Inclusion of Dynamics in the new Reference System

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U.S. Geometric Coordinates: Latitude, Longitude & Ellipsoid Heights

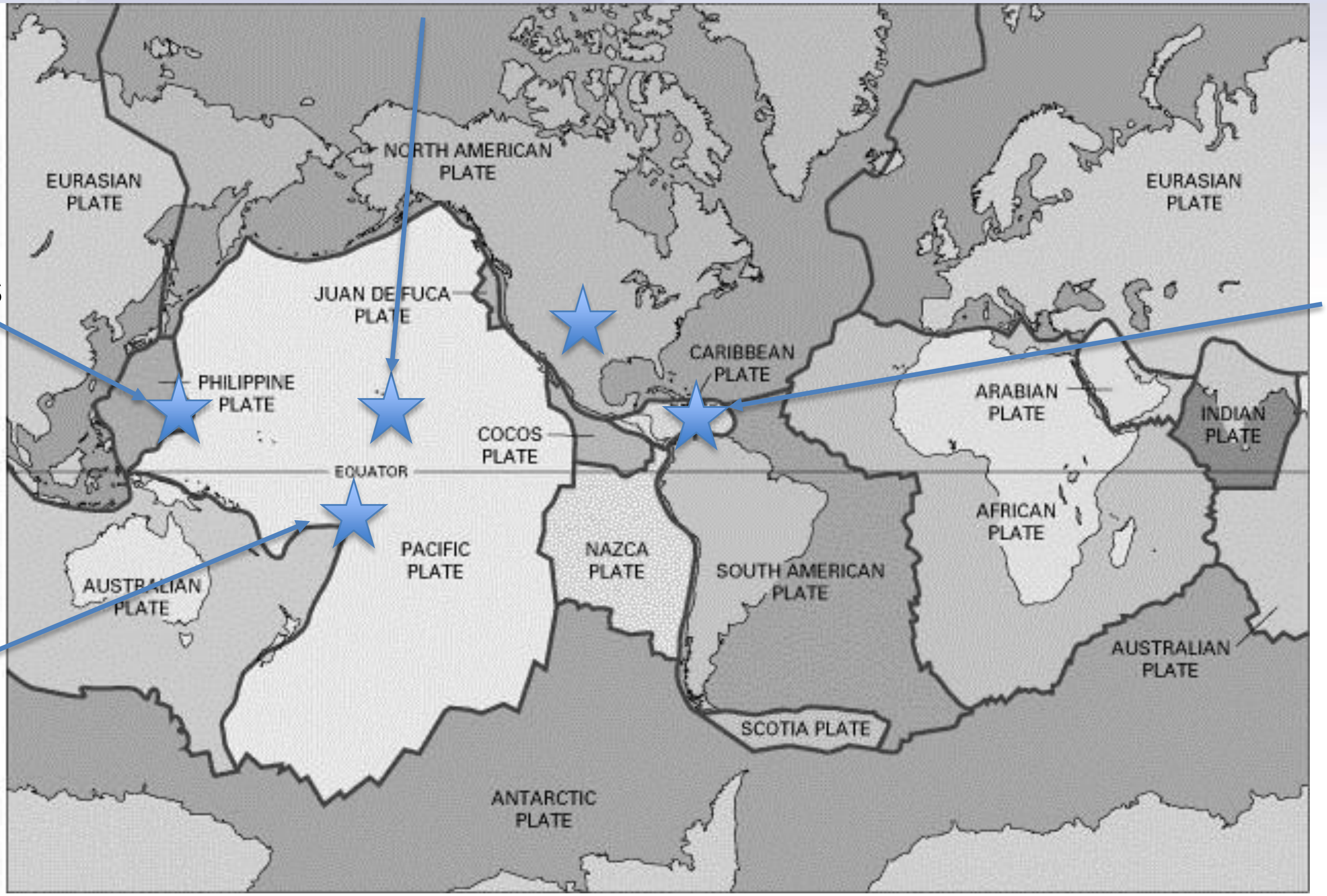
Tectonic Plates: the U.S. and its holdings

