COORDINATING COMMITTEE

Modernizing Vertical Datums: The New International Great Lakes Datum

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On Behalf of the Vertical Control – Water Levels Subcommittee
Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data

131st Annual General Meeting of the Association of Ontario Land Surveyors
Niagara Falls, ON, March 1-3, 2023
Revised June 14, 2023

What is IGLD

IGLD = International Great Lakes Datum

- The common height reference system (vertical datum) used to measure and related water levels to each other
- The official vertical datum for water levels and navigation products throughout the Great Lakes, their connecting channels and the upper St. Lawrence River
- Required for the unified, internationally coordinated collection, compilation, and use of data related to hydraulics, hydrology and water level management.

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Coordinating Committee

Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data

- Responsible for the coordination of the collection, compilation, use, and dissemination of data related to hydraulics, hydrology, and vertical control for the Great Lakes – St. Lawrence River System
- Subcommittees:
  - Hydraulics
  - Hydrology
  - Coordinated Regulation and Routing Model
  - *Vertical Control - Water Levels (responsible for IGLD)*

Members

Environment and Climate Change Canada
Environnement et Changement climatique Canada

NOAA

Fisheries and Oceans Canada
Pêches et Océans Canada

USGS science for a changing world

Natural Resources Canada
Ressources naturelles Canada

US Army Corps of Engineers

Importance of Water Levels & IGLD

- Joint harmonious use of the Great Lakes & St. Lawrence River resources by U.S. & Canada requires a knowledge of water levels for:
  - Transportation networks for a reliable port & inland waterway system that facilitates commercial trade and recreational boating, and benefits the economies of both countries
  - Power generation, both hydroelectric and nuclear
  - Domestic and industrial water use
  - Monitoring of the largest freshwater ecosystem in the world
- *The IGLD and a water level gauging network provide the framework for the accurate measurement of water levels*

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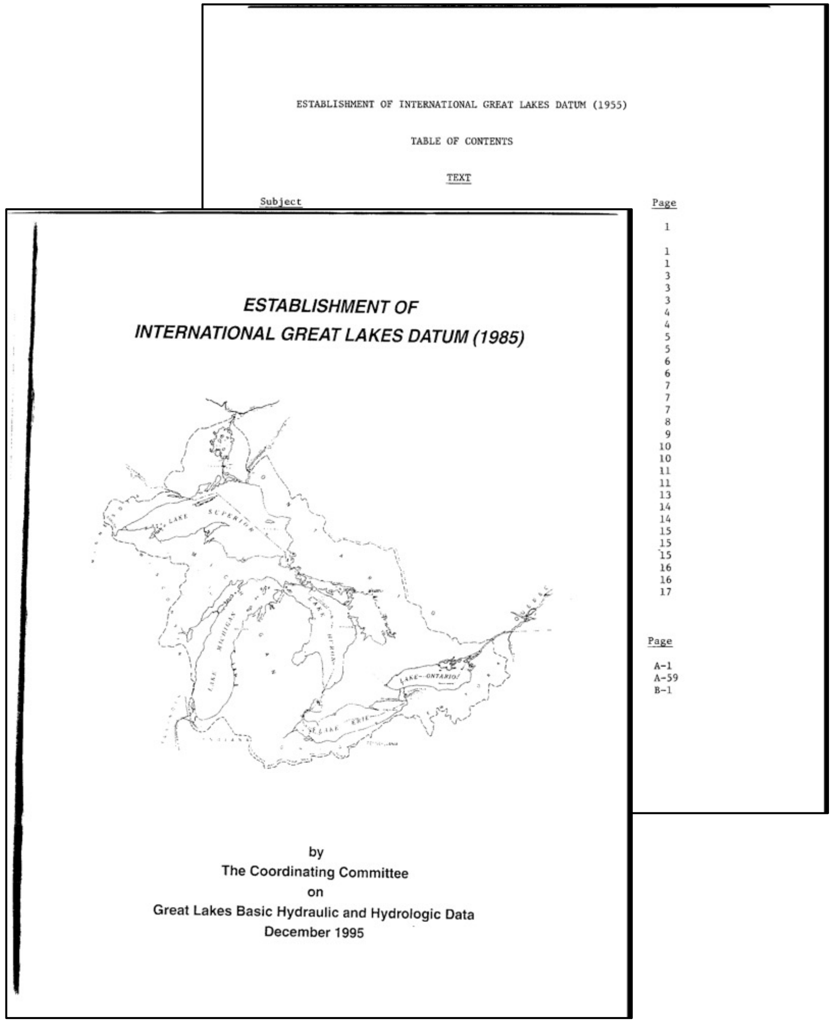
Who Uses IGLD

- Hydraulics engineers
  - To determine how deeply to dredge navigable channels and waterways
- Lock and hydroelectric dam operators
  - To monitor/regulate water levels referenced to datums
- Hydrographers
  - To generate nautical charts
- Mariners
  - To navigate waterways using nautical charts
- Ecologists
  - To determine inundation for marsh restoration projects
- Surveyors
  - To map coastlines & determine marine boundaries

The Need to Update IGLD

- Two previous realizations of IGLD
  - IGLD (1955)
  - IGLD (1985) – current IGLD based on NAVD88
  - Based on levelling from mean sea level at Pointe-au-Père, QC
- Need to periodically update because of
  - Crustal motion (glacial isostatic adjustment)
  - IGLD (1985) contaminated by systematic errors in levelling


ESTABLISHMENT OF INTERNATIONAL GREAT LAKES DATUM (1955)

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ESTABLISHMENT OF
INTERNATIONAL GREAT LAKES DATUM (1985)

by
The Coordinating Committee
on
Great Lakes Basic Hydraulic and Hydrologic Data
December 1995

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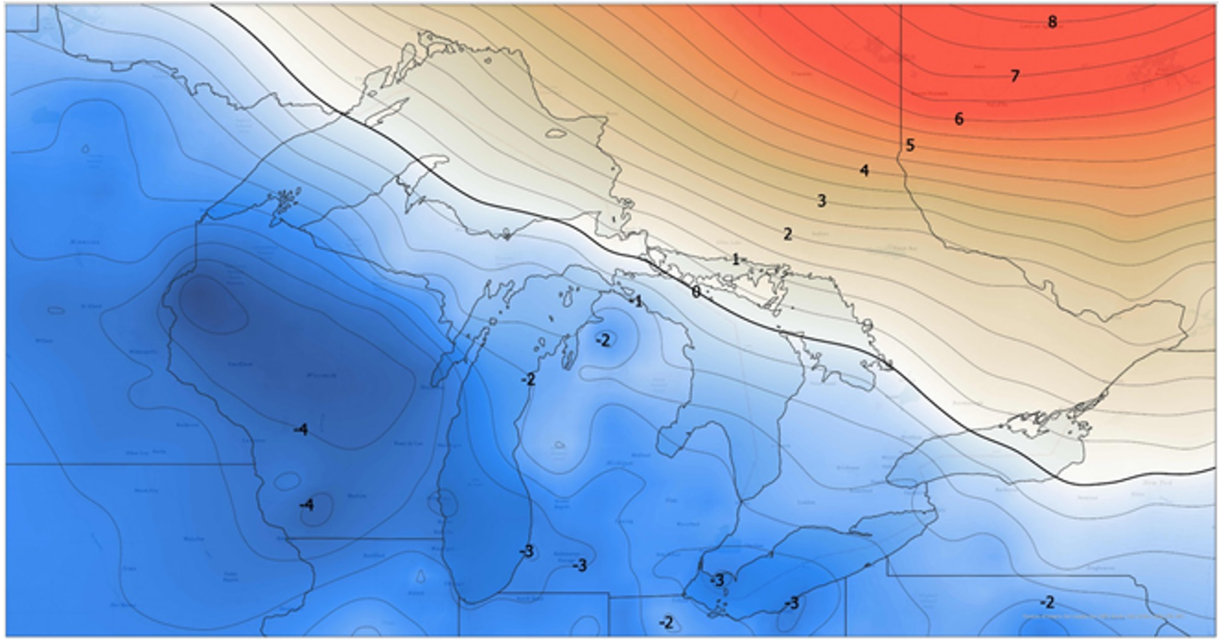
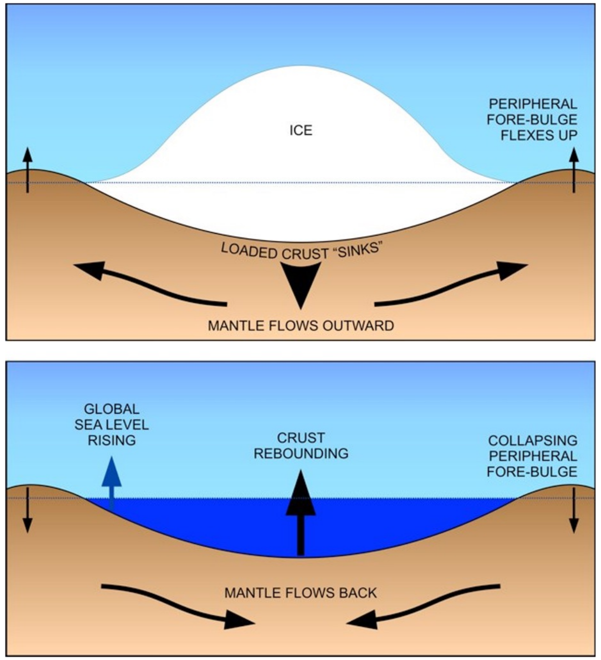
Glacial Isostatic Adjustment (GIA)

- Uplifting in north, subsiding in south
- Overall tilting ~7 mm/yr (21 cm over 30 yr)
- Need to update IGLD every 25-30 yr – *overdue!*

