United States NSRS 2022: Terrestrial Reference Frames

Daniel ROMAN, U.S.A.

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SUMMARY

In 2022, the United States will update National Spatial Reference System (NSRS) and replace the existing framework comprised of regional versions of NAD 83 and locally determined leveling datums. The new reference frames (geometric and geopotential) will rely primarily on Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS) as well as an updated and time-tracked geoid model. This paradigm will be easier and more cost-effective to maintain. There will be four frames realized in the major regions in which states and territories are located: North America (NATRF), the Caribbean (CATRF), the Pacific (PATRF) and the Mariana Islands (MATRF). In each of these frames, an Euler pole and Intra-Frame Velocity Model (IFVM) will be defined. Foundation CORS (FCORS) will be operated in all four of these frames and maintained directly or indirectly by NGS. The FCORS will aid in defining the frames and movement within the frames. This paper will focus on the selection of FCORS and their use in defining Euler pole parameters (EPP) for each of the frames. The IAG SC 1.3c WG on Stable North America was reconstituted to facilitate NATRF specifically but provided input for CATRF and PATRF. Coordination with an Asia-Pacific working group has begun to develop a collaborative model for PATRF and MATRF. Coordination as also begun with SIRGAS in the development of CATRF (IAG SC 1.3b). In particular, this paper will focus on the development of regional TRF’s, selection of FCORS and EPP determination. With the impending 2022 deadline, many aspects of this update are being frontloaded to ensure optimal development of the terrestrial reference frames as well as sufficient outreach and communication.

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1. INTRODUCTION

This paper follows up last year's introduction of the planned roll out of new reference frames in the United States in 2022 by NOAA's National Geodetic Survey (NGS). The reader is referred to last year's paper (Roman 2017) for further background as well as the NGS Blueprint Part 1, Blueprint Part 2, and New Datums webpage (NGS 2017a, 2017b, 2017c). In this paper, the four frames are reviewed with an eye to locating critical GNSS infrastructure. These Foundation CORS (FCORS) represent a commitment from the NGS to maintain sites that will be made available to the IAG's International GNSS Service (IGS) for future realizations. The most recent realization is ITRF 2014 (Altamimi et al. 2016), which may actually still be in use in 2022 and serve as the reference model (pers. comm. Altamimi 2018).

2. NATIONAL SPATIAL REFERENCE SYSTEM IN 2022

The NGS Blueprint Part 1 (NGS 2017a), serves as the primary reference for this update.

2.1 Four Frames Tied to an ITRF Model

The basic concept is that of a densified ITRF model with Euler pole transformations defined for each of the plates circled in Figure 1: North America, Caribbean, Pacific, and Mariana.