Hawaii

Mariana Micro-plate

Marianas Islands and Guam

American Samoa



Puerto Rico and the U.S. Virgin Islands

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

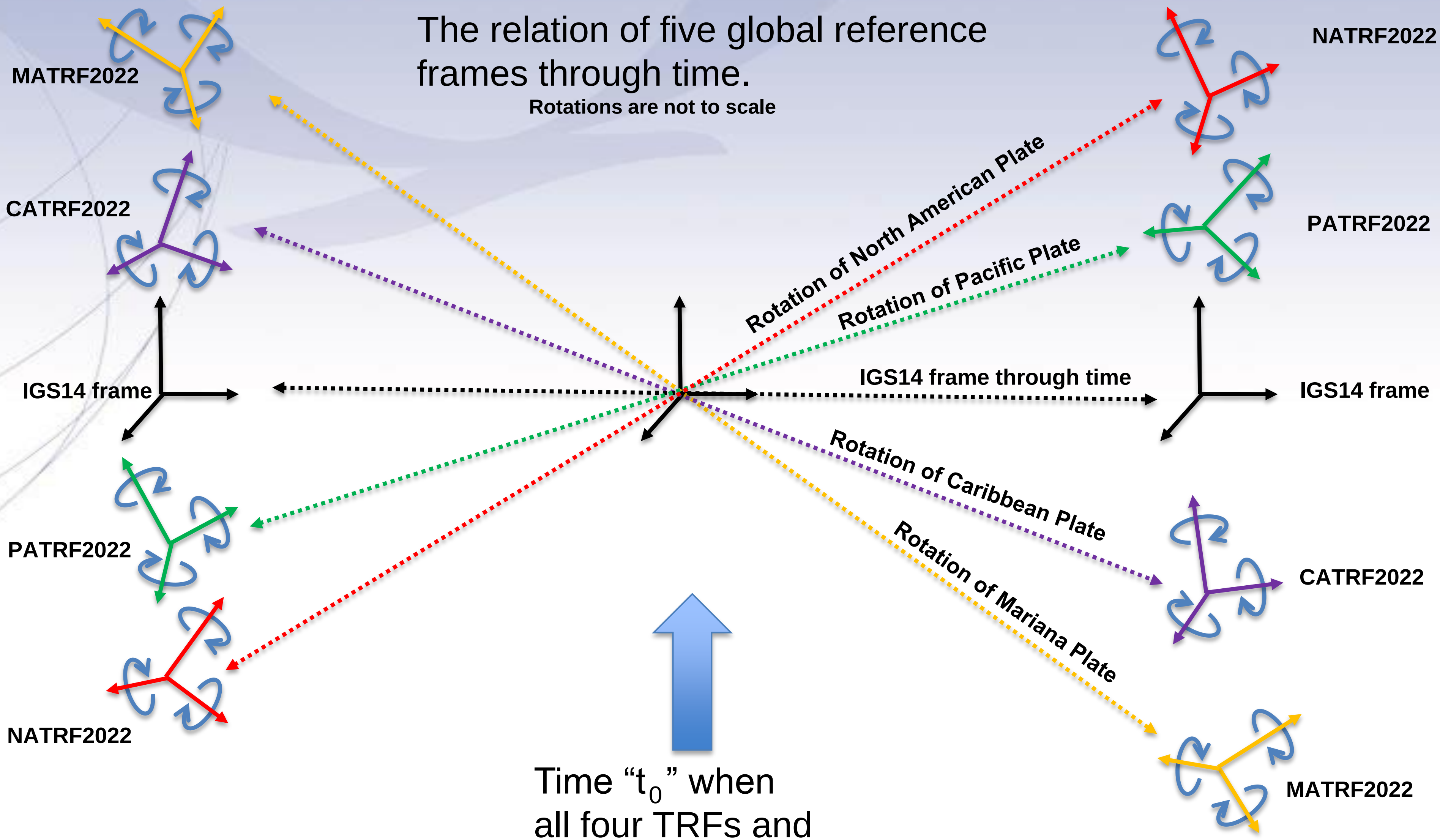
- Why: NAD 83 doesn't rotate *properly* with its plates
- Why: NAD 83 is not geocentric

