likely become commonplace.

Dewberry

Mr. Amar Nayegandhi, Vice President and Director of Remote Sensing at Dewberry, described their products and services that will be affected by moving to the new reference frames. These include: all products of the 3D Elevation Program (elevations could change by up to 30 cm); topo-bathy lidar data and shoreline vector data for NOAA/NGS, and digital ortho-imagery and planimetric maps for all clients (horizontal coordinates could change by up to 1.5 meters); and flood insurance studies for FEMA.

Our preparations to date for the new reference frame include: our digital terrain models and digital surface models are being delivered with ellipsoid heights so we can apply the new geopotential datum to easily re-compute new orthometric heights. With the new terrestrial reference frames and geopotential datum, we hope we'll be able to compute orthometric heights accurate to 1 cm when mapping ellipsoid heights from LiDAR and IFSAR and adding the geoid height.

We hope NGS datasheets and survey monuments will become relics of the past as we come to rely on the new NSRS. We anticipate GPS users will be forced to rely on CORS, as the prior use of inaccurate and un-maintainable survey monuments are phased out. We hope that we can get standard vertical datums offshore (e.g., Hawaii, Puerto Rico, U.S. Virgin Islands), and that we can more easily link to the dynamic ITRF, recognizing that the land continues to move horizontally and vertically. All horizontal and vertical coordinates should be more accurate by meters (horizontally) and centimeters (vertically).

Our biggest challenge will be to update all the elevation data, ortho-images and other geospatial datasets produced with prior datums. FEMA often revises flood insurance studies by updating prior hydrologic & hydraulic models prepared with older datums, which may take decades to fix. What we need most from NGS or other organizations are transformation tools for the new terrestrial reference frames and geopotential datum. GPS and GIS vendors should update their software to incorporate the new geometric and geopotential datums.

The outreach products we need most from NGS or other organizations are: NGS should host bi-annual summits and quarterly webinars; NSPS should distribute sample language to update state legislation that references NAD 83; and NGS should convince other federal and state agencies to act proactively to prepare for the future and to implement the new terrestrial reference frames and geopotential datum when ready.

Esri

Mr. Kevin M. Kelly, representing Esri, indicated the products and services that will be affected by the new reference frames are the Esri ArcGIS software stack and geodetic code base. Our preparations to date for the new reference frame include: building dynamic datum functionality, time-based datum—or reference frame—transformations (these are 15-parameter Helmert transformations), and point trajectory models.

The advantages we anticipate the new terrestrial reference frames and geopotential datum bringing to our products and services are: modernizing our geodetic models and tools, increased awareness and importance of geodesy to GIS, working collaboratively with NGS, and improved responsiveness by NGS. Our concerns about the new terrestrial reference frames and geopotential datum are the demand for user education; there is currently a dearth of effective educational materials. We struggle to educate our users about obsolete static datums; it will be a greater challenge to educate them about dynamic datums. Will an industry-developed algorithm that differs from an NGS one be accepted by NGS? The answer should be: if it gives the same answers as an NGS-provided test dataset, then it's acceptable. We hope this will be the case.

The tools, products, or services we need most from NGS or others are: source-code on a modern code base, detailed formulations and algorithms, authoritative test datasets and compliance criteria, and consistent grid formats. The outreach we need most from NGS or others includes: education, education, and more education; technical and user documentation; and continued summits, webinars, and scientific literature.

Trimble

Mr. Graham Briggs, representing Trimble, indicated its major products and services that will be affected by the new reference frames are the Trimble geodetic library, used by its field, office, and cloud-based positioning solutions. To prepare for the new terrestrial reference frames and geopotential datum we have released time-dependent transformation handling in some core products; we are preparing to update fixed-epoch transformation parameters; we are working on including time metadata with position information; and our research and development group is investigating the implementation of local models (US HTDP, NZ grid deformation, etc.). We are actively participating in related conventions and seminars, and educating our users and exposing them— through our beta programs—to time-dependent transformations. Overall, we are preparing for a future where time-dependent methodologies can be applied as transparently as possible in the background.

We are looking forward to the new terrestrial reference frames and geopotential datum because they will provide more accurate measurements, along with their predicted errors; and better tools, including web interfaces and APIs, allowing our users to obtain consistent results through direct use of NGS algorithms in Trimble solutions.

The concerns we have about the new terrestrial reference frames and geopotential datum are: our customers believe it is important for the CORS and RTNs to continue to work with a fixed-epoch. They will need easy-to-use tools to transform datums, if they change in the middle of their projects, or if they need to work with old data sets. Most customers don't understand this complex problem. We need to provide simple workflows in our products. We also need to upgrade our libraries and software applications quickly any time there is a change.

The tools, products, or services we need most from NGS or others are: a global standard for representing and working with deformation models; a common lexicon, to be shared by: NGS, solution

providers, universities, agencies, and others; guidelines and documented tools to work with data sets that have been collected across multiple datum epochs; and well-documented "best practices" to guide users in re-processing their observations in the current epoch.

The outreach products we need most from NGS or others are: prescribed methods for working with the NSRS in commercially available software packages; tools and algorithms written in C or C++—rather than in Fortran—for cross-platform portability; expanded use of data files—rather than software libraries—to facilitate updating our solutions with fewer code changes; collaboration between NGS and industry to bring this solution to our shared constituents and customers; and a greater focus on GIS and other professionals with more limited geodetic knowledge who work with geospatial data.

North Carolina Geodetic Survey (NCGS)

Gary Thompson, PLS, representing NCGS, indicated that his agency's major products and services that will be affected by the new terrestrial reference frames and geopotential datum include North Carolina's CORS network, its Land Records Management Program, its Flood Risk Information System, its Flood Inundation Mapping Alert Network (FIMAN), and the NC Geodetic Survey geodetic database.

To prepare for the new terrestrial reference frames and geopotential datum, we have created a 2022 Datum Working Group to develop implementation recommendations. We are also: working with the South Carolina Geodetic Survey to develop common implementation plans; working with NGS to complete GRAV-D in North Carolina; collecting terrestrial gravity data and partnering to purchase absolute and relative gravity meters; collecting statewide LiDAR elevation data (USGS QL1 and QL2); and conducting educational outreach.

We are looking forward to the new terrestrial reference frames and geopotential datum because NGS plans include developing improved "user-friendly" programs for submitting, processing, and viewing geodetic data. Our concerns about the new terrestrial reference frames and geopotential datum include: NGS tools may be developed without direct involvement from users, NGS will not have enough resources to develop "user-friendly" tools to help users transition to the new terrestrial reference frames and geopotential datum, and state and local government agencies may face high costs to make the transition to new terrestrial reference frames and geopotential datum in 2022.

The tools, products, or services we need most from NGS or others are: web-based user-friendly transformation tools; and modernized tools to provide an efficient and consistent method to submit GNSS, leveling, gravity, and traverse data to NGS for inclusion in the NSRS. The outreach products we need most are: ad-hoc groups to include datum and tide-information users to ensure they are included in the decision-making process for the transition to the new reference frame; status reports on the new reference frames; user feedback from participants in surveying and mapping conferences; and regional partnerships to support the GRAV-D project.

Mr. Thompson also directed summit participants to the recommendations in the Hydrographic Services Review Panel's (HSRP) issue paper at https://www.nauticalcharts.noaa.gov/ocs/hsrp/recommendations/2016/HSRP-US-Latitudes-Longitudes-Elevations-to-Change-26Oct2016.pdf.

