National Geodetic Survey

FY16 NGS Update

Transitioning to the new geometric and geopotential datum/reference frames by 2022

PLSO 2016 Survey Conference
Eugene, OR – Jan 20-22

NOAA's National Geodetic Survey
geodesy.noaa.gov
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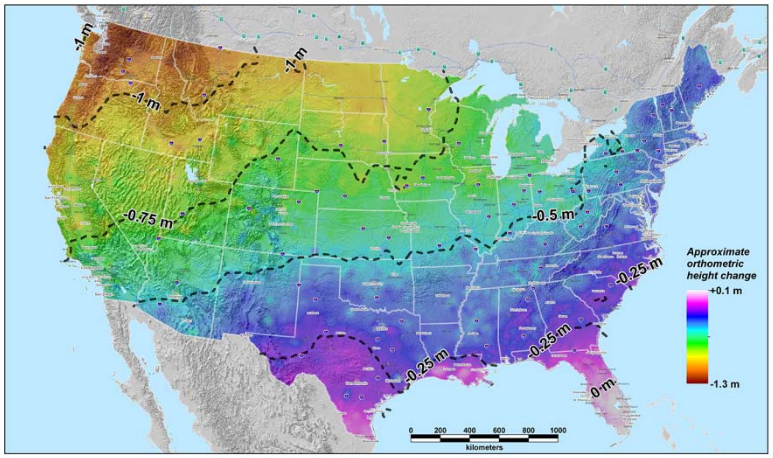
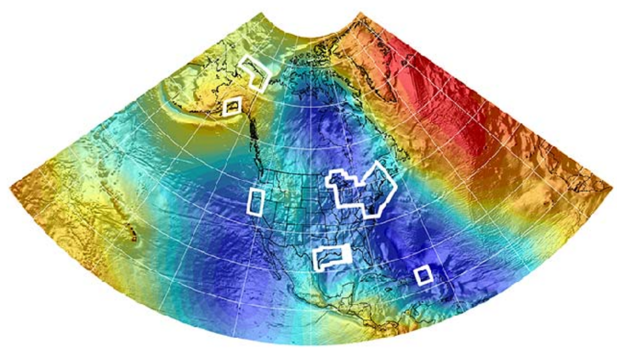
New Datum/Reference Frames Are Coming in ~2022!

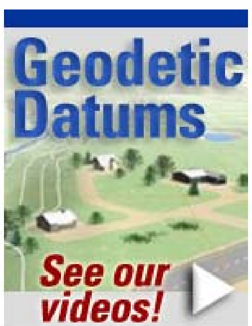
- NOAA's National Geodetic Survey will release new geometric (horizontal) and geopotential (vertical) reference frames in ~2022
- Realization of the new frames will be through GPS/GNSS receivers
- Target- 2 cm accuracy: relative to sea level (orthometric heights) using GPS/GNSS and a geoid (gravity) model from NGS' GRAV-D project.
- NGS will provide the tools to transform between the new reference frames and old datums.

Approximate predicted change from NAVD88 to new vertical (geopotential) datum



Predicted change estimated as NAVD88 "zero" (datum) surface minus NGS gravimetric geoid

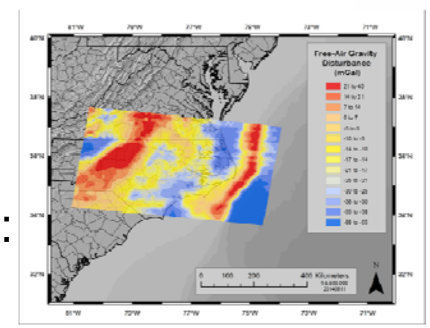




MORE INFO:

Go to the Geospatial Summit webpage:
http://www.geodesy.noaa.gov/2015GeospatialSummit/

New Reference Frame Webpage and Videos:
http://www.geodesy.noaa.gov/datums/newdatums/NewDatums.shtml



NAD 83 Datum vs New Geometric Global Frame

Access the old way

Text based datasheets

```
NAD 83(2011) POSITION- 40 03 10.11448(N) 082 58 34.91800(W)   ADJUSTED
NAD 83(2011) ELLIP HT-    239.400 (meters)        (06/27/12)   ADJUSTED
NAD 83(2011) EPOCH   -  2010.00
NAVD 88 ORTHO HEIGHT -    273.3    (meters)       897.     (feet) GPS OBS
```

Observed changes viewed as "corrections" not "movement"

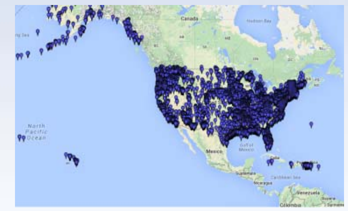
```
                         SUPERSEDED SURVEY CONTROL

NAD 83(2007)-  40 03 10.11456(N)    082 58 34.91884(W) AD(2002.00) 0
ELLIP H (02/10/07)  239.418  (m)                       GP(2002.00)
ELLIP H (03/08/05)  239.413  (m)                       GP(        ) 4 2
NAD 83(1995)-  40 03 10.11462(N)    082 58 34.91855(W) AD(        ) B
ELLIP H (08/20/96)  239.417  (m)                       GP(        ) 4 2
NAD 83(1986)-  40 03 10.12158(N)    082 58 34.92303(W) AD(        ) 1
NAD 27      -  40 03 09.89400(N)    082 58 35.26500(W) AD(        ) 1
NGVD 29 (09/26/89)  273.5    (m)  RAPSU86 model used   GPS OBS
```

Reliance on passive marks…
Fragile, unchecked passive control

Live in the present
Prepare to access the new way

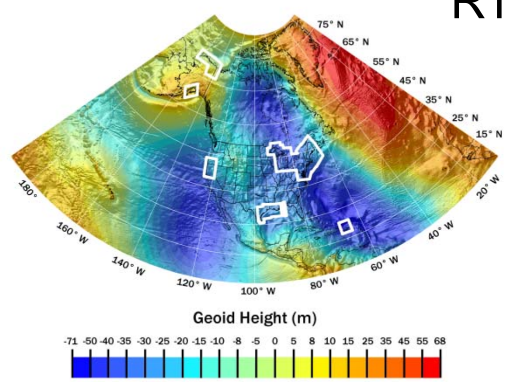
Modern datasheets

RTN

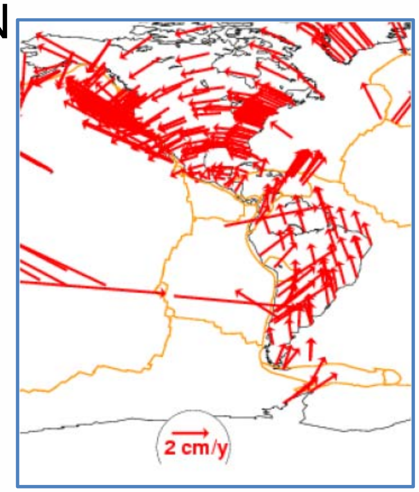


CORS

Work in the NSRS



Temporal Geoid Change



Global time/velocity changes accounted for

Improvements and advancements are on the way!

- New science yields improved methods and performance which in turn provides:
  - – **better service**
  - – **better products**
  - – **better accuracy**
  - – **better repeatability**
  - – **better sustainability**
  - – **better efficiency**

- **These changes will take time.**
- **May change the way we are used to working.**
- **May require learning new things!**

The Geometric Frame

- NGS computes all 3D coordinates (LLh) in the current NSRS global frame (ITRF08/IGS08)
- then outputs the current NSRS North American Datum: NAD 83(2011)2010.00
- This is the way the OPUS products work now.

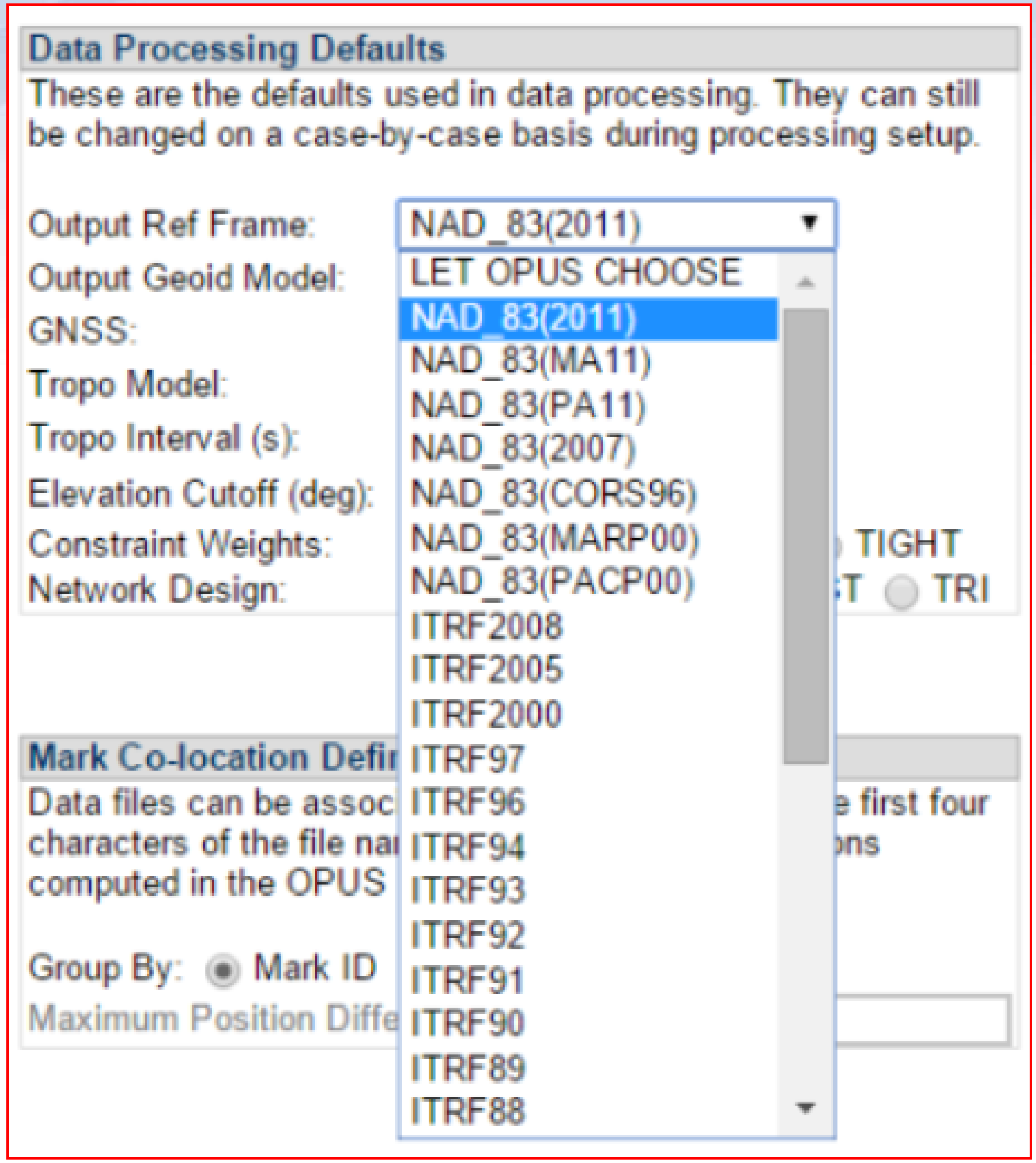
Current global frame = ITRF08 / IGS08
Next global frame = ITRF14 / IGS14
Future global frame = ITRF20 / IGS20
(there may be others - estimated dates)