- 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

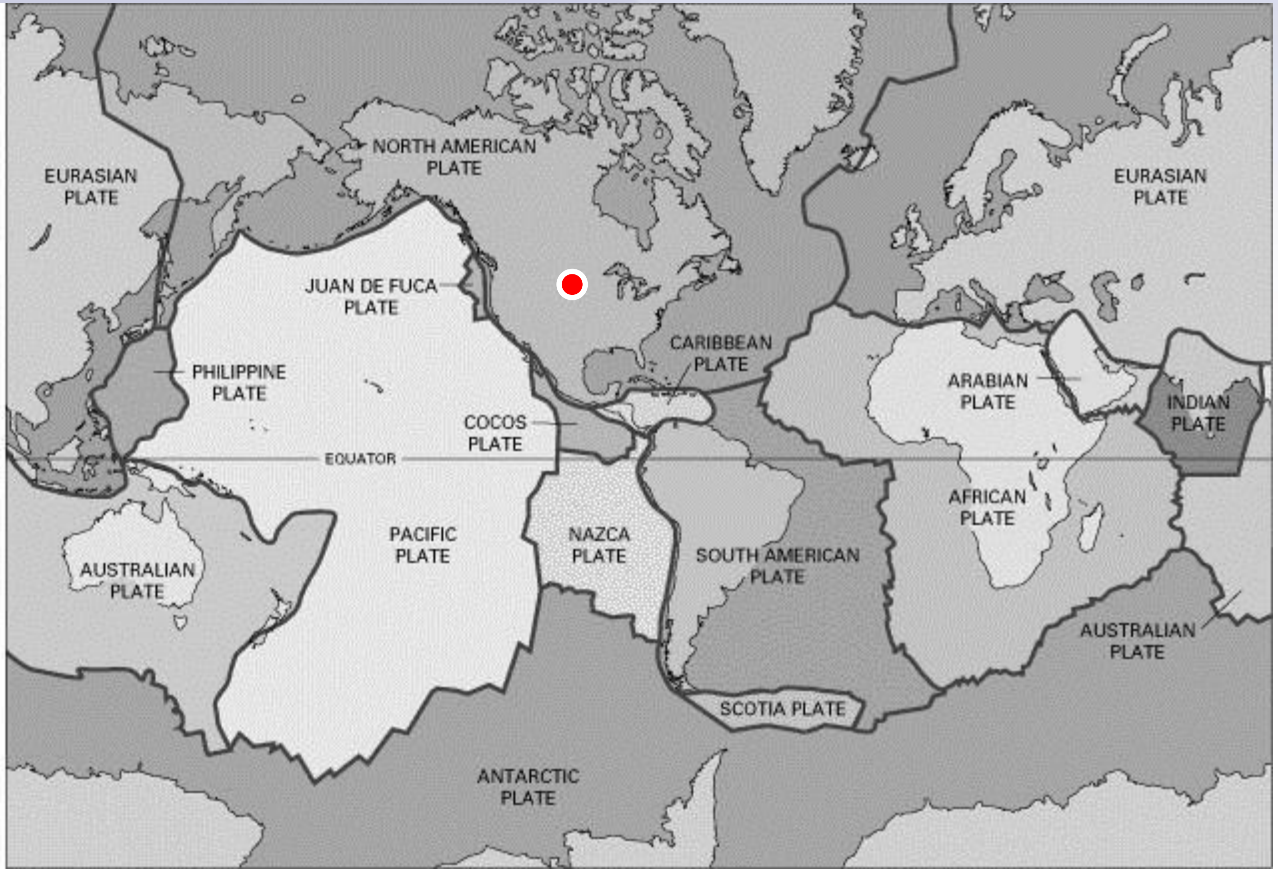


$t=t_0 - \Delta t$
("the past")

Time "t_0" when all four TRFs and IGS14 are identical. (2020.0)

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

BSMK (Bismark, North Dakota)

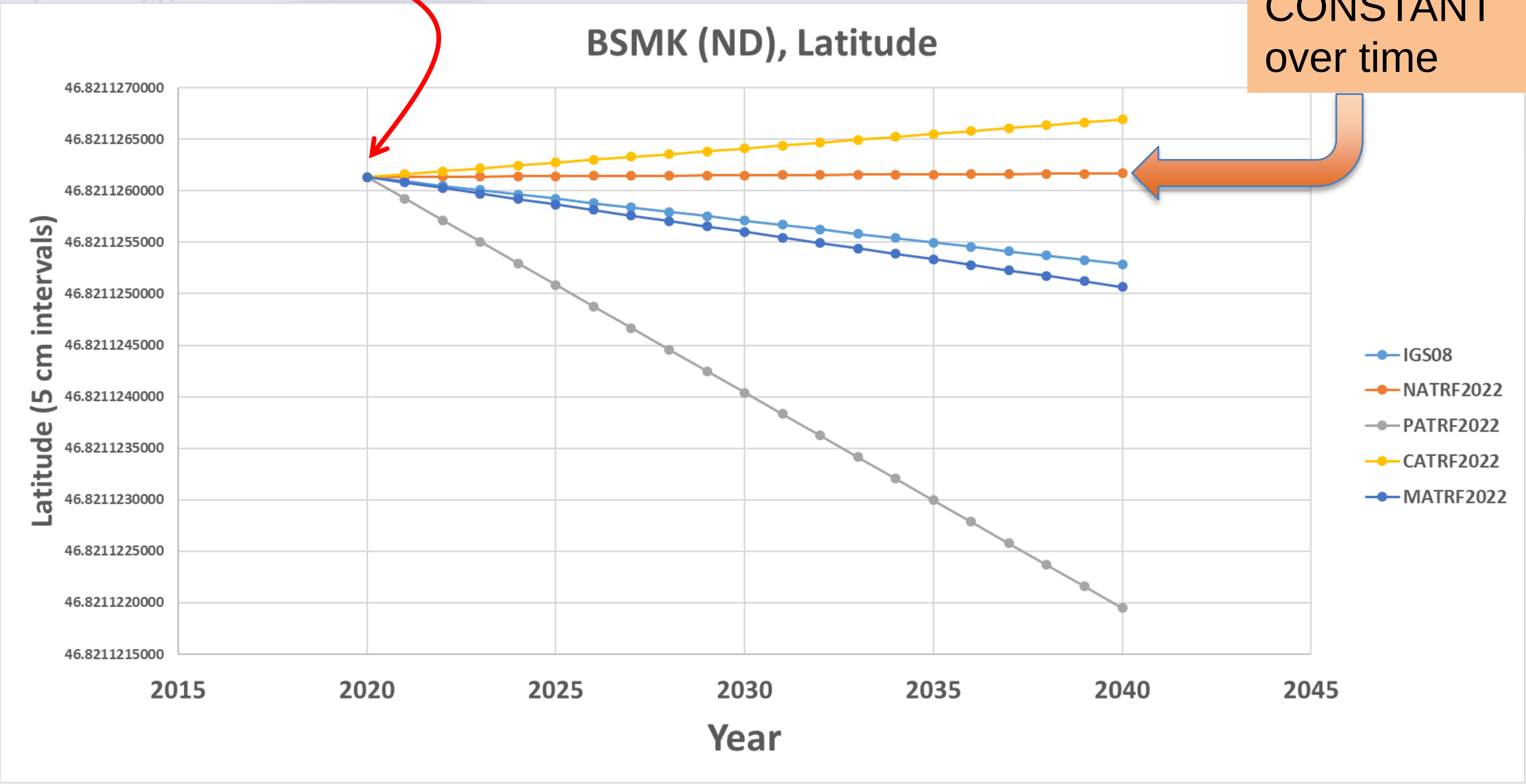


A ND Dep't of Transportation partner station in NGS' CORS (Continuously Operating Reference Station) GNSS Network. There are just over 1900 stations operating all of the world, but primarily in North America.

