Plans to support modernized CSRS and NSRS datums in Trimble software.

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Key words: Deformation measurement, Reference frames, semi-dynamic datums

SUMMARY

The purpose of this paper is to review how Trimble supports the three existing NAD83 datums in the US and NAD83(CSRS) in Canada and discuss our plans to support the modernized National Spatial Reference System (NSRS) and Canadian Spatial Reference System (CSRS) when they are released in 2025.

Currently, the National Geodetic survey has three reference frames. The first, NAD83(2011) covers CONUS, Alaska and US territories in the Caribbean region. In this, the crustal motion is modelled by an estimate of the North American Euler Pole and an associated deformation model, which contains velocity grids for Alaska and CONUS plus models for 32 earthquakes. The other two are the PA11 and MA11 frame for US territories located on the Pacific and Mariana Plates. In the PA11 and MA11 cases, the crustal motion is modelled only by a Euler pole. Trimble's implementation of the US deformation is effectively identical to NOAA's Horizontal Time Dependent Positioning program (HTDP) except that we only support earthquakes that occurred after the 2010 reference epoch. This means that instead of supporting 32 earthquakes, we only support four, two in California and two in Alaska and a model for post-seismic deformation for the 2002 Denali Earthquake.

We believe that the Trimble geodetic libraries (TGL) can be configured to support NSRS fairly easily. The deformation model in HTDP will be replaced by intra-frame velocity model which will require new velocity (and possible earthquake) grids. Of course, the velocity grids will now be three dimensional, however TGL already support this. Also, NGS will support both ITRF2020 and plate fixed coordinates, however TGL does already support both schemes so this should not be difficult to implement. NGS also has indicated that along with the 2025 realization epoch they will move to supporting measurement epochs, which may require that Trimble Software implement user selected reference epochs.

Another change is in the projections. Currently TGL supports the State Plane zones and the county coordinates for Iowa, Illinois, Indiana, Michigan, Wisconsin and Minnesota. However, SPCS2022 will have nearly 1000 projections due to the large number of low distortion zones. We have already begun to implement changes to Trimble Software to make it easier select the appropriate projection in this situation, filtering usable CRS from location.

As far as Canada is concerned, datum modernization will mean a new datum and a new IFVM and reference epoch but we do not anticipate any problems implementing these.

RÉSUMÉ

Le but de cet article est d'expliquer comment Trimble prend actuellement en charge les trois systèmes de référence NAD83 utilisés aux États-Unis et le NAD83(CSRS) utilisé Canada, puis de présenter nos plans pour la prise en charge des nouvelles versions de ces systèmes qui doivent être publiées en 2025 : le nouveau Système National de Référence Spatiale américain (en anglais NSRS) et le nouveau Système de Référence Spatiale Canadian (en anglais CSRS). Actuellement, le National Geodetic Survey (NGS) supporte trois systèmes de référence. Le premier, NAD83(2011) couvre la région CONUS, l'Alaska et les territoires américains des Caraïbes. Dans celui-ci, le mouvement de la croûte terrestre est modélisé par une estimation du pôle d'Euler de la plaque nord-américaine et un modèle de déformation associé, qui contient des grilles de vitesse pour l'Alaska et CONUS plus des modèles pour 32 tremblements de terre. Les deux autres sont les systèmes de référence PA11 et MA11 pour les territoires américains situés sur les plaques du Pacifique et des Mariannes. Dans les cas de PA11 et MA11, le mouvement de la croûte terrestre n'est modélisé que par un pôle d'Euler. La mise en œuvre du modèle de déformation américain par Trimble est en fait identique au programme de positionnement horizontal dépendant du temps (HTDP) de la NOAA, sauf que nous ne prenons en charge que les tremblements de terre qui se sont produits après l'époque de référence 2010. Cela signifie qu'au lieu de prendre en charge 32 tremblements de terre, nous n'en retenons que quatre, deux en Californie et deux en Alaska, ainsi qu'un modèle de déformation post-sismique pour le tremblement de terre de Denali en 2002.
Nous pensons que la Librairie Géodésique de Trimble (en anglais TGL) peut être configurée pour gérer le nouveau système américain assez facilement. Le modèle de déformation du programme HTDP sera remplacé par le nouveau modèle avec ses grilles modélisant les vitesses et les tremblements de terre. Bien sûr, les grilles de vitesse seront désormais en trois dimensions, mais TGL le supporte déjà. De plus, le NGS acceptera les coordonnées ITRF2020 et les coordonnées fixes sur la plaque correspondante, mais TGL prend déjà en charge les deux schémas, donc cela ne devrait pas poser de difficultés. Le NGS a également indiqué que les coordonnées pourront être exprimées à l'époque de référence 2025, ou à l'époque de la mesure, ce qui pourra nécessiter une modification des logiciels Trimble, pour permettre à l'utilisateur de définir l'époque de référence.
Un autre changement concerne les projections. Actuellement, TGL prend en charge les systèmes de coordonnées de tous les états américains, ainsi que les systèmes de coordonnées des différents comtés de l'Iowa, l'Illinois, l'Indiana, du Michigan, du Wisconsin et du Minnesota. Cependant, le nouveau modèle SPCS2022 comprendra près de 1000 projections en raison du grand nombre de zones à faible distorsion. Nous avons déjà commencé à modifier les logiciels Trimble pour faciliter la sélection de la projection appropriée dans cette situation, en filtrant les systèmes utilisables dans la région de travail.
En ce qui concerne le Canada, la modernisation du système de référence spatial nécessitera un nouveau datum, un nouveau modèle de déplacement et une nouvelle époque de référence, mais nous ne prévoyons aucun problème à intégrer ces nouveaux éléments.