OPUS Solution Report

```
bbr2230u.14o.txt created: 2015-11-30 19:13 UTC downloaded: 2016-01-13 17:22 UTC

                        NGS OPUS SOLUTION REPORT
                        ========================

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: http://www.ngs.noaa.gov/OPUS/about.jsp#accuracy

      USER: mark.l.armstrong@noaa.gov                DATE: February 24, 2015
RINEX FILE: bbr2230u.14o                             TIME: 16:31:44 UTC


  SOFTWARE: page5  1209.04 master50.pl 022814      START: 2014/08/18  20:12:00
 EPHEMERIS: igs18061.eph [precise]                  STOP: 2014/08/18  23:50:00
  NAV FILE: brdc2300.14n                        OBS USED:  8512 /  8680   :  98%
  ANT NAME: TPSHIPER_SR     NONE             # FIXED AMB:    34 /    34   : 100%
ARP HEIGHT: 0.492                            OVERALL RMS: 0.014(m)


 REF FRAME: NAD_83(2011)(EPOCH:2010.0000)               IGS08 (EPOCH:2014.6299)

         X:     -2394864.738(m)   0.019(m)          -2394865.605(m)   0.019(m)
         Y:     -3887418.647(m)   0.018(m)          -3887417.427(m)   0.018(m)
         Z:      4441294.723(m)   0.008(m)           4441294.732(m)   0.008(m)

       LAT:   44 23 59.13603      0.012(m)        44 23 59.14947      0.012(m)
     E LON:  238 21 52.68664      0.007(m)       238 21 52.62438      0.007(m)
     W LON:  121 38  7.31336      0.007(m)       121 38  7.37562      0.007(m)
    EL HGT:         1941.073(m)   0.024(m)              1940.662(m)   0.024(m)
 ORTHO HGT:         1962.449(m)   0.043(m) [NAVD88 (Computed using GEOID12A)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 10)         SPC (3601 OR N)
Northing (Y) [meters]     4917180.405           82099.445
Easting (X)  [meters]      608671.367         2409554.793
Convergence  [degrees]     0.95487424         -0.80518486
Point Scale                0.99974523          0.99998394
Combined Factor            0.99944104          0.99967968
```

OPUS Projects

User selected output reference frame

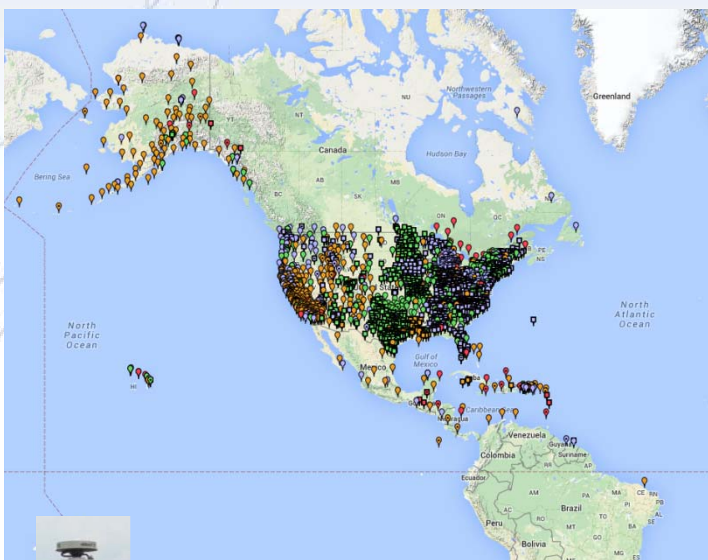


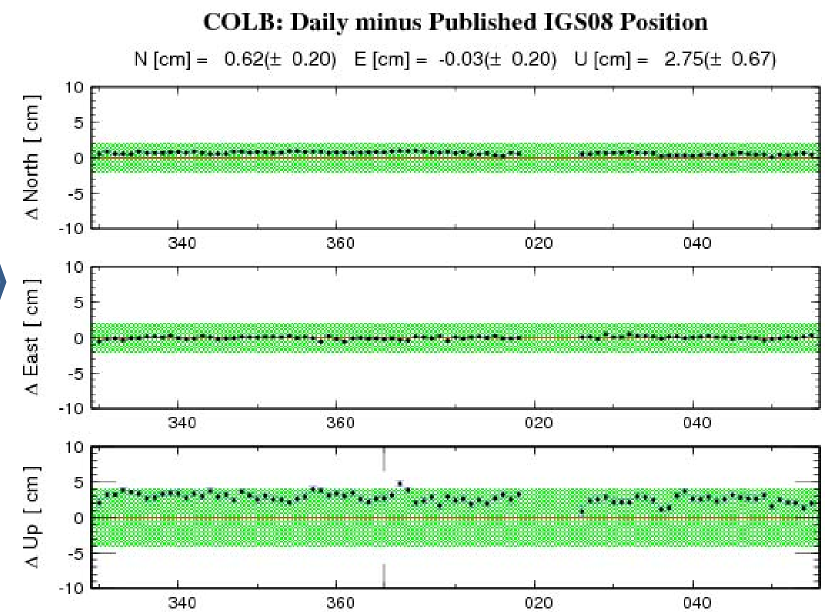
CORS

```
      Antenna Reference Point(ARP): LOUISIANA STATE U CORS ARP
      --------------------------------------------------------
                          PID = DF5754

 IGS08 POSITION (EPOCH 2005.0)
 Computed in Aug 2011 using data through gpswk 1631.
     X =    -113402.830 m     latitude      =  30 24 26.72906 N
     Y =   -5504361.332 m     longitude     = 091 10 48.94056 W
     Z =    3209404.206 m     ellipsoid height =    -6.555   m

 IGS08 VELOCITY
 Computed in Aug 2011 using data through gpswk 1631.
     VX =   -0.0119 m/yr      northward =  -0.0011 m/yr
     VY =    0.0024 m/yr      eastward  =  -0.0119 m/yr
     VZ =   -0.0025 m/yr      upward    =  -0.0031 m/yr

 NAD_83 (2011) POSITION (EPOCH 2010.0)
 Transformed from IGS08 (epoch 2005.0) position in Aug 2011.
     X =    -113402.171 m     latitude      =  30 24 26.70946 N
     Y =   -5504362.810 m     longitude     = 091 10 48.91474 W
     Z =    3209404.365 m     ellipsoid height =    -5.211   m

 NAD_83 (2011) VELOCITY
 Transformed from IGS08 velocity in Aug 2011.
     VX =    0.0021 m/yr      northward =   0.0000 m/yr
     VY =    0.0034 m/yr      eastward  =   0.0020 m/yr
     VZ =   -0.0020 m/yr      upward    =  -0.0040 m/yr
```

Also antenna models are IGS08.atx (Absolute models)

We manage (store, analyze, disseminate) data from over 2000 GNSS stations in the CORS network





90 day time series shown above

International Terrestrial Reference Frame (ITRF)

4 Global Independent Positioning Technologies

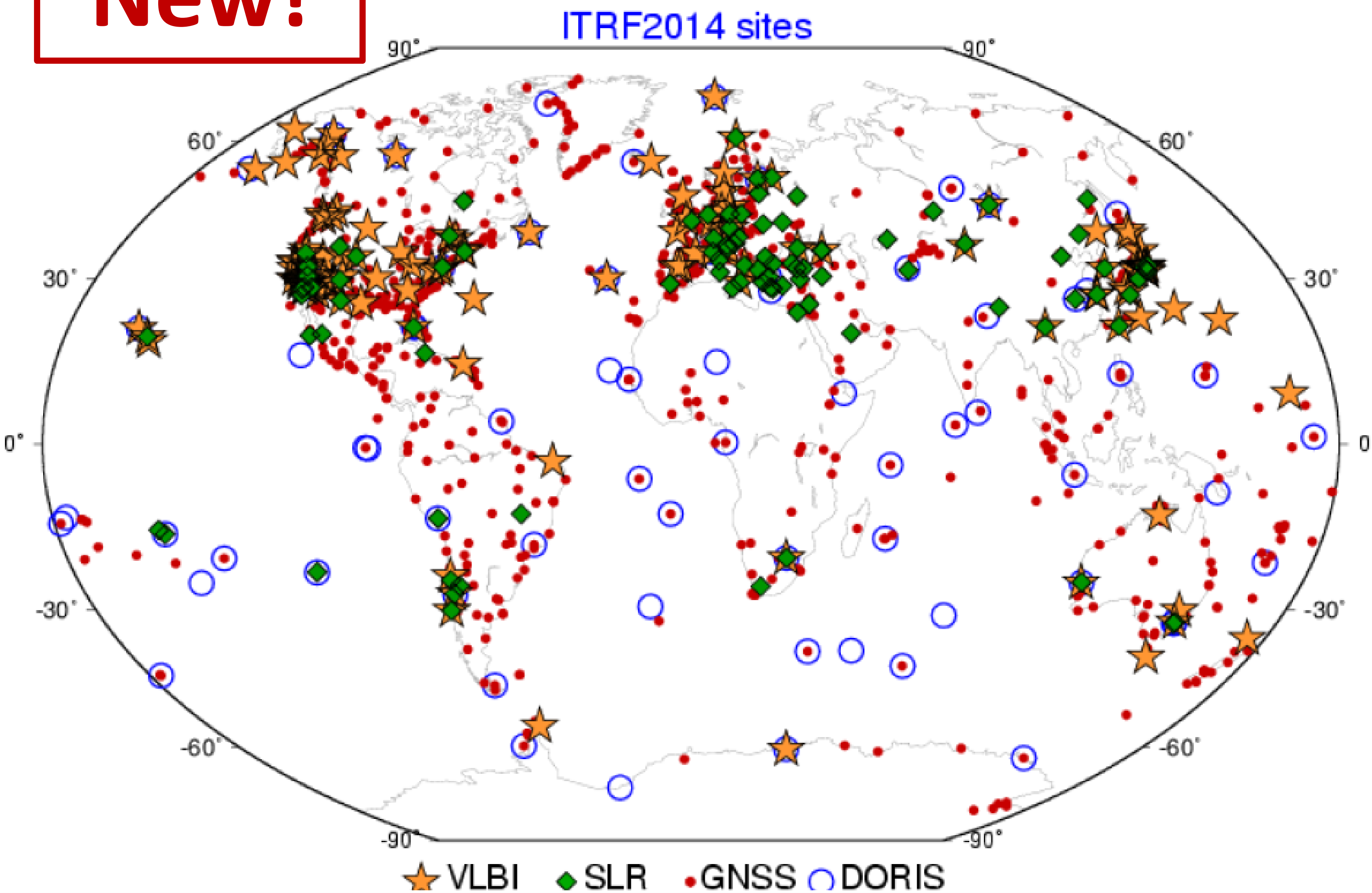
- International Global Navigation Satellite Systems Service (IGS)
- International Laser Ranging Service (ILRS)
- International Very Long Baseline Service (IVS)
- International DORIS Service (IDS)