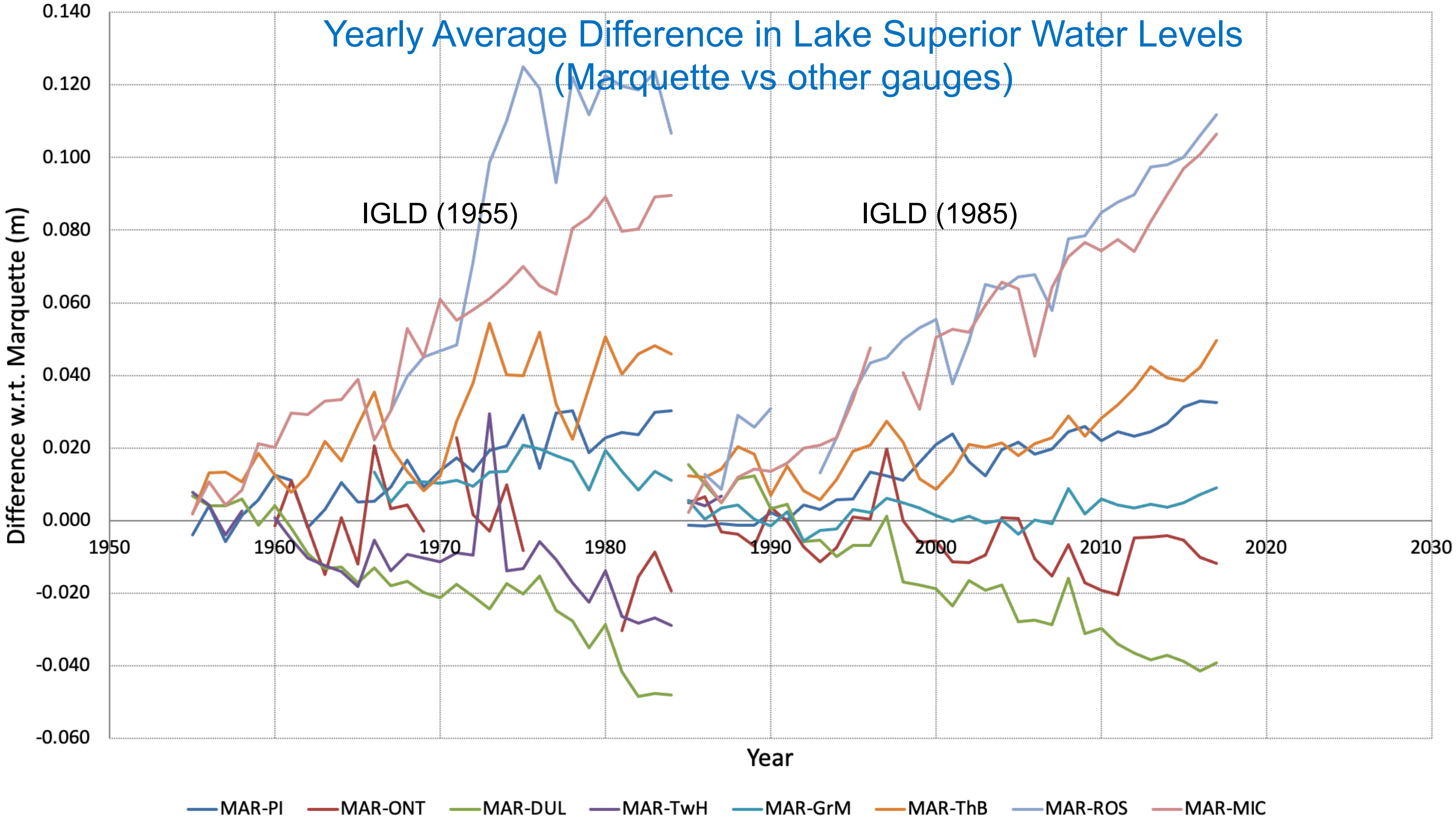


Contour map of crustal motion determined using GPS measurements (Robin et al. 2021)



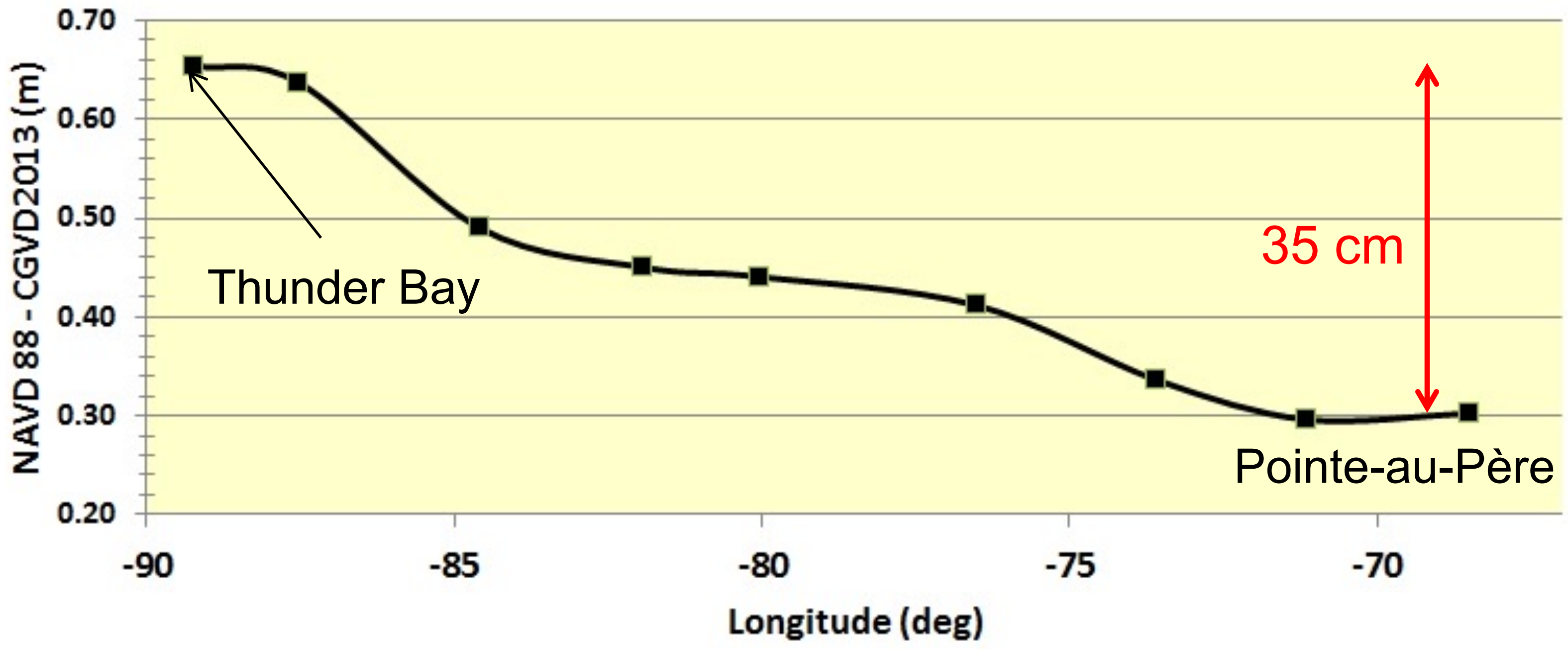
General process of GIA. Top: Heavy ice sheets load the Earth's surface. Bottom: After ice is removed, some areas rebound while others subside.

Effect of GIA on Water Level Measurements



Systematic Error in IGLD (1985)

- IGLD (1955) & (1985) used geodetic leveling to indirectly define the reference surface
- IGLD (1985) affected by accumulation of systematic error in leveling for NAVD88



New North American Datums

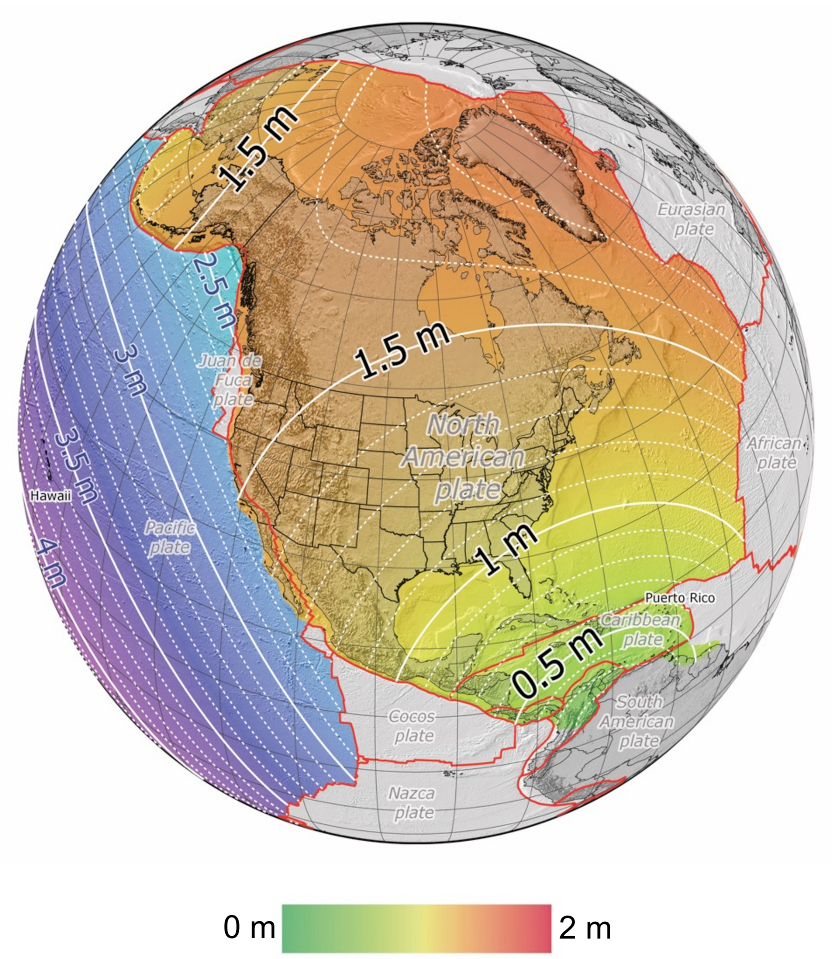
- The U.S. & Canada are modernizing their spatial reference systems
- The IGLD update is piggy-backing on this modernization
- Why change?
  - NAD83(CSRS/2011) – Canada & U.S.
    - Not geocentric nor directly compatible with global systems
    - Not accurately fixed to North America (residual drift modelled as velocities)
  - NAVD88 – U.S. only
    - Traditional leveling-based datum realized through physical benchmarks
    - Very difficult & expensive to maintain the network of benchmarks
    - Leveling too expensive over long distances
    - Significant distortions in the network
    - Not compatible with CGVD2013

