Regional Reference Frames for North America

Current Status & Future Plans of Regional Sub-Commission SC1.3c

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Reference Frames for Applications in Geosciences (REFAG)
COSPAR 2018 Scientific Assembly
Pasadena USA, July 14-22, 2018

Natural Resources Canada Ressources naturelles Canada

Outline

- Regional Subcommission objectives
- WG1 – North American Reference Frame
- WG2 – New Plate-Fixed North American Reference Frame
- WG3 – Reference Frame Transformations
- Other activities

Objectives

- Provide international focus and cooperation for issues involving the horizontal, vertical and three dimensional geodetic networks of North America, including Greenland, Mexico and the Caribbean
- **Co-Chairs**
  - Mike Craymer, Canada
  - Dan Roman, USA (replaced Neil Weston in 2015)
- **Working Groups**
  - SC1.3cWG1 – North American Reference Frame (NAREF)
  - SC1.3cWG2 – New Plate-Fixed North American Reference Frame
  - SC1.3cWG3 – Reference Frame Transformations

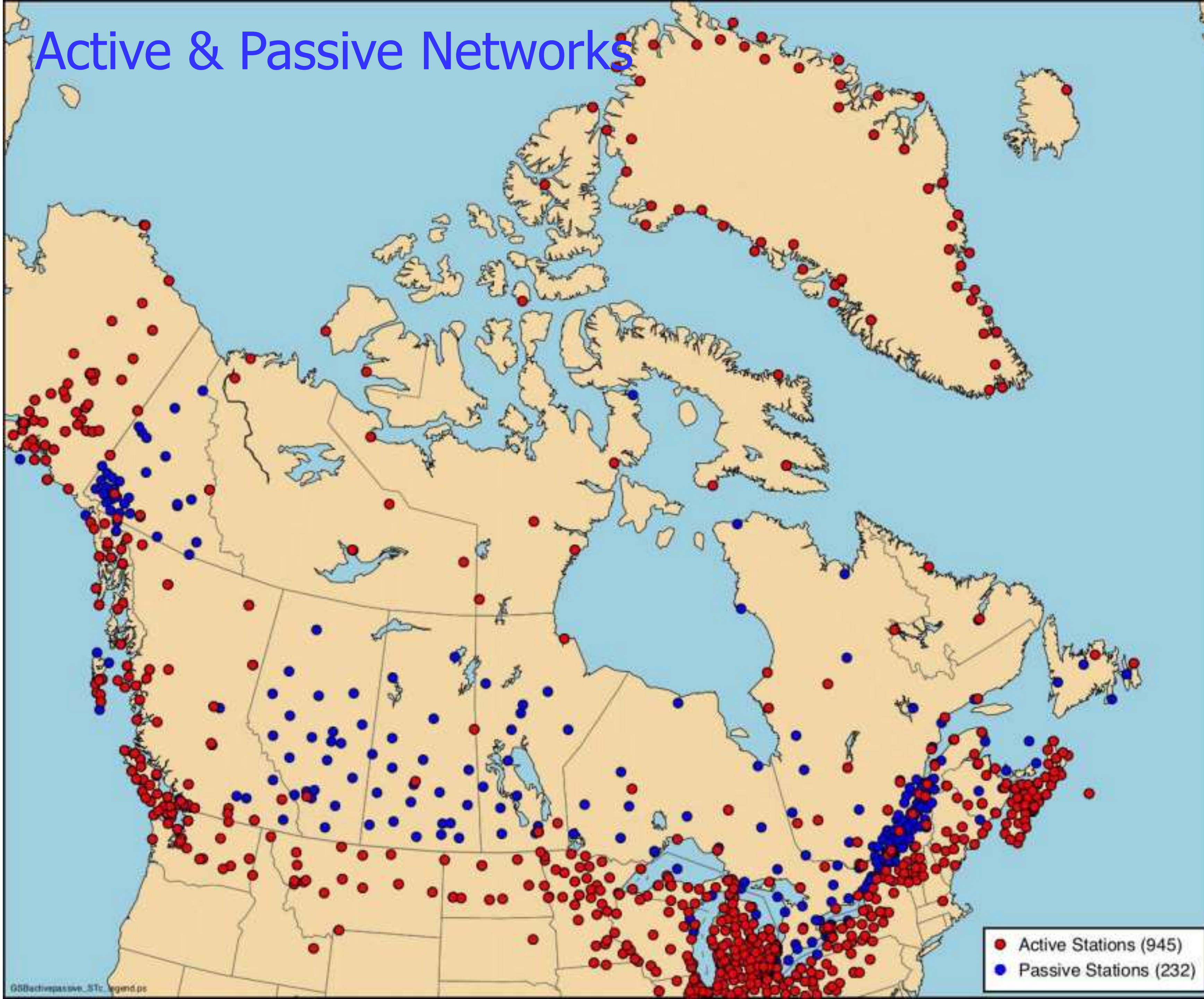
WG1 – NAREF

- **Objective**
  - Densify the ITRF/IGS global reference frame in North America
  - Compute weekly coordinate solutions
  - Combine weekly solutions into multi-year cumulative solutions
  - Integrate into ITRF via the IGS global network
  - Include all public continuous GPS sites in N.A. (4500+ stations)
  - Follow IGS processing guidelines
    - Current IGS reference frame
    - IGS orbits and EOPs
    - Current absolute antenna phase center models
- **Products**
  - Weekly coordinate solutions (combinations of regional solutions)
  - Periodic multi-year cumulative (velocity) solutions