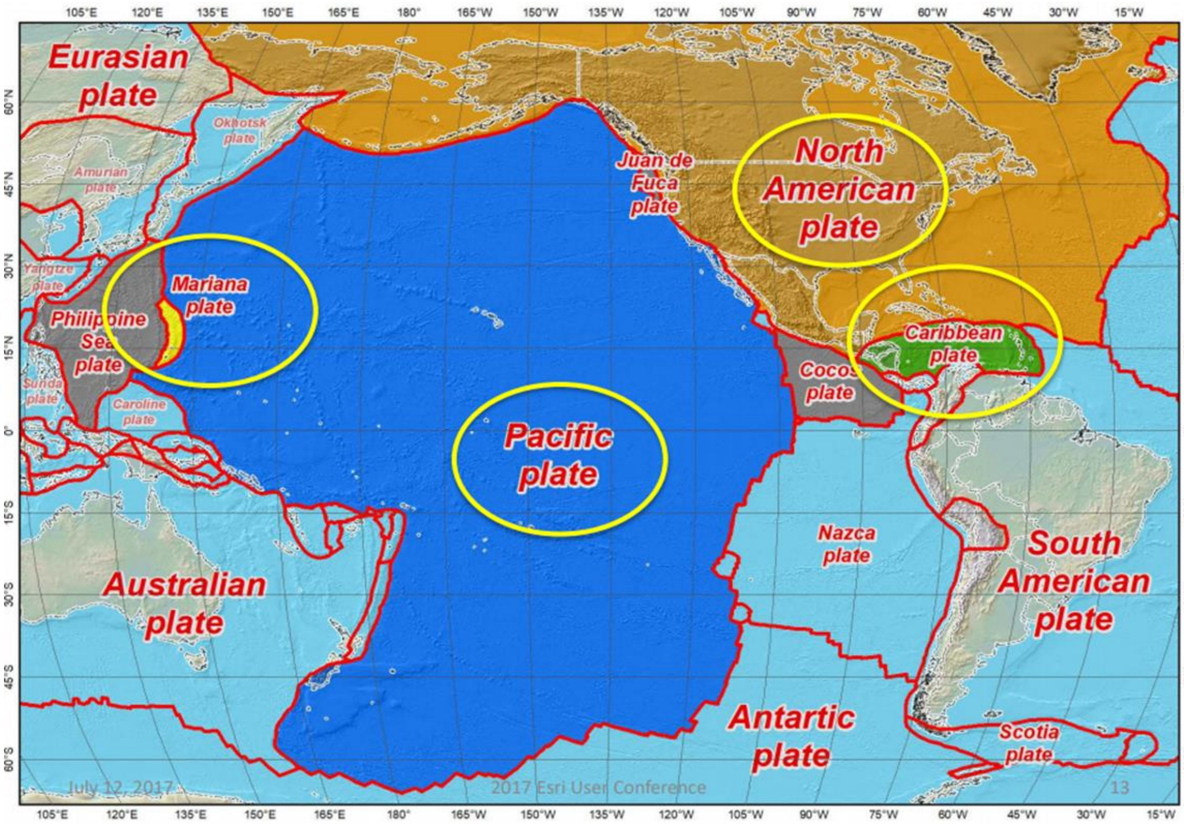

Figure 1. The four tectonic plates "fixed" for the 2022 terrestrial reference frame.

At a definitional epoch, the four frames above (NATRF, CATRF, PATRF, & MATRF, respectively) would be identical to the reference ITRF model, presumably ITRF 2014. The likely epoch would be 2020.0. Before and after that date, the four frames would rotate specific to their own Euler pole parameters that will be determined from a select set of Continuously Operating Reference Stations (CORS) on each plate.

2.2 Foundation CORS (FCORS)

Most CORS represent voluntary contributions from outside groups. NGS makes data available from nearly 2000 such sites on its website. NGS is responsible for managing and archiving the data, but has little authority to actually maintain and upgrade such sites. NGS actually operates only about 40 stations, which are actually focused on missions other than that for NGS.

As such, NGS will be divesting itself of these other sites with the intent to develop NGS-owned sites that will serve as fiducial control sites of the NSRS – which is a part of the NGS mission. These select CORS sites will serve as the Foundation for the NSRS in the U.S. Hence, they are termed Foundation CORS (FCORS).

Selection of the FCORS sites is critical as they provide the tie into the ITRF solutions. In turn, these sites serve as fiducial control for the preponderance of CORS sites. FCORS sites would be owned and operated by the NGS or NGS will have a specific memorandum in place to govern their treatment and maintenance. Figure 2 shows the likely candidates for FCORS.