International Terrestrial Reference Frame ITRF

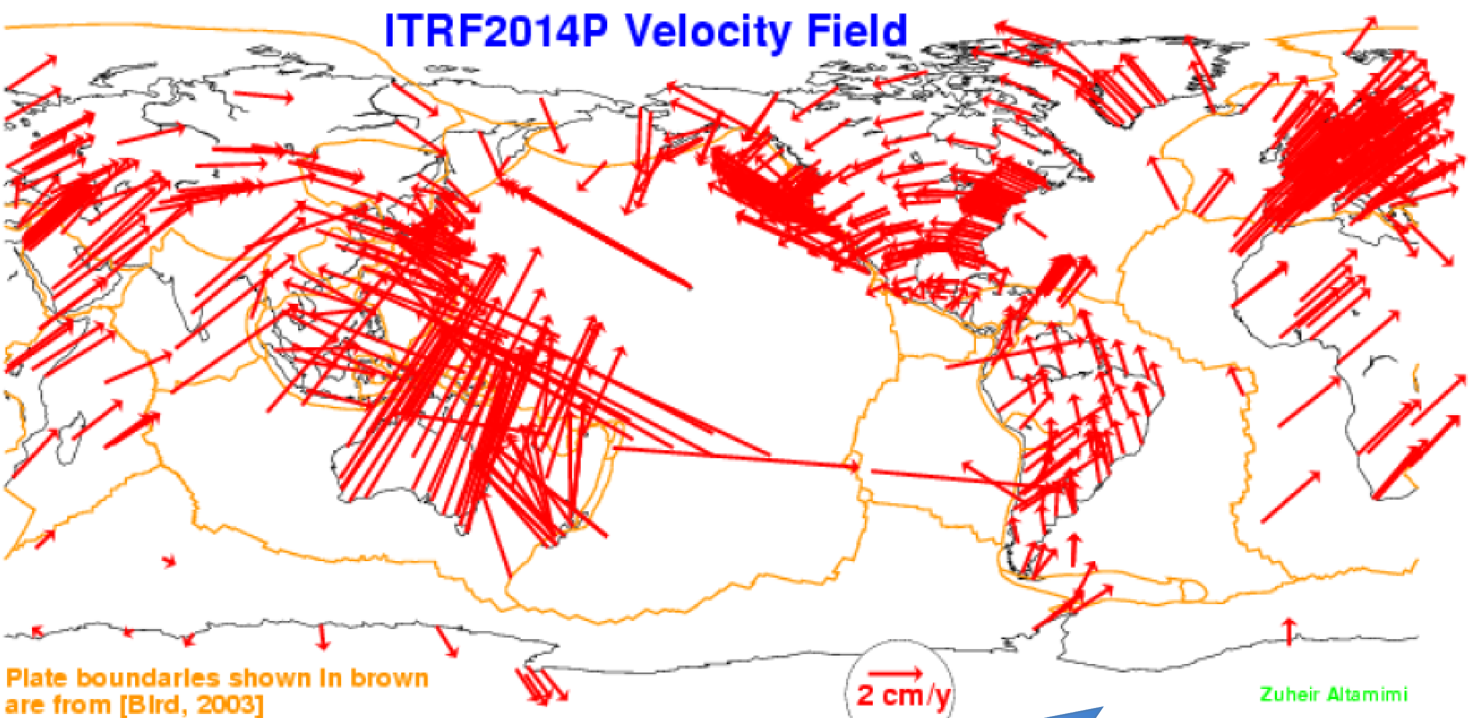
http://itrf.ensg.ign.fr/

ITRF2014

New!