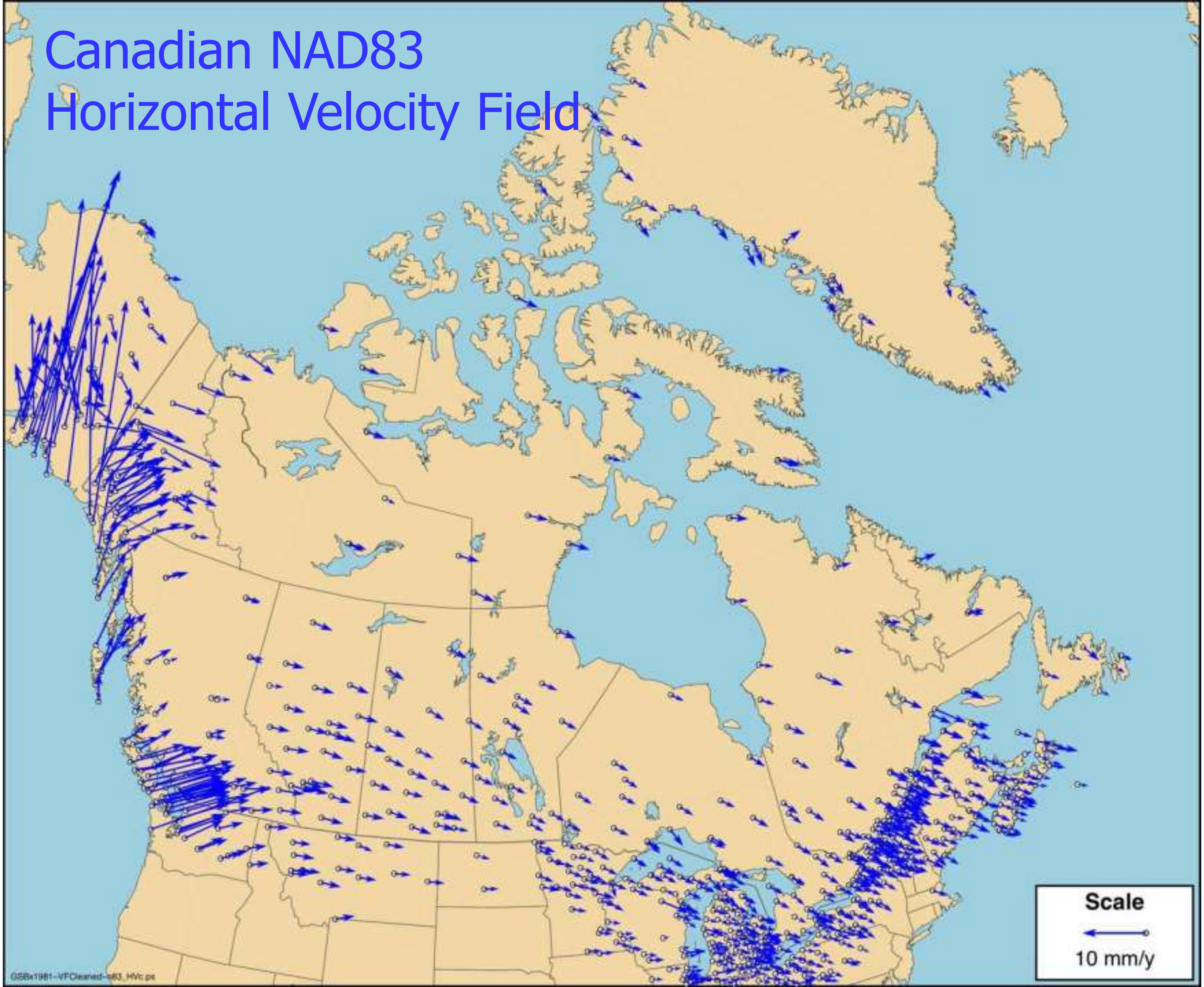
Regional Solutions – Canada

- **Network of all public GNSS stations in northern half of N.A.**
  - ~900 active stations & ~230 passive stations (high campaign)
  - Many new stations added to densify the ITRF – see map next slide
  - Mainly in targeted areas for monitoring GIA and tectonic motion
  - Considering adding ~1000 commercial RTK networks in Canada
- **Producing weekly coordinate solutions since 2000**
  - Bernese GNSS Software 5.2
  - IGS final orbits (current & repro2) and antenna calibrations
  - Aligned to IGS14 with global IGS core stations
- **Producing cumulative solutions from weekly solutions**
  - Multi-year solutions for coordinates & velocities updated monthly with new data and stations
  - Able to simultaneously estimate seasonal & post-seismic terms

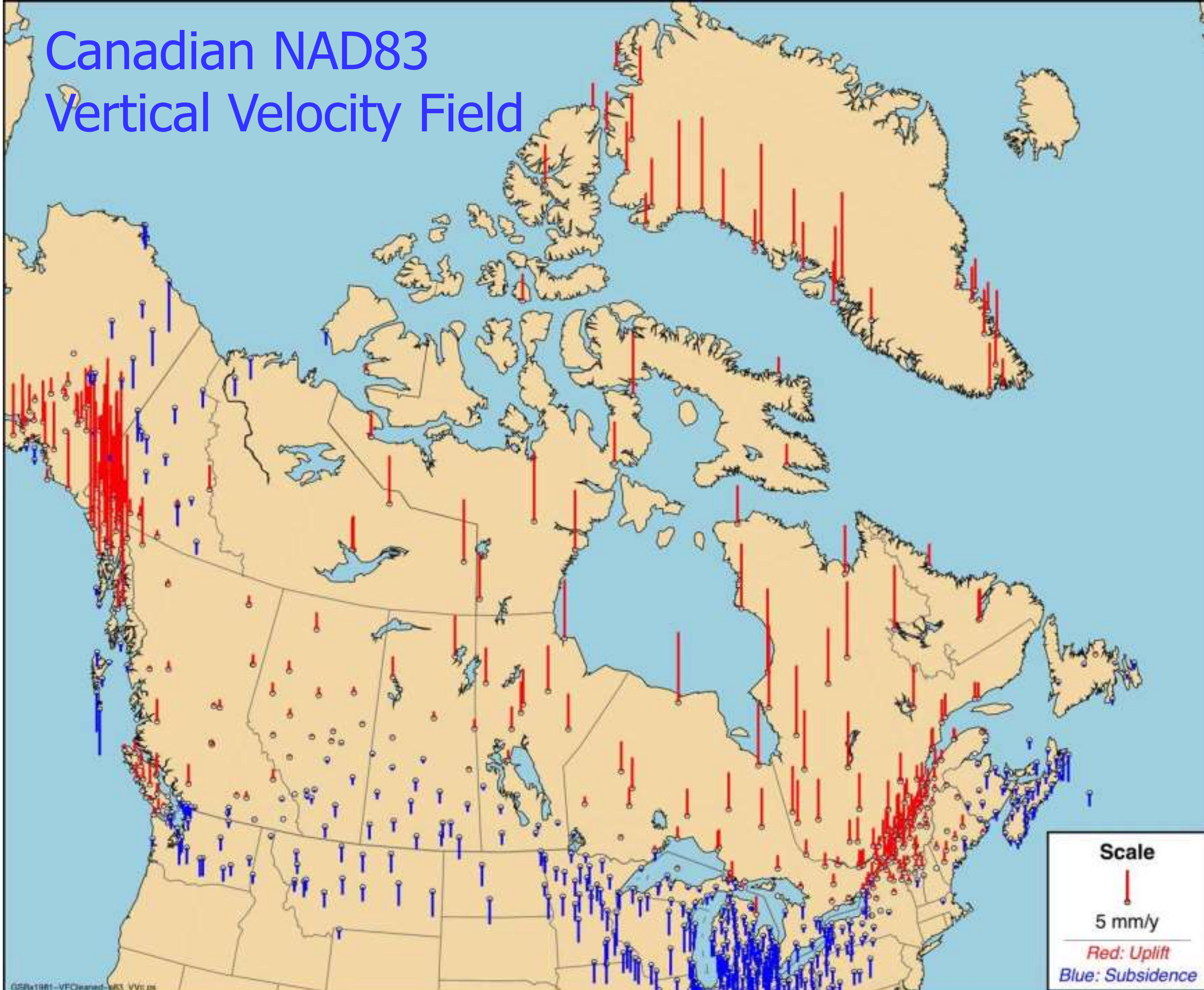
Active & Passive Networks



Canadian NAD83 Horizontal Velocity Field



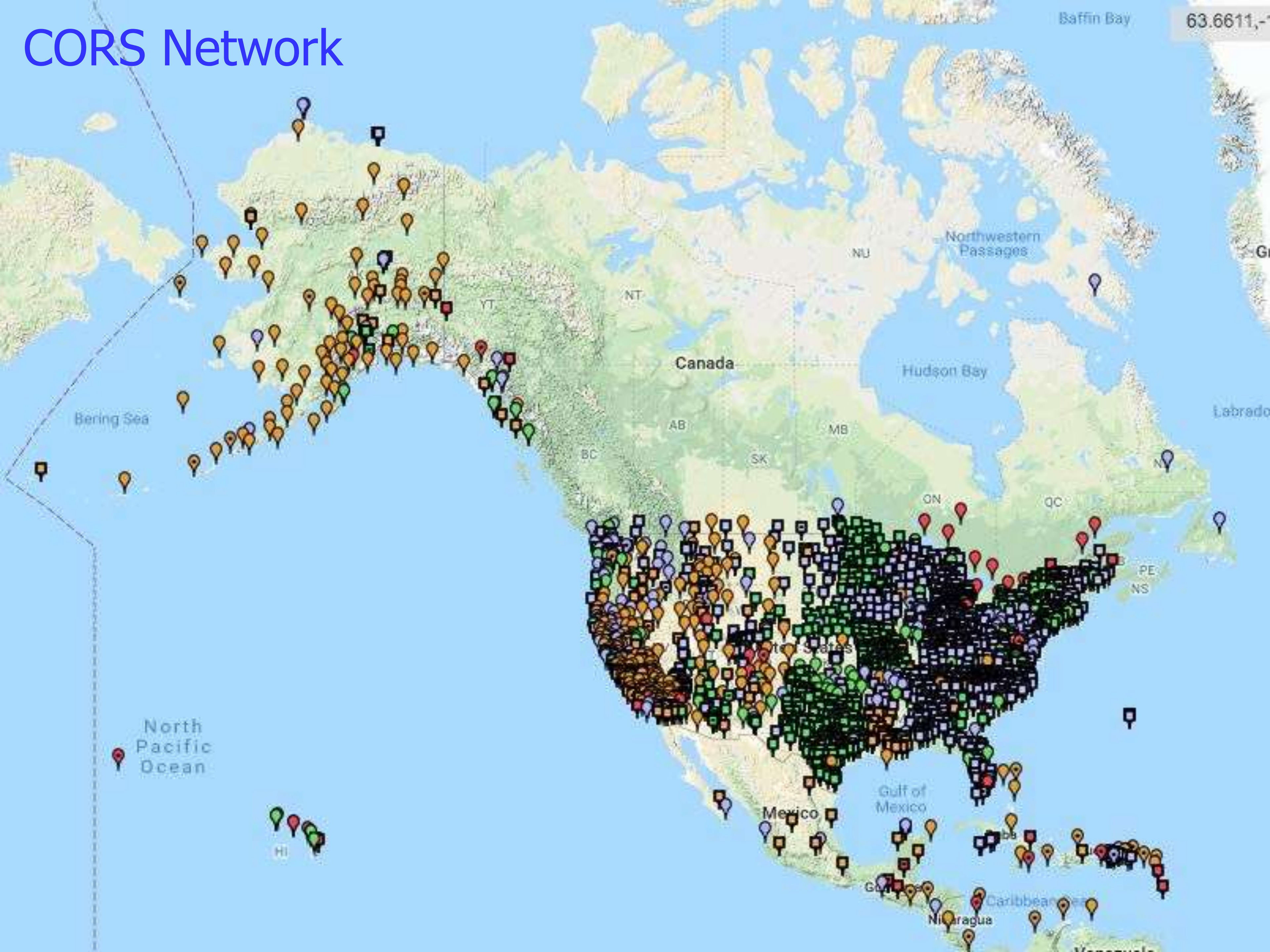
Canadian NAD83 Vertical Velocity Field



Regional Solutions – United States

- **Network of all public GNSS stations (CORS)**
  - ~2500 CORS stations
  - Covers continental US, Mexico, Hawaii and US territories in Caribbean, American Samoa, Guam & Marianas – see map
- **Weekly coordinate solutions**
  - Reprocessing all data with PAGES software
  - IGS final orbits (current & repro2) and latest antenna calibrations
  - Aligning to IGS14 with global IGS core stations
- **Multi-year solution**
  - Last solution from 2011
  - New solution from reprocessing results by end of year
  - Using recent version of CATREF

