READY, SET, MODERNIZE

ASPRS Takes on Preparing the Geospatial Industry for the Modernized National Spatial Reference System (NSRS)

ASPRS NSRS MODERNIZATION WORKING GROUP

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Context

The National Geodetic Survey (NGS) is modernizing the National Spatial Reference System (NSRS) in the United States. The modernization involves significant updates to the official reference frames and vertical datum used across the country, affecting the entire geospatial industry. Key benefits of the Modernized NSRS will include improved accuracies and enhanced interoperability and sustainability of geospatial data and systems.

The ASPRS NSRS Modernization Working Group produced this paper to help prepare the geospatial industry for the upcoming changes. It serves as a guide for industry professionals to understand the implications of the Modernized NSRS and recommendations to begin preparing for it. It emphasizes the importance of proactive measures to ensure a smooth transition to the new reference frames and vertical datum.

Your Input Wanted!

The ASPRS NSRS Modernization Working Group wants to hear your Success Stories. Please submit short news articles describing how the Modernized NSRS will benefit your work and how your organization is working to transition to the Modernized NSRS. To share your messages and success stories, please contact the Working Group through the ASPRS NSRS Modernization Working Group community page at: https://community.asprs.org/wg-nsrs/home.

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Introduction

The geospatial industry is on the brink of a major advance that will affect all facets of our work. For the first time in over four decades, the official reference frames and geopotential (vertical) datum of the U.S., including territories, are scheduled to be updated. The primary reasons for the updates include the non-geocentricity of the current North American Datum of 1983 (NAD 83) frames, bias and tilt of the North American Vertical Datum of 1988 (NAVD 88), multiple vertical datums, sea level change, the dynamic movements of geodetic control marks, and vast improvements in survey technologies and accuracies since the 1980s.[1] As large volumes of existing maps and geospatial data are referenced to NAD 83 and NAVD 88, these updates are a significant undertaking with broad-reaching implications.

The agency leading these updates is the National Geodetic Survey (NGS), a program office within the National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS). NGS is mandated to define, maintain, and provide access to the National Spatial Reference System (NSRS), the official system that defines latitude, longitude, gravity, scale, orientation, and height throughout the nation.

This paper highlights the main upcoming changes, the impacts to existing maps and geospatial data, and the benefits of NSRS Modernization for the geospatial industry, including those working in photogrammetry, lidar, sonar, remote sensing, mobile mapping, surveying and GIS, among others. We then present recommendations for geospatial firms in preparing for NSRS Modernization. These recommendations are separated into those for geospatial service providers, software manufacturers, and the entire industry. We conclude with a look ahead at the anticipated NSRS Modernization schedule and opportunities for getting involved in ongoing efforts to assist with the integration of the Modernized NSRS into geospatial infrastructure and workflows.

Key Changes and What Happens to Existing Geospatial Data

Key changes in the Modernized NSRS are summarized in Table 1. It should be noted that the information in this table is intended only as a high-level synopsis. Full details on the changes can be found in NGS's Blueprint documents for the Modernized NSRS.[2]

Terrestrial Reference Frames: NAD 83→NATRF2022

- NSRS Modernization will include the replacement of the current three NAD 83 datums (frames) with four new terrestrial reference frames (TRFs):
  - North American Terrestrial Reference Frame of 2022 (NATRF2022)
  - Pacific Terrestrial Reference Frame of 2022 (PATRF2022)
  - Mariana Terrestrial Reference Frame of 2022 (MATRF2022)
  - Caribbean Terrestrial Reference Frame of 2022 (CATRF2022)
- These four reference frames are sometimes collectively abbreviated NAT/PAT/MAT/CATRF2022. They will replace NAD 83(2011) for North America and the Caribbean, NAD 83(PA11) for the Pacific, and NAD 83(MA11) for Guam and the Northern Mariana Islands.
- NATRF2022 will be the primary terrestrial reference frame covering the contiguous U.S. and Alaska. Within this region, NATRF2022 is what will be entered in a field that, in geospatial software, is often labeled "horizontal datum." However, it should be noted that NAT/PAT/MAT/CATRF2022 are more precisely referred to as "reference frames," and like the current three NAD 83 datums (also often called "frames"), will support measurements of latitude, longitude, and ellipsoid height, such that "horizontal" is a misnomer.
- The new TRFs are "plate fixed." This means that each is tied to a specific tectonic plate and accounts for that plate's rigid motion, maintaining a higher level of coordinate