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Plans to support modernized CSRS and NSRS datums in Trimble software.

Christopher PEARSON, USA and Sebastien VIELLIARD, France

1. INTRODUCTION

The purpose of this paper is to discuss how Trimble supports the three existing NAD83 datums in the US and NAD83(CSRS) in Canada and our plans to support the modernized National Spatial Reference System (NSRS) and Canadian Spatial Reference System (CSRS) when they are released in 2025. Both of these models will contain sophisticated models of tectonic motion that can be used to project each coordinate to its position at a reference epoch, while still providing a link to the global systems. Support for such models is required for software to support accurate coordinates in either datum. This is particularly important with the advent of Precise Point Positioning (PPP) services like Trimble RTX®, which provide coordinates in the ITRF at the epoch of measurement. Fortunately, Trimble has recently made significant enhancements to Trimble Geodetic Libraries (TGL) which provide a firm basis for supporting the modernized datums for the US and Canada that we expect to be released in the next few years.

2. SEMI-DYNAMIC DATUMS

Modern semi-dynamic datums are usually based on a version of the International Terrestrial Reference Frame. Stable coordinates are produced by projecting each coordinate to its position at a common date called the reference epoch (Grant at al 2014). To make this technique work, we need a model of how the earth is moving due to plate tectonics. In stable areas, the effect of earthquakes will be small and the motion of the points will follow the motion of the tectonic plates and can be calculated using Euler Poles. Indeed, in some countries (such as Australia) these are incorporated in 14-parameter datum transformation equations, and no further corrections are necessary to provide stable accurate coordinates. However, for a country like the US where part of the country lies across a plate boundary, a different strategy must be adopted. In this case, an Euler Pole may be adopted to take care of the deformation in the stable part of the country, and a displacement model is used for residual deformation, particularly in the plate boundary zone. Coordinates are propagated to a standard epoch (2010 in the US for example) using a numerical model of deformation across the plate boundary. For this reason, Trimble software supports four distinct types of displacement models

1. First, for countries that are located in one tectonic plate, the horizontal velocity is determined by applying the absolute Euler Pole for the plate in question. Examples of this include Australia and the ETRS89 based realizations used by most European countries. In this case, the mathematical model is incorporated in the datum transformation parameters, which can be augmented by use of the ITRF2014 plate model in some jurisdictions.

2. The second category are velocity models. These are normally characterized by a constant or secular velocity (see Figure 2). The velocity can either be given relative to the absolute or No Net Rotation (NNR) reference frame or relative to a tectonic plate, in which case the velocity field is a correction to the Euler Pole predicted displacement. An example of the velocity field relative to the NNR frame is the VEMOS field used in Chile. An example of the hybrid models involving both a velocity field and a Euler Pole is the NAD83(CSRS) used by Canada.