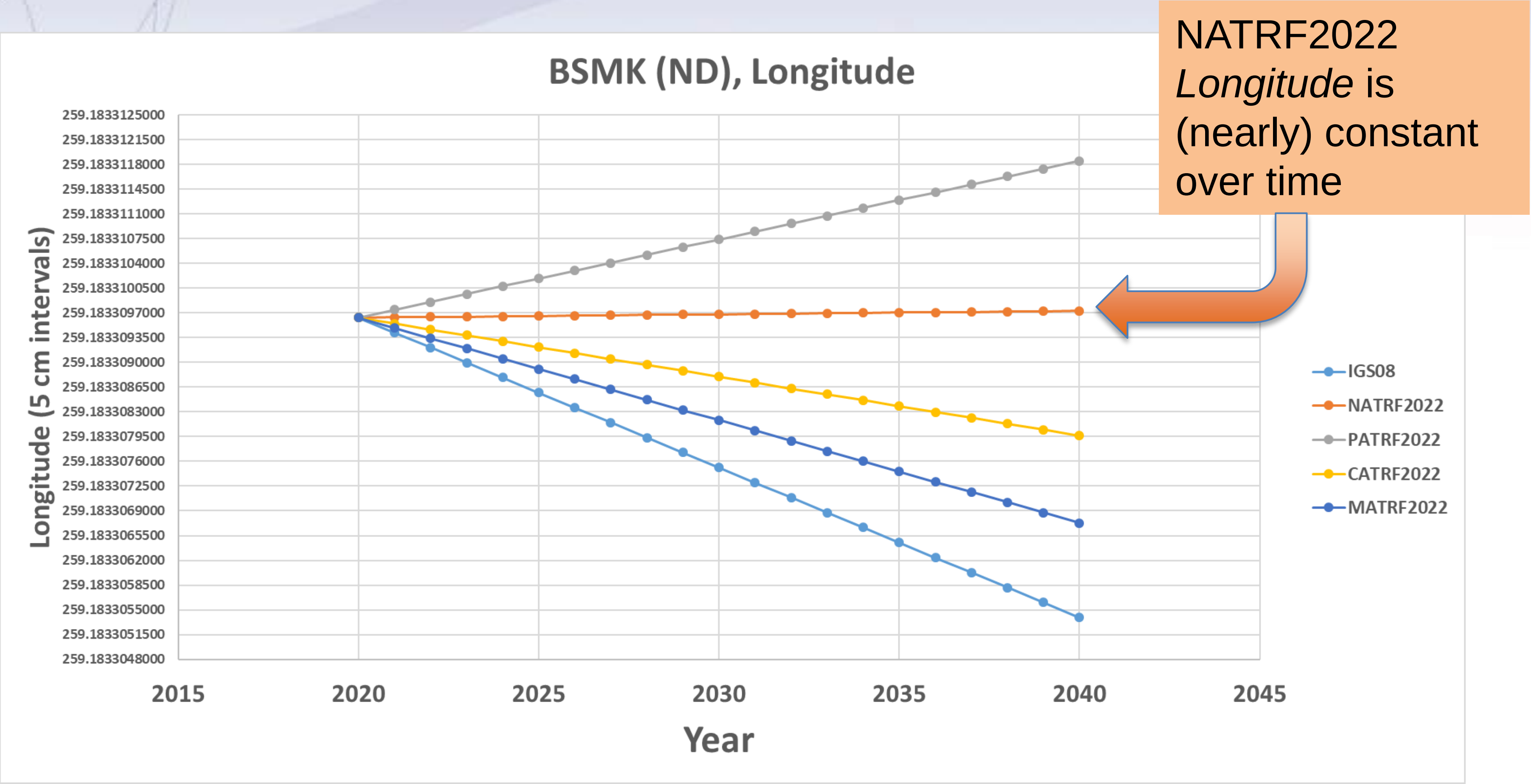
BSMK (North Dakota)