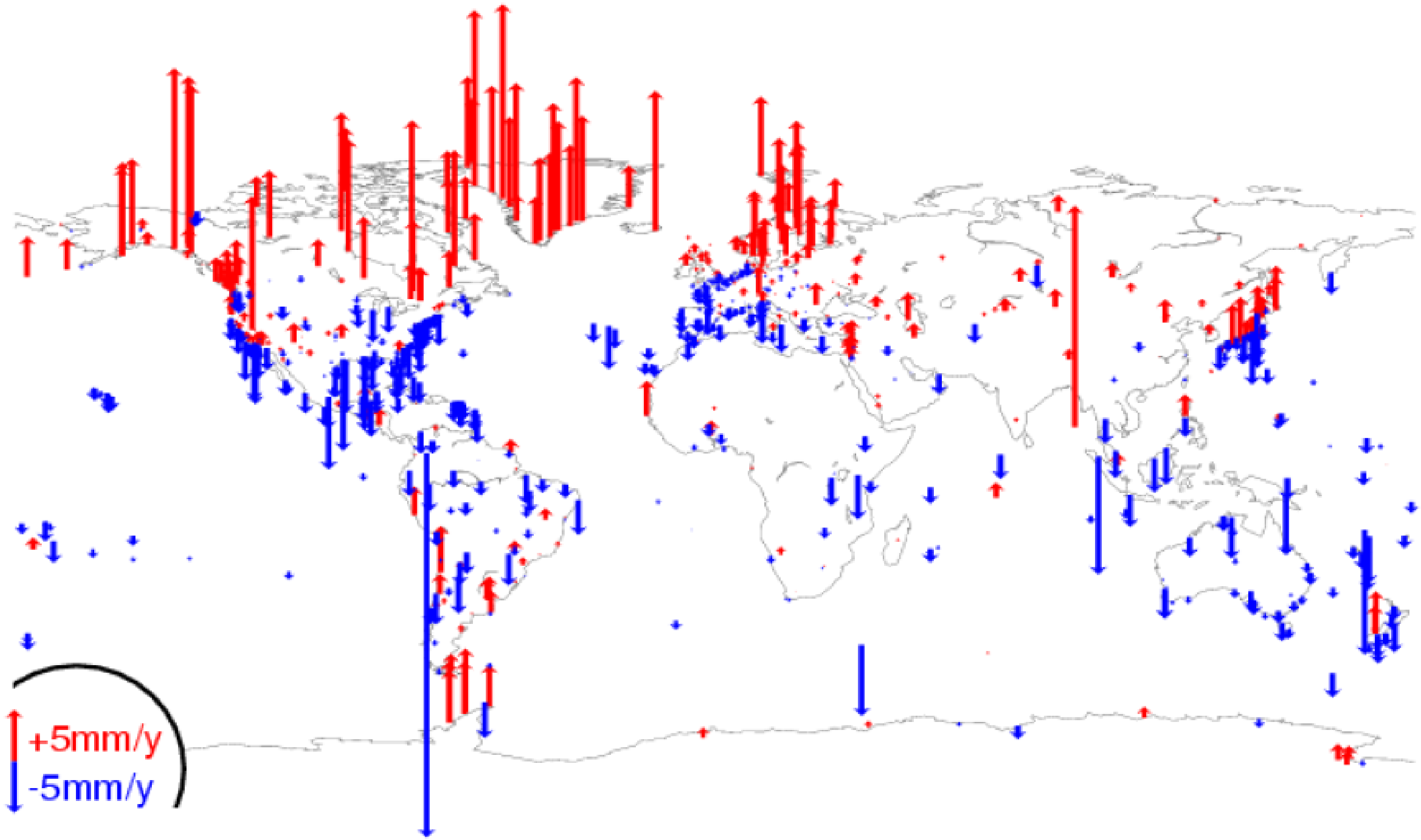


ITRF2014P: Horizontal Velocities



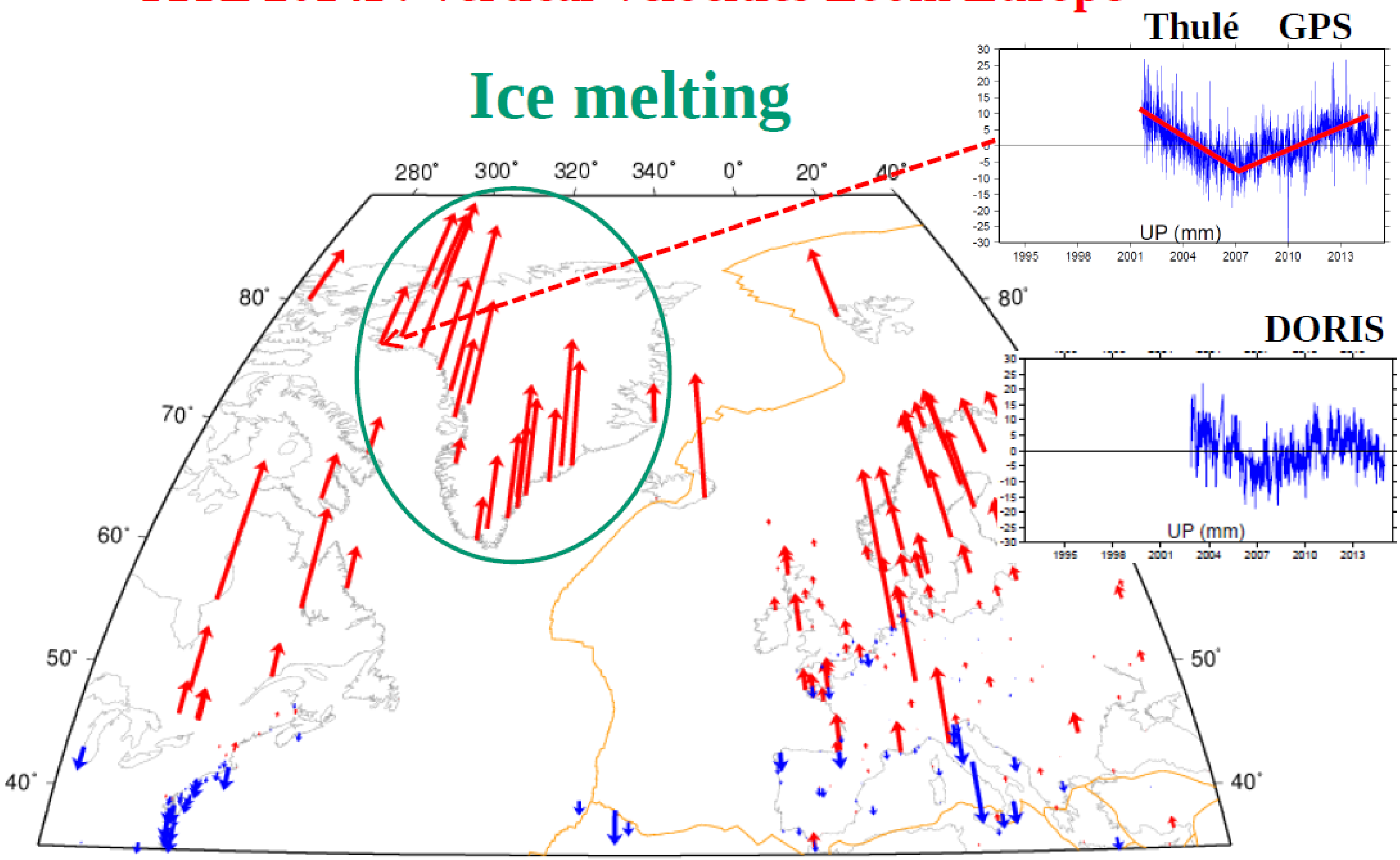
The latest global frame development

ITRF2014P: Vertical Velocities

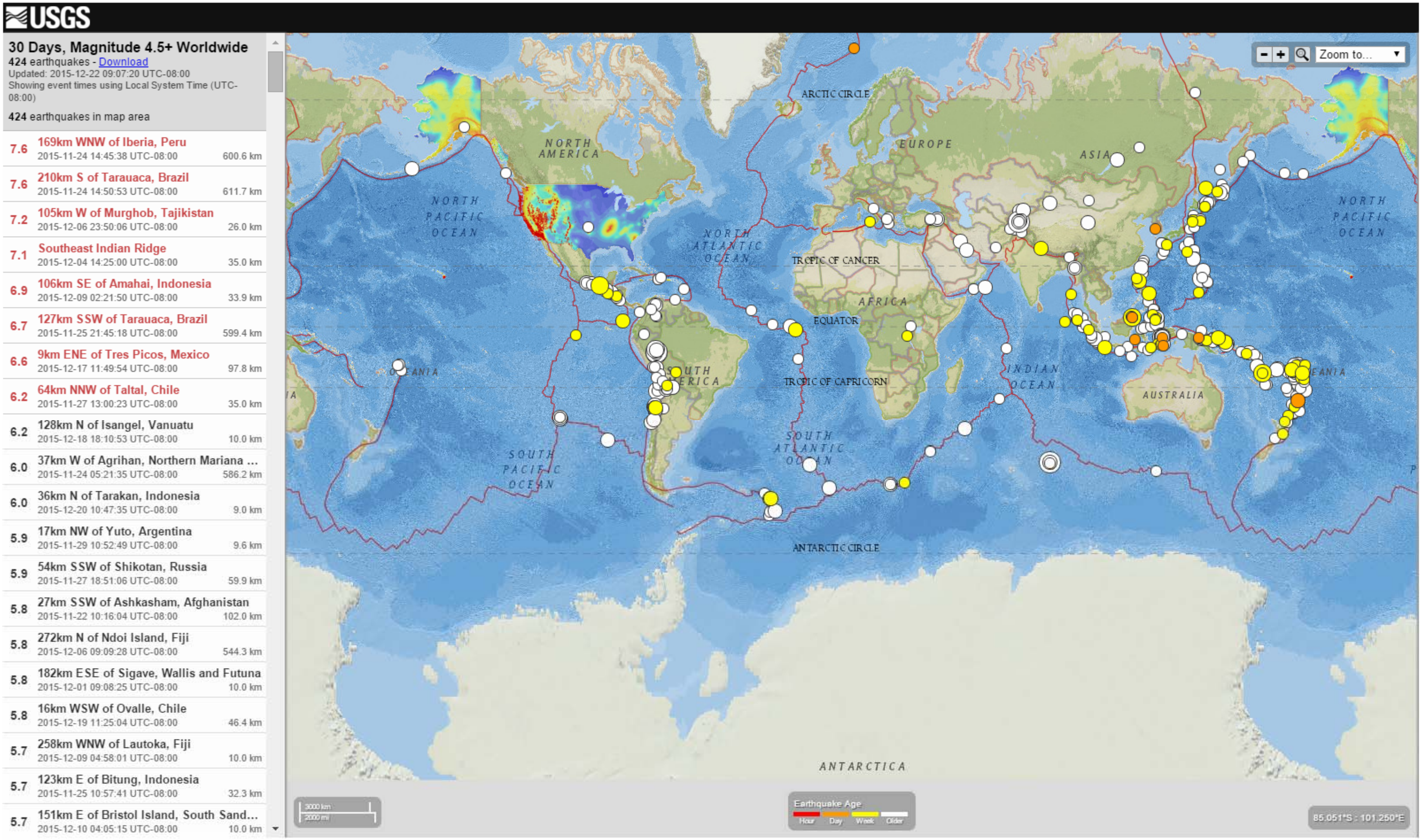


The latest global frame development

ITRF2014P: Vertical Velocities Zoom Europe



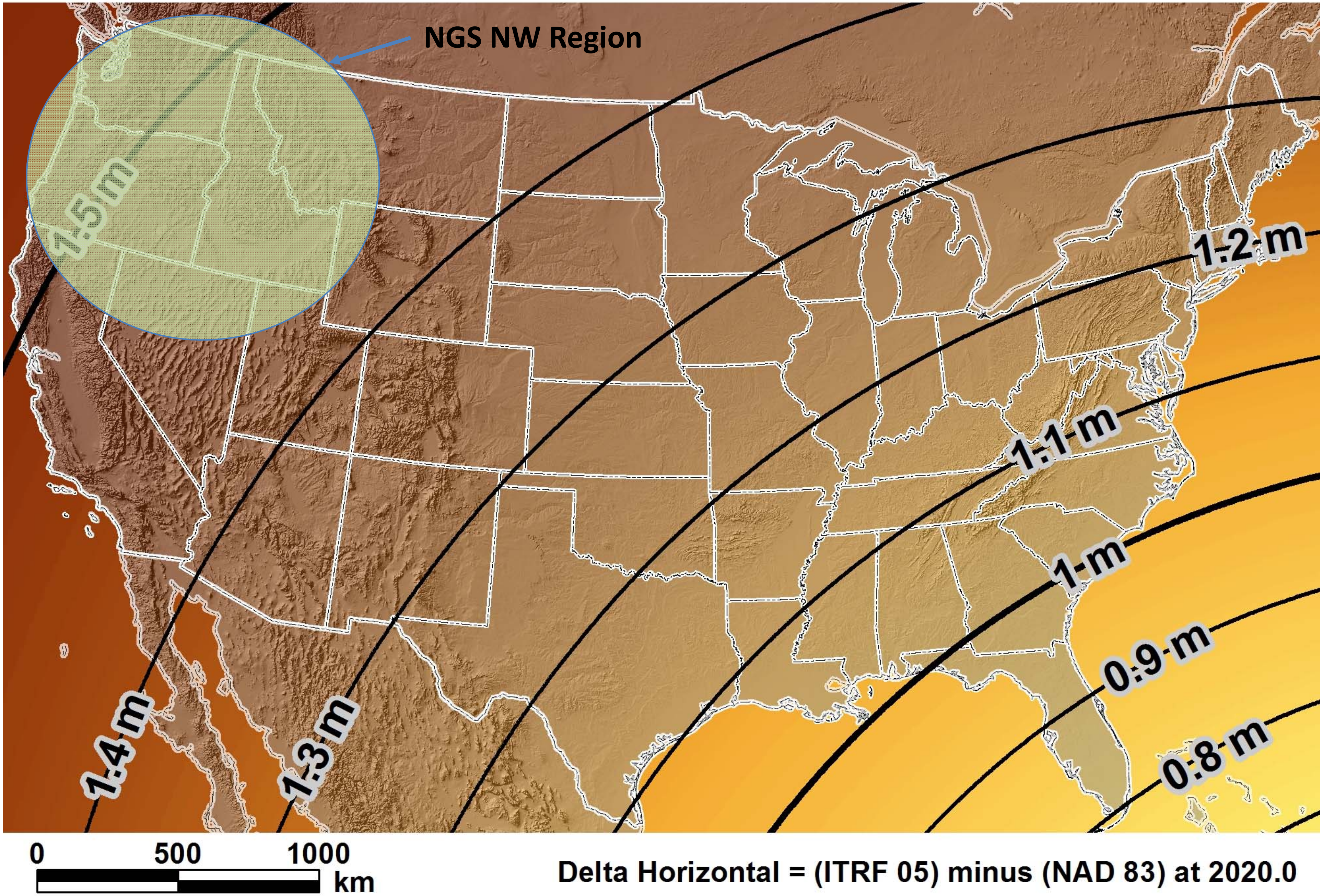
Northern latitude ice melt and post-glacial rebound



Map of 424 earthquakes magnitude 4.5+ in the last 30 days. **Quakes may cause a discontinuity in time/velocity model and need to be accounted for.**