CORS Network



Future Plans

- **US repro2 processing**
  - Currently in internal testing; public release planned for ~~September~~ October
- **Position & velocity discontinuities**
  - Determine a common set of position & velocity discontinuities for US & Canadian multi-year solutions
- **Commercial RTK networks in Canada**
  - Densify sparse active network with commercial RTK stations
  - Already processing commercial RTK data for RTK compliance agreements
  - Currently investigating stability of sites
- **Foundation CORS**
  - US National Assets to densify IGS network to meet operational needs – partnering with NASA and NSF for NATRF
  - SIRGAS and APREF for OCONUS (CATRF, PATRF)

Foundation CORS Requirements

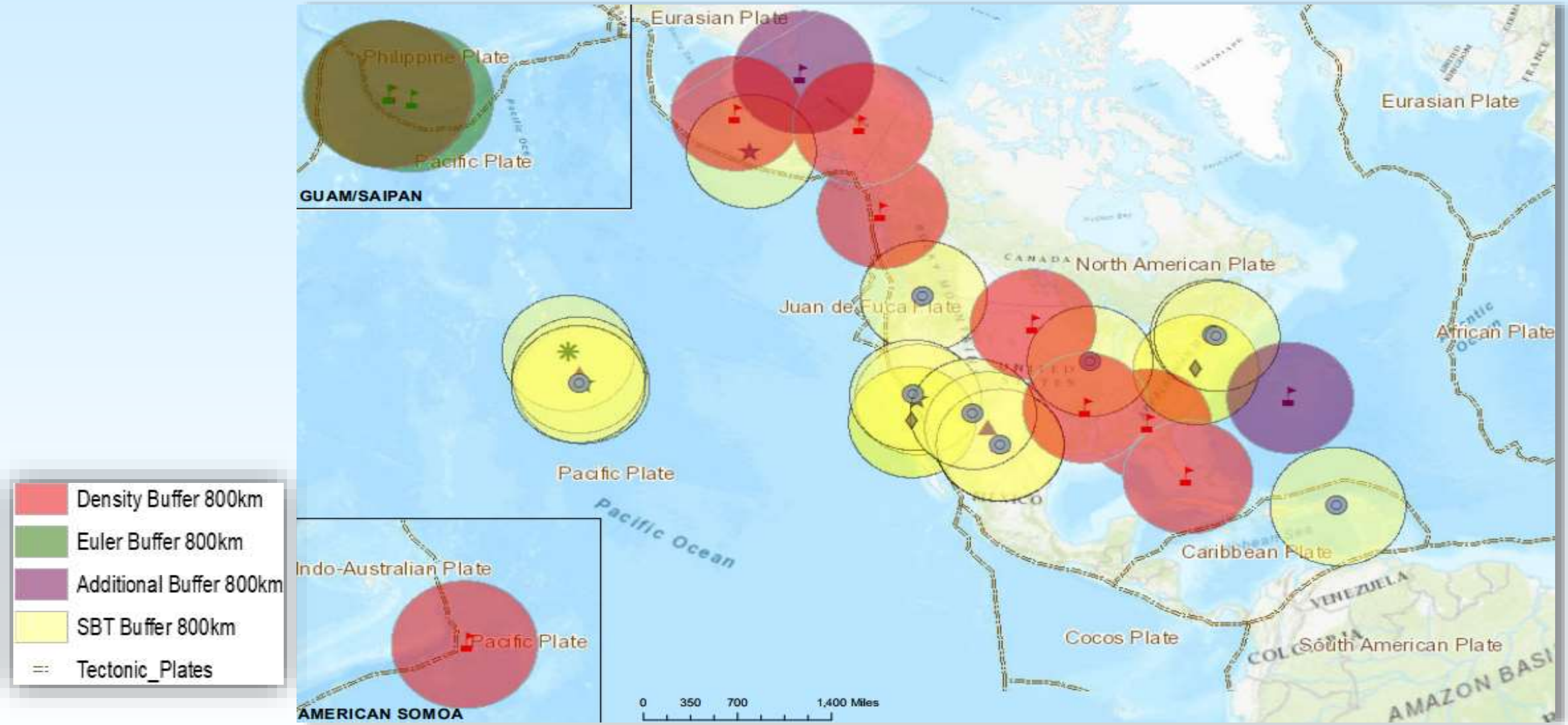
Baseline Foundation CORS Network

Collocation:
All sites within the Foundation CORS target area of the United States, with existing space geodetic techniques (SLR, VLBI or DORIS), will have a collocated Foundation CORS.

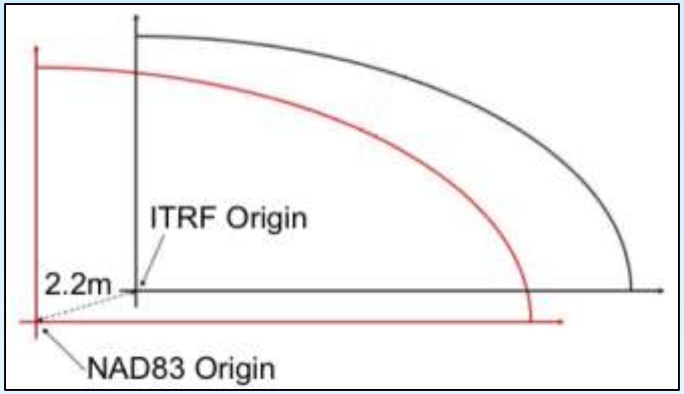
Additional Desired Foundation CORS Network Requirements

- **Density:** Install or adopt new stations within the Foundation CORS target area of the United States. (Fulfill the spacing criteria of 800 kilometers within the Foundation CORS target area.)
- **Plate Rotation (Euler Pole):** Install or adopt new stations within the U.S. Foundation CORS target area to raise the minimum number of Foundation CORS to three on each of the four plates of interest, once the above criteria are met.
- **Additional (Gap Filling):** Install or adopt new stations, on a case-by-case basis, once the above criteria is met (*).

Collocated + Density + Plate Rotation + Additional

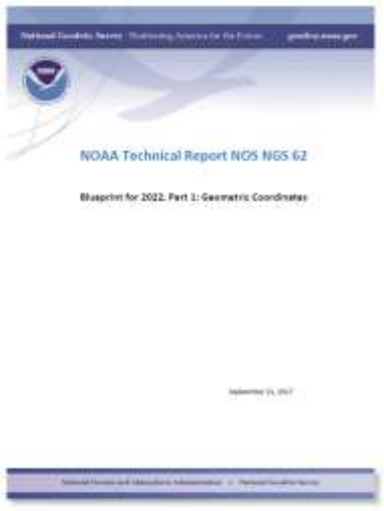


WG2 – Plate-Fixed N.A. Reference Frame



- **Problems with NAD83**
  - Offset ~2 m from geocentre (ITRF)
  - Defined by transformation from ITRF but biased by 2 mm/yr
- **Objective**
  - Establish a new high-accuracy, geocentric reference frame, including velocity models, procedures and transformations, tied to the North American tectonic plate
  - Establish similar frames for US territories in Caribbean & Pacific
  - Determine intra-frame velocity models (grids) for each frame to enable propagating coordinates to different reference epochs
  - Replace NAD83 & US vertical datum by 2022

Current Progress


NOAA Technical Report NOS NGS 62

Blueprint for 2022, Part 1: Geometric Coordinates

- **Published "blueprint" documents**
  - Defines implementation of new reference systems
  - Part 1 on geometric and Part 2 on vertical
- **Reference frame definition**
  - Will use latest ITRF in 2022 at some adopted reference epoch
  - Will estimate plate motion via Euler pole rotation to keep frames aligned to plates
- **Defined names of new reference frames for North America & other US territories**
  - NATRF2022 – North American Terrestrial Reference Frame
  - CATRF2022 – Caribbean Terrestrial Reference Frame
  - PATRF2022 – Pacific Terrestrial Reference Frame
  - MATRF2022 – Marianas Terrestrial Reference Frame