NATRF2022 *Latitude* is (nearly) CONSTANT over time

As per NGS policy decision circa 2018:
t_0 = 2020.0

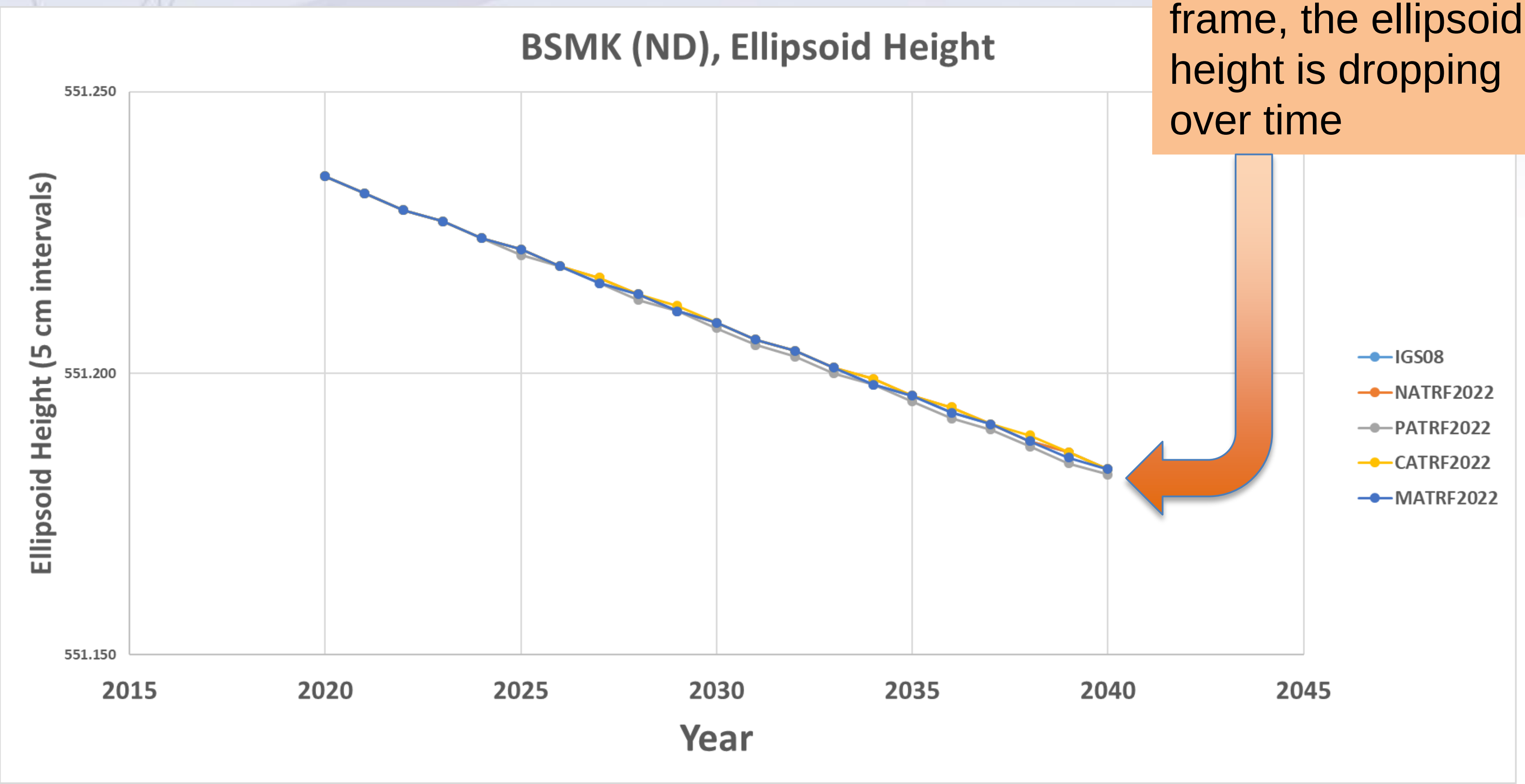


BSMK (North Dakota)