NAD83 –> NATRF2022

- North American Terrestrial Reference Frame of 2022 (NATRF2022)
- Following international standards (ISO)
  - Geocentric – will be based on the new ITRF2020
  - Accurately fixed to the N.A. tectonic plate
- Dynamic
  - Coordinates will change with time due to intra-plate crustal motions (GIA)
  - Velocities will be available for CACS/CORS stations
  - Velocity model (grid) will be available for other stations
- Reference epoch
  - Initially 2020.0
  - Plan to update to a newer epoch every 5 to 10 years
- Will be a horizontal shift from NAD83 of up to 1.5 m

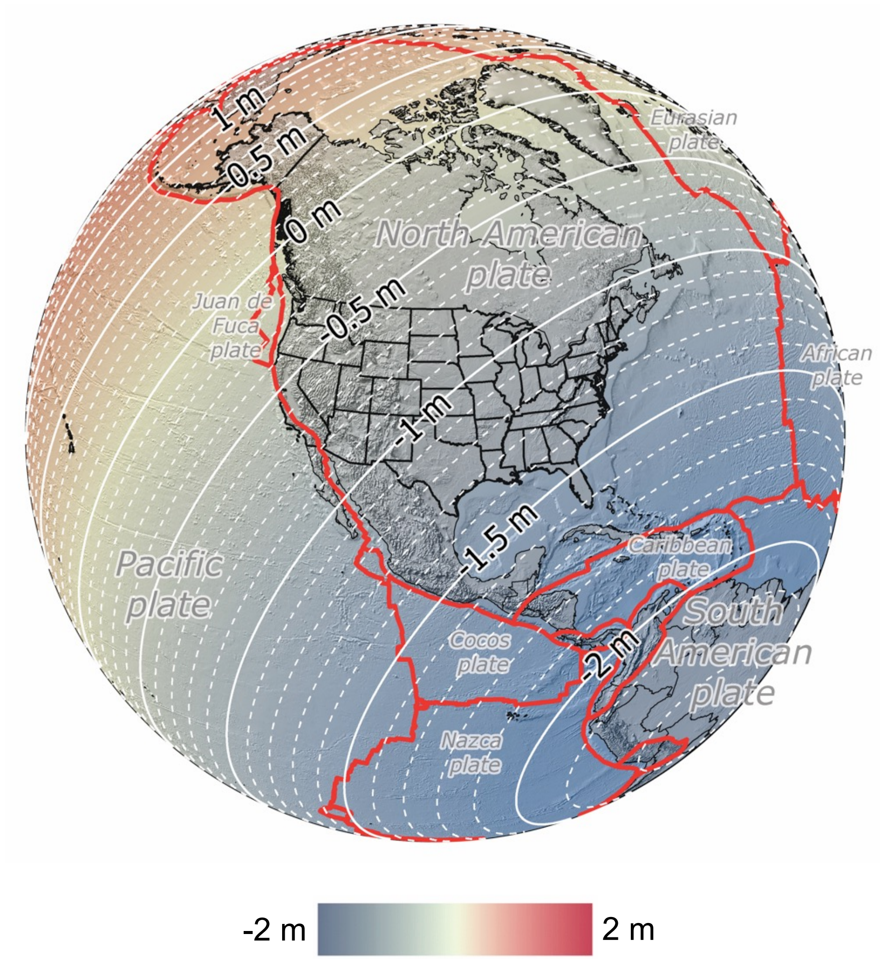
NAD83 –> NATRF2022

Horizontal Change



1.3–1.5 m along border

Ellipsoidal Height Change



0.3–1.2 m along border

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NAVD88 –> NAPGD2022

- North American – Pacific Geopotential Datum of 2022 (NAPGD2022)
- Based on a North American geoid
  - Geoid defined by gravity data
  - Not dependent on expensive leveling
  - Defined everywhere – continuous geoid surface
  - Height determined via GNSS (more efficient)
  - Local leveling will still be needed
  - Up to 1 m shift in orthometric heights in the U.S.
- Compatible with Canada's geoid-based CGVD2013
  - Using identical reference zero
  - Canada will likely adopt the same N.A. geoid as an incremental update

Attributes Defining IGLD

Reference Zero

Reference Surface

Reference Epoch

Dynamic Heights

Hydraulic Correctors

Reference Zero

- Reference to which heights are referred
  - Usually mean sea level (MSL) over a 19 year period
  - Represented by a geopotential value (W_0)
- Different realizations of MSL for IGLD
  - IGLD (1955) used MSL at Pointe-au-Père, QC
  - IGLD (1985) used MSL at both Pointe-au-Père & Rimouski (5 km upstream)
- New IGLD (2020)
  - CC has adopted same W_0 as for the new NAPGD2022 & CGVD2013
  - Represents MSL around coasts of North America
  - *IGLD (2020) will be 31 cm above IGLD (1985) at Pointe-au-Père*

Reference Surface

- Reference surface is an equipotential surface to which orthometric heights are referenced
- Extends the reference zero inland
- IGLD (1955) & (1985) used 1000's km of geodetic leveling to indirectly define the reference surface
  - Too time consuming & cost prohibitive
  - Datum accessible only where leveling exists (bench marks)
  - Susceptible to accumulation of systematic errors (see fig.)

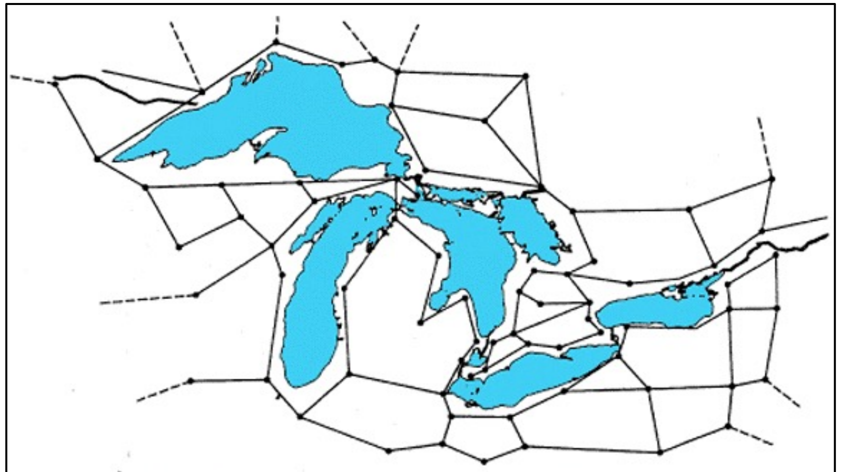

Figure 2: NAVD Leveling Loops - Network

New Reference Surface

- New NAPGD2022 will use a N.A. geoid for the reference surface*
  - Geoid is a continuous equipotential surface that will be aligned to the reference zero
  - Defined everywhere in Canada & U.S.
  - Consistent & accurate at the cm-level
  - Orthometric heights above the geoid can be obtained from GNSS-derived ellipsoidal heights
- IGLD (2020)
  - Using same reference zero & reference surface as NAPGD2022 & CGVD2013

    => IGLD (2020) compatible with NAPGD2022 & CGVD2013
  - Geoid heights will be referenced to NATRF2022*

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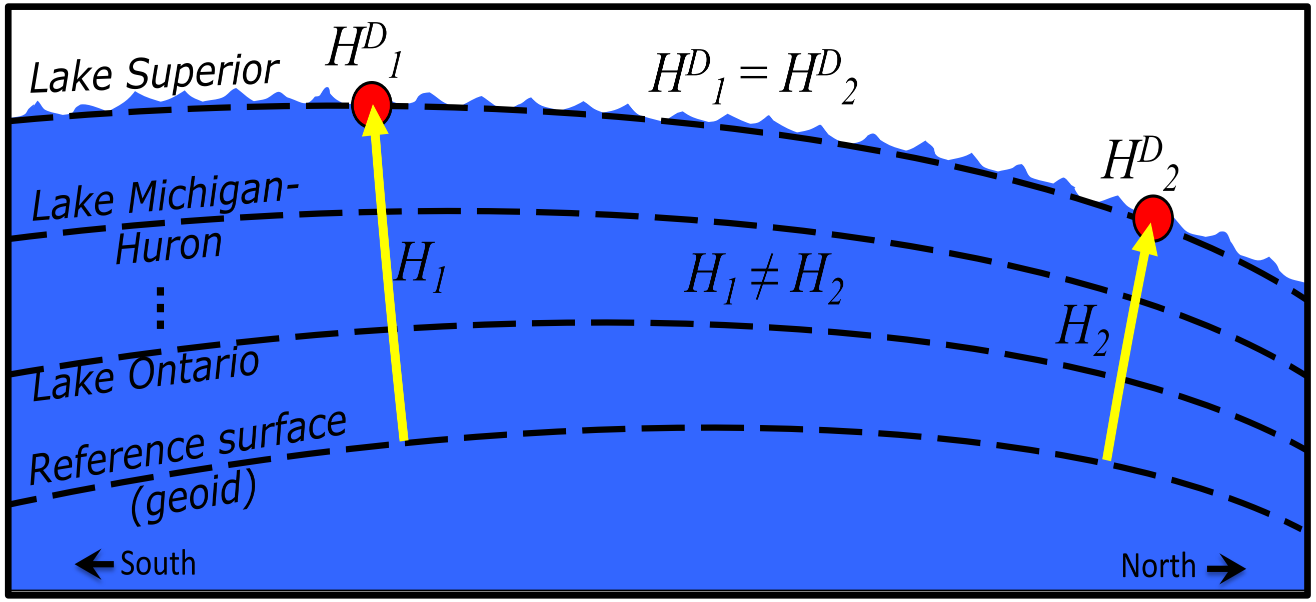
* See http://www.ngs.noaa.gov/datums/newdatums/