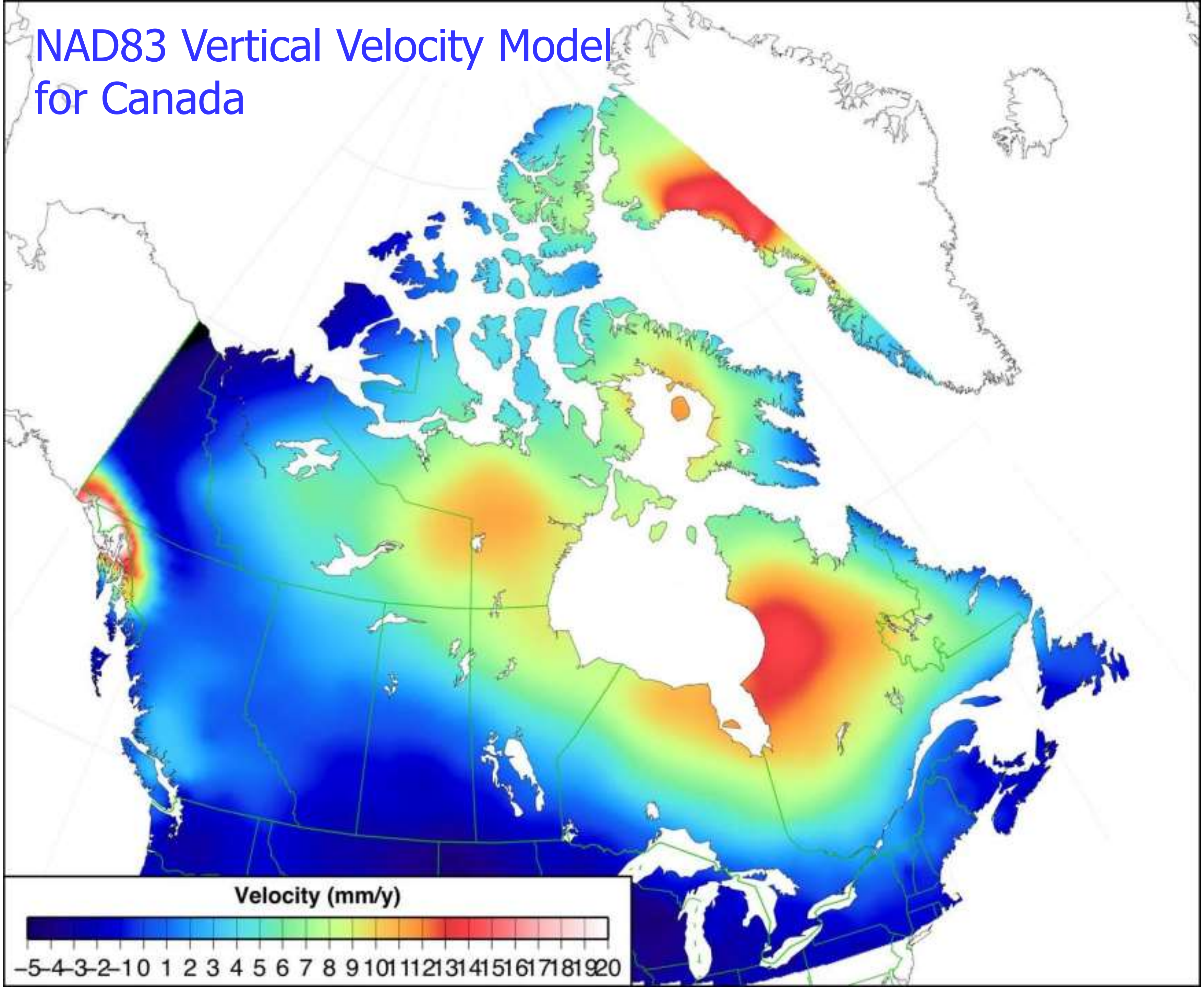
WG3 – Reference Frame Transformations

- **Objectives**
  - To determine consistent relationships between international, regional and national reference frames/datums in North America
  - Maintain and update these relationships
  - Provide tools for implementing the transformations
  - *Primarily involves maintaining the adopted relationship between ITRF and NAD83*
- **NAD83 – ITRF Transformation**
  - NAD83 is now defined by a transformation from ITRF96
  - Transformation is incrementally updated to new ITRF's using adopted IERS transformations between ITRF realizations
  - NNR-NUVEL-1A is used to keep the frame fixed to N.A.
  - Updated transformation to ITRF2014

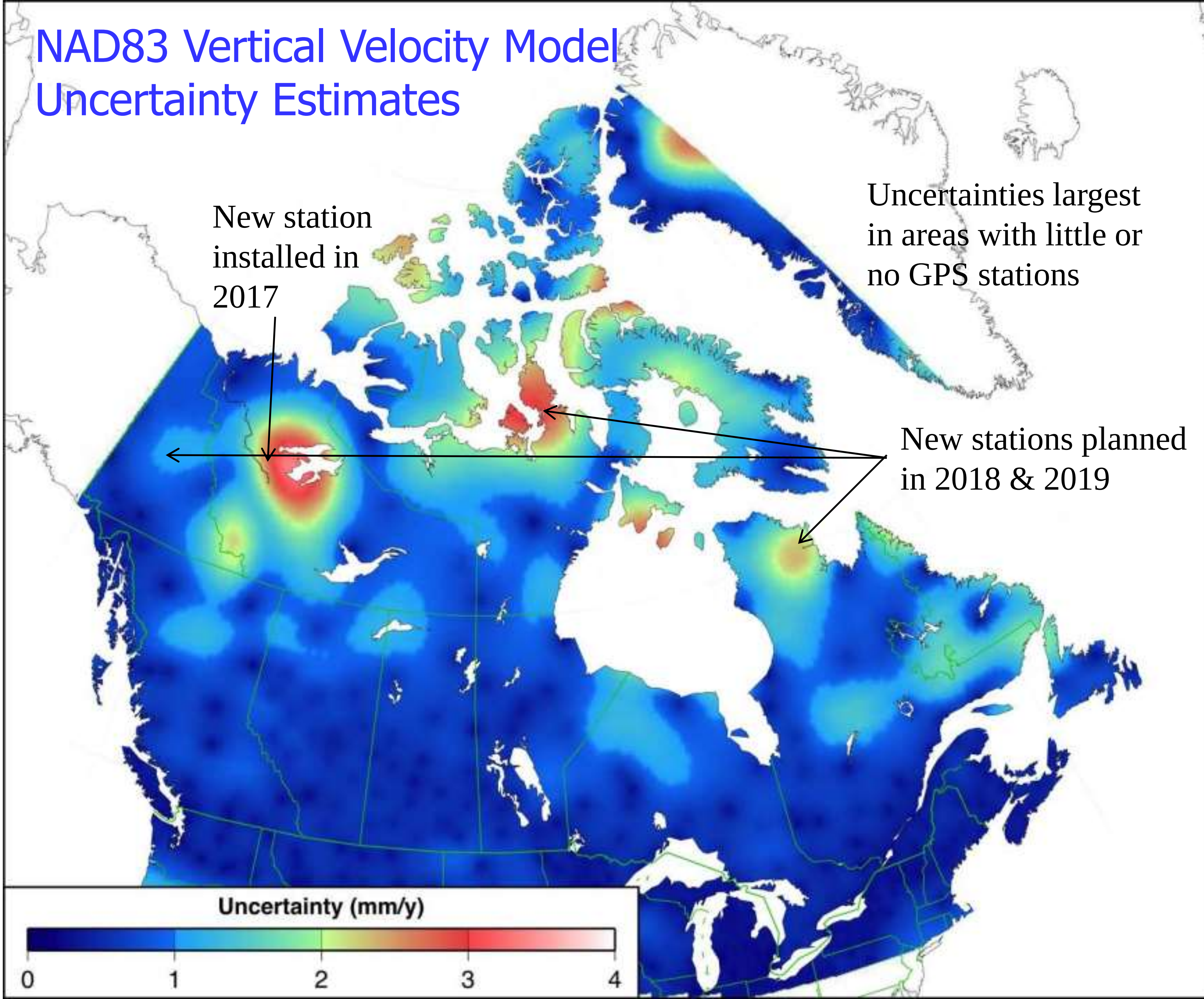
WG3 – Reference Frame Transformations

- **Transforming NAD83 coordinates between epochs in Canada**
  - Required to propagate coordinates to a common reference epoch
    - Different provinces in Canada use different reference epochs
  - Using model (grid) of 3D crustal velocities interpolated from GPS velocity field in NAD83
  - Using a "hybrid" vertical grid derived from GIA models constrained to the GPS velocity field (remove, compute, restore method)
  - Estimates of uncertainties of velocity model also provided and used to target weak areas for new GNSS stations
- **Intra-frame velocity/deformation models will be determined for new reference frames in 2022**
  - These deformation models will replace HTDP in US
  - Investigating different methods of determining deformation models