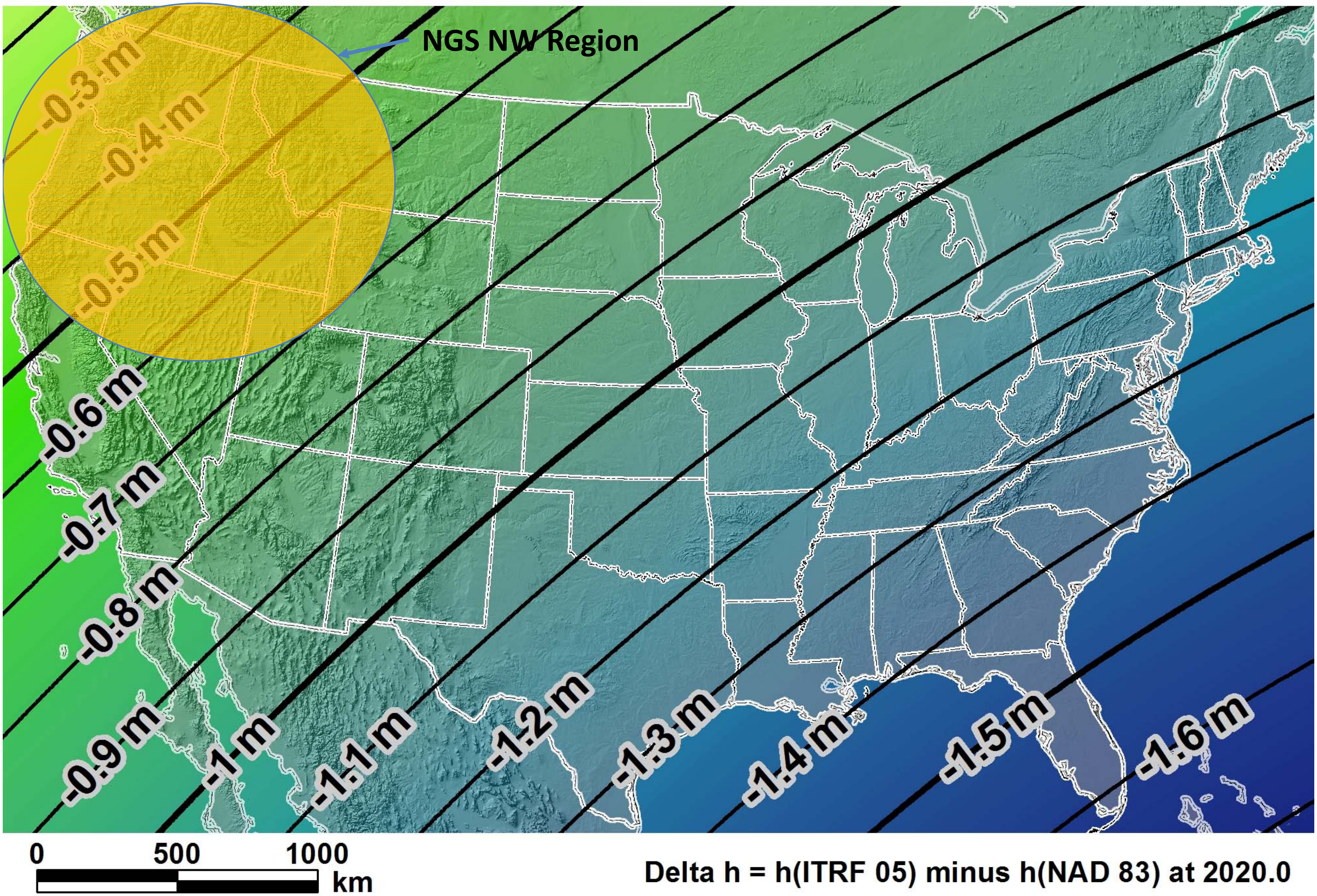
Courtesy USGS website

Estimated horizontal change from NAD 83 to new geometric datum



Delta Horizontal = (ITRF 05) minus (NAD 83) at 2020.0

Estimated ellipsoid height change from NAD 83 to new geometric datum

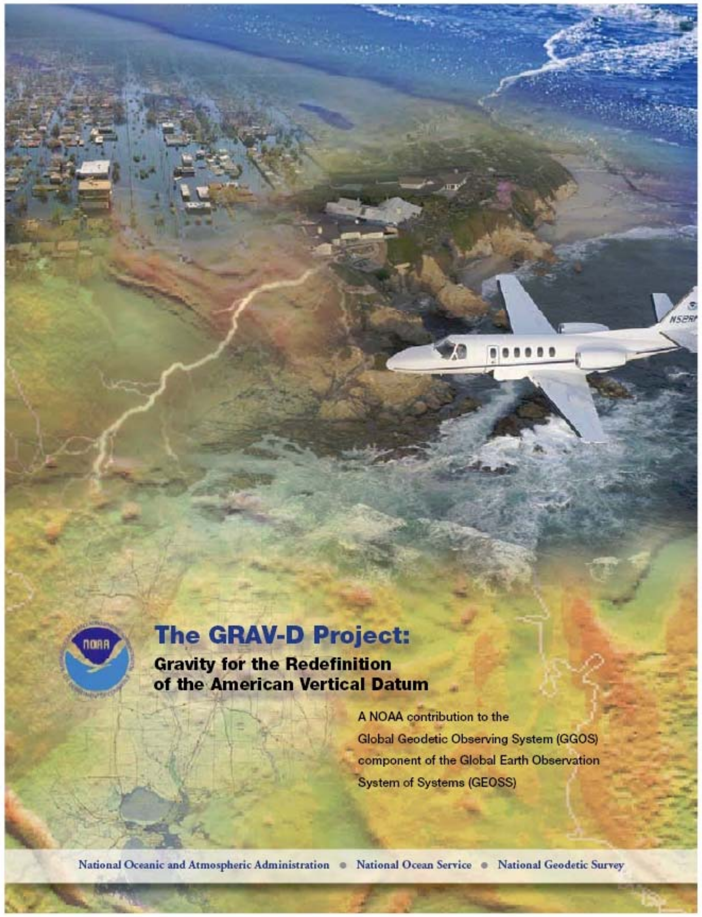


Delta h = h(ITRF 05) minus h(NAD 83) at 2020.0

Stay current and visit the NGS NEW Datums web page

The new reference frames (geometric and geopotential) will rely primarily Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS) as well as an updated and time-tracked geoid model. This paradigm will be easier and more cost-effective to maintain.

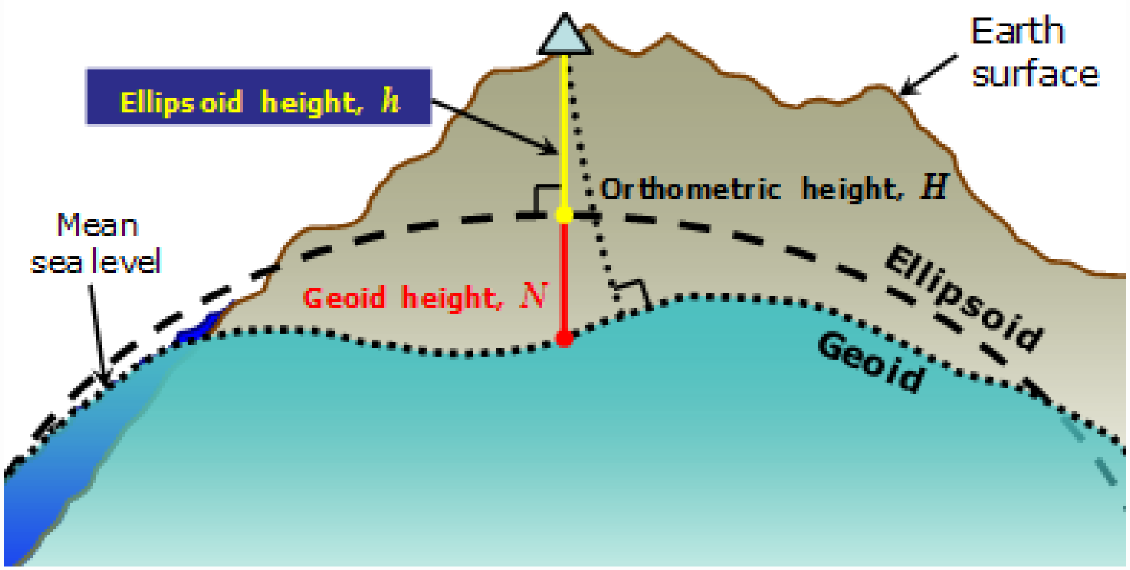
Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Update



Gravity *and* ***Heights*** *are inseparably connected*

- Goal to replace the US Vertical Datum by 2022 with a gravimetric geoid accurate to 1 cm
- 2 cm accurate orthometric heights via GNSS
  - -Airborne gravity survey of entire country
  - -Long-term monitoring of geoid change

$$H \approx h - N$$



GRAV-D Overview

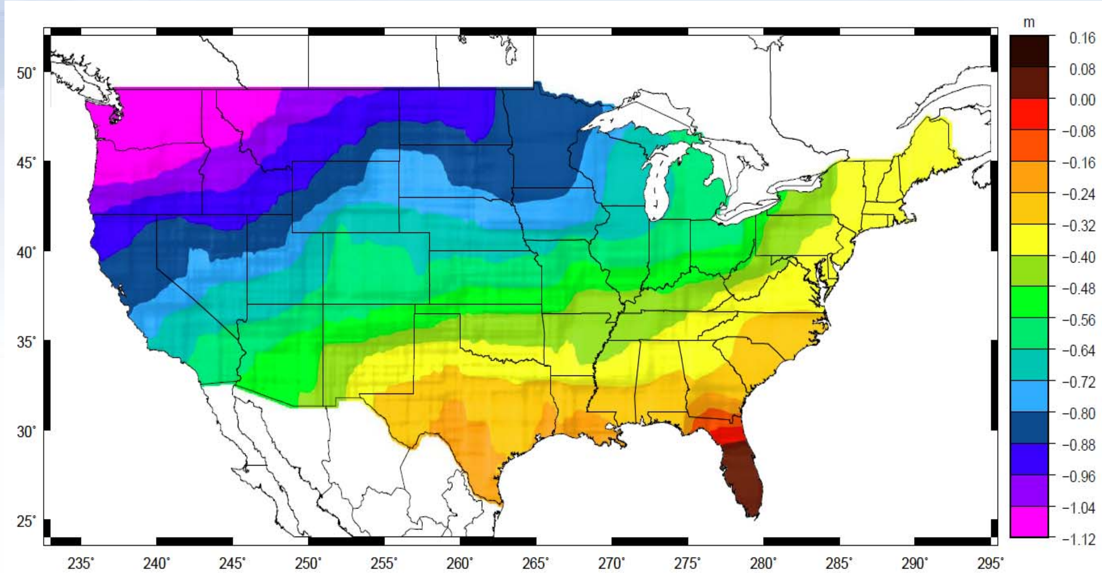
1. Background – why airborne gravity collection
2. Methods – data collection and processing
3. Validation – internal and external quality evaluation
4. Research – ongoing improvements
5. Data Use – experimental geoids

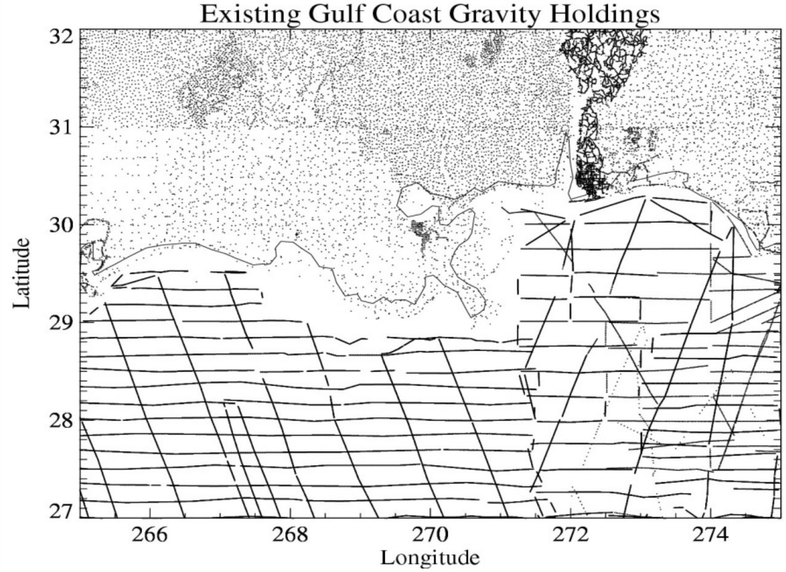
The following GRAV-D series of slides by:

- **Monica Youngman**[1], Vicki Childers[1], Theresa Damiani[1], Sandra Preaux[1], Simon Holmes[2], Carly Weil[3]
- [1]NOAA's National Geodetic Survey, [2]Stinger Ghaffarian Technologies, [3]Data Solutions Technology

Background

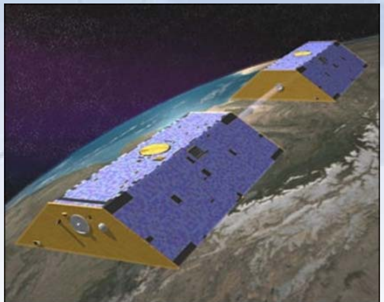
- **National Geodetic Survey mission:** define, maintain, and provide access to the National Spatial Reference System (NSRS)
- **Problem**: Known issues with the current vertical datum (NAVD 88)
- **Goal**: move to a gravity based vertical datum with a 1 cm accurate geoid
  - Gaps in gravity data coverage
  - Inconsistent terrestrial surveys
  - Medium wavelength gap





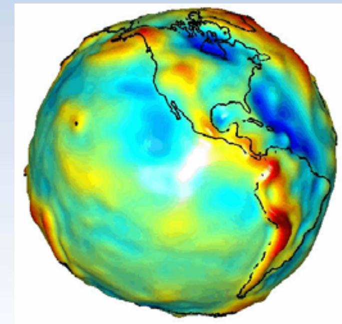
Ex. Southern U.S. Coast 20-100 km gravity gaps along coast

Measuring the Gravity Field



GRACE/GOCE/Satellite Altimetry

Long Wavelengths
(≥ 250 km)



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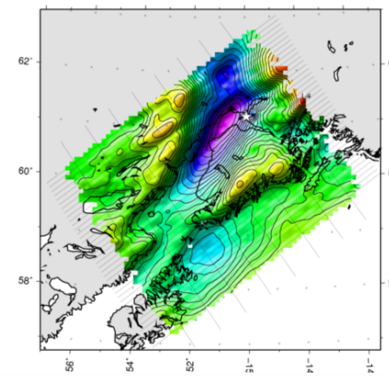
Airborne Measurement

Intermediate Wavelengths
(500 km to 20 km)