1. NOAA Technical Report NOS NGS 67 "Blueprint for the Modernized NSRS, Part 3: Working in the Modernized NSRS"; https://www.ngs.noaa.gov/library/pdfs/NOAA_TR_NOS_NGS_0067.pdf

2. NOAA NGS. Blueprint for Modernized NSRS, Parts 1, 2 and 3: https://geodesy.noaa.gov/datums/newdatums/policy.shtml

Table 1. Summary of changes from the current NSRS to Modernized NSRS.

Current NSRS	Modernized NSRS	Summary of key benefits
Three datums (frames): NAD 83(2011) NAD 83(PA11), and NAD 83(MA11)	Four frames: NATRF2022, PATRF2022, CATRF2022, and MATRF2022	Improved accuracies supporting current geospatial requirements and survey technologies; correct Earth's geocenter by ~2.24 m (Figure 1); support time-dependency of coordinates
NAVD 88 (and other vertical datums on islands and for the Great Lakes)	NAPGD2022	More accurate heights; better predict water flow; eliminate reliance on physical survey marks; replace multiple vertical datums with a single geopotential datum
GEOID18 (and GEOID12b and previous hybrid GEOID models)	GEOID2022	Better model, incorporating nearly 16 million square kilometers of new gravity data; not a "hybrid" model warped to match leveled bench marks
SPCS 83	SPCS2022	Reduce distortion; provide many more zones, incorporating stakeholder input

consistency over time. The three NAD 83 frames are also plate fixed, but the plate rotation will be more accurately modeled for the new TRFs.

- NATRF2022 will be aligned to ITRF2020 at epoch 2020.00 and then will diverge from ITRF2020 based on plate motion modeled as an Euler pole rotation. The same will be true of the three other TRFs, and each will have its own Euler pole.
- NAD 83 will remain valid datums, and not all existing maps and geospatial data will need to be transformed. This is directly analogous to the many historic maps that are referenced to the now long-superseded North American Datum of 1927 (NAD 27).
- For data that need to be transformed to the new reference frames, practitioners should be aware of the anticipated magnitudes of coordinate shifts and the uncertainty that this transformation will add. The Earth's origin will shift by ~2.24 meters (Figure 1); with this, in the conterminous U.S., transformed data will undergo shifts of up to several meters horizontally (Figure 2) and up to 1.7 meters in ellipsoid height (Figure 3). All transformations introduce some level of uncertainty, which must be accounted for when assessing the accuracy of transformed coordinates.
- In some cases, a preferred alternative to transforming coordinates will be to reprocess or readjust the original survey data in the new reference frames, or to create entirely new datasets with new observations.

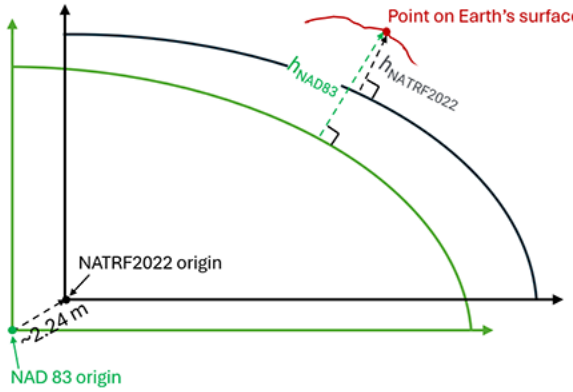

Figure 1. Simplified difference in origins of NAD 83 and NATRF2022 (adapted from NGS).

