Aspects of Intra-Frame Velocity (Deformation) Models for the United States National Spatial Reference System in 2022

Daniel Roman[1]

Received: September 2018 / Accepted: Octomber 2018 / Published: December 2018

Abstract

The National Oceanic and Atmospheric Administration's (NOAA) National Geodetic Survey (NGS) will be updating the National Spatial Reference System (NSRS) for the United States in 2022. Four Terrestrial Reference Frames (TRF's) will be defined based on the available ITRF in 2020. Euler Pole Parameters (EPP) will be determined for each frame to capture most of the horizontal plate motion. An Intra-Frame Velocity Model (IFVM) is required to account for any residual horizontal and all vertical motion within these frames. These are essentially deformation models but can be extended across the plate boundaries for practical purposes. Hence, the use of Intra-Frame instead of Intra-Plate. This paper will cover significant aspects of the IFVM that rely on increasingly sophisticated (and complicated) techniques for capturing the motion within each TRF. Simply gridding the National CORS network is the easiest and least accurate approach. The most complicated and potentially most accurate would be the use of InSAR. NGS must select the most cost-effective and accurate mechanism within the next few years to have the IFVM in place by 2022.

Keywords
Capacity building; Positioning; Reference Frames; Reference Systems; Cadastre

[1] Aspects of IFVM for the US NSRS in 2022 D. Roman
U.S. Department of Commerce, NOAA's National Geodetic Survey
1315 East-West Highway
SSMC3, N/NGS
Silver Spring MD 20910 USA
E-mail: dan.roman@noaa.gov

1. Introduction

NOAA's National Geodetic Survey (NGS) is responsible for defining, maintaining and providing access to the National Spatial Reference System (NSRS) that is the U.S. SDI. NGS will update the NSRS in 2022 to align more closely with International Terrestrial Reference Frame existing at that time. The most recent realization is ITRF 2014 [1], and this may still be in use in 2022 [pers. comm. Altamimi 2018].

The NSRS in 2022 will consist of Terrestrial Reference Frames (TRF) covering all U.S. States and territories on four plates: North America, Caribbean, Pacific and Mariana. These four TRF's will be the same as ITRF2015 at epoch 2020.0 but then diverge based on plate rotations and deformation models.

This paper provides a general overview with an emphasis on deformation models that will describe the expected motion in each of the four frames. Further background is available in the NGS Blueprint Part 1, Blueprint Part 2, and New Datums webpage [6,7,8].

2. National Spatial Reference System (NSRS) in 2022

The NGS Blueprint Part 1 [6] serves as the primary reference for this update.

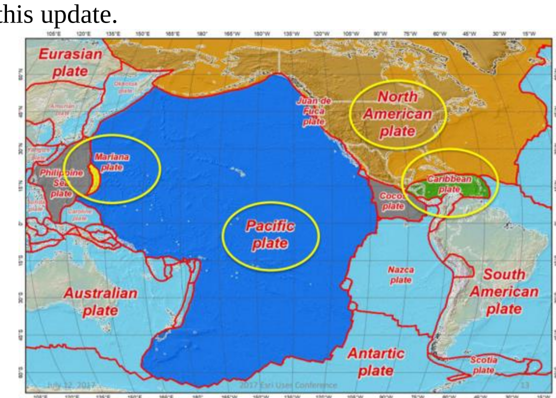

Fig. 1 The four tectonic plates "fixed" for the 2022 terrestrial reference frame.

a. 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.

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.

b. 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).

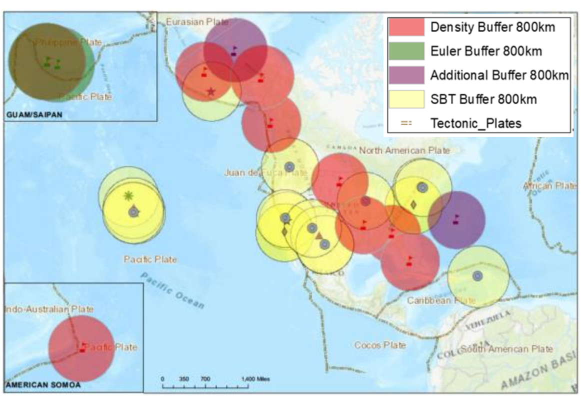

Fig. 2 Prospective sites for Foundation CORS. All circles are 800 km radius and color coded for sites collocated with other space based technique), Euler pole determination, improving spatial density, and additional sites.

c. Euler Pole Parameters

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.

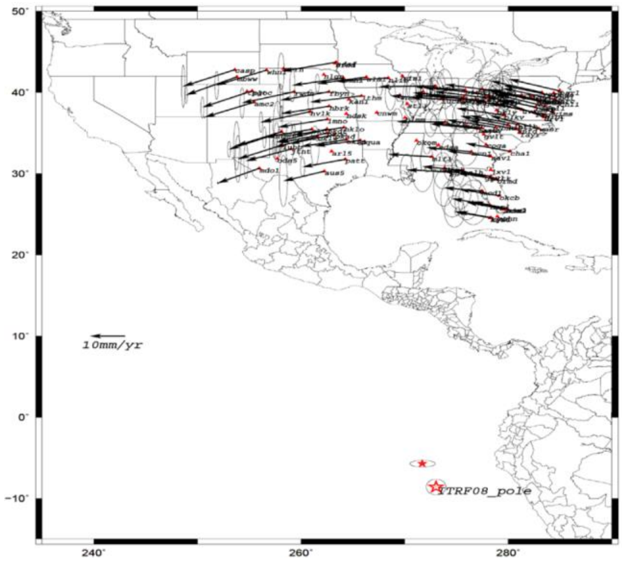

Fig. 3 Euler poles from ITRF 2008 and from a sample test. Changing which sites are included can shift the Euler pole coordinates and rotations significantly.

