Inclusion of Dynamics in the new Reference System

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CGSIC
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U.S. Geometric Coordinates: Latitude, Longitude & Ellipsoid Heights
Tectonic Plates: the U.S. and its holdings

Mariana Micro-plate

Marianas Islands and Guam

American Samoa

Plate Velocities in International GNSS Service Frame (IGS14):
N Amer: 1-3 cm/yr  Pacific: 7-8 cm/yr  Carib: 1-2 cm/yr  Mariana: 1-4 cm/yr
Replacing the NAD 83’s

• Why: NAD 83 doesn’t rotate properly with its plates
• Why: NAD 83 is not geocentric

• With Four plate-fixed reference frames
  – N. America (NATRF2022), Pacific (PATRF2022), Mariana (MATRF2022), Caribbean (CATRF2022, brand new!)

• Method: Define each of the 4 new frames equal to IGS14 @ 2020
  – IGS14 is the international frame made from world-wide data
  – Define each frame’s movement by a plate rotation only
  – Put another way: “The frame rotates so your coordinates don’t have to”
The relation of five global reference frames through time. Rotations are not to scale.

Time \( t = t_0 - \Delta t \) ("the past")

Time \( t = t_0 + \Delta t \) ("the future")

\( \Delta t \) (2020.0)
BSMK (Bismark, North Dakota)

A ND Dep’t of Transportation partner station in NGS’ CORS (Continuously Operating Reference Station) GNSS Network. There are just over 1900 stations operating all of the world, but primarily in North America.
BSMK (North Dakota)

As per NGS policy decision circa 2018:
\[ t_0 = 2020.0 \]

NATRF2022
Latitude is
(nearly)
CONSTANT
over time
BSMK (North Dakota)

Longitude is (nearly) constant over time
BSMK (North Dakota)

No matter WHAT frame, the ellipsoid height is dropping over time.
Residual Vertical Motion

- Crust uplifts and subsides
  - Variable over all spatial and temporal scales
  - Glacial Isostatic Adjustment (GIA) is uplifting much of the North half of CONUS
  - Modern ice loss of melting glaciers affects AK
  - Agricultural water withdrawal subsides the crust (see left)
  - Earthquakes, Volcanic Eruptions, Etc
Residual Horizontal Motion

“Intra-frame velocities”

GIA (left), earthquakes, deformation in CA & AK
Definitional Relationships - Geometric

User provides GNSS survey data on epoch

NGS provides CORS data on epoch

→ OPUS →

1. Geodetic Control
   a. Position in IGS/ITRF at epoch of survey
   b. Position in *TRF2022 at epoch of survey

↓ IFVM

2. All other epochs Corrected for dynamics
   a. Position in *TRF2022 at any epoch...
      or a common epoch (e.g. 2020 epoch of the new NSRS)

Time-dependent Geometric
Positions are Latitude, Longitude, Ellipsoidal Height
Historically, NGS has provided a model of horizontal motions (both plate rotational velocities and horizontal intra-frame velocities) through the Horizontal Time Dependent Positioning (HTDP) computer program. However, HTDP has never supported vertical velocities, except in central Alaska.

New *TRF2022s will already take into account plate motion and remove it from your geodetic control.

IFVM will provide a model of remaining geometric horizontal AND vertical motion over time not accounted for by plate motion (GIA, subsidence, earthquakes, etc.)

New NGS project in 2018 to create the IFVM and currently beginning research on possible methods for creating it from GNSS, InSAR, models, or other methods.

Data-driven solutions are easier to maintain for all epochs and spatial scales needed to accomplish this task than models are.

BETA soon: a model of gridded CORS motion for North America from Multi-year CORS Solution 2.
BETA IGS14 Horizontal Velocities
BETA IGS14 Vertical Velocities
Orthometric Heights
Definitional Relationship - Geopotential

\[ H_{\text{NAPGD2022}}(t_c) \equiv h_{\text{TRF2022}}(t_c) - N_{\text{GEOID2022}}(t_c) \]

Time-dependent orthometric heights

Time-dependent ellipsoid heights come from time-dependent CORS coordinates which serve as control for your time-dependent GNSS survey. They will be modeled by the Intra-Frame Velocity Model, or IFVM.

Time-dependent geoid undulations come from the dynamic component of GEOID2022 ("DGEOID2022")

They will be modeled by the Geoid Monitoring Service, or GeMS.
Geoid Monitoring Service

• Geoid: Surface of constant gravitational potential that best fits mean sea level
• Goal: Track all changes to the geoid which would prevent 1 cm accuracy
• Geoid changes are due to very large mass movements
• Three major aspects:
  – **Continuous Shape Changes**: e.g. Ice Loss Response
  – **Episodic Shape Changes**: e.g. Massive Earthquakes
  – **Definition of Geoid**: e.g. Global Sea Level Change
Continuous Shape Change

Available now: GRACE and GRACE-Follow On satellite gravity and geoid models

Pros: Global model with proven accuracy, easy to obtain, GRACE-Follow On launched this year so new data is likely available through 2023, Good first estimate for next 30 years of change

Con: Resolution is not sufficient to provide full geoid monitoring

Need: Ground gravity surveys to identify what we don’t know yet
Episodic Geoid Changes

• Massive, or cataclysmic, size events only.
• Magnitude 8+ earthquakes, Magnitude 6+ explosive eruptions
• Possible: Responsive, local re-surveys for geoid change?

All Recorded Magnitude 8+ Earthquakes, Last 110 Years
Geoid Monitoring Service

• A project since January 2017, planned to be operational and produce NGS’ first “D” dynamic geoid by 2022.

• NGS will likely work with satellite gravity experts to build on 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/measure those.

• There is a need to create a realistic plan for response to cataclysmic earthquakes and explosive volcanic eruptions.

• Although all of North America will be monitored, most change occurs in: Alaska, volcanic areas of the Western US, and N. CONUS.
Thank You

More Information: The “Blueprint for 2022” NOAA Technical Reports

Geometric: Sep 2017
Geopotential: Nov 2017
Working in the modernized NSRS: ~May 2019