Reference Epoch

- The point in time to which heights are referenced
- Mean water levels are defined over a 7-year observation period
  - Used for evaluating lake topography (see Hydraulic Correctors)
  - IGLD (1955) used 1952-1958
  - IGLD (1985) used 1982-1988
  - IGLD (2020) using 2017-2023 (central epoch = 2020)
- IGLD (2020) heights will be referenced to central obs epoch 2020
  - The NATRF2022 deformation model will be used to propagate heights to reference epoch
  - Will account for crustal motion (GIA) to ensure consistency of heights

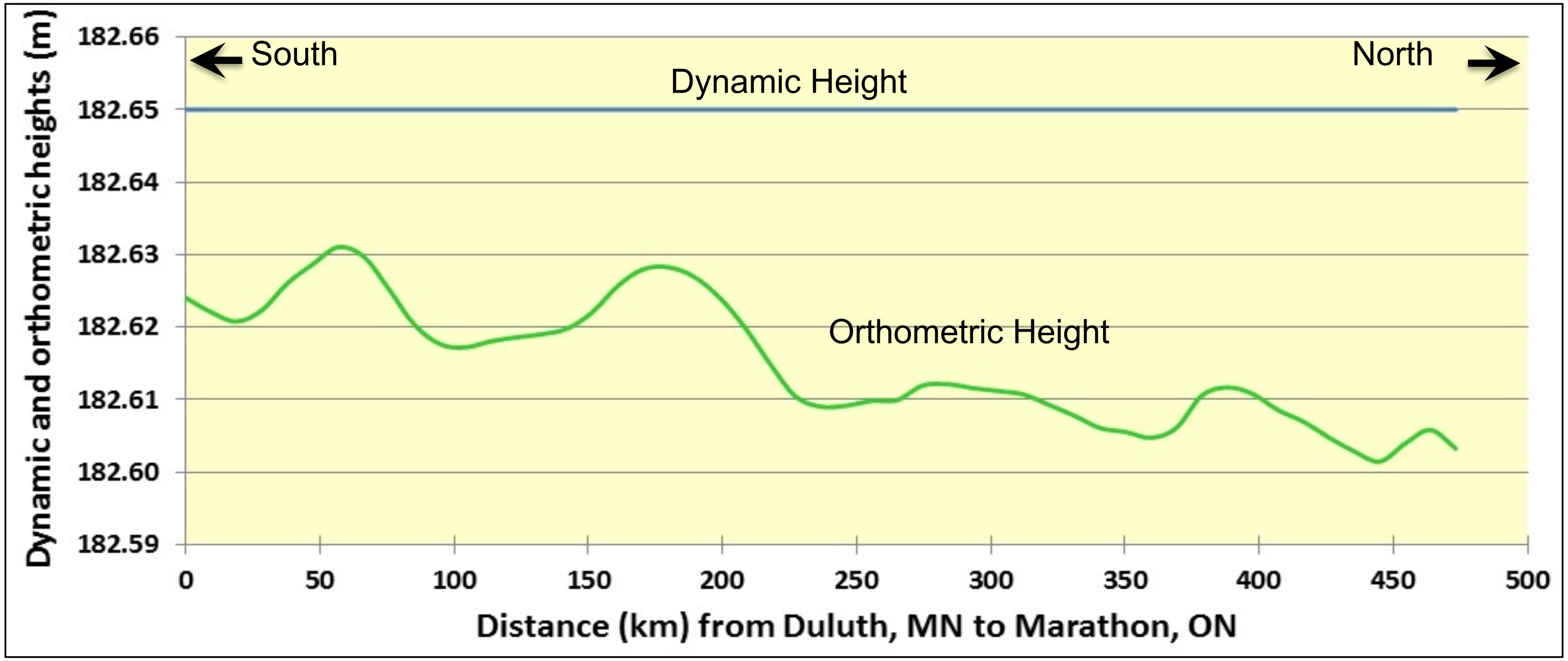
Dynamic Heights

- Orthometric heights (*H*)
  - Physical distance above reference surface (geoid)
  - Geopotential difference divided by mean gravity along plumb line
  - Not constant along an equipotential surface because equipotential convergence
- Dynamic heights (H^D)
  - Geopotential numbers scaled by constant value of Normal gravity at 45° latitude
  - Constant along an equipotential surface (lake)
  - Enables the measurement of hydraulic head for water level management
  - Used by all IGLD realizations



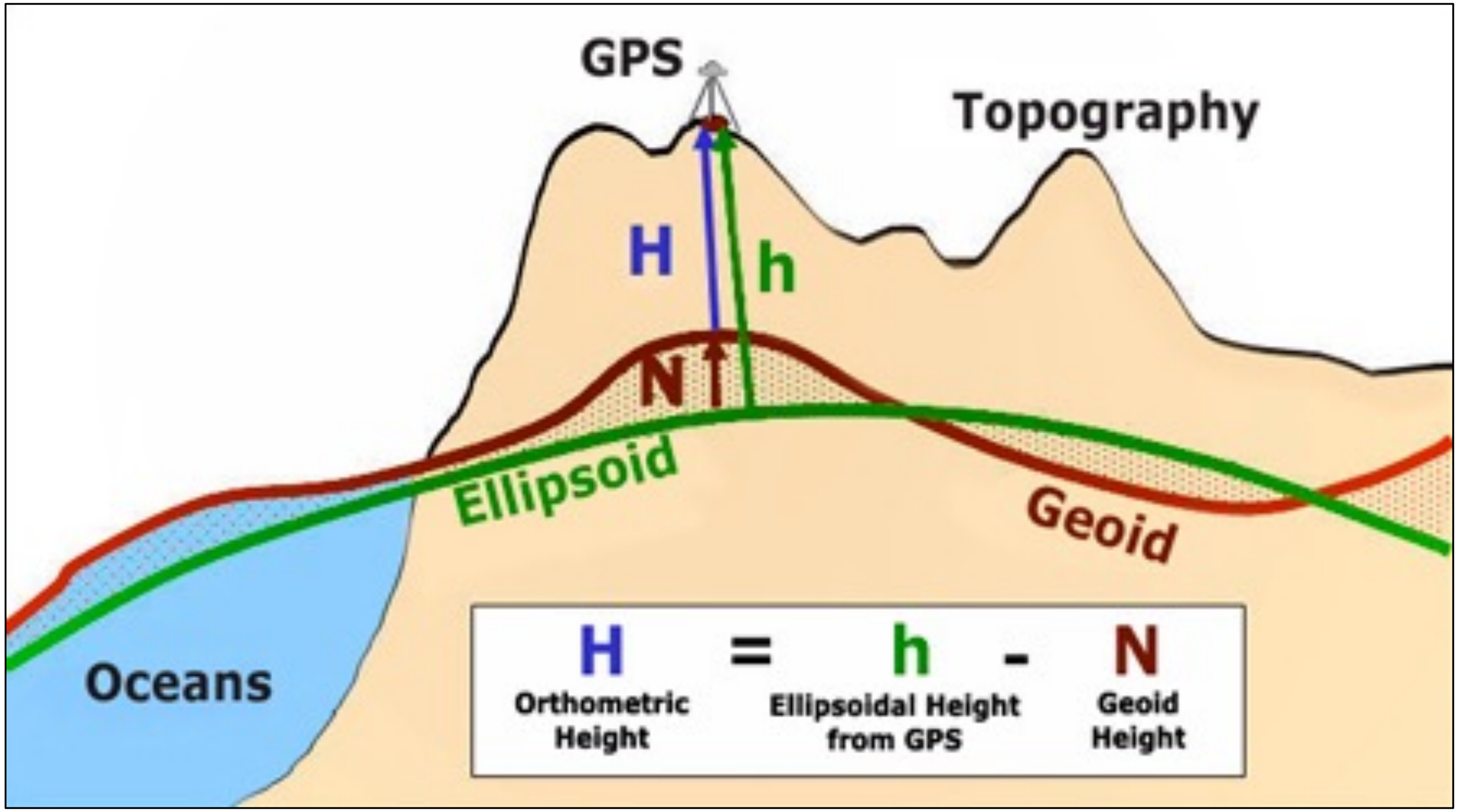
Equipotential surfaces converge toward poles

Dynamic vs Orthometric Heights



- Simulation of orthometric heights using actual gravity (green line) and dynamic heights (blue line) of Lake Superior water surface along a straight line profile from Duluth, MN to Marathon, ON
- Illustrates orthometric heights are not constant along a level water surface when dynamic heights are
- Downward trend of orthometric height is due converging equipotential surfaces