Vertical Datums: NAVD 88→NAPGD2022

- NAVD 88 will be replaced by the new geopotential (vertical) datum, **North American-Pacific Geopotential Datum of 2022 (NAPGD2022)**. It will also replace four existing vertical datums on islands (Puerto Rico, U.S. Virgin Islands, Guam, and the Northern Mariana Islands), and the International Great Lakes Datum of 1985.
- NAVD 88 will remain a valid datum, and not all existing maps and geospatial data will need to be transformed.
- Data that need to be transformed will undergo shifts of up to approximately 1.5 meters vertically in the conterminous

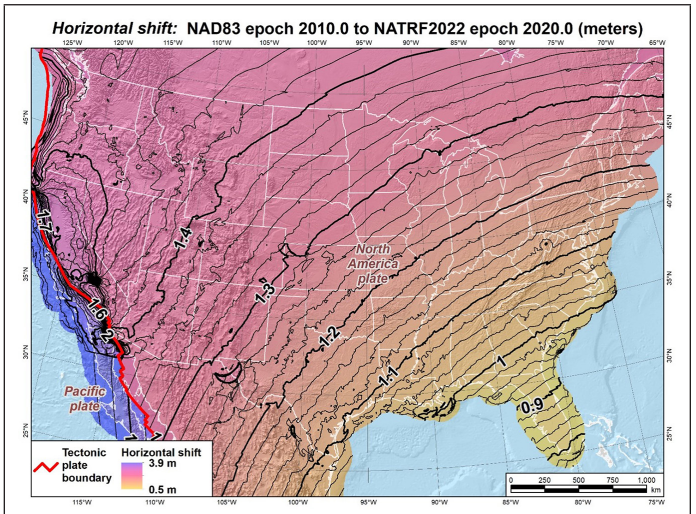

Figure 2. Estimated horizontal shift from NAD 83(2011) epoch 2010.0 to NATRF2022 epoch 2020.0 (courtesy of NGS).

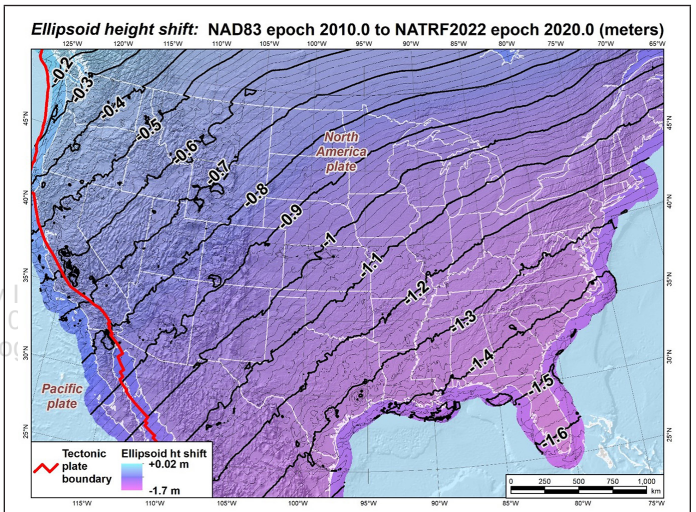

Figure 3. Estimated ellipsoid height shift from NAD 83(2011) epoch 2010.0 to NATRF2022 epoch 2020.0 (courtesy of NGS).