Fairfax County Government

Ms. Vickie McEntire Anglin, L.S. County Surveyor, (Fairfax County Government, Department of Public Works and Environmental Services, Land Survey Branch), indicated the County's major products and services that will be affected by the new terrestrial reference frames and geopotential datum are: all county GIS mapping services, especially topographic maps; coordinate values on all secondary control monuments; and flood insurance elevation certificates. To prepare for the new terrestrial reference frames and geopotential datum, we: began discussions to pre-sell budget items, identified stakeholders with legacy data, identified county codes to change, and conducted meetings with GIS personnel to discuss changes within the county.

We are looking forward to the new terrestrial reference frames and geopotential datum because: Fairfax County will switch to NSRS 2022 and be set for the future, the new terrestrial reference frames and geopotential datum will be more accurate, and the change will facilitate closer coordination with neighboring jurisdictions on floodplain mapping issues. We are concerned about the change because this is an "unfunded mandate;" we need funds for changing something that is virtually invisible, difficult to fully explain in lay terms, and is currently working well; and the effort and costs are currently unknown. Other concerns include: county code, checklists, and processes must change; users have legacy data that is not digital and will require conversion; staff education and outreach across many agencies has to be designed and administered in a continuing education format.

The tools, products, or services we need most, from NGS or others, are: NGS transformation tools to facilitate on-demand conversions; GIS, GPS, CAD, and add-on computing software packages need to incorporate conversions between datums and handle 5 parameters (X,Y,Z,t,v); and a solution to surveying a single project over a long period in which coordinate values are changing.

The outreach products we need most are: continuing monthly NGS webinars and NSRS Modernization News. We would appreciate explanations of the benefits of updating the datums in Fairfax County, how NGS perceives this change to affect the county, financial assistance options, and the process of changing and the tools that will be necessary. NSPS can help agencies accomplish outreach with a standard "speaker's kit" including practical benefits and sample language to update county code that references NAD 83 or NGVD 29.

Baltimore County Government

Patrick Simon, L.S., (Baltimore County Government - Land Survey Division), indicated the County's major products and services that will be affected by the new terrestrial reference frames and geopotential datum are the countywide survey control network, and all plats, utilities, and designs, which must be prepared using the official datum for Baltimore County (NAD 83/NAVD 88). To date the Baltimore County Government has alerted key people to the upcoming datum change, provided sessions on NATRF2022/NAPGD2022, and begun evaluating the needed field work by determining the necessary connections from CORS to the countywide survey control network.

We are looking forward to the new terrestrial reference frames and geopotential datum because Baltimore County's datum will be aligned with, or extremely close to, the internationally recognized system ITRF and WGS 84; there will be better data along the 200 miles of county waterfront land to analyze sea-level rise and land subsidence; and "It's the right thing to do."

Our concerns about the change include: we will need to tell users why we need to change coordinate values; the need to maintain the network of passive marks as the basis of land surveys performed in Baltimore County, and what happens when CORS ends or is not available? In 2014, FEMA released new flood maps for Baltimore County on NAVD 88 for the first time. Before this date, all maps were prepared on the Baltimore City/County datum. What is FEMA's plan to produce Flood Insurance Rate Maps on NAPGD2022?

The tools, products, or services we need most from NGS or others are: transformation tools from previous datums to NATRF2022 and NAPGD2022, updated software from GPS and GIS vendors, and improved or updated real-time networks. The outreach products we need most from NGS or others are: monthly NGS webinars and training classes about the datum changes at professional conferences. NGS and NSPS need to work with federal, state, and local government in language to update legislation that references datums.

Summary and next steps

More than 430 persons attended the 2017 Geospatial Summit on Modernizing the National Spatial Reference System. NGS sought and received important feedback directly from our constituents on their preparations for, and concerns about, modernizing the nation's geodetic framework.

NGS is committed to keeping its constituents informed of its progress in this modernization effort. To this end, we will continue to issue brief, regular progress reports via NGS' NSRS modernization newsletter; we will continue to improve the NGS Geodetic Toolkit with robust online coordinate transformation tools to link NAD 83 and NAVD 88 to the new reference frames; and we will summarize the scientific aspects of the modernization project in the "Blueprint for 2022" documents and publish these as soon as they become available.

We ask our constituents to provide us feedback and to participate in future geospatial summits and other constituent events. We ask you to share the information and insights you have gained from this event with your colleagues and visit our website for progress updates. Engage with professional societies such as NSPS and MAPPS; these societies have a tremendous national and local reach. NGS will leverage their communication networks in order to reach NSRS users in all locations. Preparing our users for the changes to come remains a high priority for NGS.

Appendix A: List of references used in this report

Socio-Economic Benefits Study: Scoping the Value of CORS and GRAV-D, revised January 2009, Irving Leveson, Prepared for the National Geodetic Survey, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, contract No. NCNL0000-8-37007

The Geoid Slope Validation Survey 2011, Data Files for Public Distribution, January 2013, Dru Smith, Project Manager, GSVS11

NOAA Technical Report NOS NGS 62: Blueprint for 2022, Part 1: Geometric Coordinates, April 2017, Dru Smith, Dan Roman, and Steve Hilla

Appendix B: List of abbreviations used in this report

3DEP	3D Elevation Program
(API)	application programming interface
CAD	computer-aided design
CORS	Continuously Operating Reference Station
FEMA	Federal Emergency Management Agency
FGCS	Federal Geodetic Control Subcommittee
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRAV-D	Gravity for the Redefinition of the American Vertical Datum
HIFLD	Homeland Infrastructure Foundation-Level Data
HTDP	Horizontal Time-Dependent Positioning
IERS	International Earth Rotation and Reference Frame Service

IfSAR	Interferometric synthetic aperture radar
IGS	International GNSS Service
ITRF	International Terrestrial Reference Frame
Lidar	Light Detection and Ranging
NAD 83	North American Datum of 1983
NAPGD2022	North American-Pacific Geopotential Datum of 2022
NATRF2022	North American Terrestrial Reference Frame of 2022
NAVD 88	North American Vertical Datum of 1988
NFIP	National Flood Insurance Program
NGA	National Geospatial Intelligence Agency
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NSRS	National Spatial Reference System
NSRS DB	National Spatial Reference System Database
NWLON	National Water Level Observation Network
OPUS	Online Positioning User Service
RTN	Real Time Network
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WGS 84	World Geodetic System of 1984

Appendix C: Summit attendance breakdown

Department of Commerce, local	127
Department of Commerce travelers	33
Invitational travelers	0
Non-Department of Commerce	56
Non-federal	220
Total attendees	436

Appendix D: Summit agenda

GEOSPATIAL SUMMIT DAY 1 **Monday April 24**

12:30 - 1:00: Arrival / Registration

1:00 - 1:15: **Welcome:**
Juliana Blackwell, Director, National Geodetic Survey

1:15 - 2:00: **Keynote:** Russell Callender,
National Ocean Service Assistant Administrator

2:00 - 2:50: **Introduction to modernizing the National Spatial Reference System:**
Why is NGS Replacing NAD 83 and NAVD 88, and what is the status of effort?
Joe Evjen, Geodetic Standards and Applications Branch Chief, SRSD, NGS

Recap: Previous geospatial summits and customer concerns:
Joe Evjen, Geodetic Standards and Applications Branch Chief, SRSD, NGS

Recent Decisions: Naming conventions, managing velocities, and white papers: Dru Smith, NSRS Modernization Manager, NGS

2:50 - 3:10: Break

3:10 - 4:30: **Project updates related to NSRS modernization**
Modernizing the geometric reference frame:
Dan Roman (acting Chief Geodesist, NGS); Steve Hilla (Geosciences Research Division Chief, NGS); and Kevin Choi (CORS Branch Chief, NGS)