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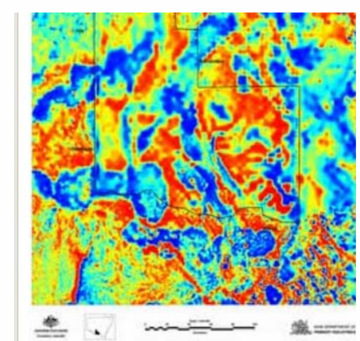
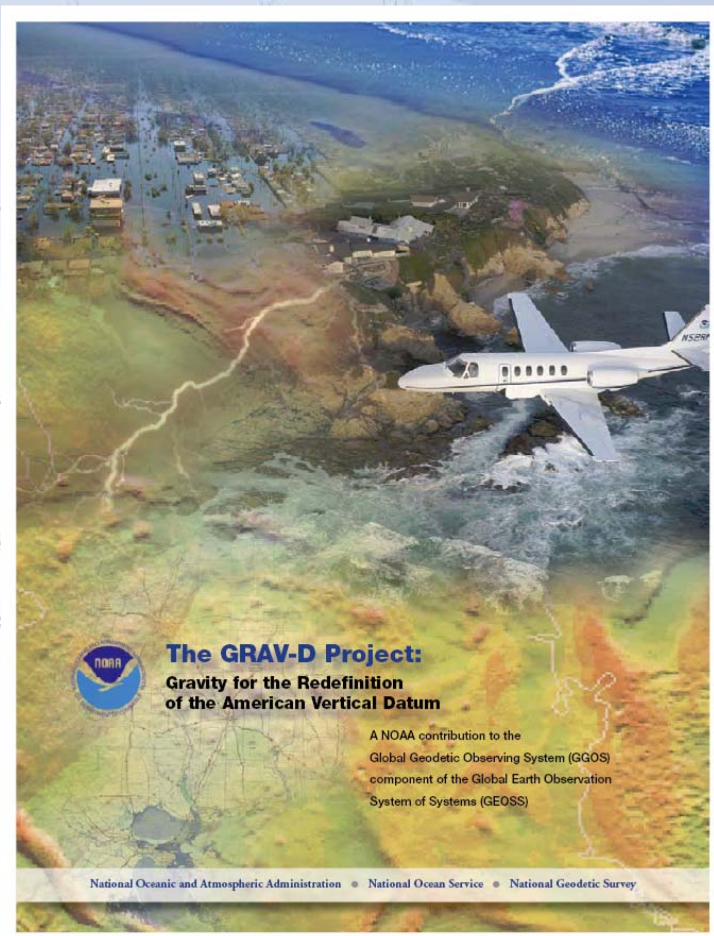
Surface Measurement and
Predicted Gravity from Topography

Short Wavelengths
(< 100 km)



GRAV-D Project Overview



- **Overall Target**: orthometric heights accurate to 2 cm from GNSS and a geoid model
- **GRAV-D Goal**: Create gravimetric geoid accurate to 1 cm where possible using airborne gravity data
- **GRAV-D**: two phases
  - Airborne gravity survey of entire country and its holdings
  - Long-term monitoring of geoid change
- Leveraging partnerships to improve and validate gravity data

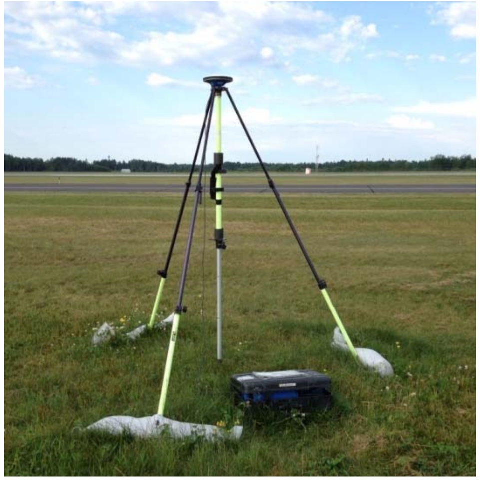
Data Collection Scope

- Entire U.S. and territories
  - Total Square Kilometers: 15.6 million
  - ~200 km buffer around territory or shelf break if possible
  - Initial target area for 2022 deadline

Methods: Survey Reconnaissance

Parking spot ID

A10 measurement



GPS Base Stations

Vertical gravity gradient

GRAV-D Aircraft

- NOAA
  - Gulfstream Jet Prop
  - Orion P-3
  - Cessna Citation (Jet)
- DOI Bureau of Land Management
  - Pilatus PC-12
  - King Air 200
- Naval Research Lab
  - King Air RC-12
- Contract Aircraft
  - King Air E-90A (Fugro)
  - Cessna Conquest (Fugro)
  - King Air 200T (Dynamic Aviation)

Pilatus PC-12

King Air RC-12

King Air E-90A

Turbo Commander

Data Collection

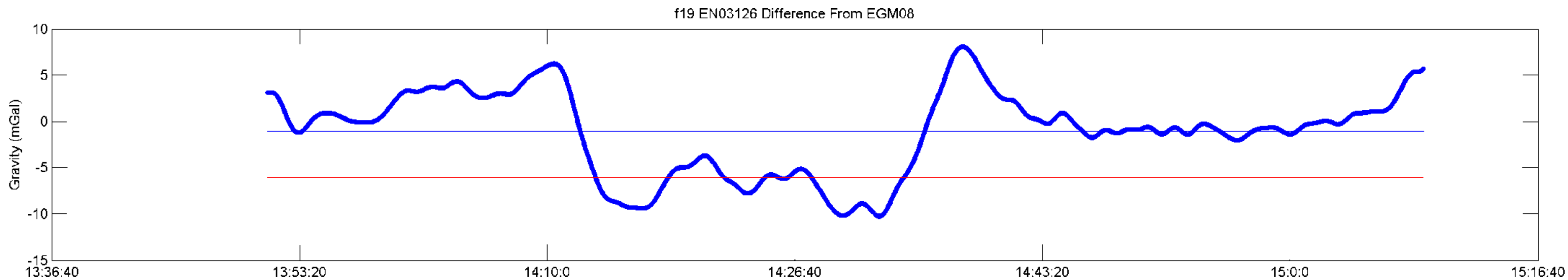
- Equipment
  - Micro-g TAGS III Air-Sea Gravimeter
  - GNSS Antenna and Receiver on aircraft
  - NovAtel SPAN Inertial Measurement Unit with Honeywell μIRS IMU
  - At least 2 GNSS antennas and receivers at the airport
- Data Collection
  - 10 km data line spacing
  - 80 km cross line spacing
  - 20,000 ft (6090 m) flight height
  - ~250 kts flight speed

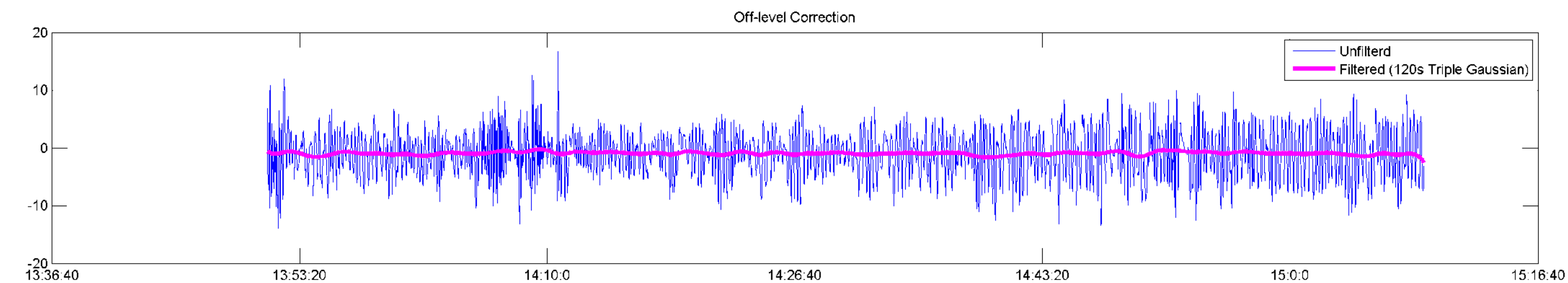
Micro-g LaCoste TAGS Gravimeter

NovAtel SPAN-SE

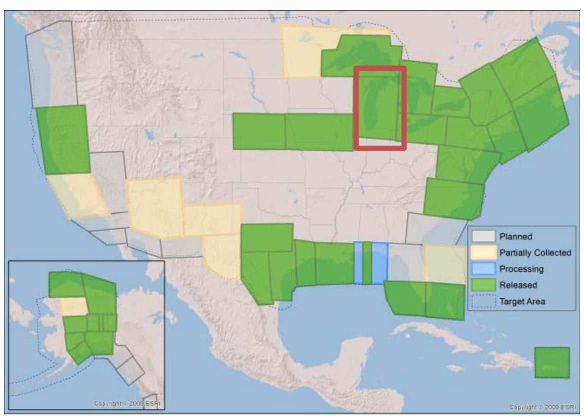
Data Processing

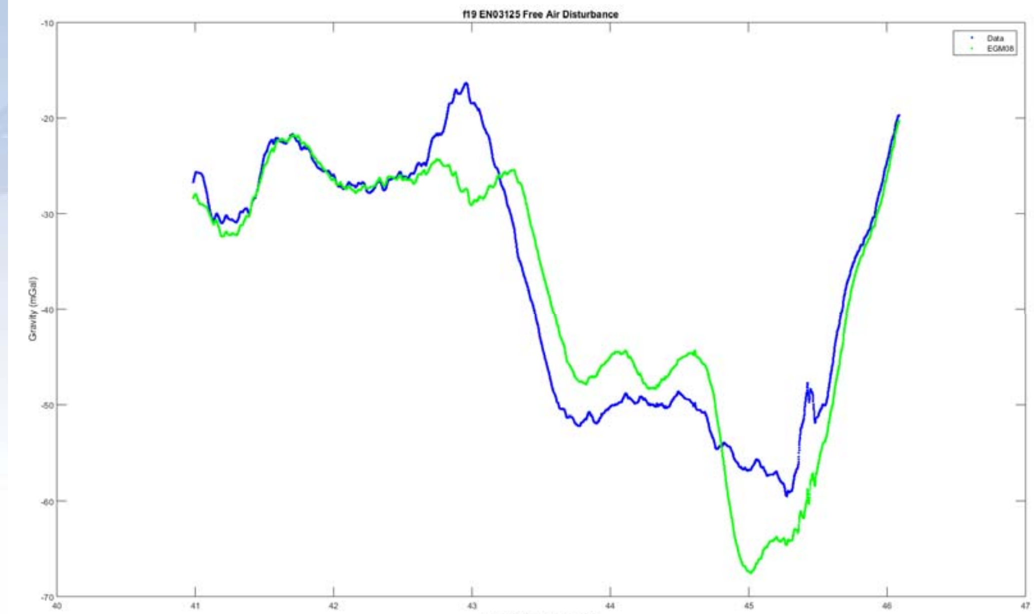
- **Field Quality Control Processing**
  - GPS/IMU combined solution using differential positioning
  - Gravity processing with Issac (internal software)
- **Final Processing**
  - GPS/IMU combined solution using Precise Point Positioning (PPP)
  - Gravity processing with Newton (internal software)
  - Quality evaluated and data minimally trimmed
  - Processed data and documentation released