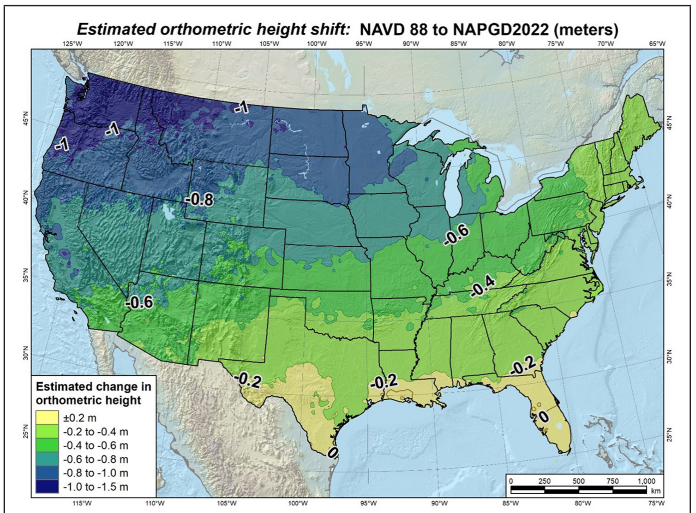

Figure 4. Estimated orthometric height shift from NAVD 88 (epoch undefined) to NAPGD2022 epoch 2020.0 (courtesy of NGS).

U.S., depending on location (Figure 4). Again, all transformations introduce some level of uncertainty, which must be accounted for in assessing the accuracy of transformed coordinates, and in some cases, a preferred alternative will be to reprocess the original survey data in the new datum, or to make new observations.

- Orthometric heights (heights above the geoid along a plumbline) in NAPGD2022 will be defined through NATRF2022 ellipsoidal heights and a new geoid model, GEOID2022.

Geoid Models: GEOID18→GEOID2022

- GEOID18, as well as previous geoid models, will be replaced with **GEOID2022**.
- GEOID2022, which incorporates the latest airborne and terrestrial gravity data acquired by NGS in its Gravity for the Redefinition of the American Vertical Datum (GRAV-D) program**,** will be defined in a manner that best fits global mean sea level at the epoch of NAPGD2022. When global sea level changes by some threshold level, a new geoid model, and thus new geopotential datum, will likely need to be released.
- GEOID2022 will be a purely gravimetric geoid model. Unlike "hybrid" models such as GEOID18, it will not be warped to match leveled heights on bench marks that were observed using GNSS. Thus GEOID2022 will be a more consistent and stable model.

State Plane Coordinate System: SPCS 83→SPCS2022

- The current State Plane Coordinate System of 1983 (SPCS 83) will be replaced by **SPCS2022** in the Modernized NSRS.
- The main change is that linear distortion (scale error) is minimized at the topographic surface rather than the reference ellipsoid surface. Additionally, SPCS2022 is designed to minimize distortion in areas of high usage or populated areas. States can have zone "layers." By incorporating zone layers and allowing state contributions, SPCS2022 represents a customer-driven evolution of SPCS, intended to meet the wide-ranging needs of the nation's diverse geospatial community (Figures 5 and 6).
- Another critical difference between the current SPCS 83 and upcoming SPCS2022 is that only the international foot (1 foot = 0.3048 meter, exactly) will be supported. This differs from the current SPCS 83, in which there are two different definitions of the foot, the international foot and the U.S. survey foot (1 foot = 1200/3937 meters, exactly), with states differing in which is officially adopted. Although these two definitions of the foot differ by only 2 parts per million, the difference in State Plane coordinates can reach tens of feet. In addition, only the international foot definition will be supported in all other components of the Modernized NSRS (such as orthometric heights).

Benefits of a Modernized NSRS for the Geospatial Industry

The improved accuracies and data interoperability that will be enabled through NSRS Modernization will provide tremendous benefits across all segments of the geospatial landscape. The Modernized NSRS will better support data sustainability, meaning that geospatial data will remain useful over longer time periods and across multiple applications. Just a few examples of specific applications that stand to benefit tremendously from the Modernized NSRS include:

- Floodplain modeling
- Coastal storm inundation modeling
- Improved hydrodynamic modeling (e.g., in support of salmon migration protection on the Columbia River)
- Precision navigation (including autonomous vehicles)
- Marine navigation safety, including computation of real-time under-keel clearance
- Infrastructure positioning and monitoring
- Transportation and engineering projects construction and maintenance

Also of importance, NGS is building in mechanisms to support time-dependent coordinates through the use of reference epoch coordinates (RECs), which will be computed by NGS every 5 or 10 years, and survey epoch coordinates (SECs), which will provide the position at the time of survey.