4:30 - 4:50: **Getting prepared for NSRS modernization:**
How to update state and local legislation using suggested template:
Dave Doyle, National Society of Professional Surveyors

4:50 - 5:00: Wrap-up and Closing

GEOSPATIAL SUMMIT DAY 2 **Tuesday April 25**

8:00 - 8:30: Arrival / Registration

8:30 - 10:05: **Collecting geodetic control data in the future**
Leveling in a GNSS (GPS) World:
Dan Gillins (PhD Geodesist, Project Analysis Branch, OAD, NGS); and Kendall Fancher (Instrument and Methodologies Branch Chief, GSD, NGS)

Monitoring changes in the geoid:
Theresa Damiani (PhD Geodesist, Geosciences Research Division, NGS)

Implications of a dynamic world on traditional passive geodetic control:
Dru Smith (NSRS Modernization Manager)

10:05 - 10:25: Break

10:25 - 12: 00 **Submitting, processing and viewing data in the future**
OPUS Projects to NGS Integrated Data-Base:
Mark Schenewerk (PhD, Geodesist, OPUS Projects Project Manager, Geosciences Research Division, (GRD), NGS)

Replacing bluebooking:
Dave Zenk (Northern Plains Regional Advisor, State Advisor Branch, GSD, NGS)

Geospatial visualizations:
Brian Shaw (GIS Specialist, State Advisor Branch, GSD, NGS); Jason Woolard, and Jon Sellars

12:00 - 1:30: Lunch on your own

1:30 - 3:05: **Impact of new terrestrial reference frames and geopotential datum of programs and partners (Part 1)**
Coastal Mapping Program and Vdatum
Mike Aslaksen (Remote Sensing Division Chief, NGS); Stephen White (Cartographer/remote sensing specialist, and VDatum Program Manager, Systems and Quality Assurance Branch, Remote Sensing Division, NGS)

Federal Emergency Management Agency (FEMA):
Kimberly Pettit, FEMA

U.S. Geological Survey (USGS):
Kari Craun, USGS
U.S. Army Corps of Engineers:
Jim Garster, USACE

National Geospatial-Intelligence Agency:
Stephen Malys, NGA

3:05 - 3:25: Break

3:25 - 4:55: **Impact of New terrestrial reference frames and geopotential datum of programs and partners (Part 2)**

Geospatial and Remote Sensing Customers:
Amar Nayegandhi, Dewberry

Geographic Information System (GIS) Customers:
Kevin Kelly, Esri

GNSS Equipment Customers:
Graham Briggs (replacing Hamid Mahmoudabadi), Trimble

State Government Partners:
Gary Thompson, NC Department of Public Safety

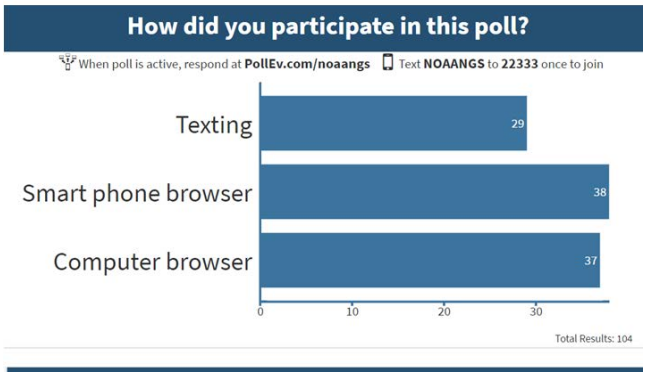
Local Government Partners:
Vickie Anglin, Fairfax County Government, Virginia
Pat Simon, Baltimore County Government, Maryland

4:55 - 5:00: Wrap-up and closing

Appendix E: Live poll results

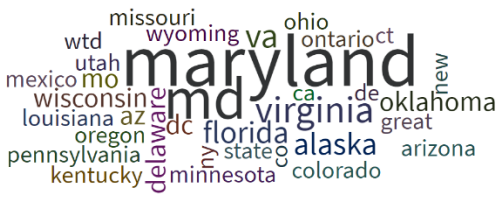
Both in-person and webinar participants were invited to vote in live polls about their roles as NSRS users, and their preferences and concerns about modernizing the NSRS and NGS' products, services, and program activities. Participants could respond to these polls via text message or web browser, participation was voluntary, and all responses were anonymous. Following are results from the live participant polls.

Live poll results Day 1: April 24, 2017



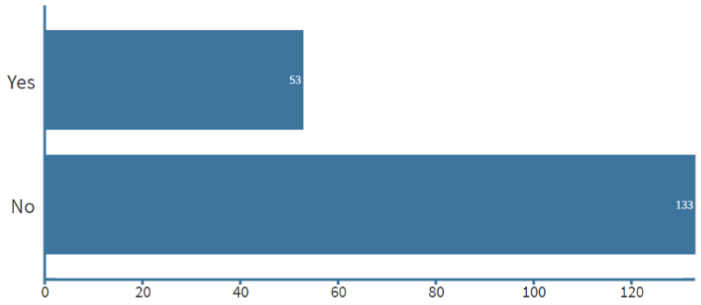
In one word: what state do you live in? (e.g. NY, New_Jersey, Maryland, other)

Poll is full and no longer accepting responses



Do you work for NOAA's National Geodetic Survey?

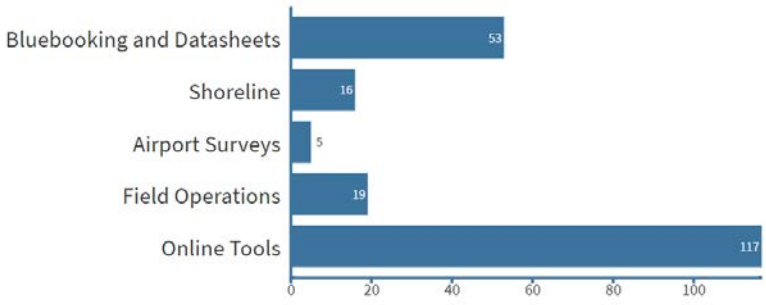
When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join



Total Results: 186

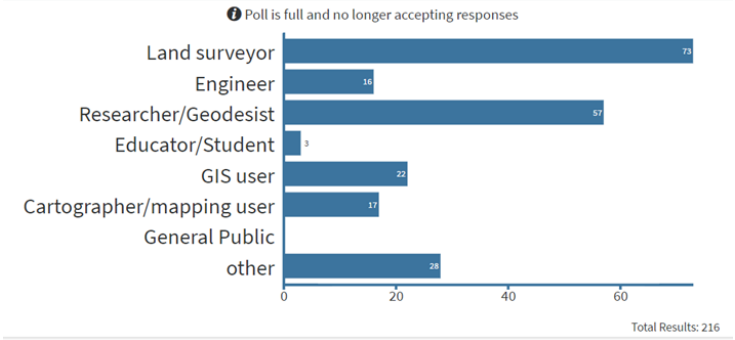
What is most critical to support National Spatial Reference System (NSRS) users today?