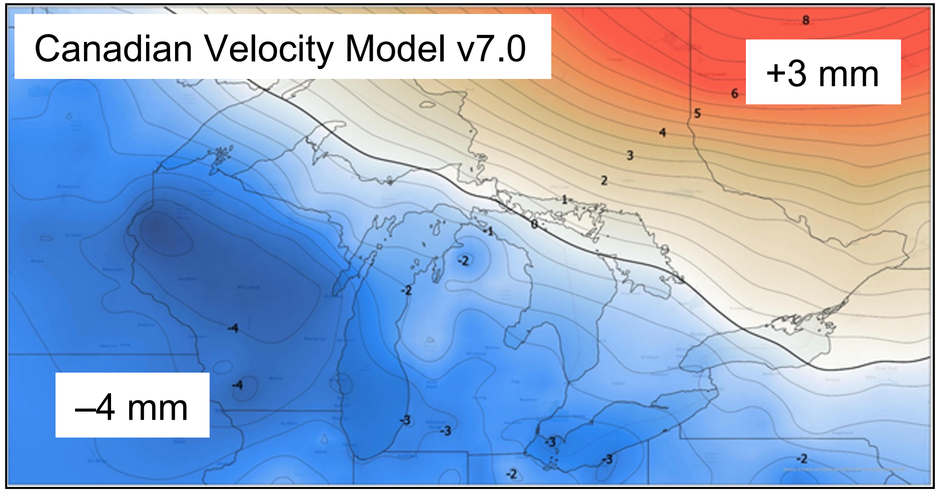
IGLD (2020) Heights from GNSS



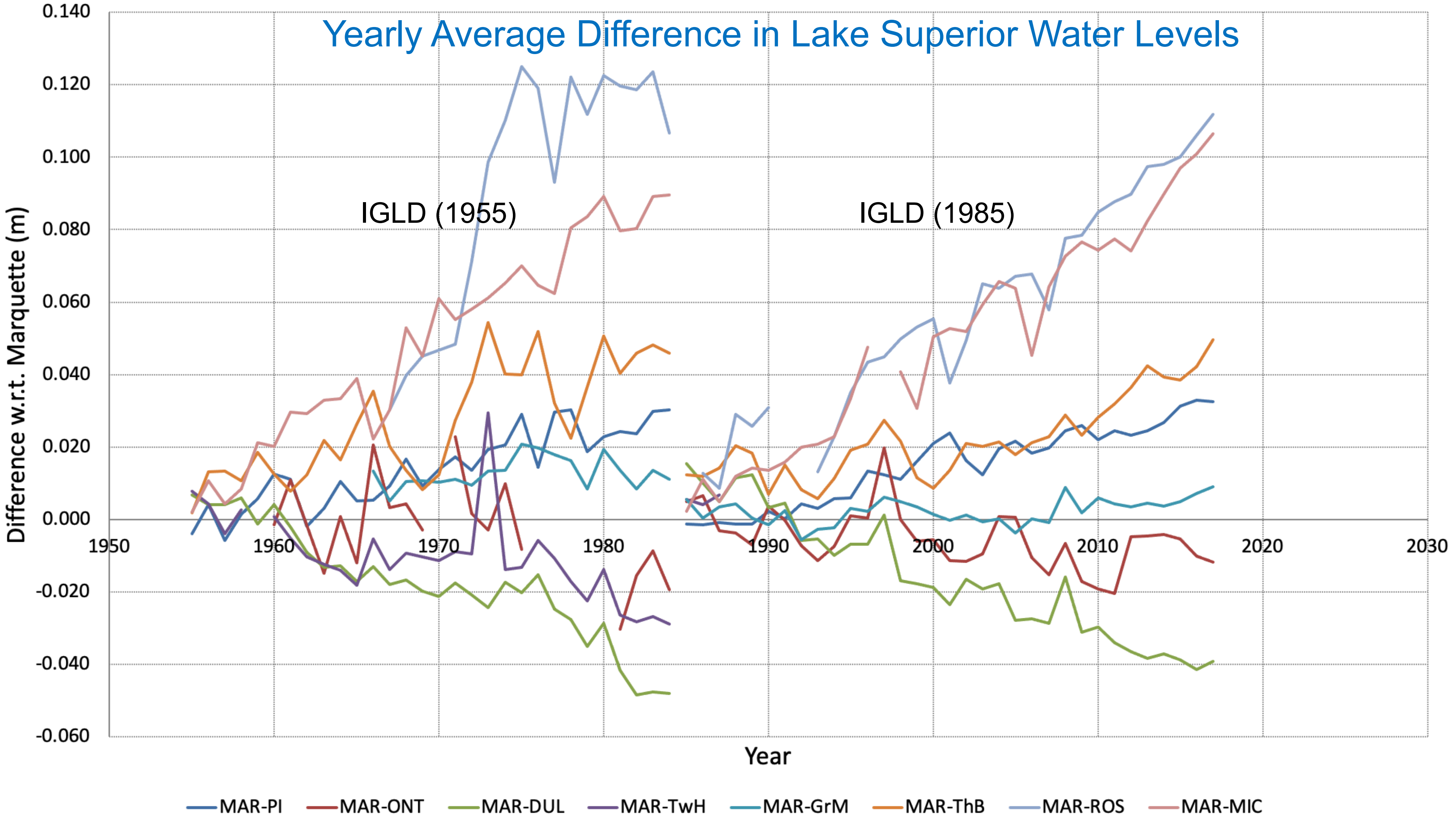
- IGLD (2020) heights determined via GNSS
  - Accurate & efficient
- h & N must be referenced to the same reference ellipsoid (NATRF2022)
- Dynamic heights are derived from H using a gravity model (grid)

Dynamic Nature of IGLD (2020)

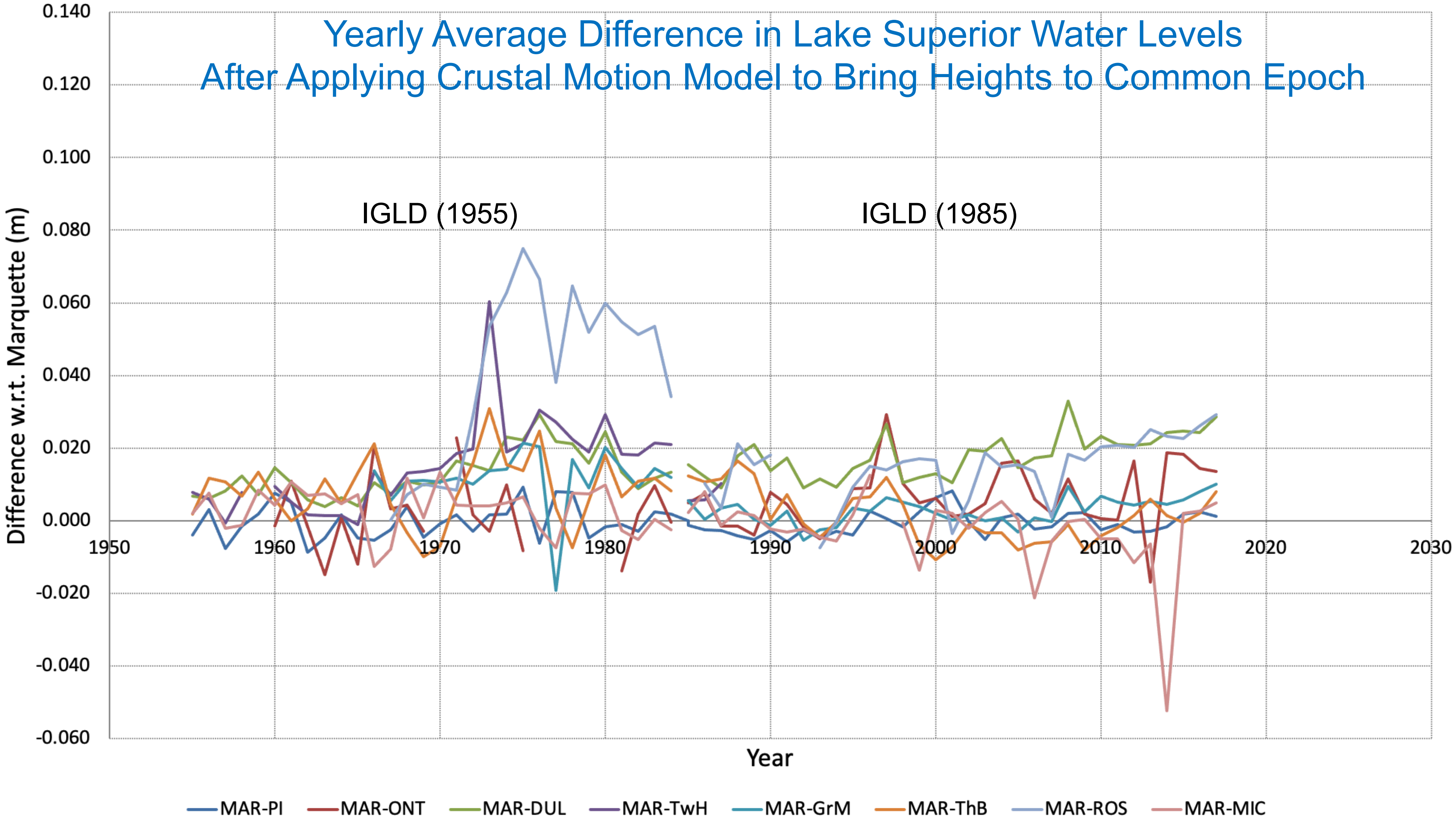
- IGLD (2020) & NAPGD2022 are dynamic datums
- Heights are changing due to regional & local crustal motions
- A velocity model will be used to propagate heights between epochs
  - Estimated from a long time series of CACS & CORS positions
  - Implemented as an interpolation grid
  - Can be used to account for crustal motion by propagating heights to a common reference epoch (e.g., 2020.0)
  - Model will be provided by CGS & NGS
  - Expected to be also incorporated into commercial software (e.g., ArcGIS)
  - *Should be no need to update IGLD in future because of crustal motions*