NAD83 Vertical Velocity Model for Canada



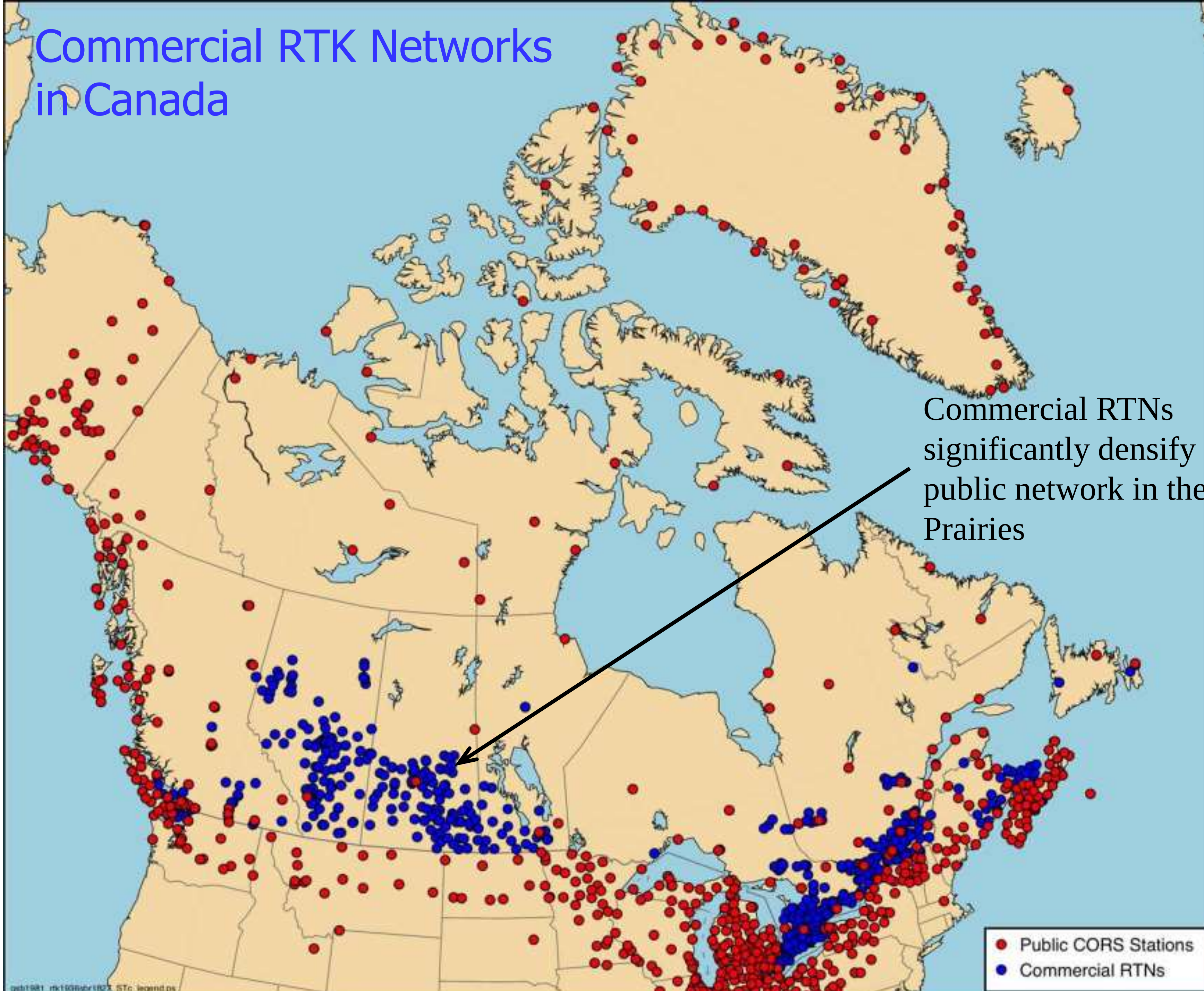
NAD83 Vertical Velocity Model Uncertainty Estimates



Other N.A. Activities

- **Commercial RTK network certification in Canada**
  - Commercial RTK networks (RTNs) effectively acting as access points to NAD83 for many users
  - Problem – RTNs integrated into different realizations of NAD83 and in inconsistent ways
  - Canada (CGS) has implemented “compliance” agreements with 4 largest RTN service providers
    - Providing official NAD83 coordinates for all RTN stations (~1000 stations)
    - Monitoring stations using weekly coordinate solutions – time series publicly available online
    - Classifying stations as non-compliant when weekly coordinates differ from official values by defined tolerance (2 cm horz, 3 cm vert)

Commercial RTK Networks in Canada



Commercial RTNs significantly densify public network in the Prairies

Other N.A. Activities – cont'd

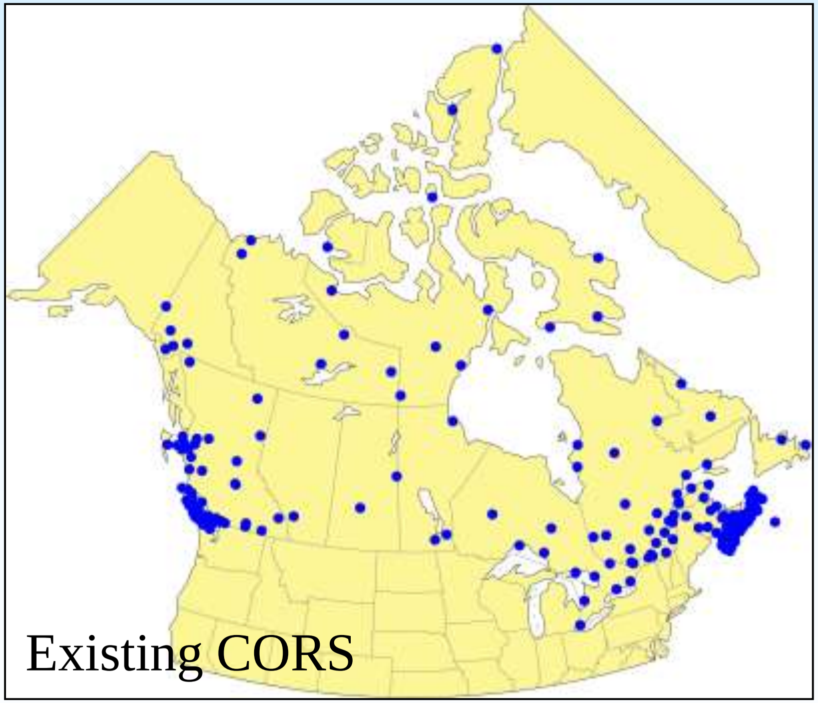
- **Commercial RTK networks in United States**
  - US (NGS) has no plans to certify RTNs in United States
  - RTN users validate RTN services by comparing RTN positions of known geodetic markers to published positions or OPUS-Share solutions
  - Developing alignment/tracking tool for RTNs and other private CORS networks

Other N.A. Activities – cont'd

- **Initiative to enhance geodetic infrastructure in Canada**

  General areas of discussion for PNT initiative:

  - Densification of CORS, more real-time, perhaps in partnership with industry/provincial governments
  - Greater GGOS contribution
  - Improved real-time PPP availability
  - Resilience through integrity monitoring
  - Consideration of non-geodetic uses of GNSS data (e.g., meteorology)



Other N.A. Activities – cont'd

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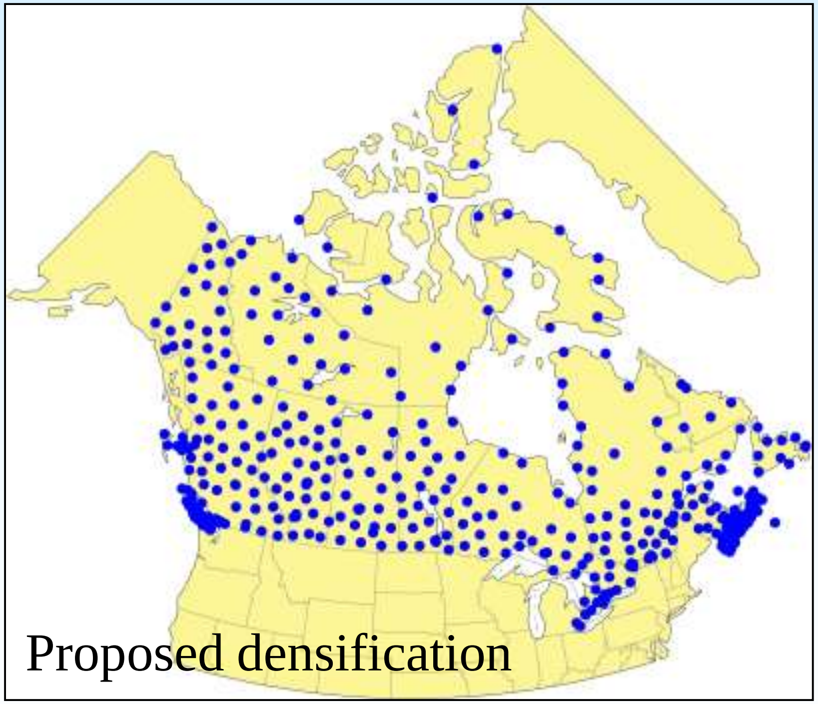
Proposed densification

Questions?