Poll is full and no longer accepting responses

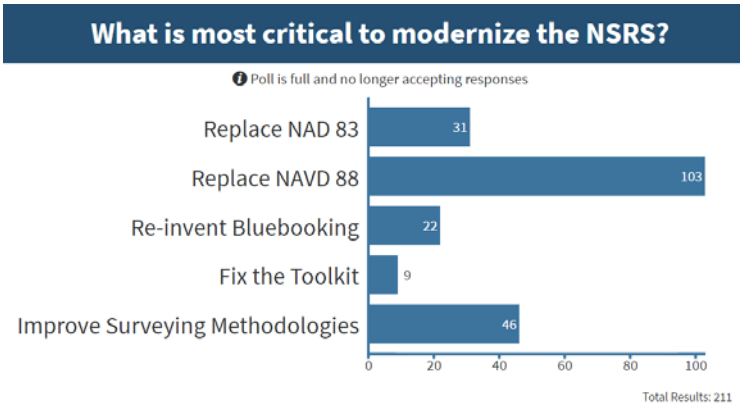


Total Results: 210

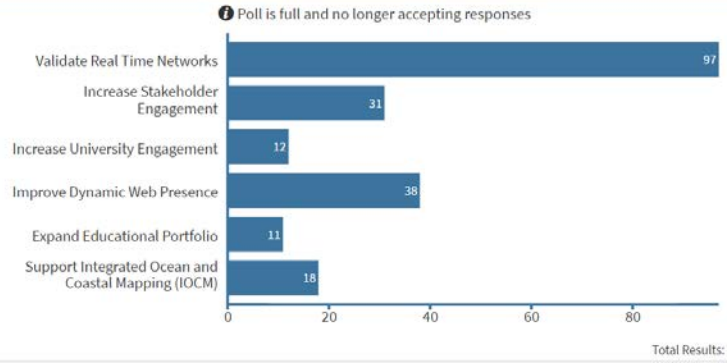
Which term best describes your role?



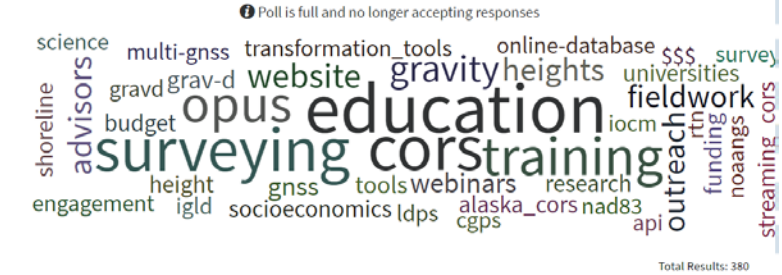
What is most critical to modernize the NSRS?



What is most critical to support NGS customers?

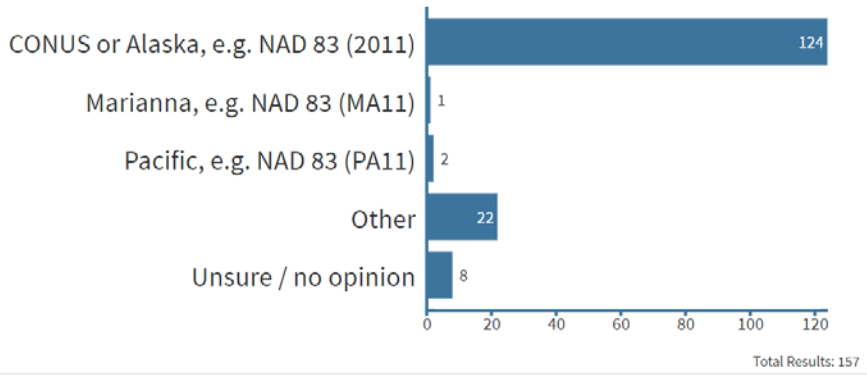


In one word: what activities are most critical to help NGS meet its mission? (e.g. CORS, education, OPUS, fieldwork, heights, gravity, training, webinars, universities, surveying, website, GNSS, etc)



In which reference frame do you primarily work?

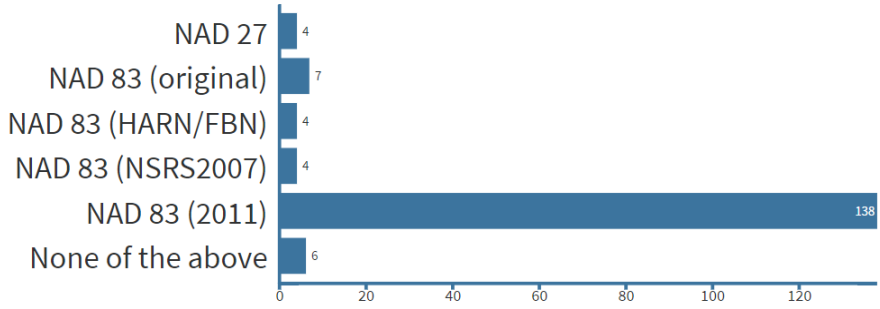
When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join



Total Results: 157

Which horizontal or geometric U.S. datums do you use most frequently?

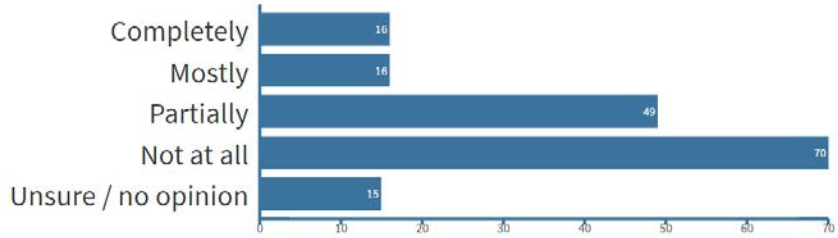
When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join



Total Results: 163

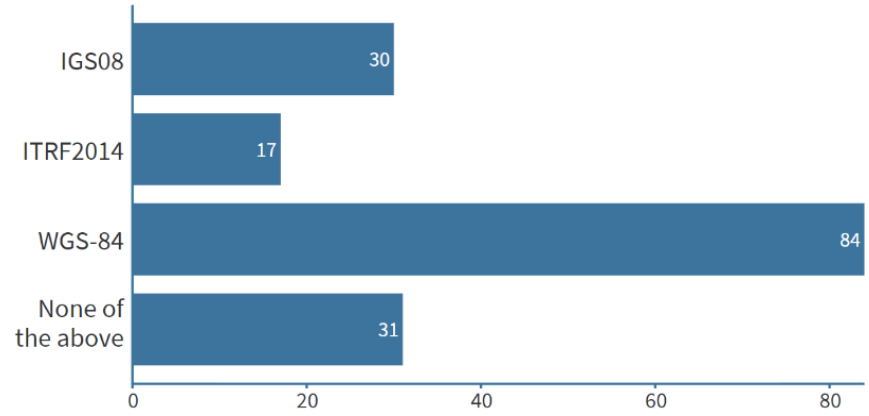
How much do you rely on horizontal time-dependent positioning (HTDP) software to transform coordinates between dates?

When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join



What other datums do you use? (pick the most frequently used)

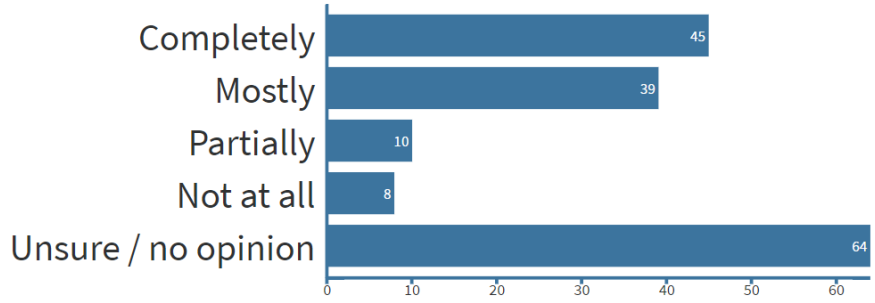
When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join



Total Results: 162

If HTDP were replaced by a time-dependent 3D velocity model, how adequately would that support your work?