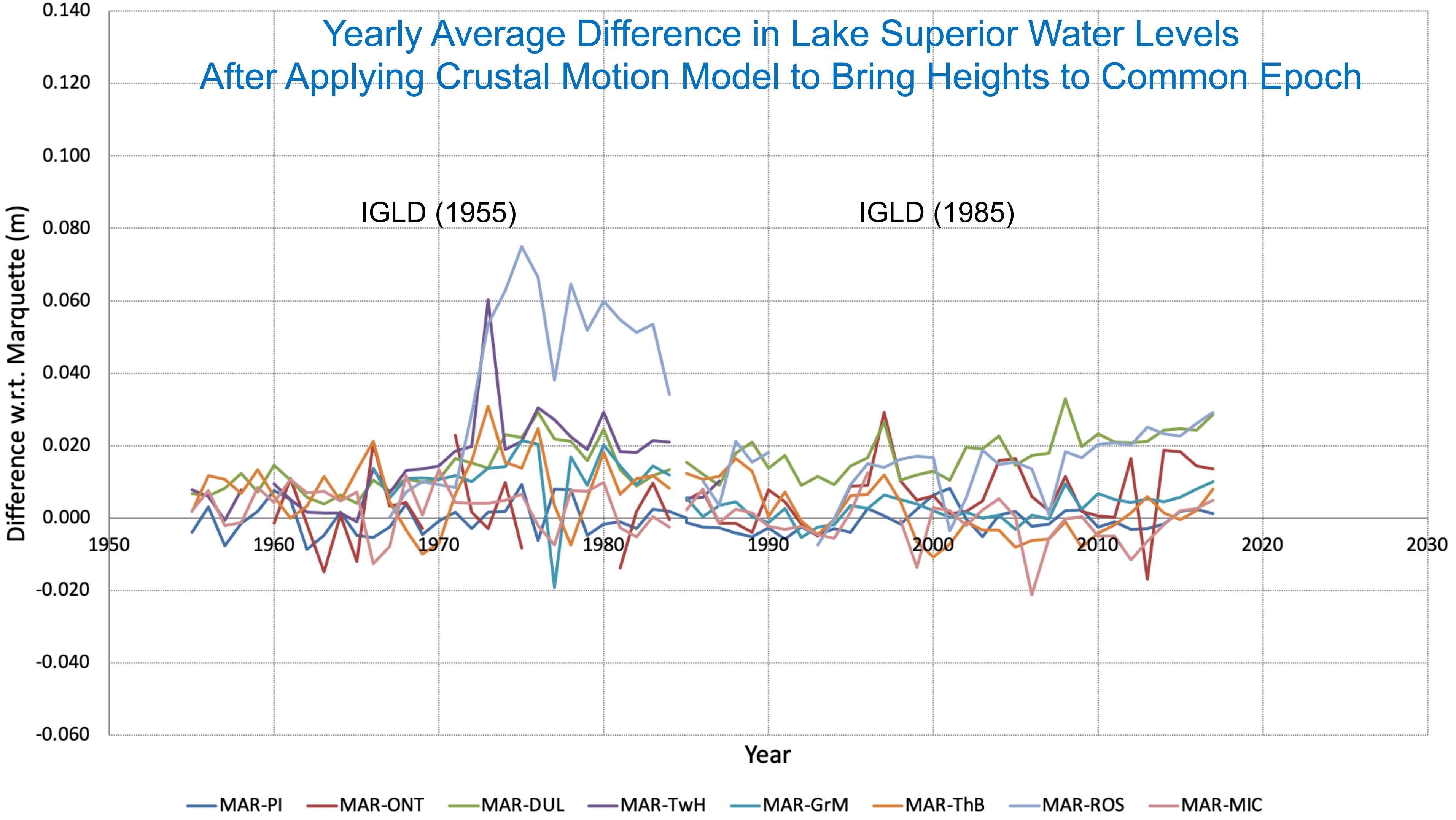
Water Levels Measurements



Corrected Water Levels Measurements



Corrected Water Levels Measurements



Hydraulic Correctors

- Water surface of each of Great Lakes considered to be an equipotential surface (level surface)

  => dynamic heights at gauges should be the same
- In reality this is not the case because of
  - Currents, river discharge, temperature/density variations, prevailing winds, outlet drawdown
  - Creates a lake surface “topography”
- Hydraulic correctors are used to correct for these effects
  - Dynamic heights at gauges are adjusted to agree with a single “master” gauge or mean water level on each lake
  - Corrections are interpolated elsewhere

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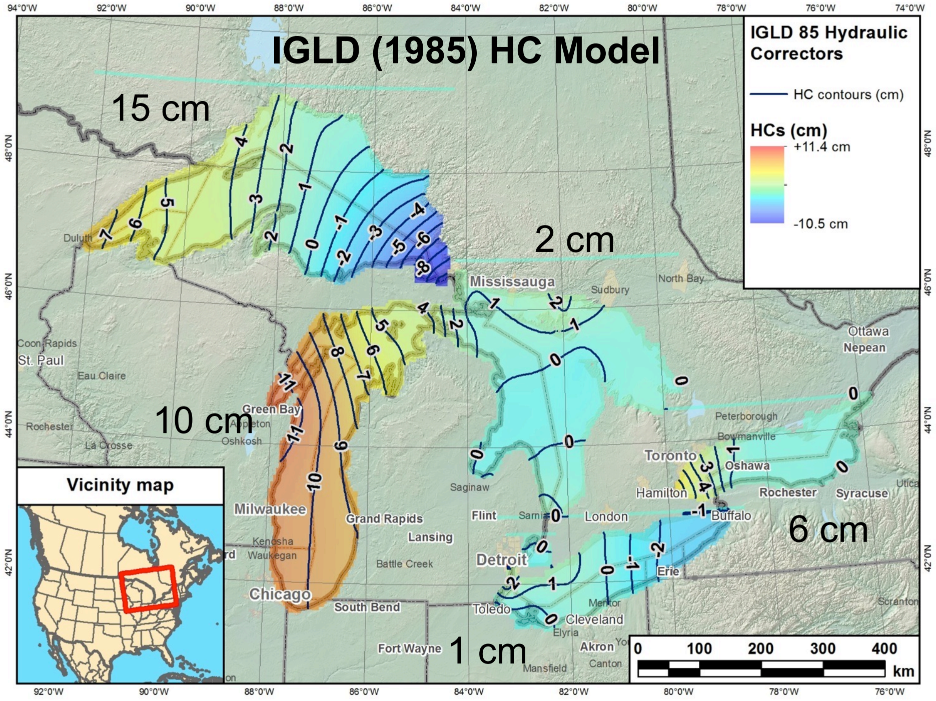
Hydraulic Correctors

- In IGLD (1985), HCs mainly represent the errors in datum/leveling (±0.11 m)
- In IGLD (2020), HCs should mainly represent lake topography
  - Initial analyses with high accuracy GNSS indicat
    IGLD (2020) is expected to be much smaller
  - May not need hydraulic correctors at all
- Temporary "seasonal" gauging being used for IGLD (2020)
  - To densify the permanent gauge network
  - Will help provide a more accurate HC model



Realizing IGLD (2020)

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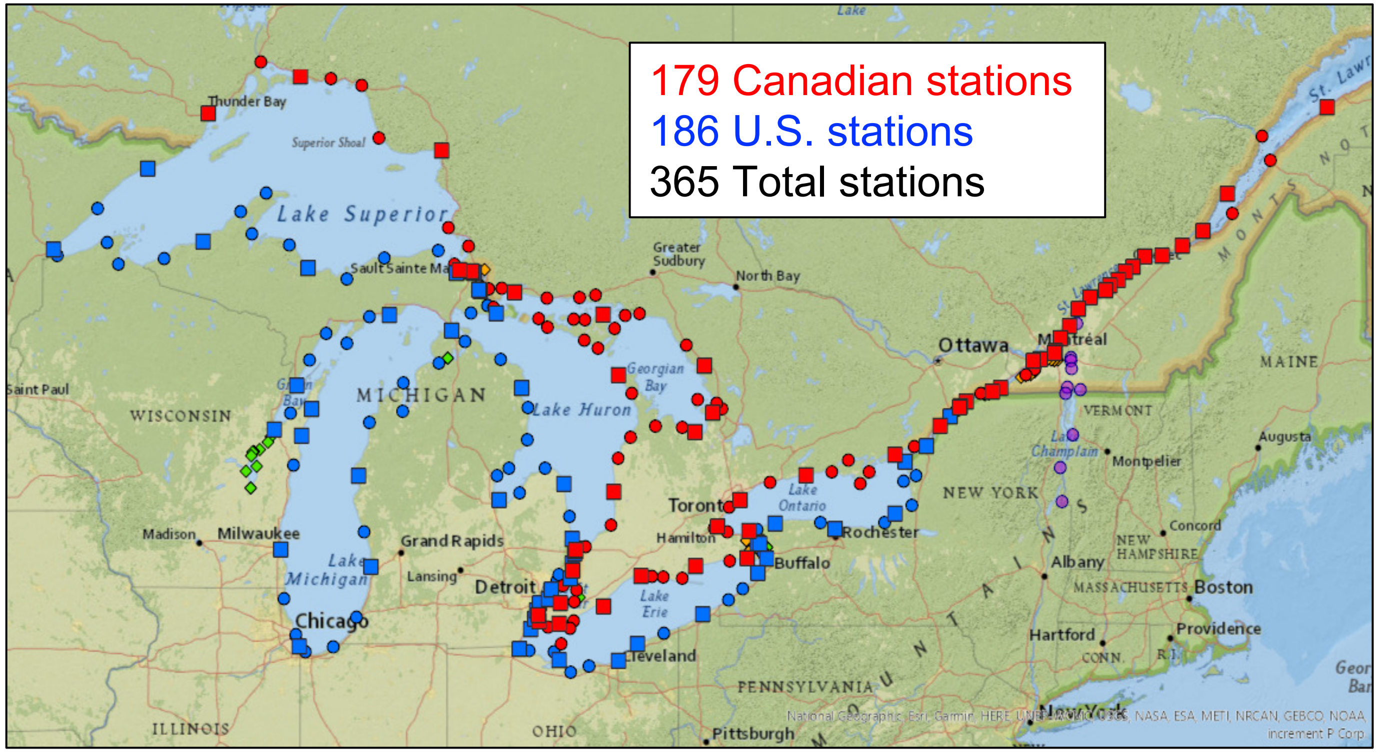
Updating Heights to IGLD (2020)

- Need to determine IGLD (2020) heights for all water level gauges
- GNSS provides most accurate way to tie to the IGLD (2020)
- Coordination Committee members performed a high accuracy GNSS survey on all water level gauges in 2022
    - Occupied 350+ gauges
    - Included seasonal gauges
    - Coordinated effort among multiple U.S. and Canadian agencies
    - Led by CGS & NGS



GNSS Survey Campaign Participants

Canada

✓ CGS (5-6 weeks) – 11 (8 FTE)
✓ CHS (4 weeks) – 4
✓ ECCC (1 week) – 1
OPG (doing own gauges)
Hydro Quebec (doing own gauges)