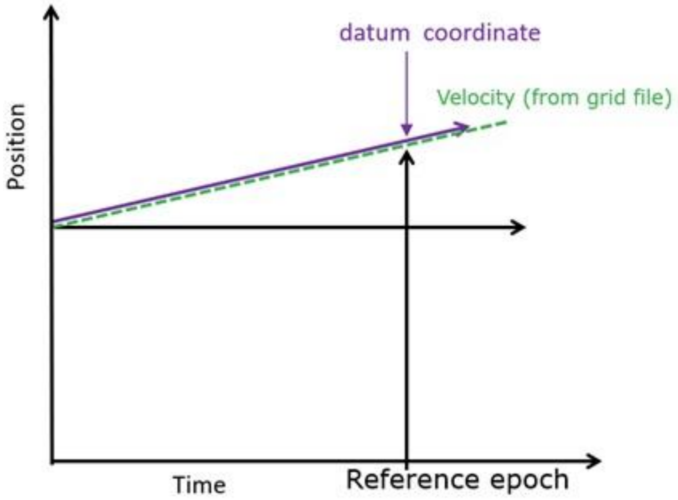


Figure ~~1~~2 Displacement model with only a constant velocity

3. The third type of displacement model incorporates a velocity field augmented with grids representing earthquake displacement and sometimes post-seismic relaxation. These models contain separate models of the secular (continuous) velocity field associated with on-going deep-seated tectonic processes and displacements associated with significant earthquakes. Other (smaller) effects, like post seismic relaxation that sometimes occurs after large earthquakes, are also included in some cases. The models are shown schematically in Figure 3. Note that the effect of earthquakes is an instantaneous offset while the effect of the velocity increases linearly with time. The total motion is just the sum of the earthquake and constant velocity terms. NAD83(2011) implemented with NOAA’s Horizontal Time Dependent Positioning (HTDP) program is a good example of this.

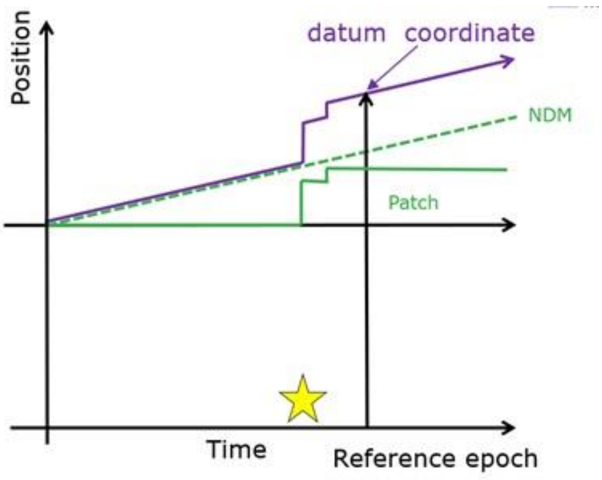
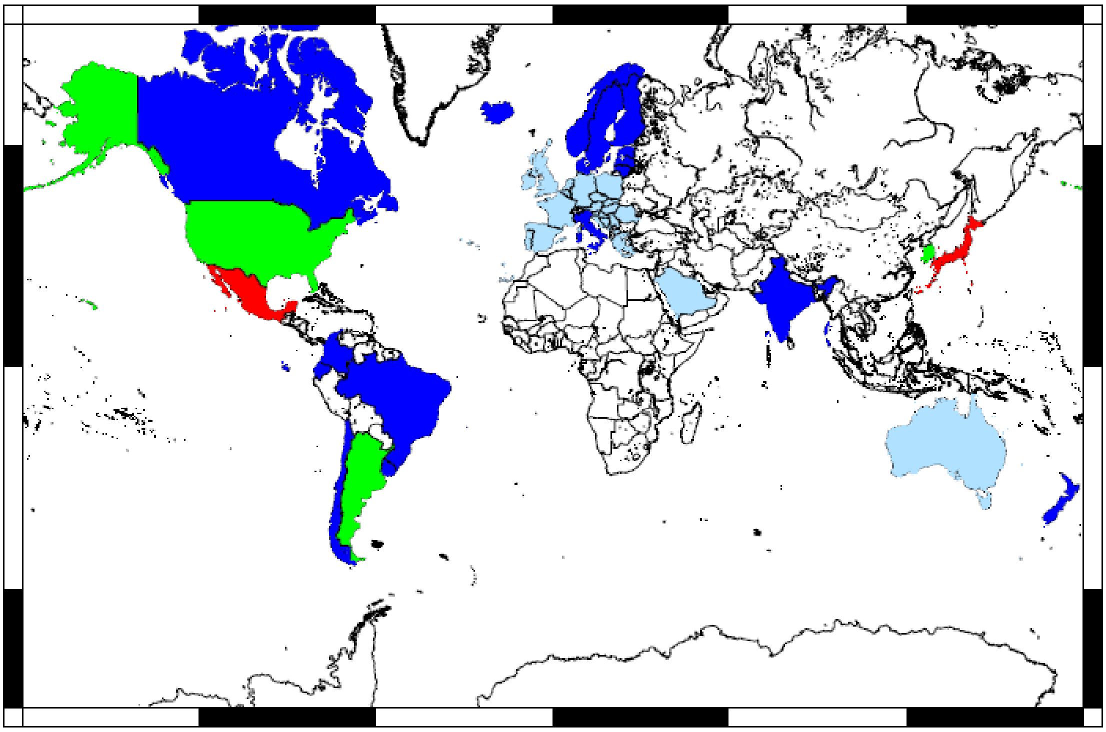