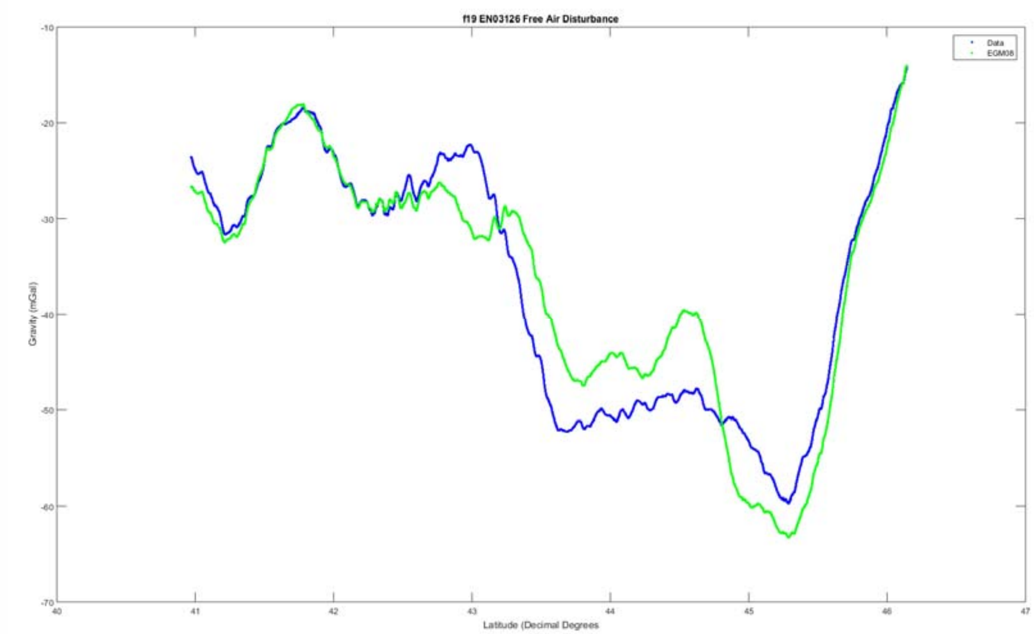




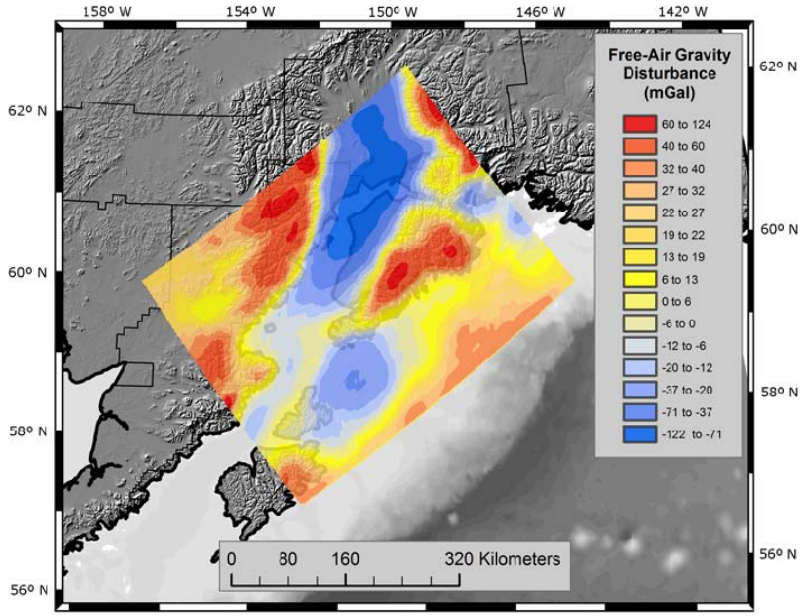
Lake Michigan



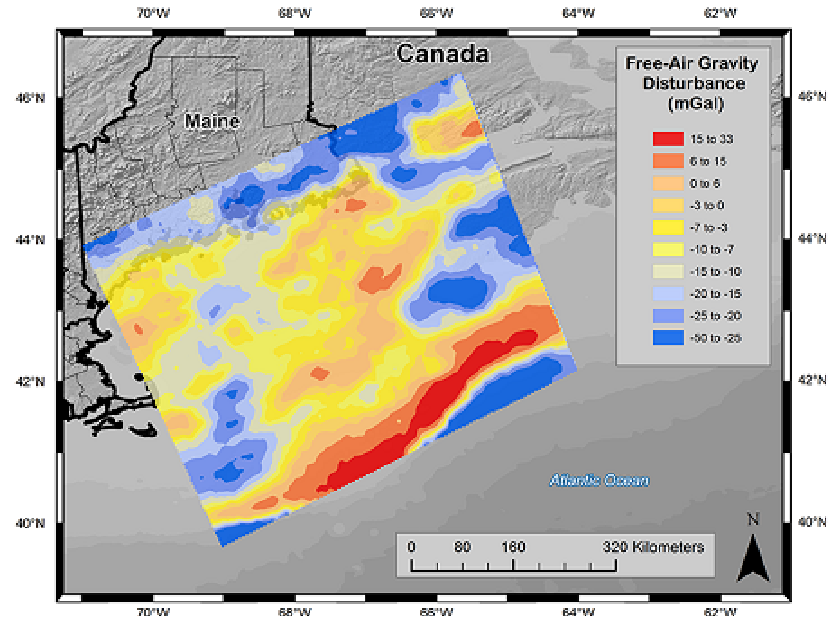




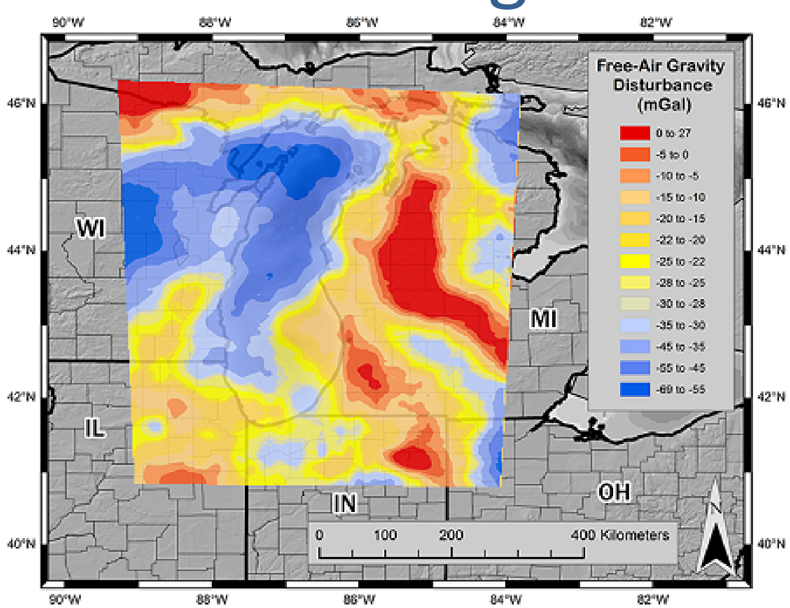
Southern Alaska



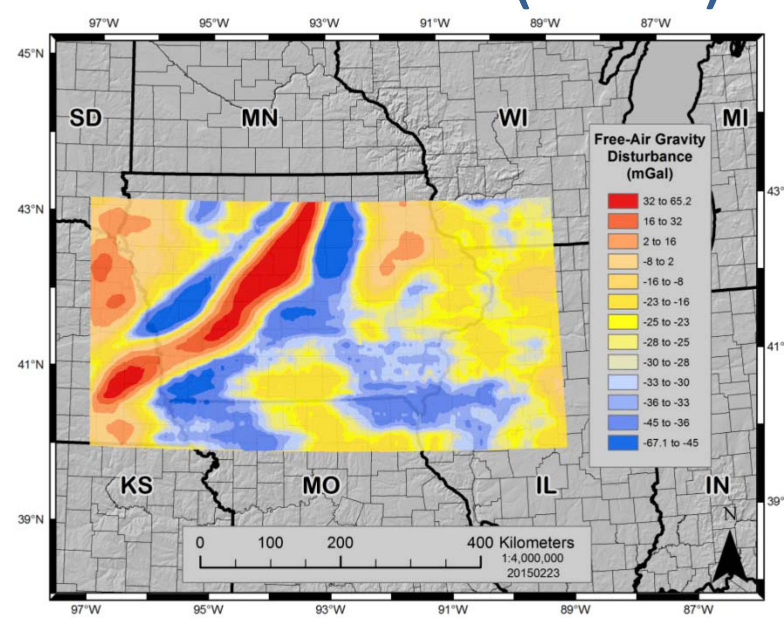
Northeast Coast



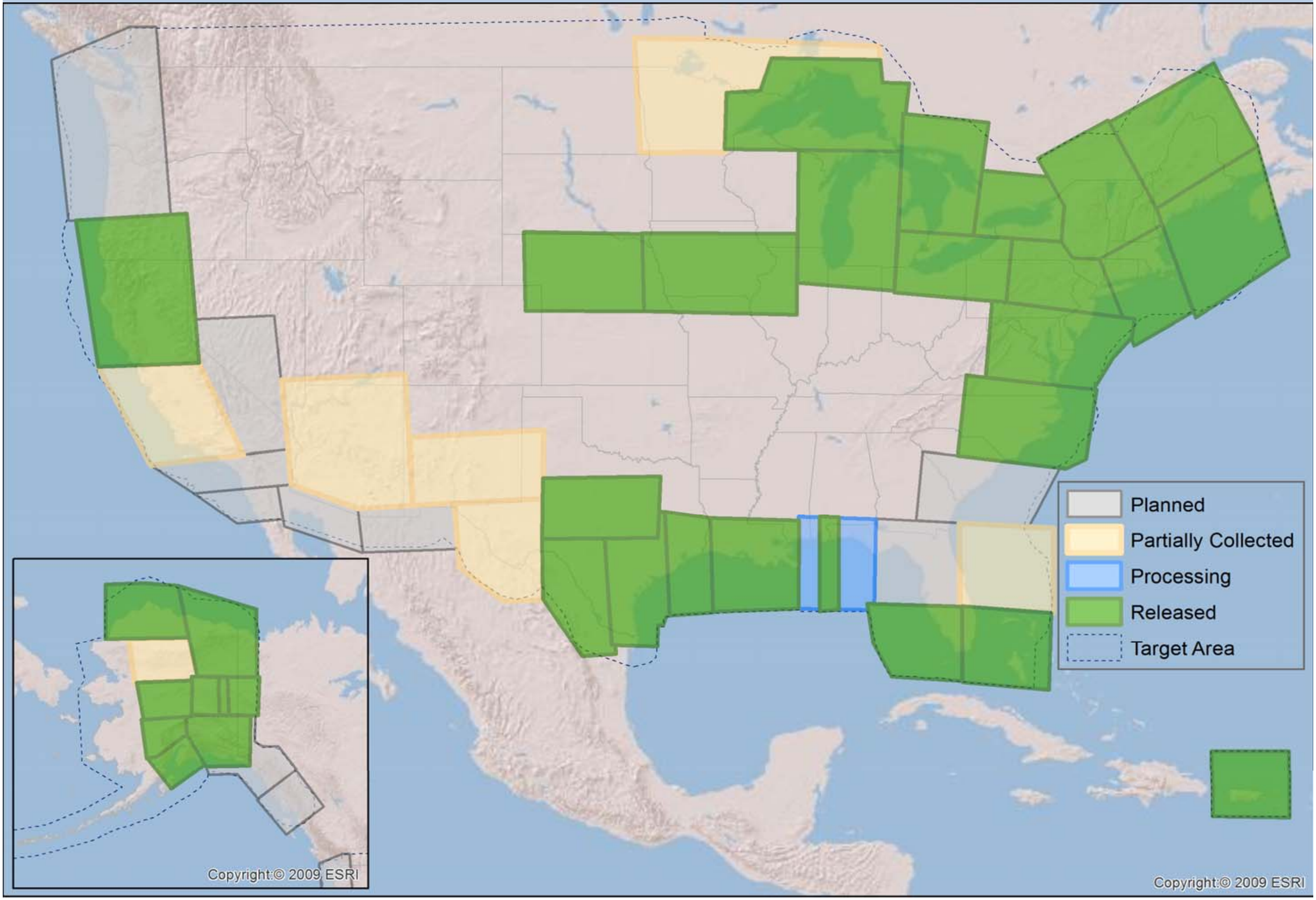
Lake Michigan



Central U.S. (Iowa)