Other N.A. Activities – cont'd

- **International Coordination**
  - SIRGAS
    - Focus is by definition on all of the Americas
    - US is now member of SIRGAS
    - Coordination between IAG 1.3b and 1.3c
  - UN-GGIM-Americas
    - WG 3 on Geospatial Data Infrastructure
    - Oversight of SIRGAS activities proposed
    - Consistent with EUREF and UN-GGIM-Europe
  - UN-GGIM-Asia/Pacific
    - WG 1 on Reference Frames
    - Aligned with APREF
    - US joining in support of PATRF and MATRF development

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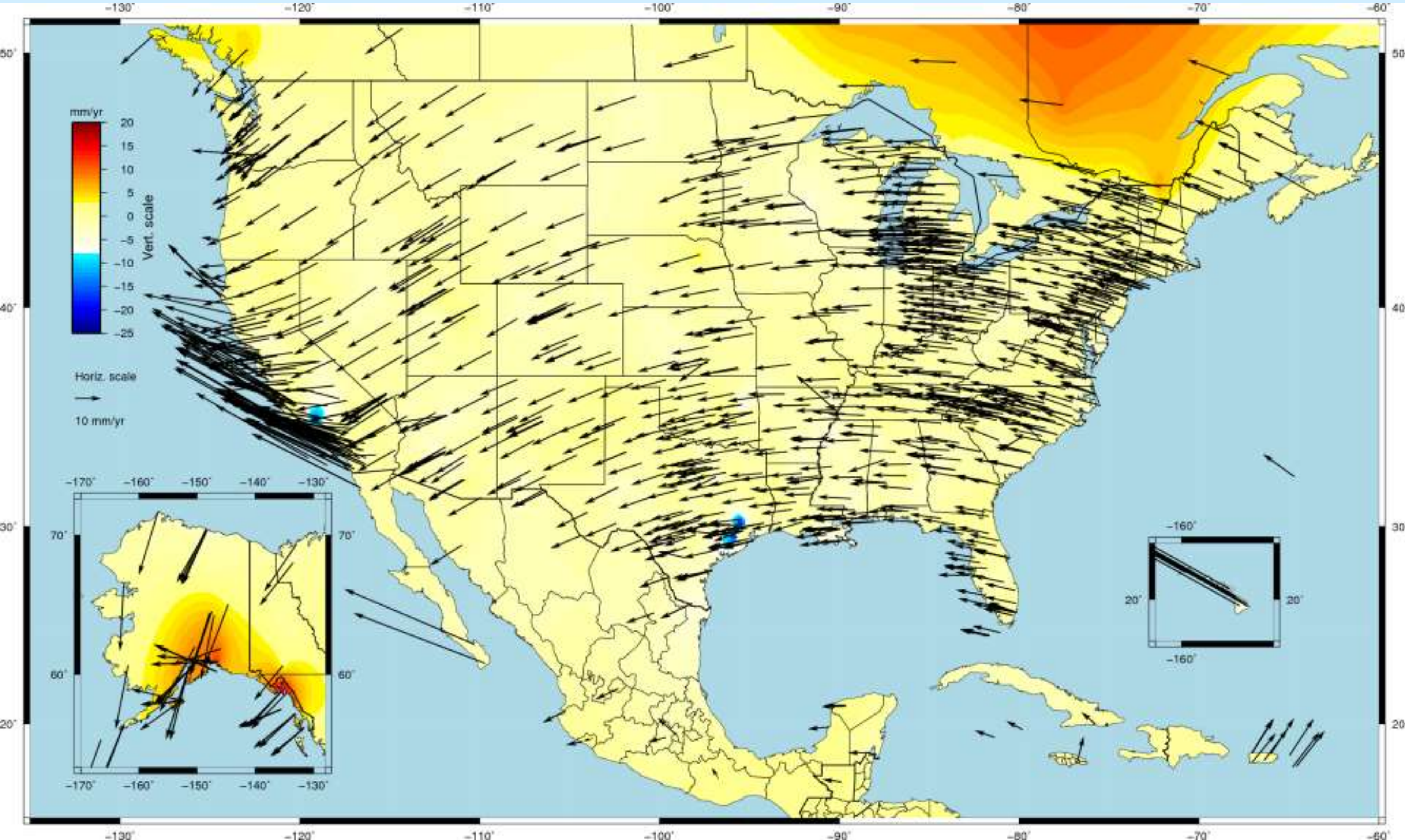
Regional Reference Frames for North America

NGS Multi-Year IGS08 Solution from 2011



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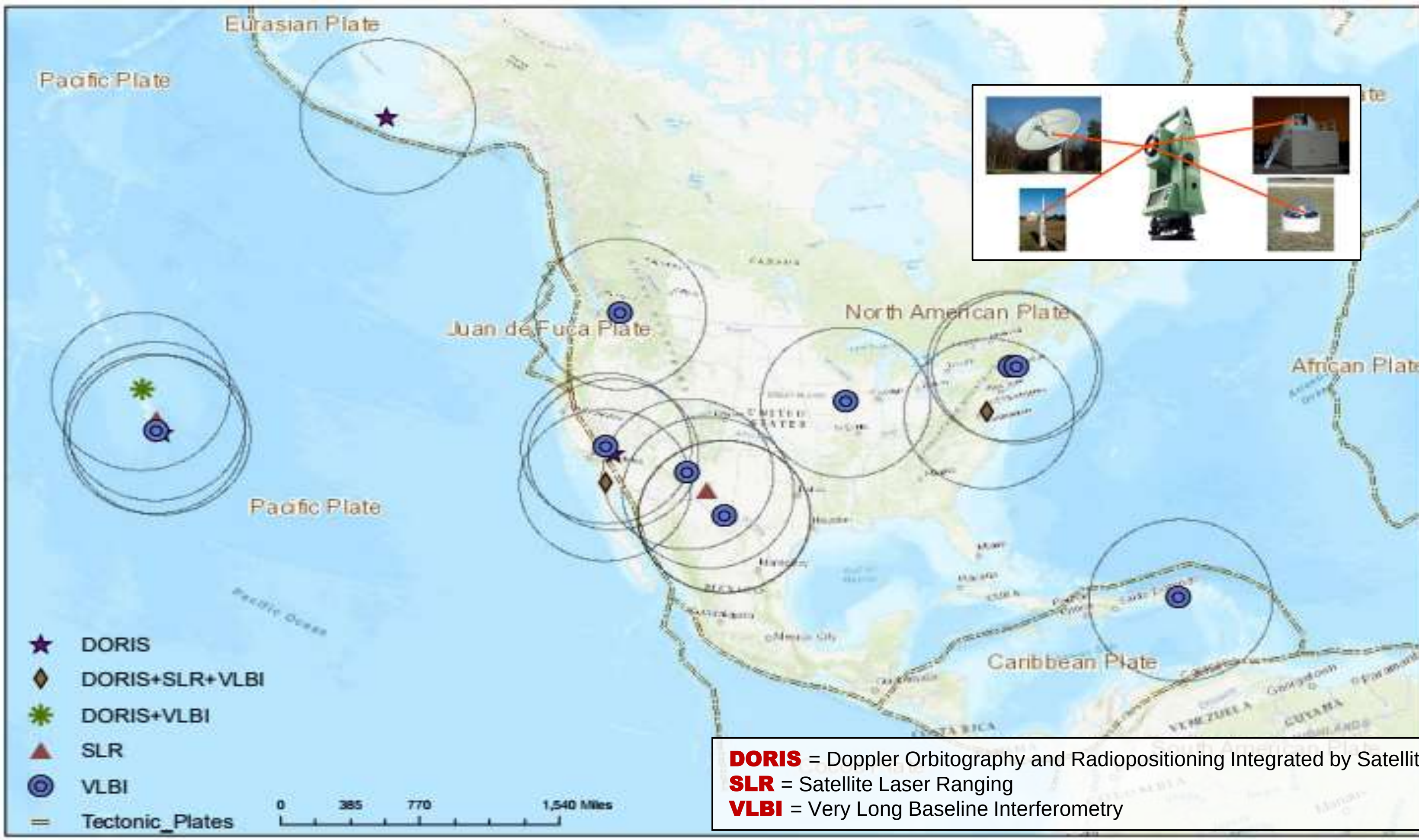
Collocated w/ NASA Spaced-Based Technology