United States

✓ NGS (6 weeks) – 9 + 1 “triage”
✓ NGS Regional Advisors – 2
✓ USACE Detroit (doing own gauges)
✓ NYPA St. Lawrence contractor
✓ WisDOT + contractor

Survey Procedures

- Geodetic-quality GNSS receivers and antennas used
- Antennas with absolute antenna PCV calibrations
- Fixed-height masts or tripod
- Two independent 24 hr occupations on all benchmarks
  - Different equipment
  - Different observers when possible
- CGS & NGS coordinated occupation of benchmarks to ensure cross-border ties

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Typical GNSS Occupations


Canadian Setup


American Setup

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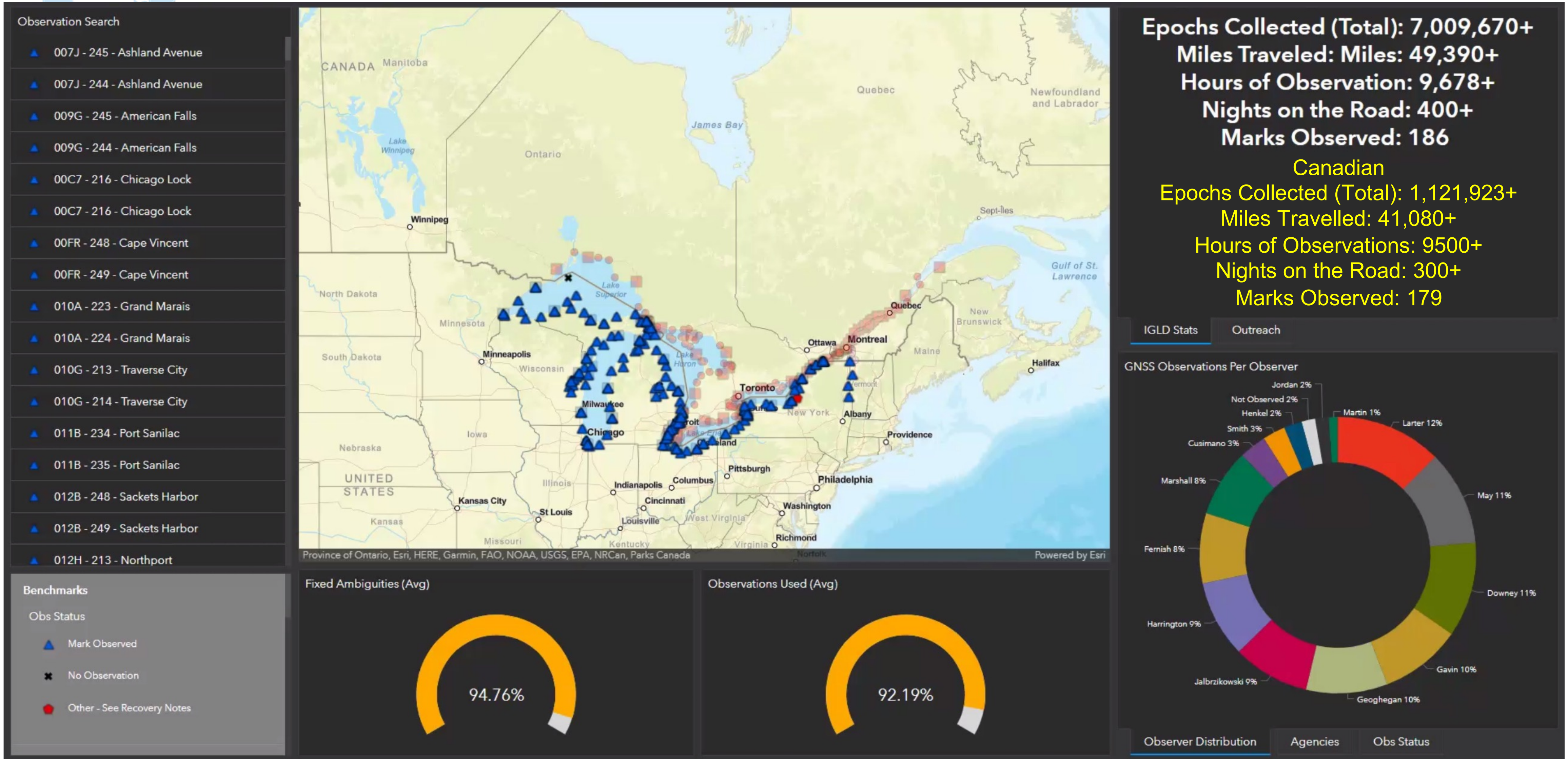
NGS IGLD Survey Dashboard



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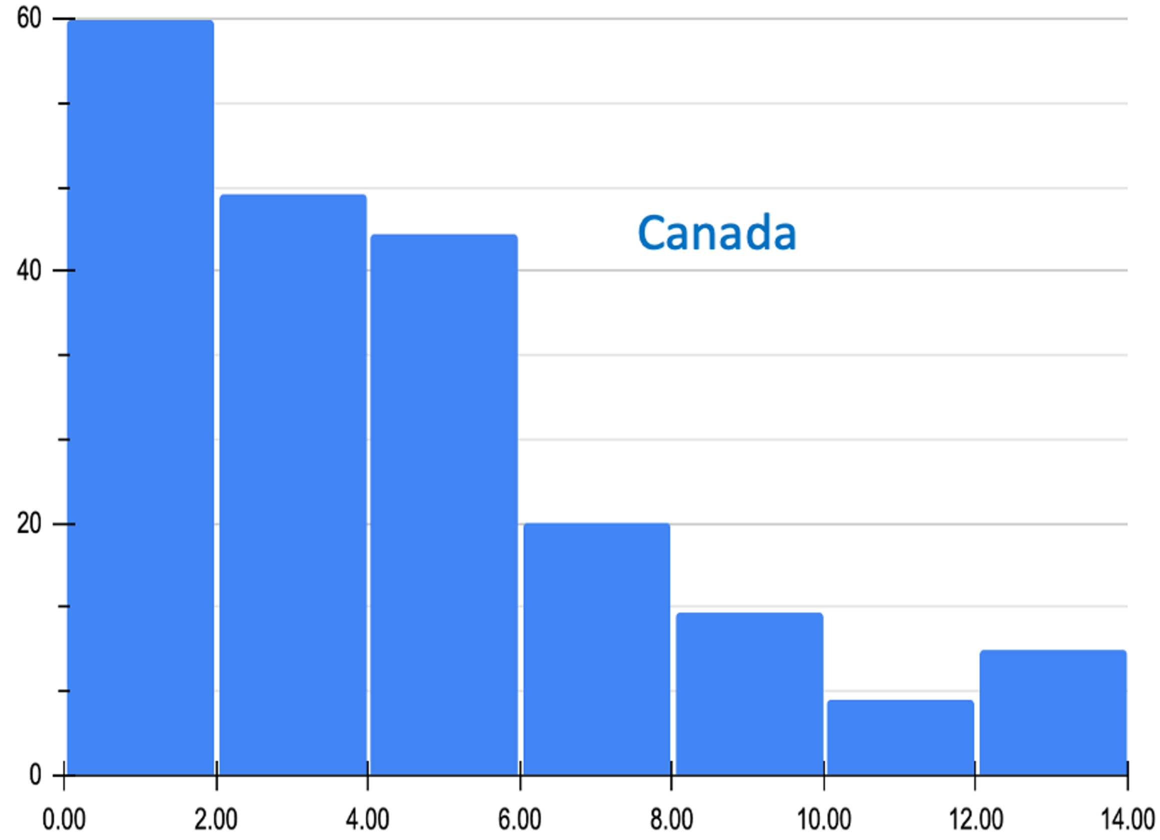
Issues Encountered

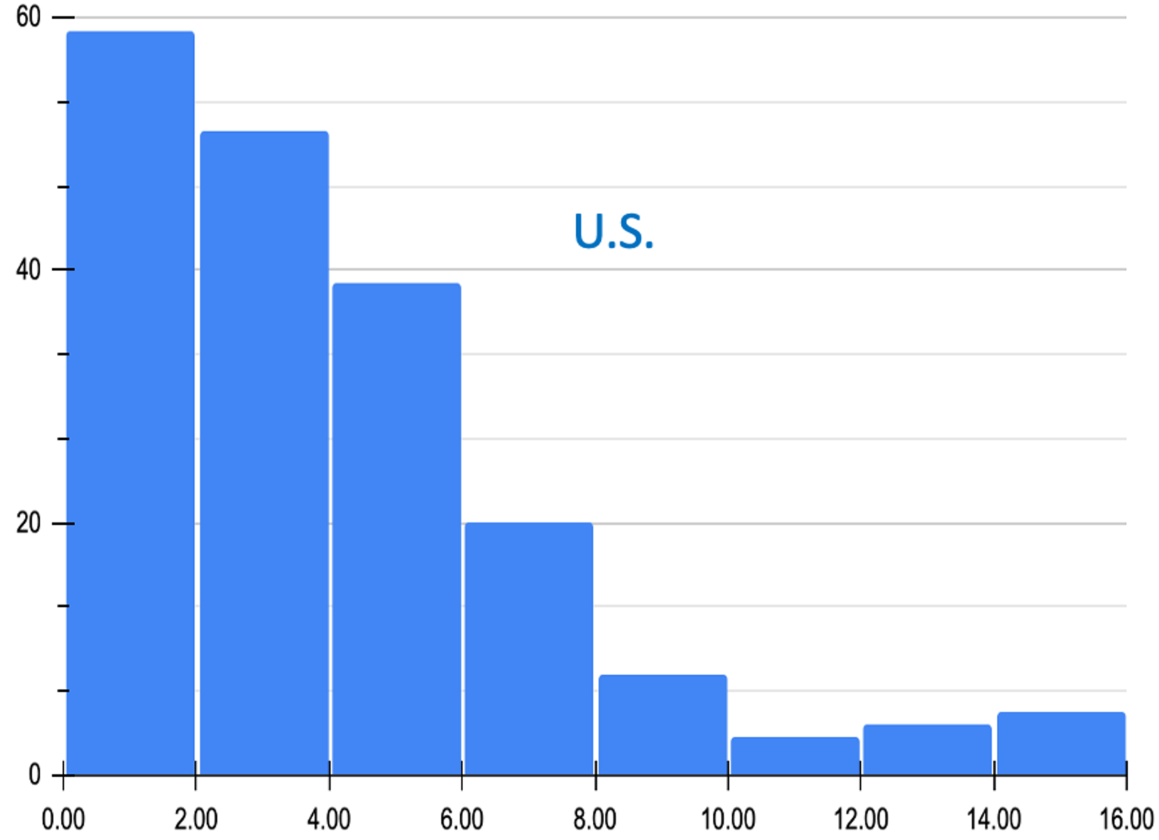
- Insufficient preparation after CGS party chief resigned
  - Digital field log formulas & antenna info not checked/prepped
  - Field software not tested – had to rerun data with new version
- Canadian stations
  - A few were missed during survey but occupied at end
  - Three stations not occupied at all due to access issues
- Some late occupations due to long travel times, site access, overgrown brush, freighter obstructions, damaged BMs, local construction
- Documenting issues for future campaigns