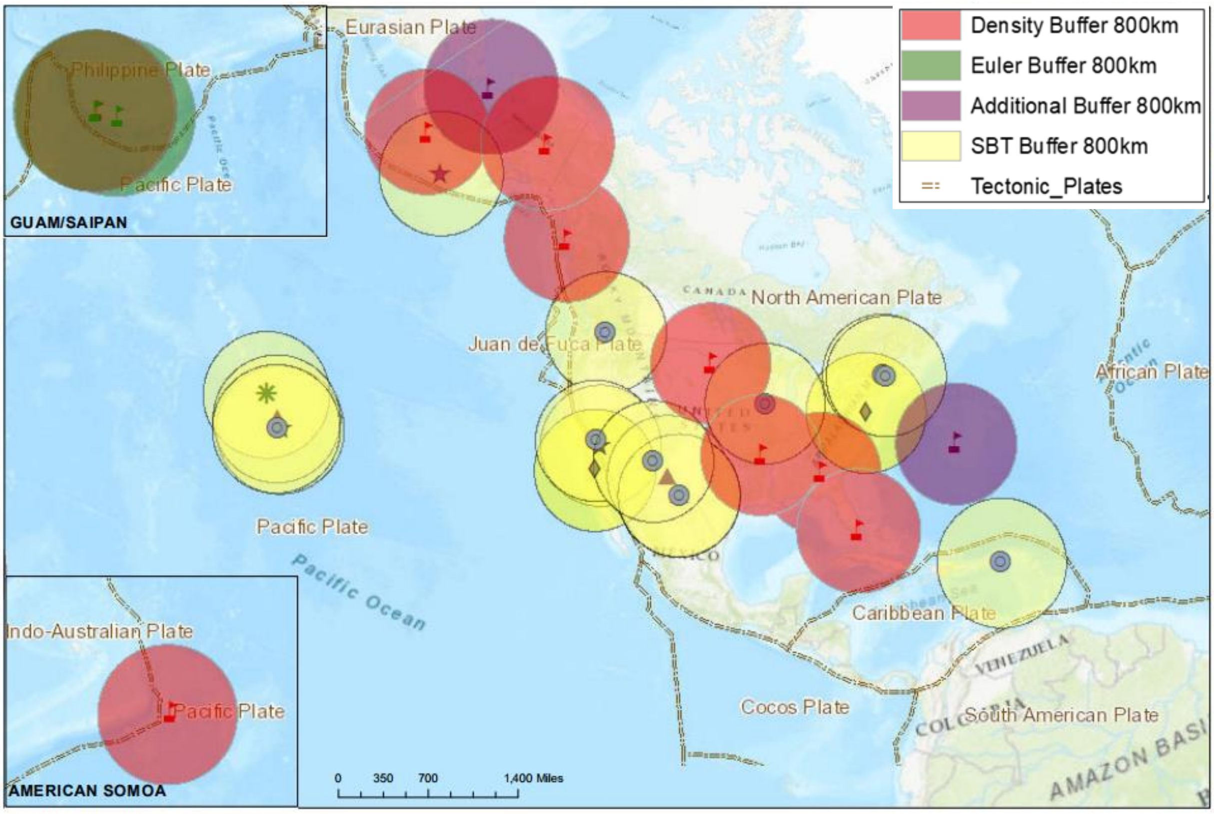

Figure 2 Prospective sites for Foundation CORS. All circles are 800 km radius and color coded for sites collocated with other space based technique), Euler pole determination, improving spatial density, and additional sites.

2.3 Euler Pole Parameters

Several of these FCORS sites will be utilized for determining the Euler pole parameters (EPP). The EPP are the latitude and longitude of the rotation point and the rotation rate around that point. The concept is that most motion in stable plate areas can be described as an angular rotation about a fixed point. It is likely that many CORS will also be utilized in that determination. There are certainly many CORS available for determining NATRF. Selection of which sites to use for this purpose can be difficult. Figure 3 highlights how changing the GNSS sites used in making the Euler pole determination can affect the Euler pole location. The IGS08 solution used a different set of GNSS sites than that for this test case. The offset between the EPP determined from the set of data in Figure 3 and that for the IGS08 would impact position determination at all sites.

Hence, an international working group under the auspices of the North American Reference Frame (IAG SC 1.3c) will convene to determine optimal candidates for determining the EPP.