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

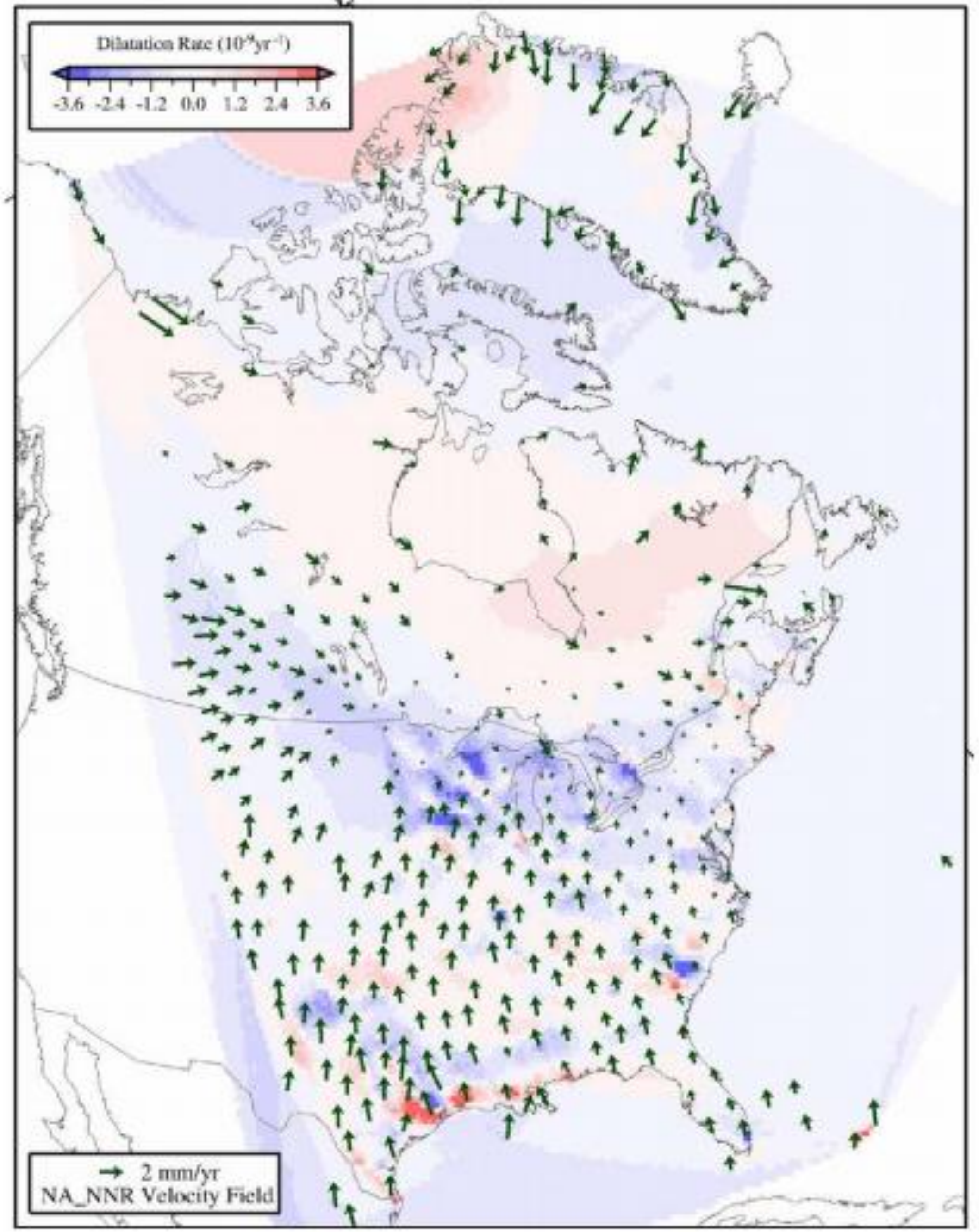


Figure 4: GIA-specific horizontal non-Eulerian velocities (Euler Pole Rotation Removed) using the MELD model (Blewitt, et al, 2016)

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

IFVM

- 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.

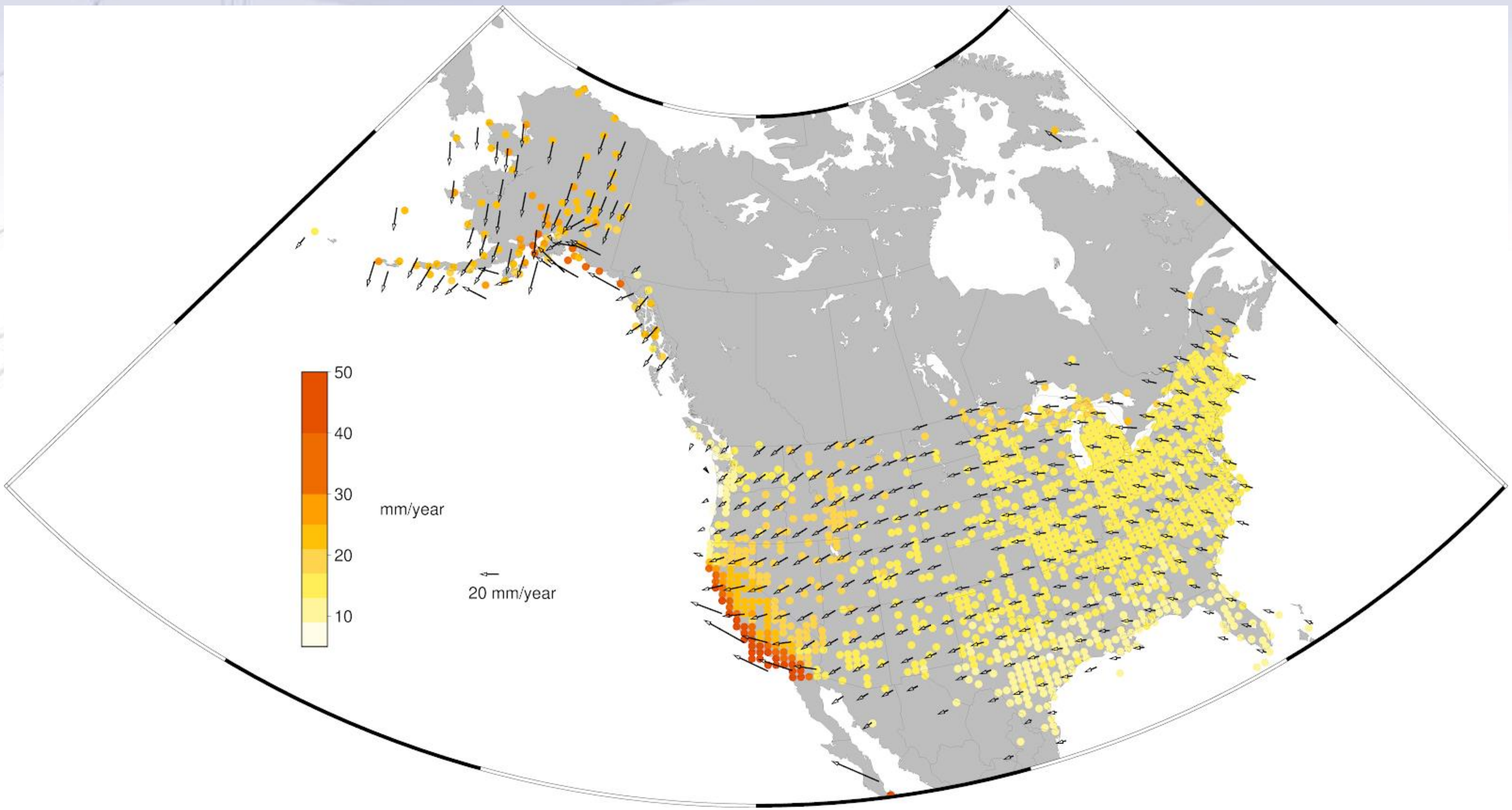
- IFVM will provide a model of remaining geometric horizontal AND vertical motion over time not accounted for by plate motion (GIA, subsidence, earthquakes, etc.)