DORIS = Doppler Orbitography and Radiopositioning Integrated by Satellite
SLR = Satellite Laser Ranging
VLBI = Very Long Baseline Interferometry

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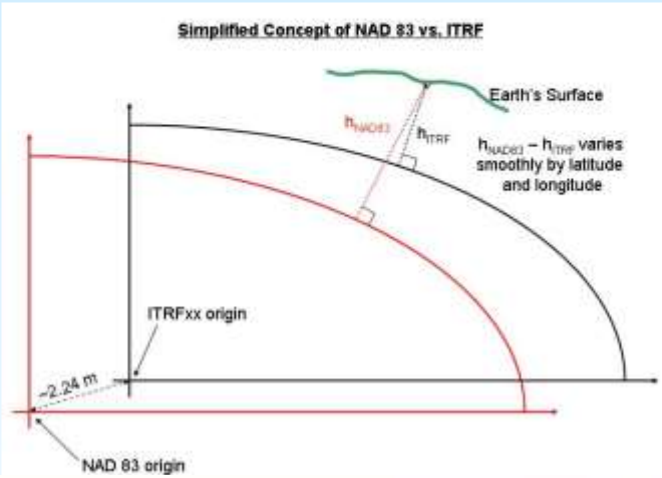
Current Progress – cont'd

- **US Foundation CORS**
  - Creating a network of ~36 highly stable CORS sites
  - Densifies IGS network and provides a more stable network to define the new frames in US territories
  - NGS either owns/operates or has MOAs with other US Agencies
  - First site installed in Miami
- **Outreach efforts**
  - Public US Federal Geospatial Summits held in 2010, 2015 & 2017
  - AGU 2016 Fall Meeting session on new reference frames
  - WG2 workshop held at CGU 2018 Annual meeting in June
    - Discussed different methods of determining Euler pole rotation
  - AGU 2018 Fall Meeting session on new reference frames planned

Why Update the US NSRS?

- **NAD83 issues**



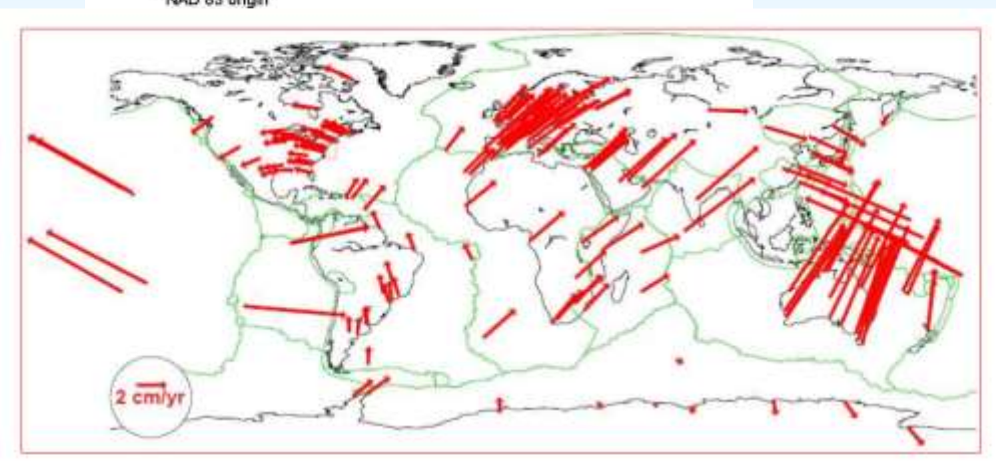
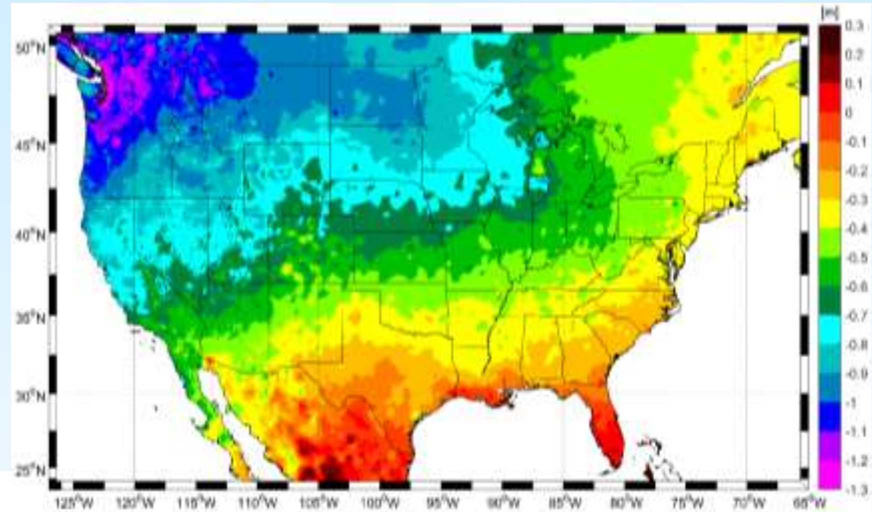
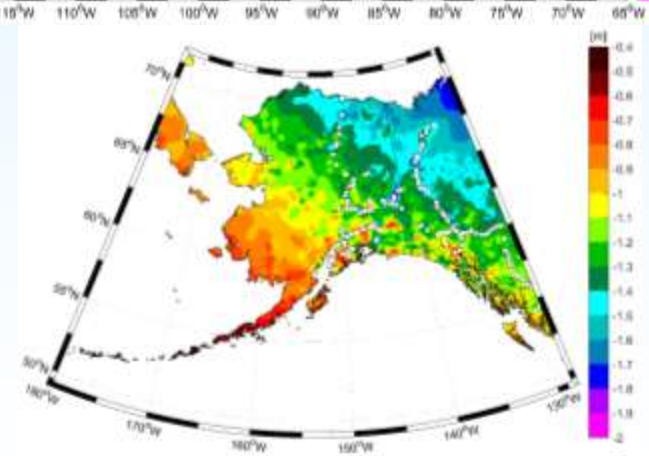


Figure 1. Horizontal velocities of the 203 selected sites for the ITRF2008 PMM estimation

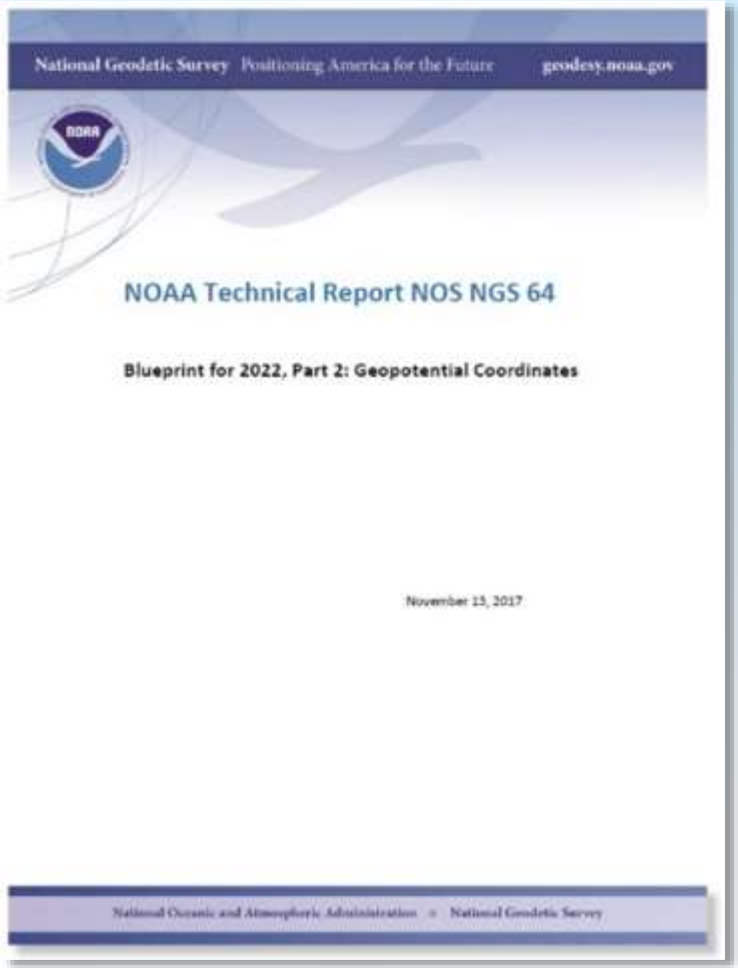
- **NAVD 88 issues**





NAPGD2022

- Mutual consistency of heights, gravity, etc.
- Time dependent coordinates
- Geoid definition decoupled from GMSL
- Orthometric heights defined by GNSS & geoid heights