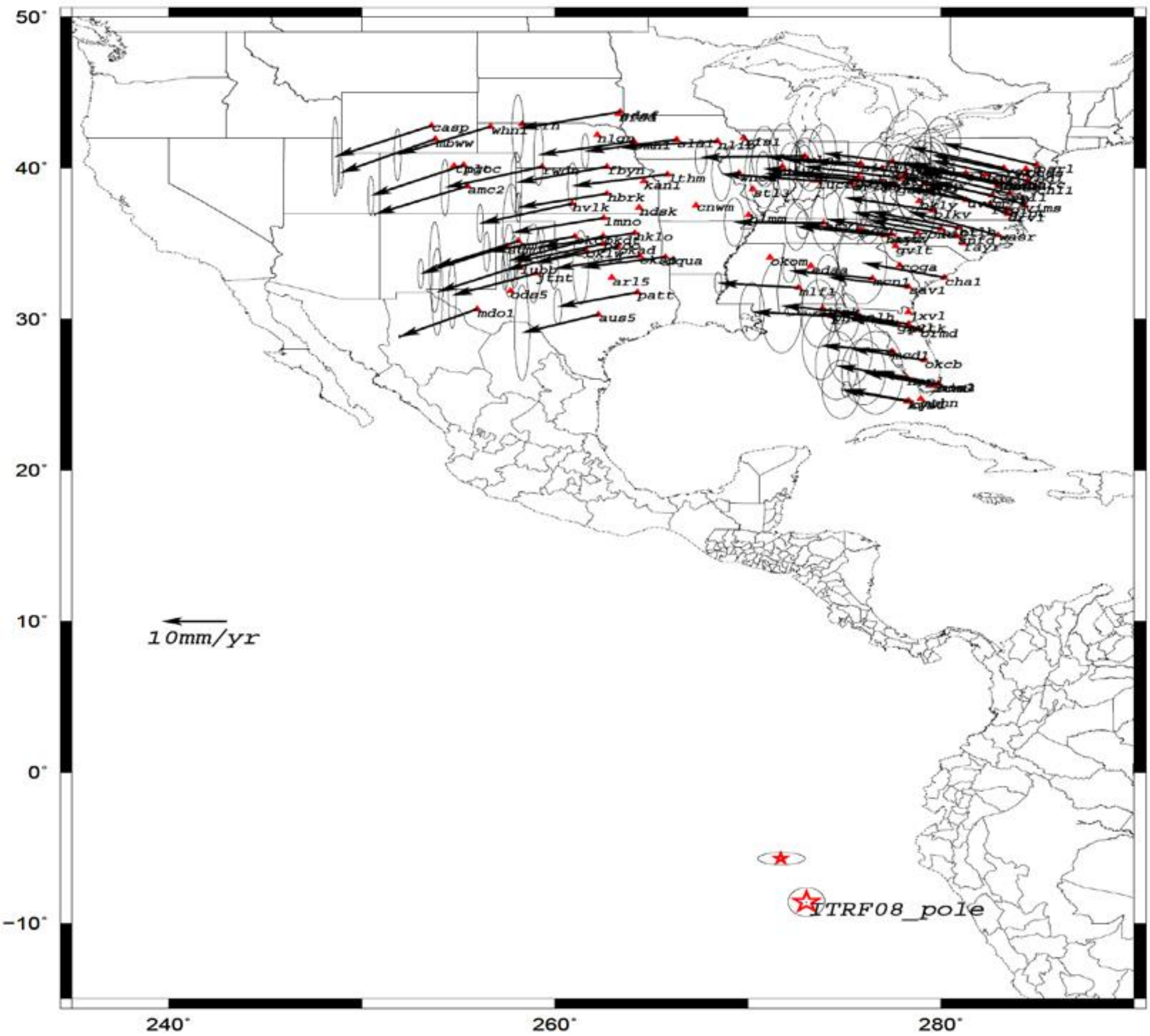

Figure 3 Euler poles from ITRF 2008 and from a sample test. Changing which sites are included can shift the Euler pole coordinates and rotations significantly.

The intent of NATRF is to support positioning throughout all of North America. Other sites will be incorporated such as those shown in Figure 4 from Natural Resources Canada.