Figure ~~3~~2 Schematic diagram of a dynamic datum. Dashed green line shows the secular velocity solid green line shows the co-seismic contribution to the displacement model. The solid purple line shows the displacement model with both contributions combined.

4. The fourth type of displacement model supports datums like JGD2011 where semidyna.exe, an online app, provides estimates of the tectonic motion from the reference epoch to the current year. We implement this using a constant displacement grid from which we can interpolate the tectonic motion for any point.

- 

- *Figure ~~1~~3 Map showing countries with Dynamic Datums. Countries in light blue model crustal motion using an Euler Pole. Countries in dark blue have a velocity grid. Countries in green use a full displacement mode including* *a velocity model and earthquake grids and countries in red provide an online calculator, which we implement as a distortion grid.*

With the exception of the displacement grid option (#4), all of these models have a critical role to play in supporting the modernized NSRS2022 and CSRS2022 datums.

3) FUNCTIONAL MODELS

The Trimble Geodetic Library (TGL) underlying many Trimble products has been recently upgraded to support semi-dynamic datums. This requires that TGL support time-dependent datum transformations (introduced with Trimble Access 2020.00 and Trimble Business Center (TBC) 5.30) and displacement models (introduced with Trimble Access 2020.20 and TBC 5.40). With these enhancements TGL can support all four types of displacement models discussed above. The correction equation is shown in Equation 1 below:

Equation 1

$$m_k(t,\theta,\varphi) = v(\theta,\varphi)_k t + E(\theta,\varphi)_{ki} H(t-t_i) + P(\theta,\varphi)_{ki} H(t-t_i)\left(1 - e^{-\frac{(t-t_i)}{tc_i}}\right) + d(\theta,\varphi)_k$$

- ν is a constant velocity grid
- E is the earthquake shift (patch)
- P post-seismic decay constant
- H is the step function
- d is a constant displacement grid

In case one, the Euler Pole is applied using the datum transformation parameters and it does not involve Equation 1. In case two only ν() is nonzero. In the case three, ν(), E() and potentially P() are nonzero and in case four, only d() is nonzero. All of the types of displacement models we support except for the Euler Pole (case 1) use grid files and bi-linear interpolation to estimate the parameters for Equation 1.

4. Support for NAD83(2011)

As an example of how grid files are used in Trimble geodetic libraries, consider our model for the contiguous US (CONUS). In this case the model includes 8 grid files, five of which are associated with the velocity model and three are associated with earthquake models. The geographical extents of the areas covered by the grid files are shown in Figure 4.