- 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.

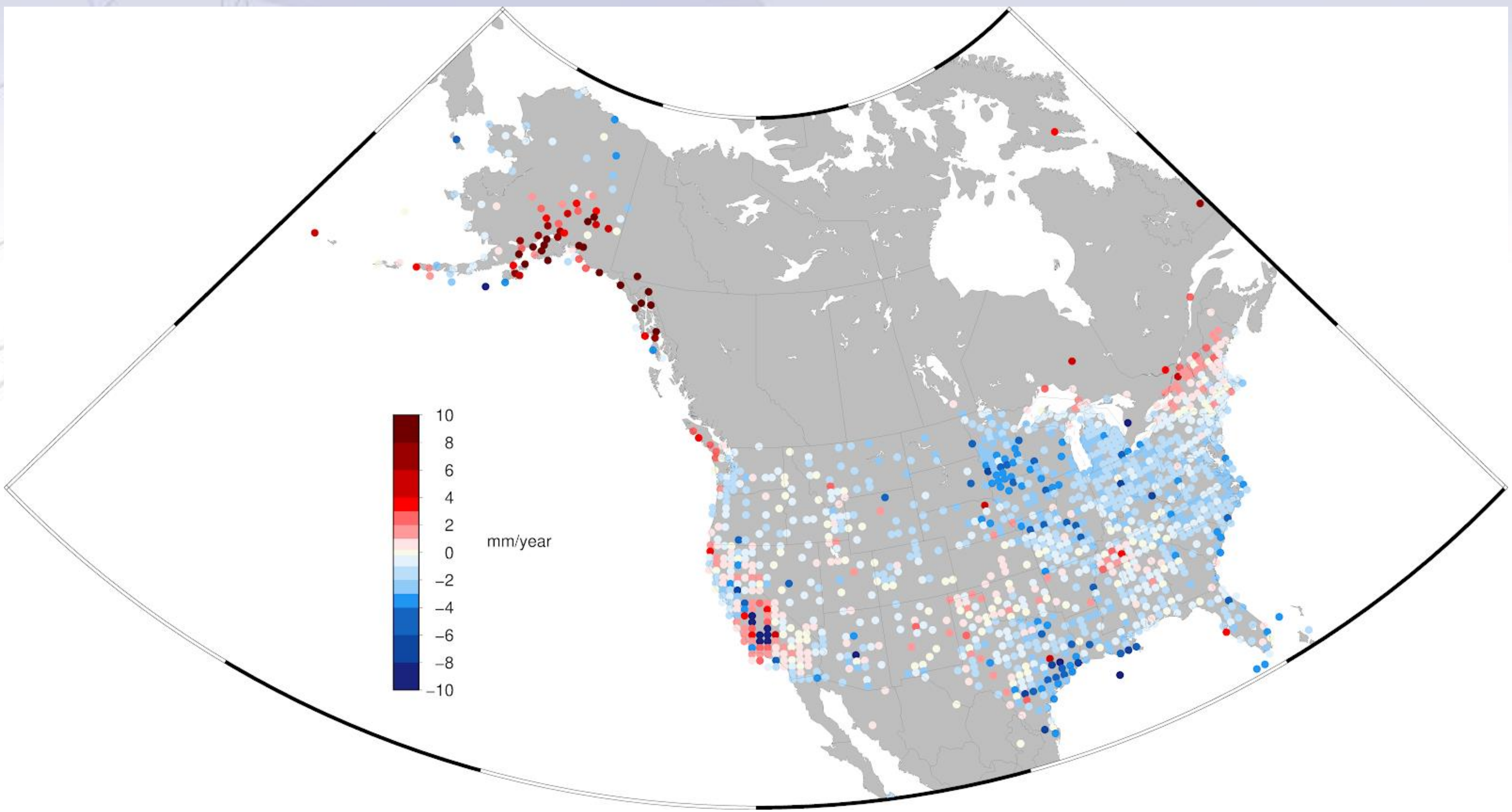
- Data-driven solutions are easier to maintain for all epochs and spatial scales needed to accomplish this task than models are.

- 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

$$H_{NAPGD2022}(t_c) \equiv h_{*TRF2022}(t_c) - N_{GEOID2022}(t_c)$$

Time-dependent <u>orthometric heights</u>

Time-dependent <u>ellipsoid heights</u> 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**