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. The intent of NATRF is to support positioning throughout all of North America. Other sites will be incorporated such as those from Natural Resources Canada. Similar efforts will also be made in the Caribbean where a different set of issues must be addressed [4].

d. Intra-Frame Velocity Models (IFVM)

The remaining 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. Many countries (e.g., Mexico) plan to adopt this approach, which is essentially a densified ITRF frame. However, for the U.S. case, we will remove most of the motion with the EPP. The remaining motion within the frame is then the IFVM. This term is adopted because the frame may be extended over a plate boundary. For example in southern California, parts of the state are arguably on the Pacific plate. However, a North American frame would be applied to develop a consistent model over the conterminous United States. This will produce significant residual velocities that must be modeled. Additionally, EPP will not model any vertical motion (e.g., subsidence) at all. Hence, alternative mechanisms are needed to describe the IFVM. Possibilities include gridding the existing CORS network, gridding a densified horizontal and vertical network supplemented by geophysical modeling, and use of Interferometric Synthetic Aperture Radar (InSAR). The next section provides potential solutions for the IFVM.

3. Possible Solutions for the IFVM

a. Gridding CORS

By far, the simplest and cheapest approach would be gridding the extensive U.S. CORS network. NGS just recently completed reprocessing over 20 years of CORS data in order to align with ITRF2014. These data provide both horizontal (Figure 4) and vertical (Figure 5) motions throughout significant portions of the U.S.

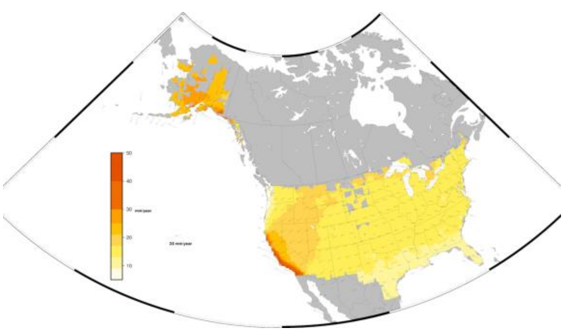

Fig. 4 Horizontal velocities in IGS14 (ITRF2014) frame after reprocessing over 20 years of CORS data. Grey areas lack sufficient data to be resolved.

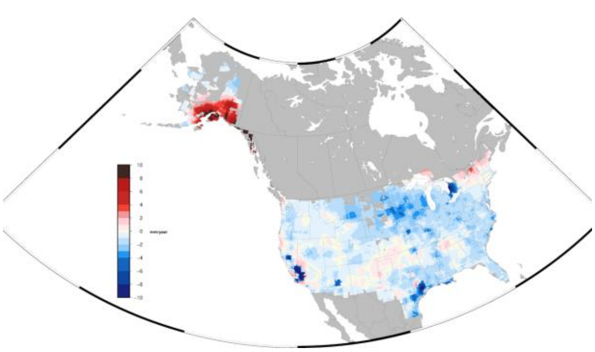

Fig. 5 Vertical velocities in IGS14 (ITRF2014) frame after reprocessing over 20 years of CORS data. Grey areas lack sufficient data to be resolved.

However, this approach will only work if the density of points is equitable, which is not the case. Particularly with small regions where dynamic activity occurs (e.g., southern California), this approach fails to capture signal in between the control points. There are broader networks of GNSS available outside of the CORS [12,13] that may help improve the reliability of a GNSS-only approach.

b. CORS Plus Geophysical Modeling

Another approach would be to fill in signal between the GNSS control points using geophysical models. Snay et al. [11] produced the Trans4D model to this effect. Others have done likewise. This has the benefit of matching at the GNSS control used to access the reference frame while providing solid geophysical models to describe what happens in between. The control GNSS data constrain the geophysical models. However, the earthquakes and other physical phenomena will require episodic updates to such a model. Hence, it must be maintained regularly.

c. InSAR

The third possibility is the use on InSAR data to map changes in the surface of the Earth over time. This would result in an improved topographic map and associated velocities. Bekaert et al. [3] show how the Hampton Roads region of Virginia was thus modeled and describe the subsidence in the region very well.

The Sentinel-1 satellites [2] 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. However, some type of service is required to process the InSAR into some velocity model. Additionally, InSAR may not work in all areas. Mountainous regions or swamps are two regions that may be problematic. With the Rocky Mountains in the western U.S. and the southern swamps, this may not be ideal.

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.

4. 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. The likely solution will be some combination of all with InSAR used in remote regions and GNSS augmented with physical models in more populous regions.

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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