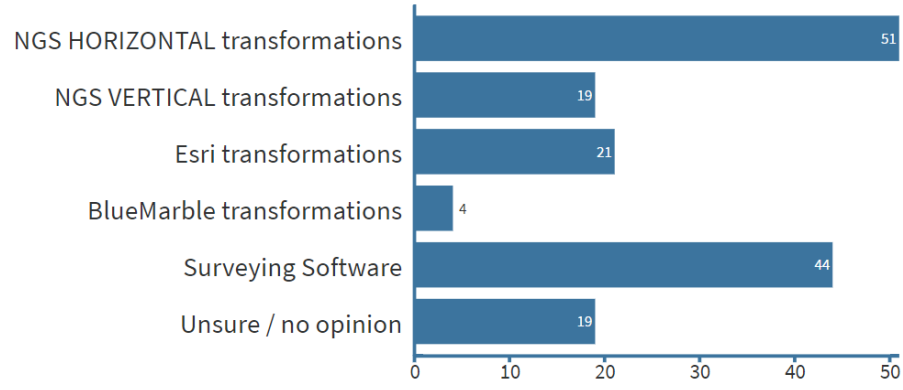
When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join



Total Results: 166

What do you use most frequently for transformations between datums?

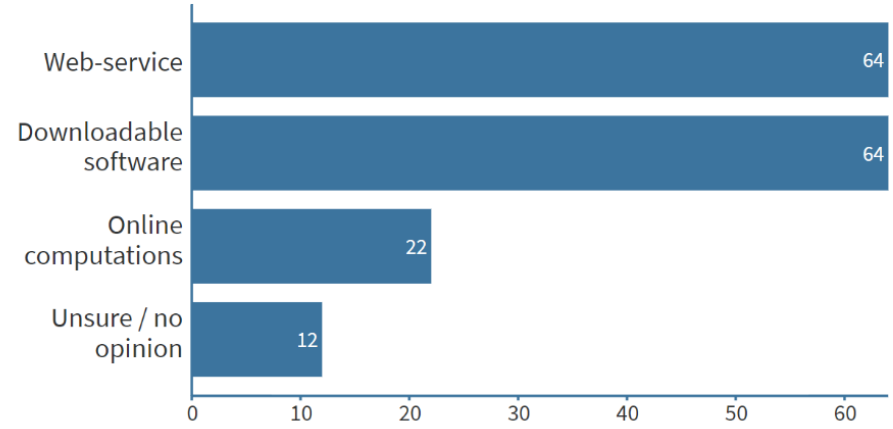
When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join



Total Results: 158

What is your preferred way to use NGS transformation tools (e.g. NADCON 5.0)?

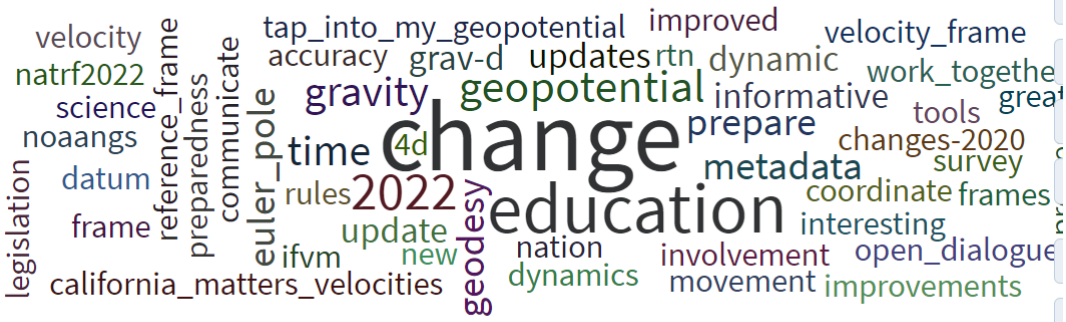
When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join



Total Results: 162

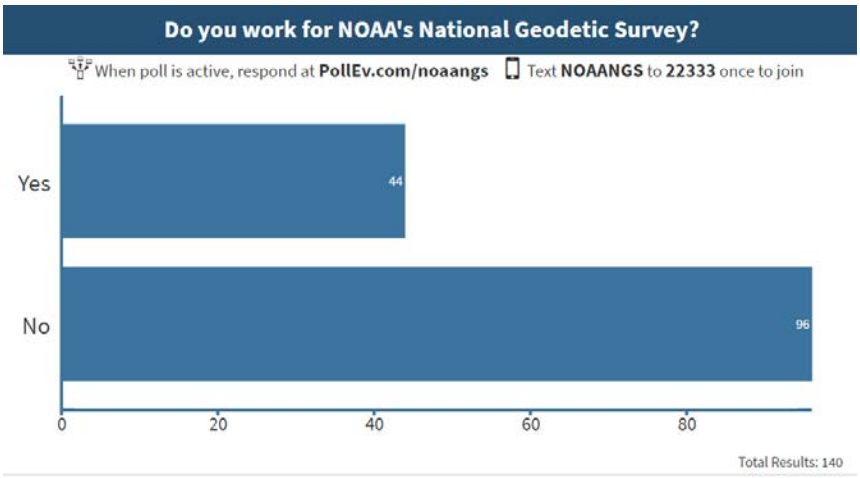
In one word: what was the most important take-away from day 1 of this Summit?

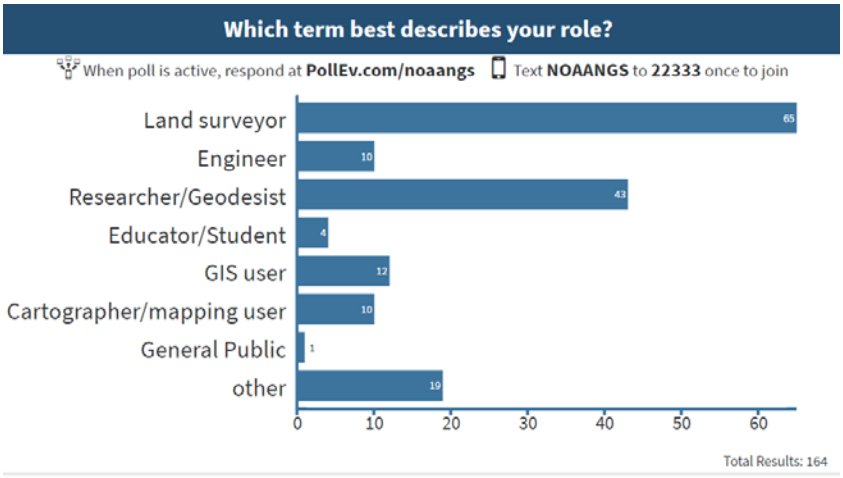
When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join