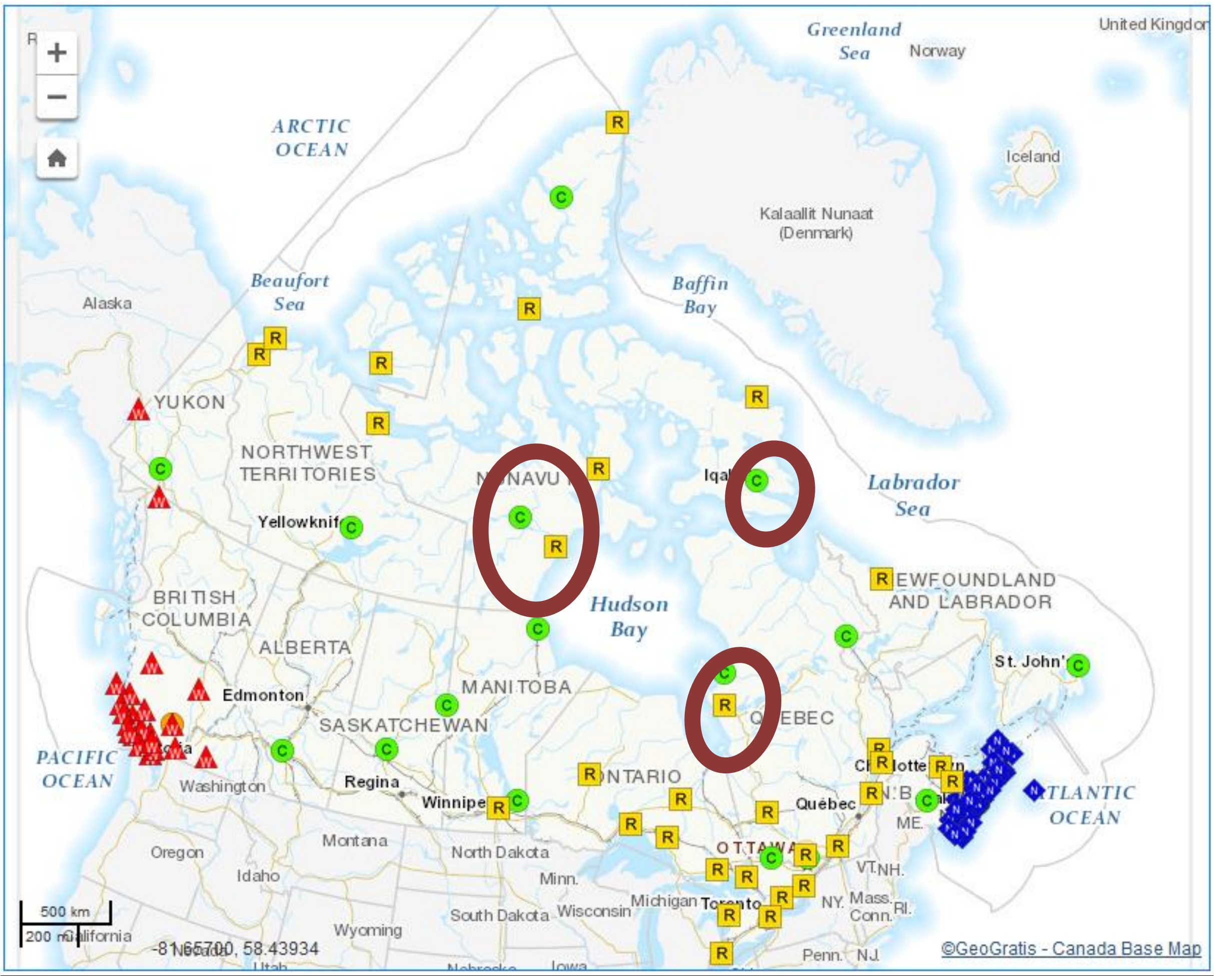

Figure 4 Canadian Active Controls Stations available for use in determining the NATRF EPP. Red circles show the extents of the uplift domes.