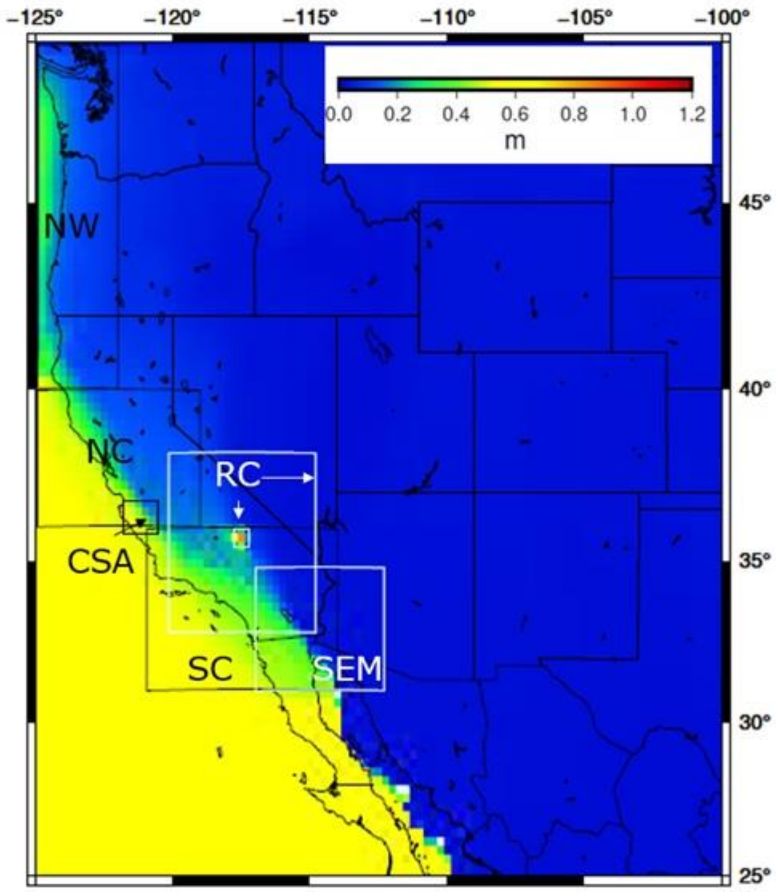


Figure 4 Western part of CONUS. The colors indicate velocity magnitudes from the top-level grid that covers all of CONUS. The geographical extents of all of the other grids in the model are shown as rectangles. Black rectangles show the extents of velocity grids. NW, NC, SC and CSA refer to the Pacific Northwest, Northern California, Southern California and Creeping San Andreas grids respectively. White rectangles show the extents of earthquake grids. SEM stands for the 2010 M 7.2 El Mayor–Cucapah earthquake and the RC stands for the 2019 M 7.1 Ridgecrest, California earthquake. Note that the Ridgecrest model consists of two nested grids.

Velocity grids

Our velocity model of Contiguous US (CONUS) consists of five nested grids, a top-level grid covering all of the contiguous US with a grid spacing of 0.25 ° and four sub-grids with a finer grid spacing. The Northwest (NW), Northern California (NC) and Southern California (SC) grids cover the tectonically active parts of Pacific Northwest and California. They have a grid spacing of 0.0625 ° and the CSA with a grid spacing of .01 ° covers the special case of the creeping section of the San Andreas fault. Our velocity grids are identical to the ones used internally by HTDP (Pearson and Snay 2012 table 3).

Earthquake grids

When it comes to earthquakes, TGL and HTDP differ in that HTDP uses mathematical models of the earthquake while TGL uses grids. We developed the earthquake grids from HTDP by using the capability of HTDP to transform positions on a regular grid between two dates. For this purpose, we chose the two dates so was one immediately before the earthquake and one immediately after.

We include two earthquakes in our model of CONUS, the 2010 M 7.2 El Mayor–Cucapah earthquake (SEM in Figure 4) and the 2019 M 7.1 Ridgecrest, California earthquake (RC in Figure 4). The SEM model consists of a single grid with a grid spacing of .02°. This is a fairly course grid for an earthquake but the epicenter is well south of the US border so this grid is sufficient to model the deformation in the US portion of the radius of influence for the earthquake.

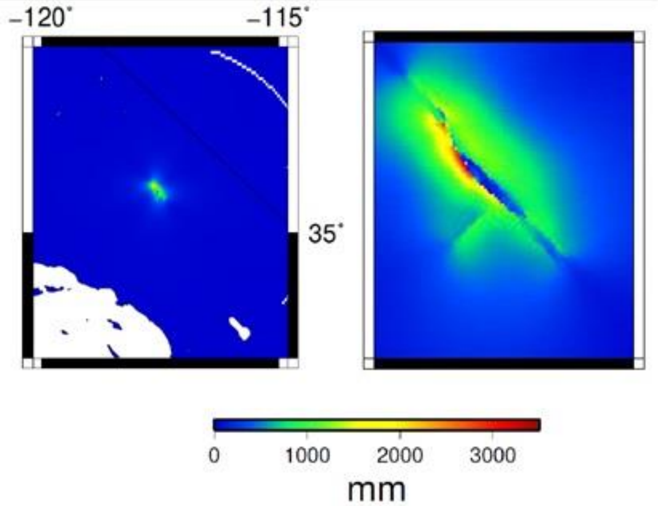


Figure 5 Grids for the Ridgecrest earthquake. The left-hand image shows the full earthquake grid and the right-hand image shows the immediate epicentral region.