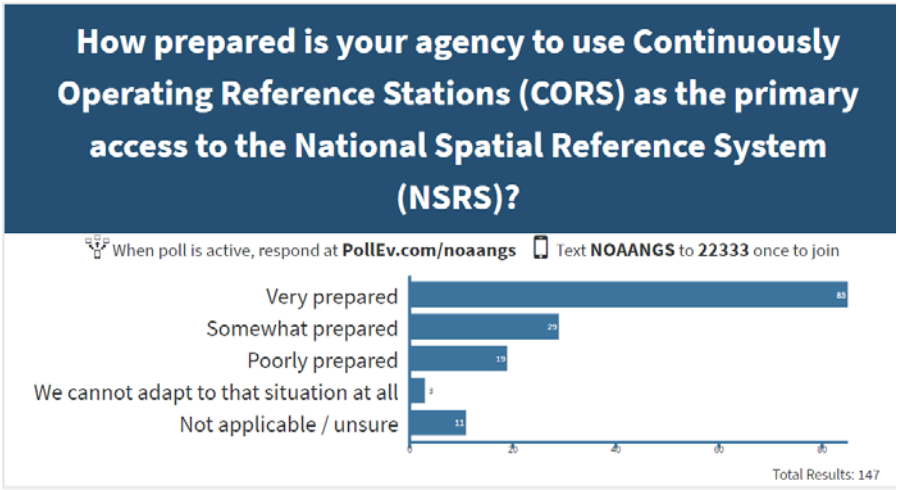


Total Results: 149

Live poll results Day 2: April 25, 2017

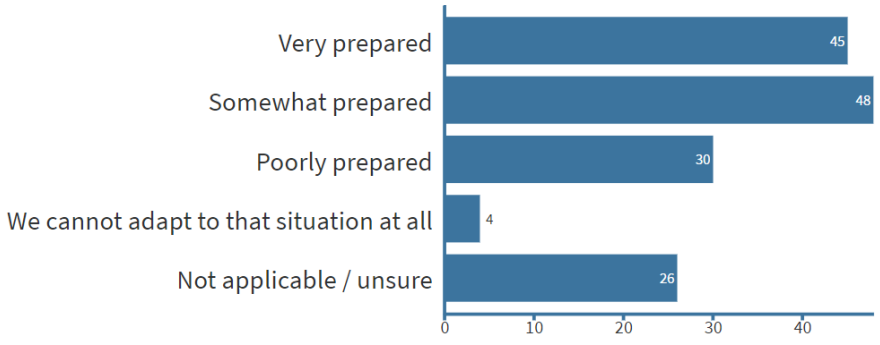






How prepared is your agency to use passive control with coordinates that are time-dependent (although still plate-fixed)?

When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join



Total Results: 153

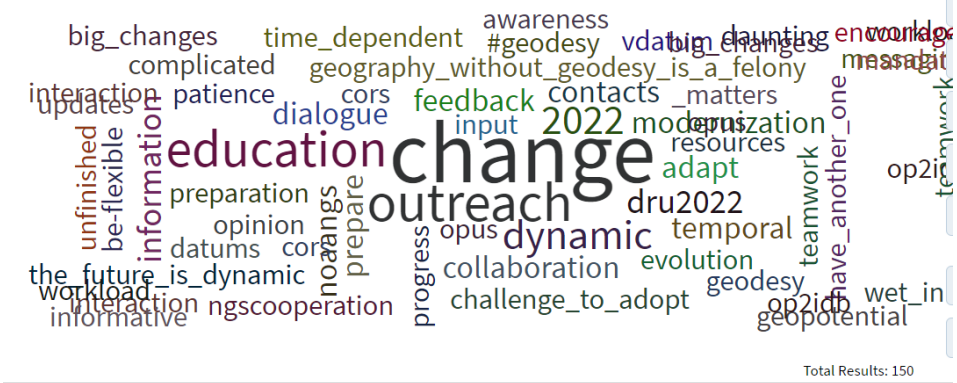
In one word: what part of your job or organization will be most affected by the new datums?

When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join

Total Results: 183

In one word: what was the most important take-away from this Summit?

When poll is active, respond at **PollEv.com/noaangs** Text **NOAANGS** to **22333** once to join



Total Results: 150

Appendix F: Summit attendee feedback from evaluation forms

Background:

- Evaluation was completely optional.
- In-person evaluation forms were printed and included in meeting folder.
- Webinar evaluation form was opened at the end of day 1 and day 2.

Evaluation Questions:

- Questions 1-5 required one response / question (i.e., multiple choice).
- Question 6 was open-ended.
- Questions 7-8 were session specific questions.

1. Which day of the summit are you evaluating?
   A. Only Monday, April 24
   B. Only Tuesday, April 25
   C. Both days

2. Do you work for NOAA's National Geodetic Survey (NGS)?
   A. Yes
   B. No

3. How clear were the objectives of the event?
   A. Extremely
   B. Very
   C. Moderately
   D. Slightly
   E. Not at all

4. How organized was the event?
   A. Extremely
   B. Very
   C. Moderately
   D. Slightly
   E. Not at all

5. Overall, how satisfied were you with the event?
   A. Extremely
   B. Very
   C. Moderately
   D. Slightly
   E. Not at all

6. Do you have any other questions, comments, or suggestions?

7. Please evaluate each session by circling your responses in the table below:

Session	**7A) How organized was the content?**	**7B) How beneficial was the information?**	**7C) How technical was the content?**	**Other comments**
Keynote Address	Very organized Organized Slightly organized	Very beneficial Beneficial Slightly beneficial	Too technical About right Not tech. enough	
Introduction to Modernizing the NSRS	Very organized Organized Slightly organized	Very beneficial Beneficial Slightly beneficial	Too technical About right Not tech. enough	
Project Updates Related to NSRS Modernization	Very organized Organized Slightly organized	Very beneficial Beneficial Slightly beneficial	Too technical About right Not tech. enough	
Getting Prepared for NSRS Modernization	Very organized Organized Slightly organized	Very beneficial Beneficial Slightly beneficial	Too technical About right Not tech. enough	
Collecting geodetic control data in the future	Very organized Organized Slightly organized	Very beneficial Beneficial Slightly beneficial	Too technical About right Not tech. enough	
Submitting, processing and viewing data in the future	Very organized Organized Slightly organized	Very beneficial Beneficial Slightly beneficial	Too technical About right Not tech. enough	
Impact of New Datums on Programs and Partners	Very organized Organized Slightly organized	Very beneficial Beneficial Slightly beneficial	Too technical About right Not tech. enough	

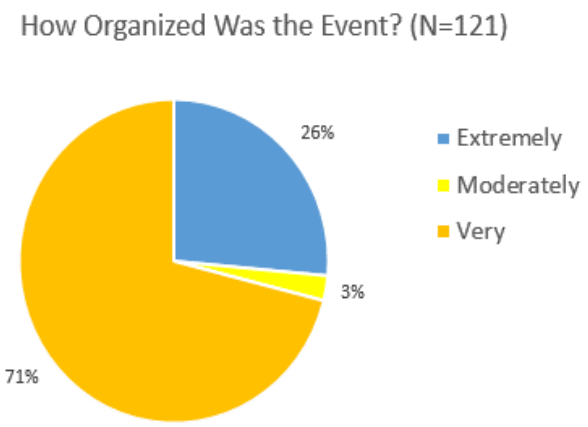
8. What sessions did you find most useful? (Circle as many as you like)
    A. Keynote address
    B. Introduction to modernizing the National Spatial Reference System (NSRS)
    C. Project updates related to NSRS modernization
    D. Getting prepared for NSRS modernization
    E. Collecting geodetic control data in the future
    F. Submitting, processing and viewing data in the future
    G. Impact of new datums on programs and partners