Of particular interest would be sites located near the center of the three uplift domes in Canada from the last glacial maximum (denoted by red circles in Figure 4). The Glacial Isostatic Adjustment (GIA) in Canada will produce vertical motion only on the uplift domes. In all other spots, GIA will have horizontal and vertical components. Separating the horizontal GIA signal from the general plate rotation is somewhat difficult. The easier solution is to include sites farther from the GIA signal and those on the ice domes. It should be noted that many sites in the western U.S. will also be excluded based on the active deformation occurring there near the Pacific plate boundary.

Beyond North America, the Caribbean has its own difficulties. Figure 5 highlights the active deformation around most of the perimeter. There are a few select sites that are being investigated for developing a consistent EPP model for the Caribbean (denoted by red dots). St.

Croix in the U.S. Virgin Islands is a likely candidate in the eastern Caribbean. However, other sites in the central and western areas will require international collaboration.

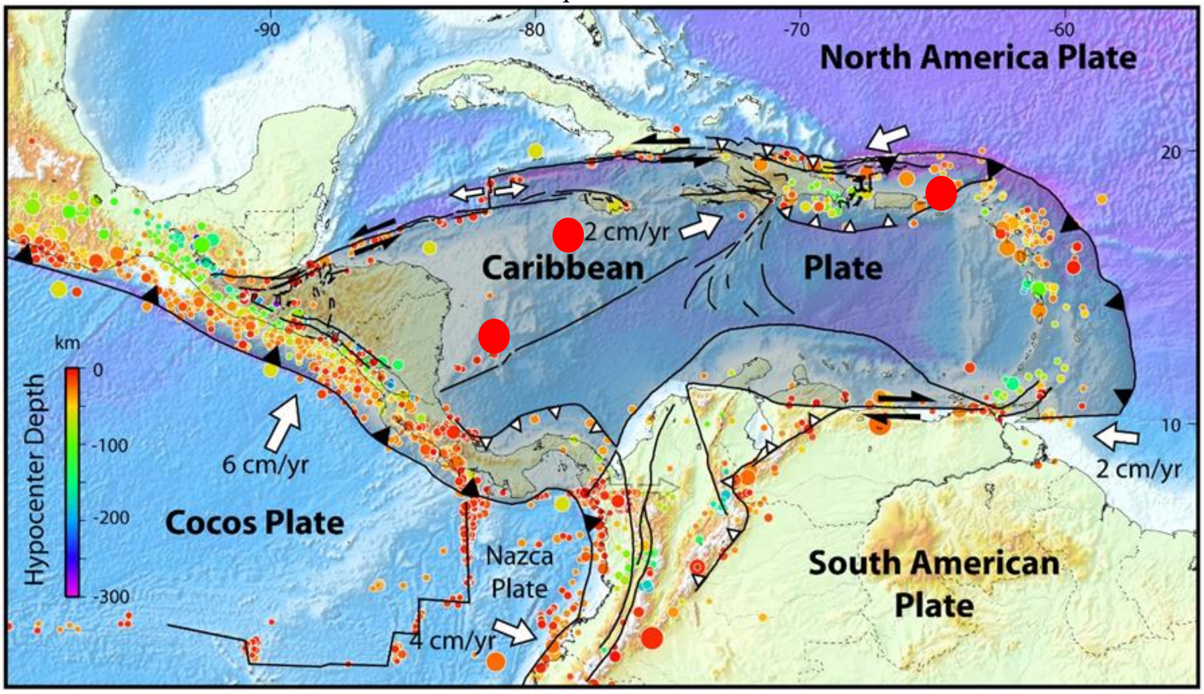

Figure 5 Geophysics of the Caribbean from Demets 2007. Note that most land areas are located along deformation zones making most sites less useful for EPP determination. Red dots denote possible locations for FCORS.