Preparing for NSRS Modernization in the Geospatial Industry: ASPRS Working Group Recommendations

To prepare to take full advantage of the benefits enabled by NSRS Modernization, it is imperative that geospatial service firms and software providers take certain steps now. The following are ASPRS Working Group recommendations for geospatial firms, separated into those that apply mainly to geospatial service providers, those that apply mainly to geospatial software manufacturers, and those that apply to the entire profession. A critical aspect of these recommendations is ensuring forwards and backwards compatibility of coordinates.

Working Group Recommendations for Geospatial Service Providers

Geospatial Service Providers - including those who collect, process and provide aerial and satellite imagery, lidar, sonar, hyperspectral imagery and other forms of geospatial data - are advised to take the following steps:

1. Ensure that all metadata for all archived data (not just final deliverables) is complete and correct, paying particular attention to reference frames, coordinate epochs, units (if feet, be sure to document whether international feet or U.S. survey feet), geoid models applied (e.g., GEOID12b, GEOID18), and acquisition dates and times.
2. For all **control points** and **checkpoints**, archive the survey report and store the **observation data files** (for example, RINEX raw observation files, processed GNSS

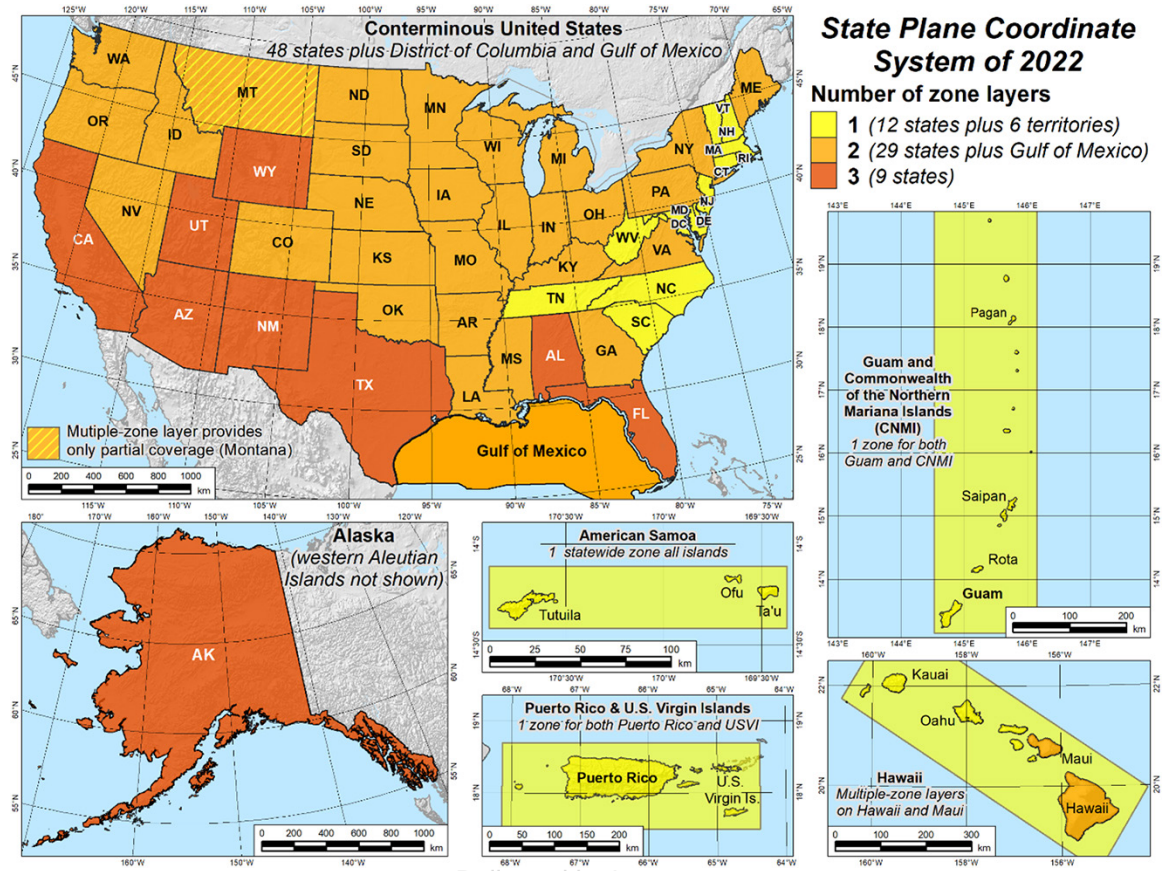

Figure 5. Preliminary SPCS2022 design: number of zone layers per state (courtesy of NGS).

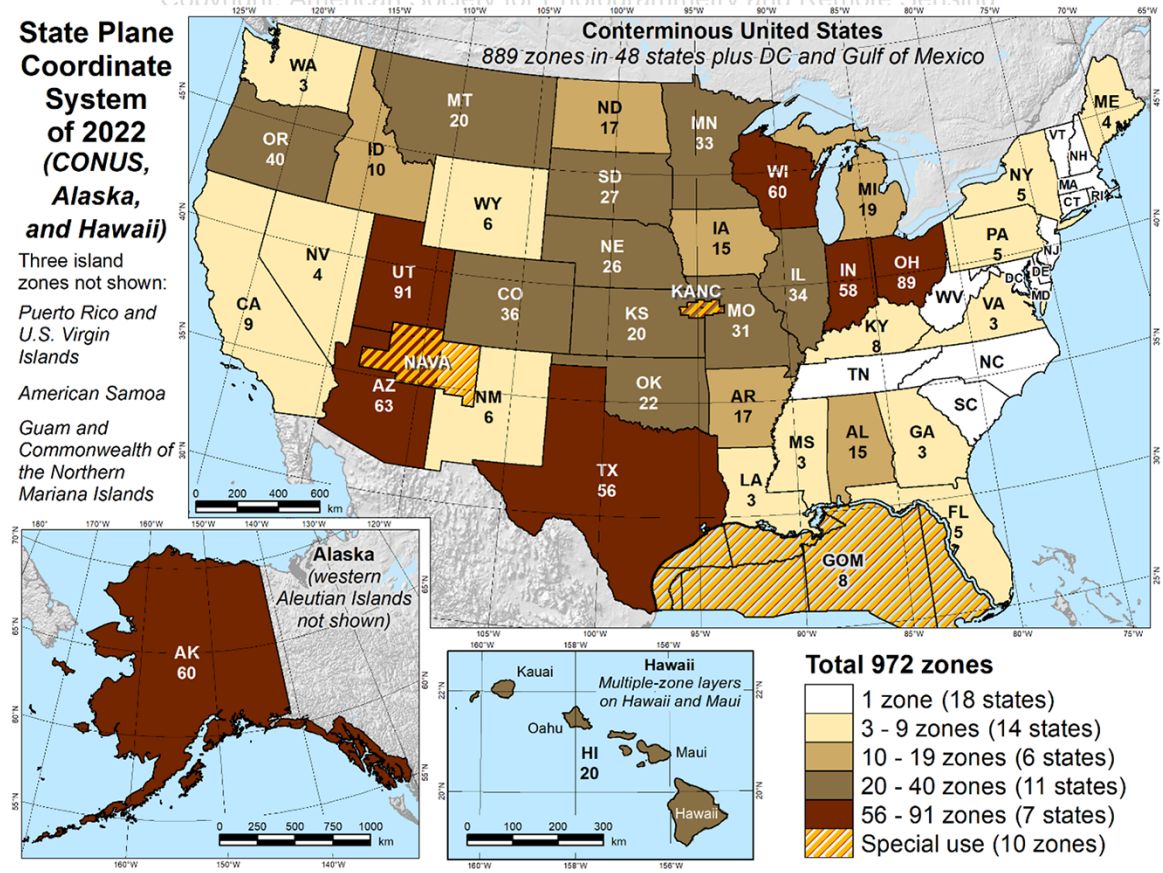

Figure 6. Preliminary SPCS2022 design: number of zones per state (courtesy of NGS).