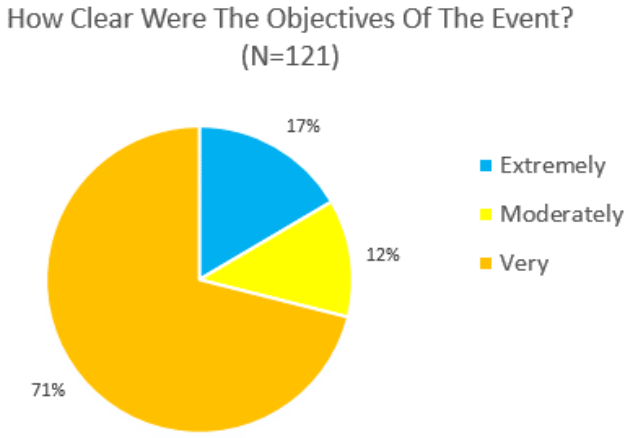
FEEDBACK RESULTS:

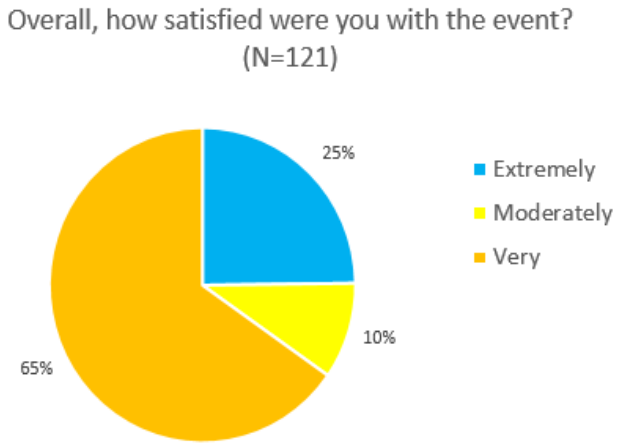
Audience Profile

	MONDAY			TUESDAY		
	In-Person	**Webinar**	**Total**	**In-Person**	**Webinar**	**Total**
Constituent completed eval.	45	46	**91**	47	61	**107**
NGS completed eval.	12	5	**17**	12	5	**17**
Total completed eval.	57	51	**108**	59	66	**124**
Meeting attendance	267	170	**437**	270	162	**432**
Response rate	21%	30%	**25%**	22%	41%	**29%**

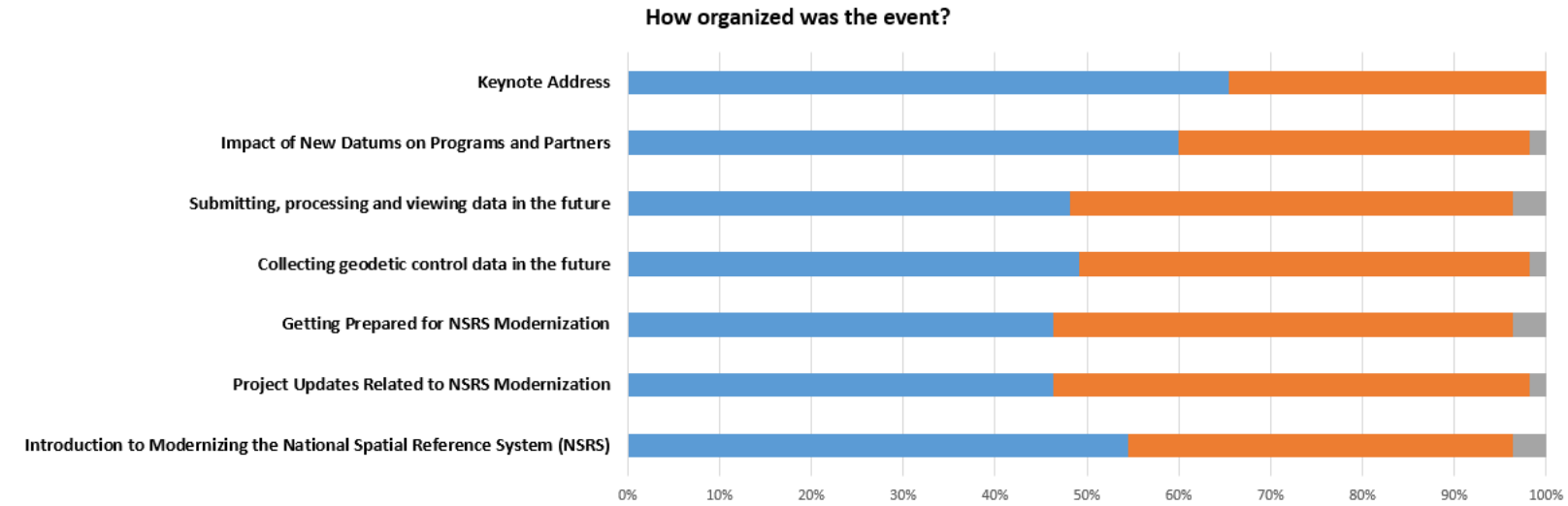
*Those attending both days are included in each day's total.