This international collaboration is primarily through the IAG SC 1.3b (Central and South American Reference Frame), which is also known as SIRGAS. More broadly, coordination will also be made through the United Nations Global Information Management regional entity for the Americas (UN-GGIM-Americas). Coordination of the technical and scientific aspects will be with SIRGAS, while UN-GGIM-Americas will be focus for governance oversight and implementation.

Likewise, the determination of EPP for the Pacific will require coordination with a larger United Nations entity defining the frame for that region. Finally the definition for the Mariana plate is more of a U.S. concern as the entire plate has U.S. territories upon it. Given the lack of CORS sites to select for FCORS, a different strategy has been employed. Campaign GNSS surveys were recently completed in order to determine positions based on previous campaigns dating back to 2003. While conducting campaigns does not replace a continuous monitoring program, it will suffice until and unless a more robust CORS and FCORS network can be put in place.

2.4 Intra-Frame Velocity Models (IFVM)

A final area of concern is the residual velocity in each of these plates. In a larger sense, they are a part of the same problem. If highly accurate positions could be monitored on a periodic basis, then an accurate velocity model could be defined in that same frame. The Sentinel-1 satellites

(Attema et al. 2007) are currently online and collecting InSAR data across most of the Earth's surface. These models can help develop a densified ITRF 2014 velocity model, essentially tracking movement anywhere on the Earth.

In turn, the EPP for each of the four plates would be removed from this ITRF 2014 field to produce a plate specific IFVM. Because they are all defined from the same densified ITRF 2014 model, it would be possible to rotate back through to a common epoch and express coordinates in an adjacent frame (e.g., determine the positions of islands off of California in the PATRF frame instead of the NATRF frame). This would also prevent any discontinuities in the velocity models near the edges of the plates. An IFVM will then account for remaining horizontal velocities and all vertical velocities. The remaining vertical velocities would represent motion in the frame likely tied to crustal deformation. Because an EPP model would only account for the continent-wide horizontal motion, all vertical motion would be expressed by the IFVM.

3. Summary and Outlook

NOAA's National Geodetic Survey continues to progress towards the release of four new frames in 2022 that will be closely tied to most recent ITRF model at that period, which is likely to be ITRF 2014. They will be exactly aligned a reference epoch - possibly 2020.0. A model of surface velocities will be calculated from InSAR data from Sentinel-1 and other sources in the ITRF 2014 frame.

Euler pole parameters (EPP) will be determined from Foundation CORS and possibly some regular CORS sites on each plate to account for most horizontal motion. These EPP velocities would be removed from the common densified ITRF velocity model to produce a frame-specific set of velocities accounting for any remaining horizontal and vertical motions.

NGS remains committed to delivering these reference frames in conjunction with updated vertical datums from geoid height models in 2022. The expected results of this update of the U.S. National Spatial Reference System is cm-level accurate and precise positioning. This will be two orders of magnitude improvement over the current realizations of the NSRS realized by the North American Datum of 1983 and the North American Vertical Datum of 1988. Furthermore, it will better align the U.S. NSRS with those of other nations in the region and around the world.

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BIOGRAPHICAL NOTES

Daniel Roman graduated from the Ohio State University with a Master of Science in Geodetic Science and Surveying in 1993 and a Ph.D. in Geological Sciences (emphasis in geophysics/gravity & magnetism) in 1999. He then joined the National Geodetic Survey as a Research Geodesist, where he led geoid modeling efforts for over a decade and then served as Chief of Spatial Reference System Division for three years. He is now the Chief Geodesist for NGS and involved in developing and implementing the new National Spatial Reference System for 2022 and international collaboration.

CONTACT

Dr. Daniel Roman
NOAA's National Geodetic Survey
SSMC3, N/NGS
1315 East-West Highway
Silver Spring MD
U.S.A
Tel. +1-240-533-9673
Fax + 1-301-713-4324
Email: dan.roman@noaa.gov
Web site: https://geodesy.noaa.gov/