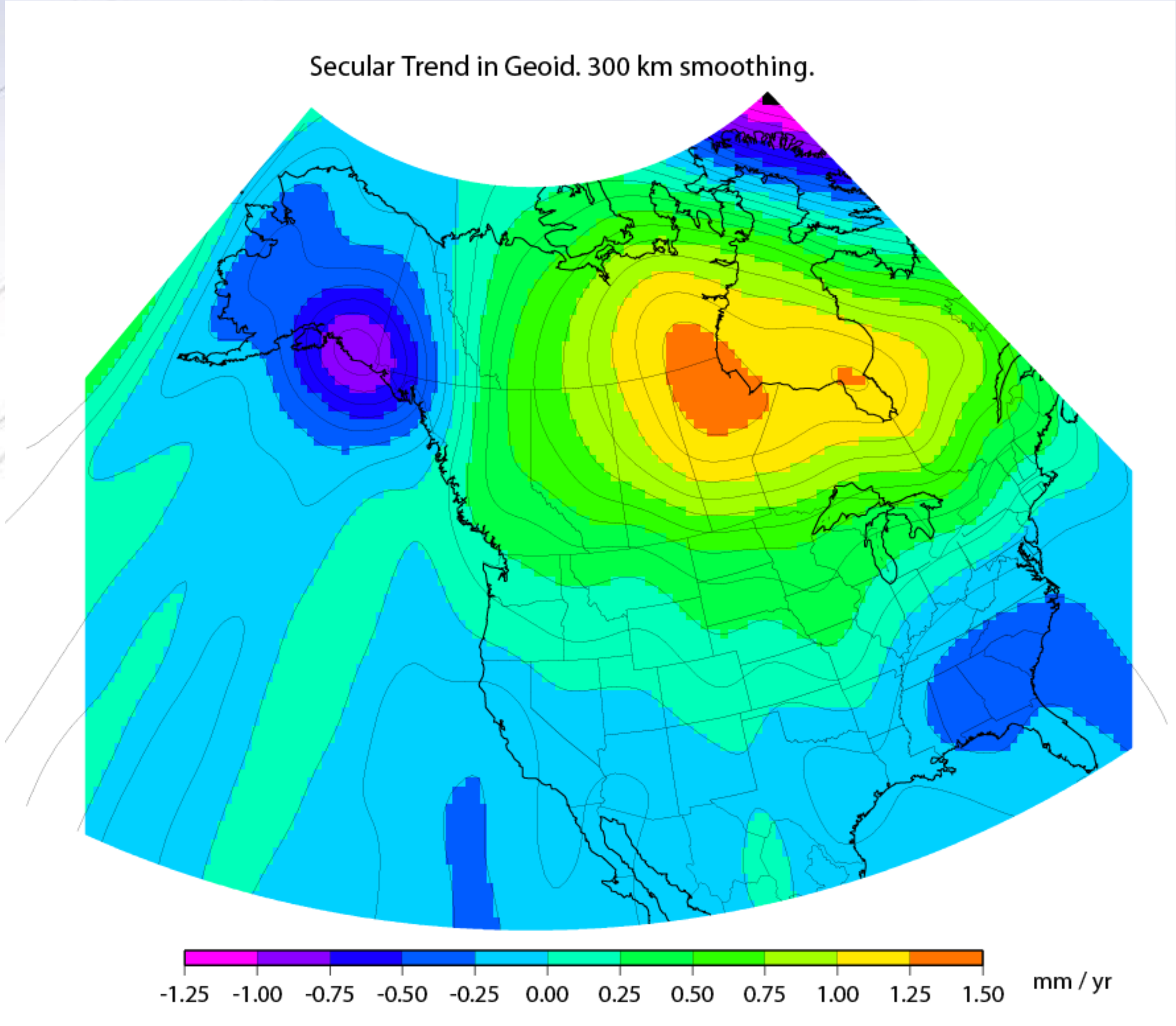
Time-dependent <u>geoid undulations</u> come from the dynamic component of GEOID2022 ("DGEOID2022")

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

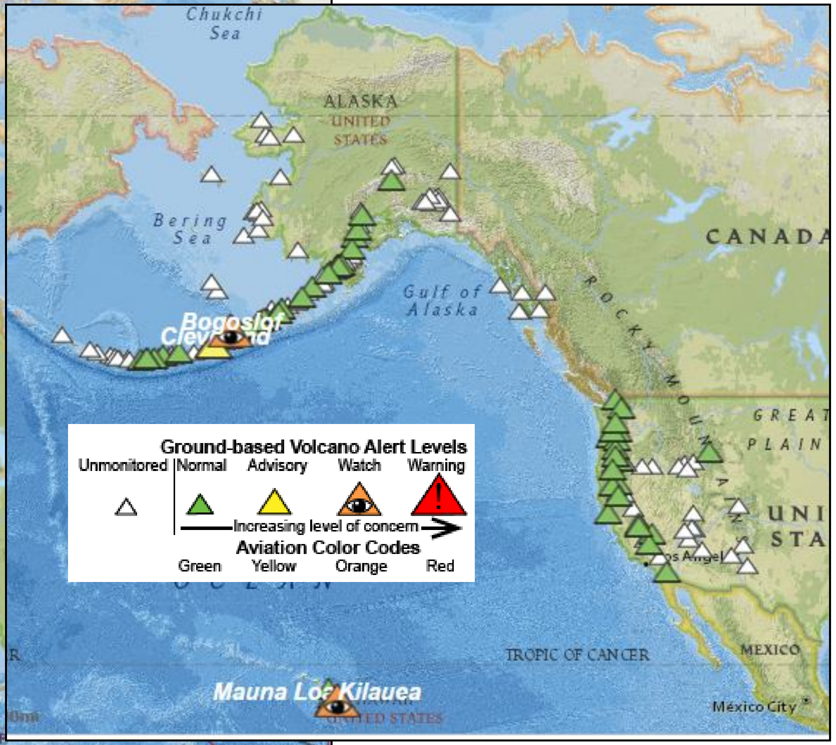
Con: Resolution is not sufficient to provide full geoid monitoring

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