National Geodetic Survey Positioning America for the Future geodesy.noaa.gov

NOAA Technical Report NOS NGS 64

Blueprint for 2022, Part 2: Geopotential Coordinates

November 15, 2017

National Oceanic and Atmospheric Administration • National Geodetic Survey

Definitional Relationship

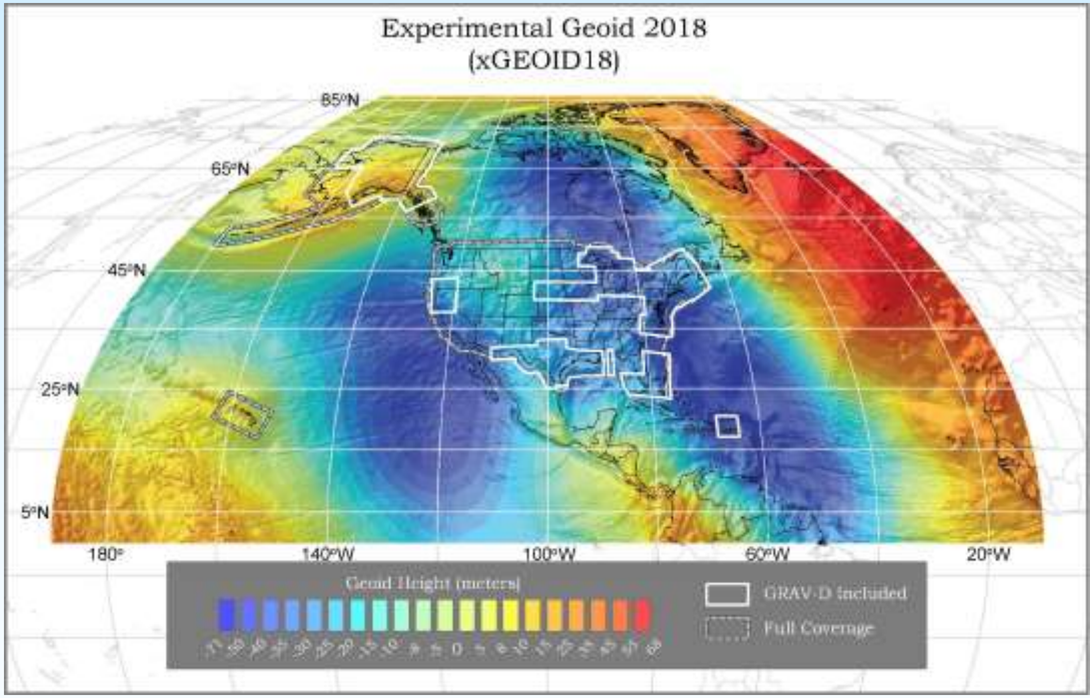
$$H_{NAPGD2022}(t) = h_{ITRF2022}(t) - N_{GEOID2022}(t)$$

Time-dependencies of <u>ellipsoid heights</u> come from OPUS, where time-dependent CORS coordinates serve as control for your time-dependent GNSS survey.

Time-dependencies of <u>geoid undulations</u> are captured in the dynamic component of GEOID2022 ("DGEOID2022"), which will come from the geoid monitoring service, or GeMS.

Experimental Geoids

- **Combining most recent satellite, airborne, and terrestrial gravity data to test methods for 2022**
- **Published annually**
  - Updated with airborne gravity data
  - Available on the website
- **Testing methods**
  - Blending techniques
  - Density
  - Terrestrial data improvements



https://beta.ngs.noaa.gov/GEOID/xGEOID18/

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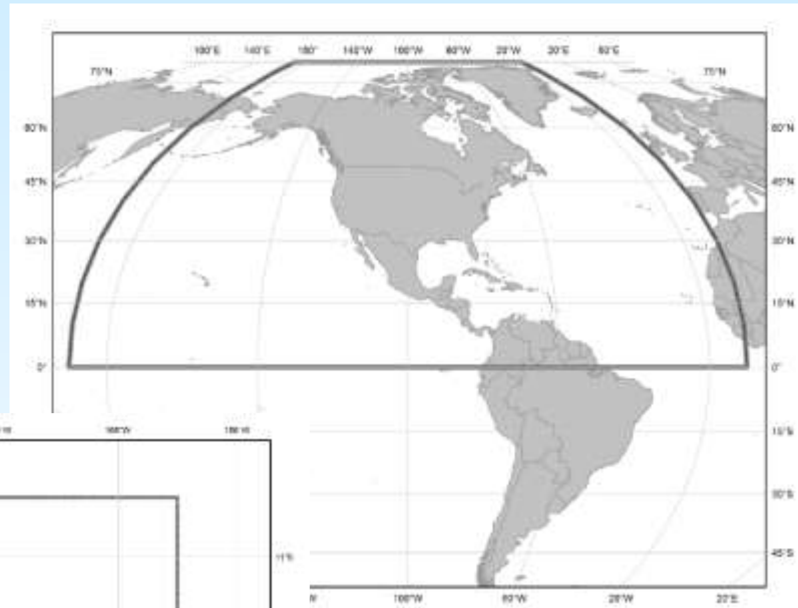
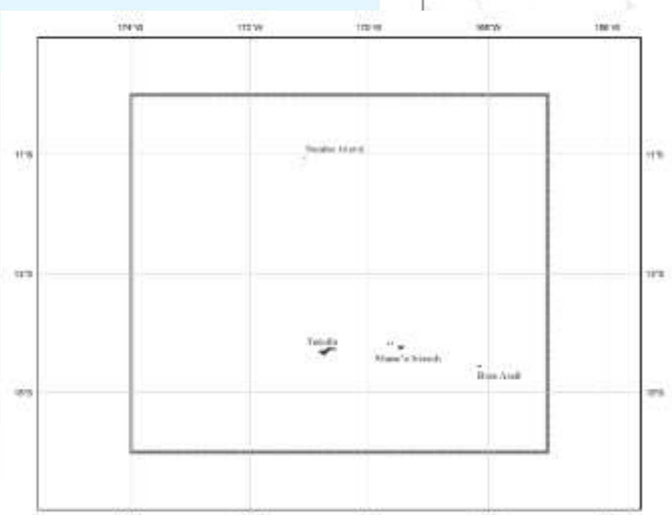
High resolution products

- **All will be 1 x 1 arcminute grids**
- **All will cover three finite regions of the globe**
- **All will have a static and dynamic component**
  - Dynamic surface gravity not expected to be ready by 2022
- **GEOID2022**
  - Official converter of *TRF2022 ellipsoid heights into NAPGD2022 orthometric heights
- **DEFLEC2022**
  - Surface deflections of the vertical in N/S and E/W
- **GRAV2022**
  - Surface acceleration of gravity

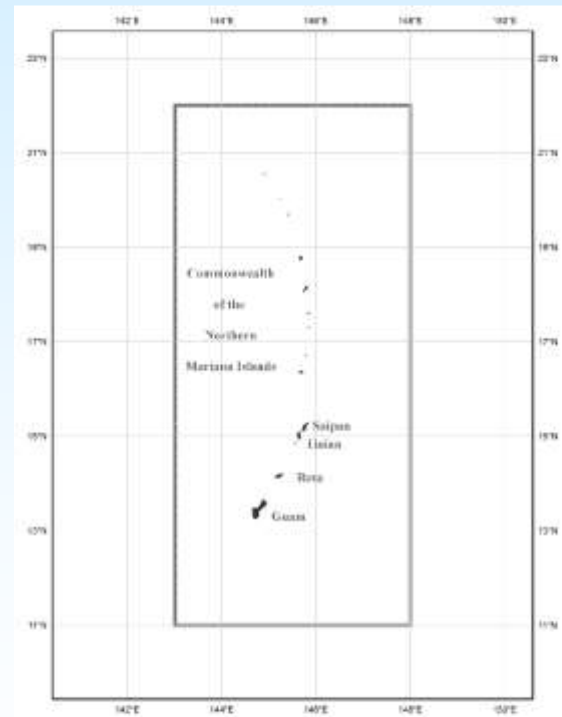
The three gridded regions



North American region
¼ of the Earth



American Samoa region



Guam/CNMI region