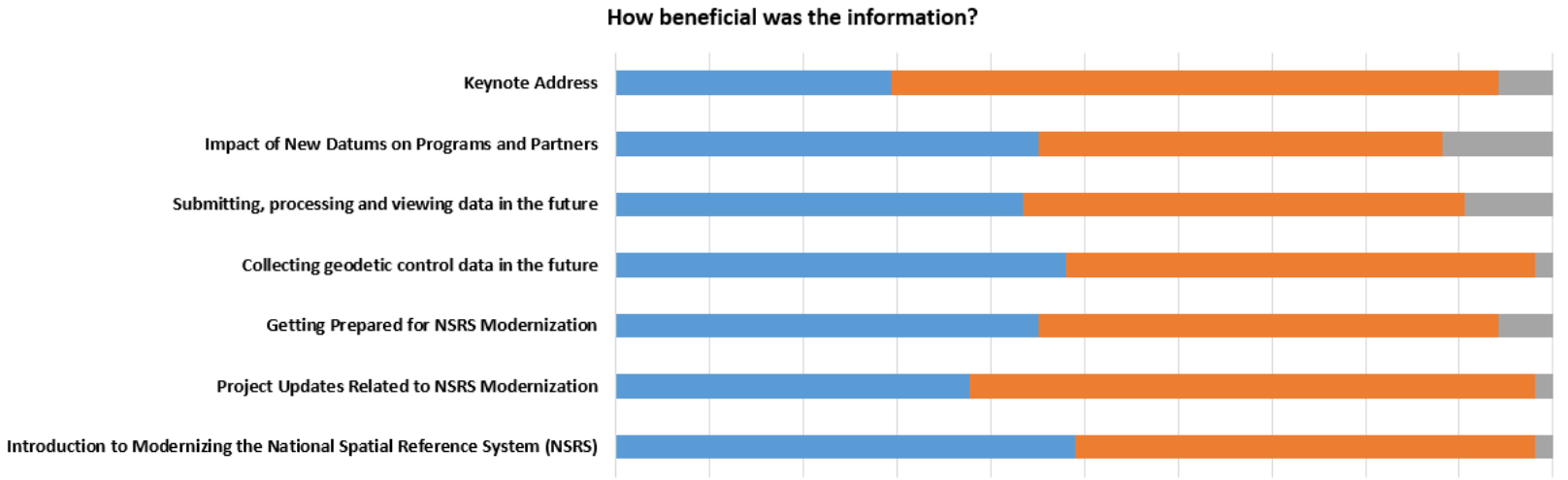


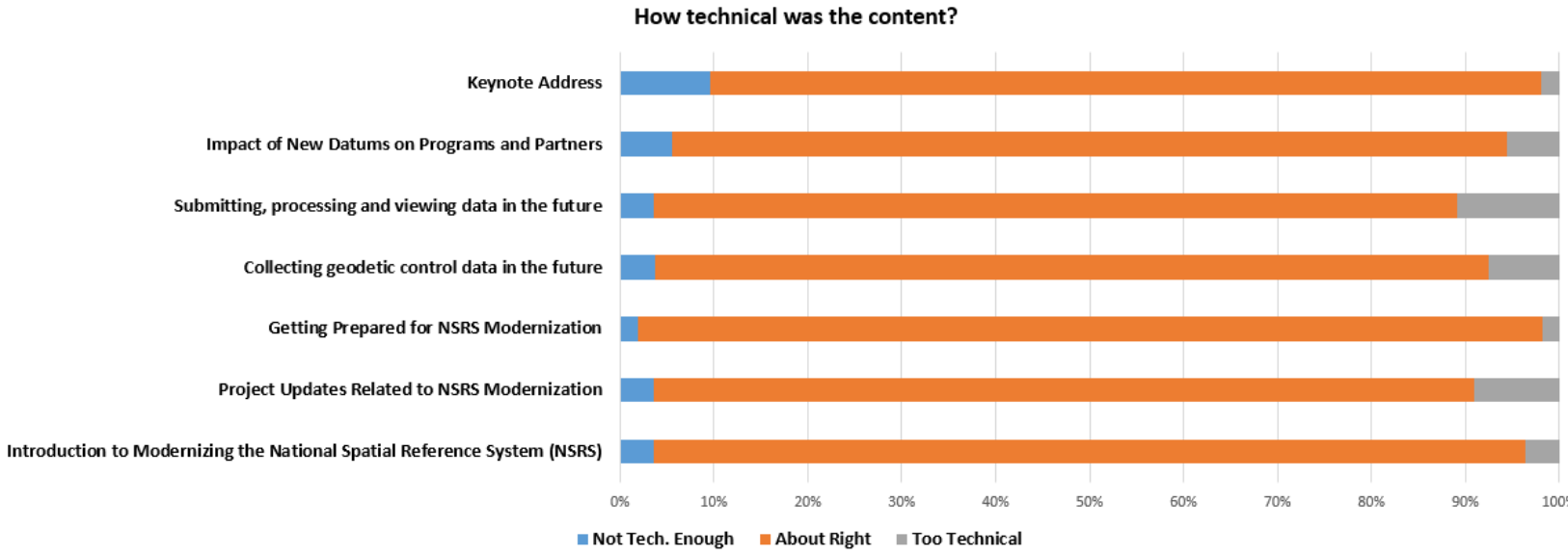


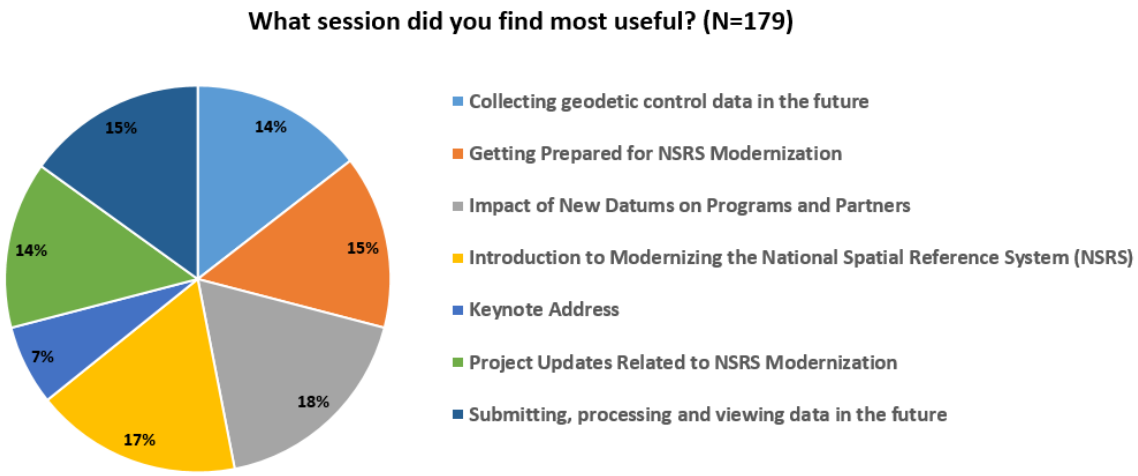


Session-specific feedback questions: Sessions were rated highly overall with respect to organization, beneficial information, and the right amount of technical content.









Participants could vote more than once, but did not rank their preferences. All sessions were noted to be useful, with *Introduction to Modernizing the NSRS* and *Impact of New Datums on Programs and Partners* receiving the most votes.

Participants' verbatim responses to the question, "Do you have any other questions, comments, or suggestions" are summarized below. These responses illustrate and augment the common themes outlined in the presentations from NGS partner organizations on pages 17-18.

<u>Agencies anticipate educational and resource challenges</u>:

- Implementation of the new datum will be difficult for local counties and states to complete. NGS will need to collaborate with existing software vendors to make this happen. NGS can make this easy or very hard depending upon their rigidity of process and formats.
- I expect more workshops/webinars will follow up on development, transformation, tools, and procedures. It would be useful that the NGS can work with partners from state/local governments and commercial companies to develop and conduct a few demo projects, which will facilitate the adoption.
- There is a huge chasm between the theory and practical users. Education and translation into practical application is lacking. Incorporating theory into software/black-box makes it more likely it will be misused. People want to push the "I believe" button, and cutting costs at local levels has led to replacing experienced staff with a "button-pusher" and new equipment. We are between a rock and a hard place.
- As a surveyor in land development, we normally set a project datum at beginning. Projects can last for 10-15+ yrs. Will we still be able to use an RTN/CORS to establish a pre-2022 datum after 2022? It sounds like an added cost to transform the project datum is we will be unable to use RTN without transformations.

Need for NGS to participate in continuing education and updating local legislation:

- This was great for people with a good understanding of geodesy, but states will need educational outreach materials to present to people without the geodesy education background.
- Very well presented, will have to begin on legislation and getting all players on board.
- Please have more Survey training @Corbin or Silver Spring: GPS, Advanced 3D Laser Scanning & point cloud processing, modeling from 3D scanning; UAV flight training & photogrammetry training; remote sensing.
- The NGS needs to send personnel to every state conference to discuss this & its implication to the practitioner, or it will fall flat. Plus, the presentations have to be at a level that non-educated office personnel understand.

Need to collaborate with equipment vendors and diverse users of geospatial data:

- We need to communicate, collaborate to ensure Trimble and other manufacturers can provide capabilities in our products that customers need to work with new reference frame and NGS products.
- Excellent sessions. Maybe one of these more focused on the mapping/GIS community.
- It would have been helpful if FAA were here to discuss the impact of this datum change as it relates to airport surveys, airport control and how they need to update the advisory circulars.

Feedback on logistics, or other-than-content aspects of the event:

- Lost a bit of content due to room acoustics and microphone inconsistencies with speakers. Most were very good about restating the question before answering.
- Thank you for making this available online for all of us that could not attend in person.
- The standardized format that was used by the non-NGS presenters was an excellent idea. It insured that the Summit purpose was the focus of their presentations.
- Provide list of attendees in packet. It's easier to network that way.
- Turn off main lights-only use cam light to reduce light pollution on screen- also close back doors.

Expressions of thanks for a worthwhile event:

- Thanks for the outreach and keep up the good work!
- Great conference. So glad I could come. I learned a lot and feel more prepared to implement this in the future.
- Very well organized. Excellent speakers.
- NGS staff were very well prepared and articulate. Materials clear, well designed, well printed. Good agenda.

End of report: 2017 Geospatial Summit on

Modernizing the National Spatial Reference System