vector solutions, or total station observation files), so that they can be reprocessed later relative to the Modernized NSRS. To the extent possible, store data using the NGS standard file formats (https://www.ngs.noaa.gov/web/science_edu/presentations_library/files/Gillins_FileFormats.pdf). Reprocessing or readjusting the raw data or processed observations (such as GNSS vectors) are the most accurate forms of relating legacy data to the new datums. Users can also transform data, but the transformed coordinates will not be as accurate as if the raw data are reprocessed in the new datums.

3. For all data deliverables (and possibly important intermediate products), store versions with **geodetic coordinates (latitudes, longitudes, and ellipsoid heights)** relative to the current NSRS (e.g., NAD 83(2011) epoch 2010.00), even if the project deliverables call for, say, SPCS 83 northings, eastings, and NAVD 88 heights.
4. Document the full project **workflows** with particular attention to any **coordinate transformations** or **conversions**.
5. Work with **software manufacturers** for all steps in your end-to-end project workflow to ensure they are aware of and preparing for NSRS Modernization.
6. Assess and document the **uncertainty of spatial coordinates** in all geospatial data products. This will enable additional uncertainties associated with transformations to be accounted for and used in assessing whether transformed products still meet requirements.

Working Group Recommendations for Geospatial Software Manufacturers

Geospatial software manufacturers are advised to take the steps listed below. As a note on terminology, many of these recommendations refer to handling of what are widely (if somewhat loosely) referred to as "Coordinate Reference Systems" or "CRSs" in geospatial software. Ideally, a CRS provides a complete definition of the reference frame (e.g., NAD 83, ITRF2020, or, in the future, NATRF2022), the realization (e.g., 2011), and epoch (date for which coordinates are valid), and, if applicable, the map projection system (e.g., Universal Transverse Mercator (UTM) or SPCS 83), zone, units (e.g., international feet, or meters), and vertical datum. (Unfortunately, current methods of storing CRS do not allow specifying the epoch, except in the remarks, but this is anticipated to be addressed in future standards revisions.)

- If your software uses **European Petroleum Survey Group (EPSG) codes or International Organization for Standardization (ISO) Geodetic Registry (ISOGR)** to define CRSs internally and/or in exported data products, ensure that the EPSG codes or ISOGR entries for new terrestrial reference frames and NAPGD2022 and SPCS2022 are supported. (Side note: the intent is for EPSG to be replaced with ISOGR, although the timeline is yet to be determined.)
- Ensure **SPCS2022** coordinates can be computed in units of both **meters and international feet** (1 international foot = 0.3048 meter, *exactly*)
- Ensure **coordinate conversions and transformations** (if provided in your software) are consistent with those of NGS
- Ensure **proper and consistent use of geoid models**. Importantly, any geoid model is designed for and valid for only a specific reference frame (and often also a specific realization of the frame) and region. For example, in the current NSRS, NGS's GEOID18 is designed only for coordinates in the North American Datum of 1983 (2011) epoch 2010.00 and will convert ellipsoid heights to orthometric heights in the following datums: NAVD 88 (in the conterminous U.S. only, not Alaska), the Puerto Rico Vertical Datum of 2002 (PRVD02), or the Virgin Islands Vertical Datum of 2009 (VIVD09). Applying GEOID18 geoid heights to WGS84 ellipsoid heights is invalid and does not provide heights in any recognized system. Similarly, applying Earth Gravitational Model 2008 (EGM08) geoid heights to NAD 83(2011) ellipsoid heights is invalid and does not provide heights in any recognized system. Other examples of geoid models designed for specific reference frames include GEOID09 associated with NAD 83 (NSRS 2007) and GEOID99 or GEOID96 with NAD 83 (HARN). When a geoid model is used to compute heights relative to a particular datum, it is important to **document the specific geoid model** (e.g., GEOID12b, GEOID18, etc.). In some software and metadata, the geoid model is included in parentheses after the datum, such as NAVD 88 (GEOID18).
- Provide **uncertainties in output geospatial data products**, accounting for uncertainties associated with coordinate transformations. Note that NGS is planning to provide uncertainties for transformations between current and modernized reference frames conducted using NGS's software utilities. This is already done in the existing NGS Coordinate Conversion and Transformation (NCAT) software for transformations between all frames and datums, and that will continue in the Modernized NSRS.