The Ridgecrest model consists of two nested grids. The inner grid covers only the immediate epicentral area and has a grid spacing of .005° and the outer grid which covers much of southern California and has a grid spacing of .05°. Figure 5 shows both of these grids. Note that deformation in the epicentral region is discontinuous with a 3 m change across the fault. This is a feature of earthquakes where the fault plane breaks the surface. Because of the shallow depth the faults broke the surface producing complex displacements with discontinuities, the modeled displacements from HTDP in the immediate vicinity (say within 1 km or so) of the fault are almost certainly not accurate. Consequently, any coordinates that are measured after an earthquake and corrected to a pre-earthquake reference epoch may lose some accuracy and this is particularly true if the measurements are located close to a fault trace. For this reason, Trimble is considering adding functionality to Trimble Business Center (TBC) so that users will be aware that positions in this area may be suspect. It is important that geospatial professionals are aware of this problem.

NAD83(CSRS) v7 for Canada

The current datum for Canida is NAD83(CSRS), supported by the NAD83(CSRS) v7 Velocity Grid – NAD83v70VG which is a velocity only model supported by a single four point per degree grid covering all of Canada.

5. Support for the modernized US National Spatial Reference System (NSRS) and the Canadian Spatial Reference System (CSRS)

Nearly all of the expected features of the modernized NSRS and CSRS can be supported using existing fuctionalty in Trimble Geodetic Libraries (NOAA 2019a, Erickson 2019). The only exception is the dynamic portion of the geoid model, DGEOID2022 discussed below.

Euler poles and plate fixed datums

The modernized NSRS and CSRS will support plate fixed datums where the coordinates are aligned to the motion of the underlying tectonic plates through applying appropriate Euler Pole models. In the case of modernized CSRS, this is restricted to the North American plate which underlies all of the Canadian territory (Erickson 2019, Natural Resources Canada 2020). However, for the United States, there are plate fixed datums for the North American, Caribbean, Pacific and Mariana plates (NATRF2022, PATRF2022, CATRF2022 and MATRF2022), each of which has its own Euler Pole. Currently, Trimble Geodetic Library's will automatically choose the appropriate Euler Pole for a datum however, NOAA_TR_NOS_NGS_0067 indicates that users will be allowed to select any of the four-plate fixed datums or ITRF2020. We anticipate that most users will choose the plate fixed frame associated with the underlying plate so we to use this as the default choice for the plate fixed frame will be the one associated with survey location but the user will be able to override this. This will support the overwhelming majority of users but in the case of the portion of California west of the San Andreas Fault which is nominally part of the Pacific Plate but connected to CONUS, there are valid use cases for either NATRF2022 or PATRF2022. In this case the default for the plate fixed frame will be NATRF2022, as it will be for the rest CONUS however, users who need PATRF2022 will be able to override this choice. Within Trimble Software we plan to support transformations between ITRF2020 and NATRF2022, PATRF2022, CATRF2022 and MATRF2022 which will allow users to choose the appropriate plate fixed datum for their project.

IFVM and modernized NSRS and CSRS for the US and Canada

We anticipate that initially the IFVM (Intra-frame Velocity Model) for CONUS US will be similar to one currently implemented in TRANS4D (Snay et al 2016). Since Trimble Geodetic Libraries already support vertical velocities, our existing algorithms will support vertical velocities so no change is necessary aside for updating the velocity grids. The model consists of 7 grids, four for CONUS, one each for Western, Northern Eastern South Eastern sections plus a high-resolution grid for the creeping San Andreas Fault, one for Alaska, one for the Caribbean plate and one for Hawaii. We also plan to add a low resolution base grid which will allow us to combine all of CONUS (or potentially all US territories in the US and Alaska) in a single model. Since the IFVM will be in ITRF2020, the velocities will have to be converted to plate fixed datum before they are used in coordinate operations in TGL.