Bent Mast

PPP QC Results

Histogram of Vertical Discrepancies Between Occupations





GNSS Data Processing

- CGS & NGS using similar baseline processing methodologies
  - CGS using Bernese GNSS software – NGS using OPUS Projects
  - Latest IGS products (orbits & corresponding antenna calibrations)
  - Agreed on a set of IGS stations for reference frame alignment
  - GLONASS data available but only processing GPS data for now
- Expect to complete by summer and compare results
- PPP solutions already complete
  - Much faster and more efficient than baselines processing
  - Uses all available data – does not discard non-common data for baselines
  - Will compare with baseline processing

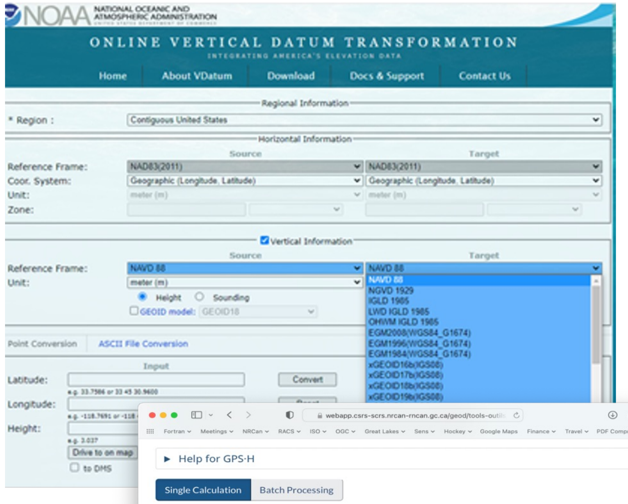
Transformations

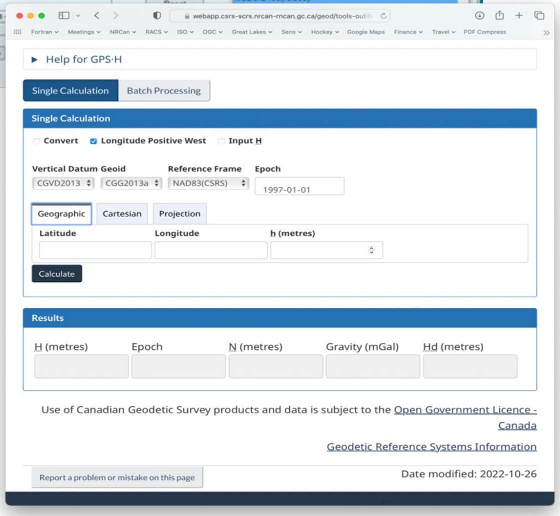
- Many IGLD users will need to convert large amounts of data from older datums to IGLD (2020)
- Transformation grids will be required
  - Need heights at common points in old and new datums
  - Tools must be capable of transforming thousands of data points
  - Will use a common (binational) grid format based on international standards
- Accuracy of transformations depends on
  - Homogeneous spatial coverage of stations in older datums
  - Included as many such stations as possible in the 2020 GNSS campaign

Tools

- Tools already in use
  - GNSS processing services (CSRS-PPP & OPUS)
  - Velocity model to propagate heights to the 2020.0 reference epoch (TRX & HTDP/TRANS4D)
  - Vertical transformations & conversions (GPS-H & VDatum)
- Commercial software
  - Working with developers to ensure their users have the tools
  - Held a workshop with developers Nov 30 – Dec 1, 2022
  - Most developers committed to having transformation tools ready by 2025
- Guidelines
  - Will be provided for determining heights in IGLD (2020)
  - Procedures will be mostly the same as for working in NAD83(CSRS), and CGCD2013, which are already dynamic datums

NOAA’S VDatum





CGS’s GPS-H

Impacts of a New IGLD

- Updating water levels to a new IGLD will have significant impacts on many operations, products and services in the Great Lakes region
  - Economic viability and safety of commercial and recreational navigation, including charts, ports/harbors and dredging of navigation channels
  - Water level regulation and forecasting
  - Coastal zone management and planning, including flood & erosion prediction and response, and coastal structure design, construction & maintenance
  - Coastal habitat restoration under the Great Lakes Restoration Initiative (GLRI)
- The CC is conducting a major outreach effort to inform stakeholders

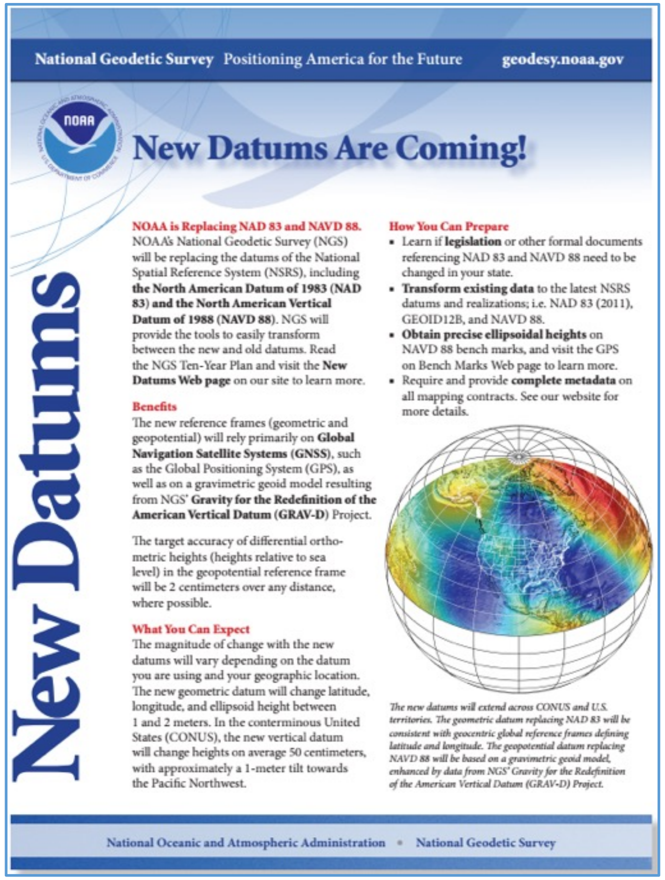
For More Information

IGLD datums

- Website: https://GreatLakesCC.org/
- Email: info@GreatLakesCC.org

New NAPGD2022 & NATRF2022 datums

- https://geodesy.noaa.gov/datums/newdatums/



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

New Datums Are Coming!

New Datums

NOAA is Replacing NAD 83 and NAVD 88.
NOAA's National Geodetic Survey (NGS) will be replacing the datums of the National Spatial Reference System (NSRS), including **the North American Datum of 1983 (NAD 83) and the North American Vertical Datum of 1988 (NAVD 88)**. NGS will provide the tools to easily transform between the new and old datums. Read the NGS Ten-Year Plan and visit the **New Datums Web page** on our site to learn more.

Benefits
The new reference frames (geometric and geopotential) will rely primarily on **Global Navigation Satellite Systems (GNSS)**, such as the Global Positioning System (GPS), as well as on a gravimetric geoid model resulting from NGS' **Gravity for the Redefinition of the American Vertical Datum (GRAV-D)** Project.

The target accuracy of differential orthometric heights (heights relative to sea level) in the geopotential reference frame will be 2 centimeters over any distance, where possible.

What You Can Expect
The magnitude of change with the new datums will vary depending on the datum you are using and your geographic location. The new geometric datum will change latitude, longitude, and ellipsoid height between 1 and 2 meters. In the conterminous United States (CONUS), the new vertical datum will change heights on average 50 centimeters, with approximately a 1-meter tilt towards the Pacific Northwest.

How You Can Prepare
- Learn if **legislation** or other formal documents referencing NAD 83 and NAVD 88 need to be changed in your state.
- **Transform existing data** to the latest NSRS datums and realizations; i.e. NAD 83 (2011), GEOID12B, and NAVD 88.
- **Obtain precise ellipsoidal heights** on NAVD 88 bench marks, and visit the GPS on Bench Marks Web page to learn more.
- Require and provide **complete metadata** on all mapping contracts. See our website for more details.

The new datums will extend across CONUS and U.S. territories. The geometric datum replacing NAD 83 will be consistent with geocentric global reference frames defining latitude and longitude. The geopotential datum replacing NAVD 88 will be based on a gravimetric geoid model, enhanced by data from NGS' Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project.

National Oceanic and Atmospheric Administration • National Geodetic Survey

Extra Slides

Low Water Datum

- LWD or "chart datum" is defined as a surface so low that the water level will seldom fall below it
- Different LWD surfaces are used for different lakes & rivers
- Depths on navigation charts & for navigation improvements refer to LWD
- LWD determined in 1933 and has not been reviewed since
- Re-evaluation of LWD needed due to
  - Historically high and low water levels since 1933
  - Changes to hydraulic and hydrologic conditions
  - Effects of GIA
- May redefine at same time as updating IGLD