Working Group Recommendations for the Entire Geospatial Industry

A recommendation on terminology is to avoid using the term "height above mean sea level" or "MSL height" when referring to NAPGD2022 orthometric heights. The correct term for height above the geoid, measured along a plumbline, is "**orthometric height**." To explain, local mean sea level (MSL) is a tidal datum that varies along the coast, not only in response to changes in geopotential, but also to currents, local hydrodynamics and other variables. For example, if one were to set a series of benchmarks along the coast, each adjacent to a tide gauge and each set at MSL = 0.000 m, differential levels run between these marks would show them to be at different NAVD 88 (or, in the future, different NAPGD2022) orthometric heights. Future versions of NOAA's vertical datum transformation tool, VDatum, will enable transformation

between NAPGD2022 and tidal datums, such as MSL, mean lower low water (MLLW), and mean high water (MHW).

A final, and most important, recommendation for everyone in the geospatial industry is to take advantage of NSRS Modernization educational materials and opportunities. NGS, as well as university partners, have developed training modules, workshops, and short courses related to coordinate transformations, geoid models, map projections and distortion (including overviews of SPCS2022), and geodesy. A list (although not intended to be comprehensive) of recommended training modules and continuing education resources is below:

- NGS Educational Videos: https://geodesy.noaa.gov/corbin/class_description/NGS_Video_Library.shtml
- NGS Webinar Series: https://geodesy.noaa.gov/web/science_edu/webinar_series/index.shtml
- NGS Online Lessons: https://geodesy.noaa.gov/web/science_edu/online_lessons/index.shtml
- Geospatial Center for the Arctic and Pacific Workshop Series: https://gcapgeospatial.org/education/

Additional Resources

- NGS Presentations Library: https://geodesy.noaa.gov/web/science_edu/presentations_library/
- Bojan Šavrič (Esri) blog: Prepare your data for the National Spatial Reference System modernization of 2022 in the U.S.: https://www.esri.com/arcgis-blog/products/arcgis-pro/data-management/prepare-your-data-for-the-nsrs-2022/#:~:text=To%20prepare%20for%20the%20NSRS,2011)%20Epoch%202010.0%20and%20NAVD88.
- NGS's Modernized National Spatial Reference System (NSRS) presentations: https://geodesy.noaa.gov/training/nsrs-modernization/index.shtml
- NGS's Blueprint Documents for the Modernized NSRS: https://geodesy.noaa.gov/datums/newdatums/policy.shtml
- NGS's "Get Prepared" page: https://geodesy.noaa.gov/datums/newdatums/GetPrepared.shtml
- NGS SPCS2022: https://alpha.ngs.noaa.gov/SPCS/

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How to Get Involved

For those interested in contributing to preparing the geospatial industry for NSRS Modernization, there are many opportunities to get involved. ASPRS recently launched an NSRS Modernization Working Group, which is seeking new members. Both NGS and commercial geospatial software manufacturers will be seeking beta testers and early adopters during the rollout of the Modernized NSRS. Serving as an early adopter or beta tester will provide an opportunity to stay ahead of the curve on NSRS Modernization and also to benefit the entire geospatial community by finding and reporting issues in early releases. The NGS Alpha (Preliminary Products) website (https://alpha.ngs.noaa.gov/) and Beta (Beta Products Release) website (https://beta.ngs.noaa.gov/) are important starting points for early adopters.