For co-seismic models, we anticipate that NGS will move to grid-based models rather than the ones based on dislocation model equations from Okada (1985). Since Trimble Geodetic Libraries already use a grid-based approach, this change will bring TGL and IFVM2022 into closer alignment. One challenge is that the IFVM will go back to 1994 (NOAA 2021) while TGL currently TGL only supports earthquakes back to 1 January 2010 (the reference epoch for the NAD83(2011) NGS's current realization). This is all that is needed to support transforming "epoch of measurement" to the current reference epoch but with NGS signaling support for a variety of epochs including the observation epoch of the control, TGL may have to support all of the NGS's earthquake models. If the IVFM adopts a grid based approach, adding coverage for earthquakes between 1994 and 2010 supporting the full catalogue of earthquakes will be much easier

Currently, we understand that the IFVM for Canada will be a velocity only model similar to the NAD83v70VG grid (B. Donahue pers com 2022). As a result, aside for updating the transformation parameters and the velocity grid we do not anticipate any changes in TGL will be required to support Canada's new IFVM.

A new North American-Pacific Geopotential Datum of 2022 (NAPGD2022) will be part of the modernized NSRS (NOAA 2021b). We understand that the US will adopt NAPGD2022. For Trimble users the most important constituent will be GEOID2022, a new geoid covering three regions (the first covering the entirety of North and Central America, Hawaii, Alaska, Greenland and the Caribbean, the second covering American Samoa and the third covering Guam and the Commonwealth of the Mariana Islands). GEOID2022 will contain two components. The first will be a time independent geoid fixed at its value for epoch 2020.00 called the Static Geoid model of 2022 (SGEOID2022). The second component will be a time-dependent geoid undulation model, Dynamic Geoid model of 2022 (DGEOID2022). We do not anticipate any problem supporting SGEOID2022 in TGL as soon as they are released. At this stage we do not plan to support the dynamic portion of the geoid model, DGEOID2022 however after NAPGD2022 is released we will evaluate DGEOID2022 and we may support it in a later release of TGL if it will have a significant effect users coordinates. Canada will continue to use CGVD2013 which is equivalent to NAPGD2022 (Erickson 2019), which is already supported by TGL so no change is necessary.

PROJECTIONS

Trimble Geodetic Libraries currently supports all of the state plane zones for the US plus the county coordinate systems for Iowa, Illinois, Indiana, Michigan, Wisconsin and Minnesota. We are committed to support all of new State Plane Coordinate System (SPCS2022) projections (NOAA 2019b) however, with the addition of the low distortion projections we anticipate the number of projections will increase to about one thousand. In order to make this manageable we have revised the projection menu so that the relevant projections, based on the user's location will be listed first. In the case of Canada, we do not anticipate any significant change in the projections.

6. CONCLUSIONS

Trimble has recently upgraded its geodic transformation libraries to support dynamic datums and displacement models following a schema developed by Land Information New Zealand. Using these we have been able to support 44 national datums including NAD83 in the US and Canada. We anticipate that, with this upgrade, Trimble software will be able to support the modernized NSRS/ CSRS datums without significant change. However, implementing all of the new models, grids, projections and parameters such as the new velocity model, (IFVM2022), new projections in SPCS2022, new transformation grids and a new geoid will take some time. For this reason we urge NGS and NRCanada to make beta versions of these available as soon as possible so we can start the process of updating and testing our software well in advance of the 2025 release date. We also support the adoption of appropriate international standards (along the lines of the OGC's draft standards on GGXF) to ease the integration of the new displacement models in vendor's products.

7. FUTURE PLANS

In future we hope to incorporate estimates of uncertainties into displacement models where these are available and provide tools for users to visualize velocity and earthquake grids. We also plan to integrate Trimble Geodetic Libraries in Trimble VRS and Pivot.

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Chris completed a PhD at the University of Otago in 1991. He then worked at Columbia University and the University of Otago as a research fellow specializing in GPS processing and measuring crustal deformation. Between 2001 and 2011 Chris worked for the US National Geodetic Survey where he was geodetic advisor for Illinois and was responsible for maintaining the HTDP program. Between 2011 and 2018 Chris was a lecturer at the University of Otago. Since 2018, Chris has been the geodetic advisor at Trimble.

Sebastien Vielliard, Senior Software Engineer, Trimble
Sebastien obtained a Master’s degree in Computer Science in 1993 from Polytech’Nantes, France. Since then, he has worked as a software engineer developing Survey & GIS Office Software for Sercel, Dassault Electronics, Thales Navigation, Magellan, and Ashtech. After Ashtech became a Trimble company in 2011, Sebastien joined the Trimble Business Center team as a senior software engineer, specializing in geodetic libraries and algorithms.

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