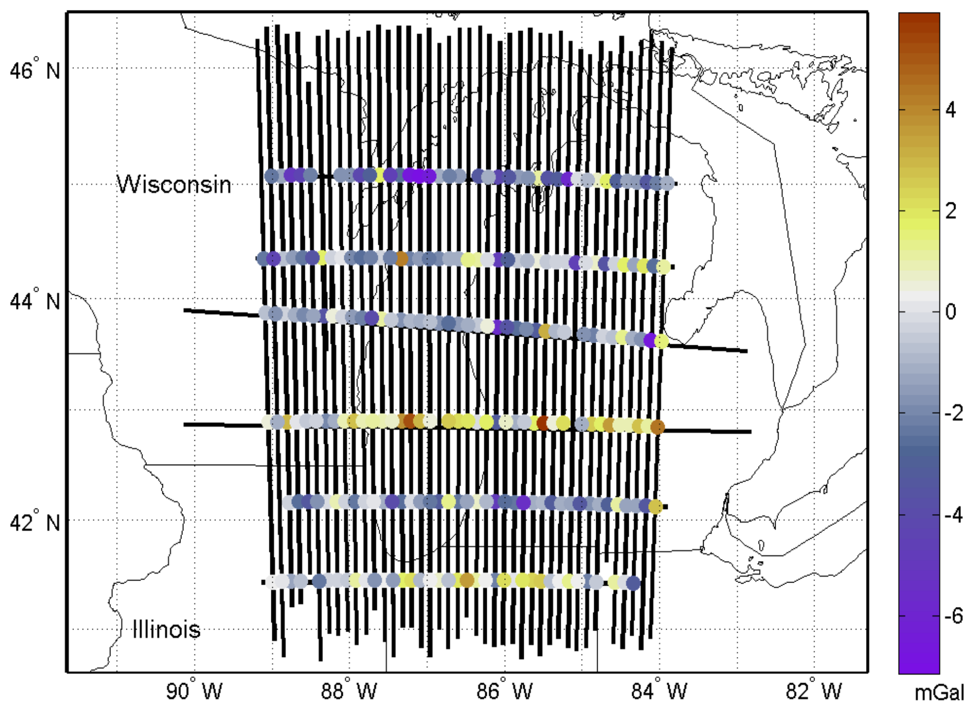


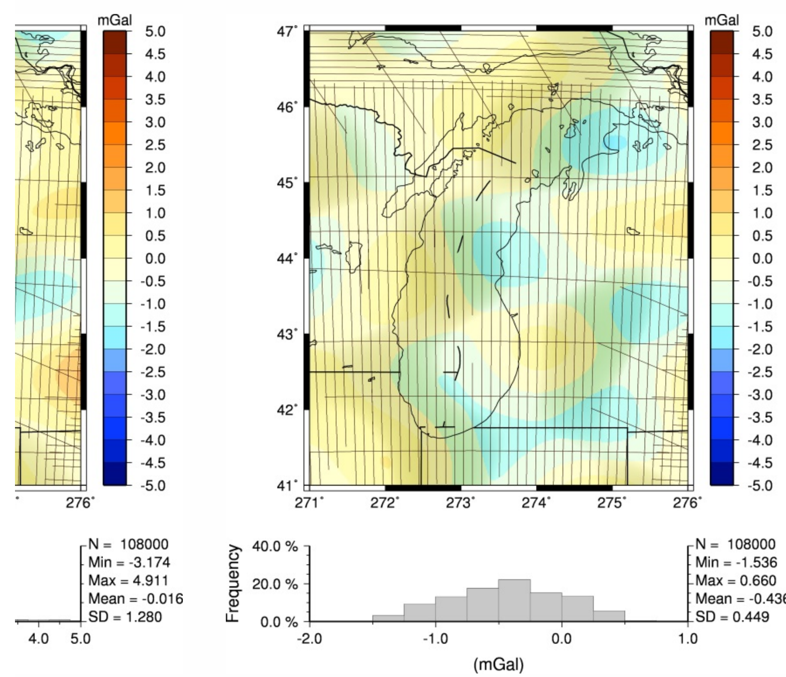
GRAV-D Data Status



Aerial data collection validation

- **Internal Validation**
  - Crossover analysis
  - Line to line comparison
  - Line re-flights
- **External Validation**
  - Updates to EGM08 compared to GOCE
  - **Geoid Slope Validation Surveys (2011, 2014, 2017)**





GSVS2011, GSVS2014, GSVS17

- Field ground surveys that provide for external confirmation check on the GRAV-D geoid model.
  - **GSVS2011 located near sea level in TX**
  - **GSVS2014 located mid elevation in IO**
  - **GSVS2017 located high elevation in CO**
    - » **Survey methods include:**
      - Differential Leveling
      - Campaign GPS
      - RTN-based GPS if available
      - Absolute Gravity
      - Gravity Gradients
      - Deflections of the Vertical
      - Airborne LIDAR
      - Airborne Imagery

Continental consistency

In the new geopotential reference frame, heights will be consistent from pole to equator and Aleutians to Greenland.

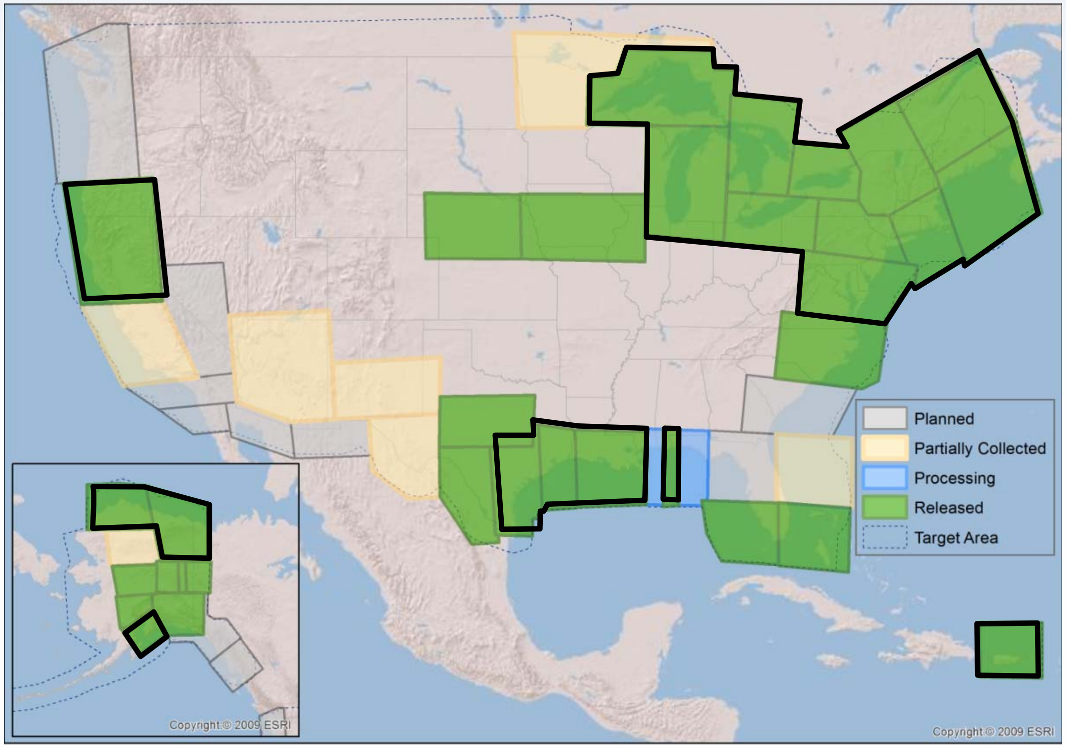
Extent of 2022 geoid model used for new geopotential reference frame

Data Use: Experimental Models

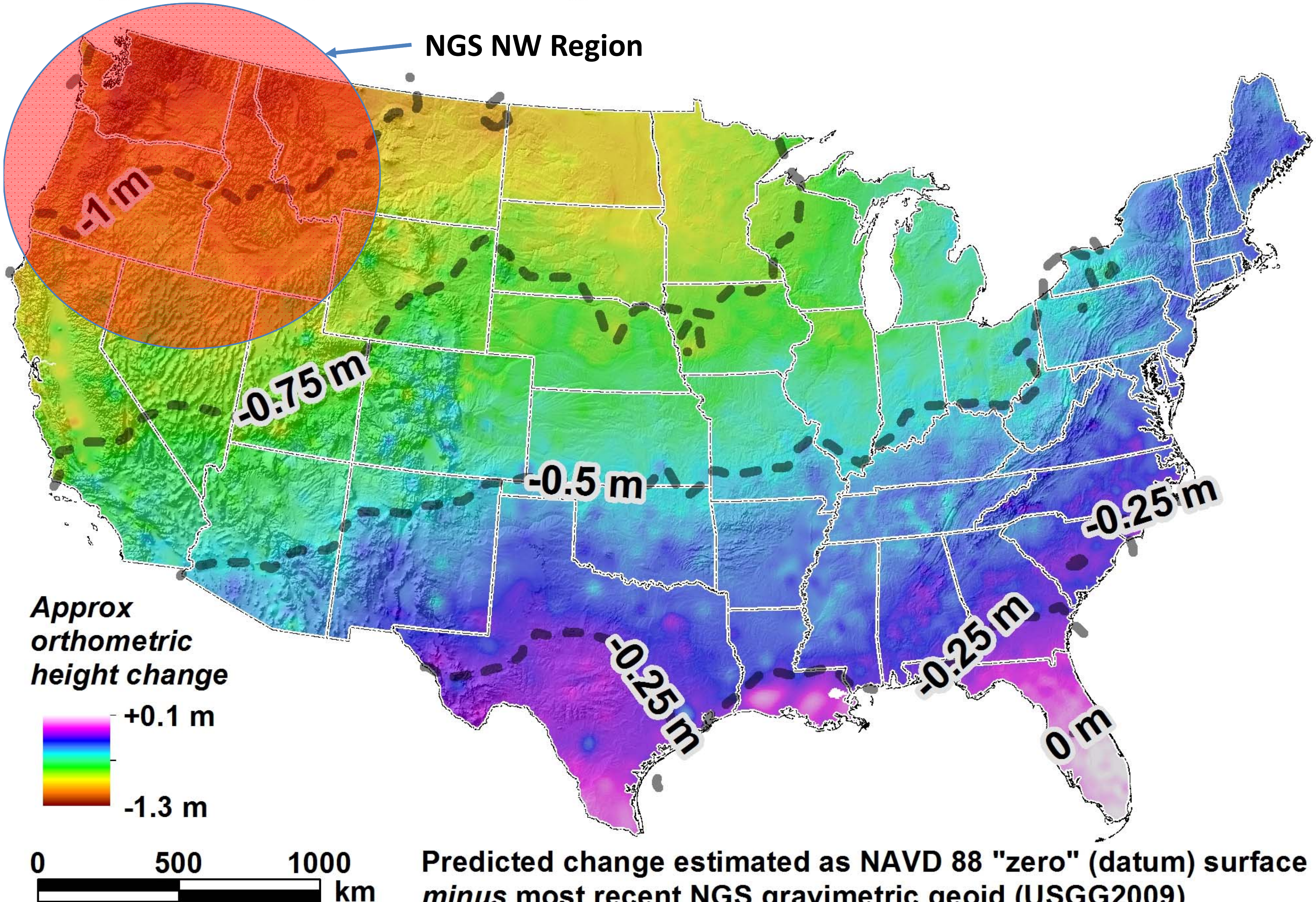
Annually update and release an experimental gravimetric geoid with airborne gravity data

- Gravimetric Geoids
  - from USGG2012 (last non-GRAV-D gravimetric geoid)
  - through xGG201? (annual experimental geoid)
  - to USGG2022 (the final geoid with GRAV-D)
- Improve computation methods
- Website access allows point queries

xGG2014 (June 2014)



Approximate predicted change from NAVD 88 to new vertical datum



Predicted change estimated as NAVD 88 "zero" (datum) surface *minus* most recent NGS gravimetric geoid (USGG2009)

BETA

This is a BETA Release Site

xGEOID15 Evaluation Computation

National Geodetic Survey

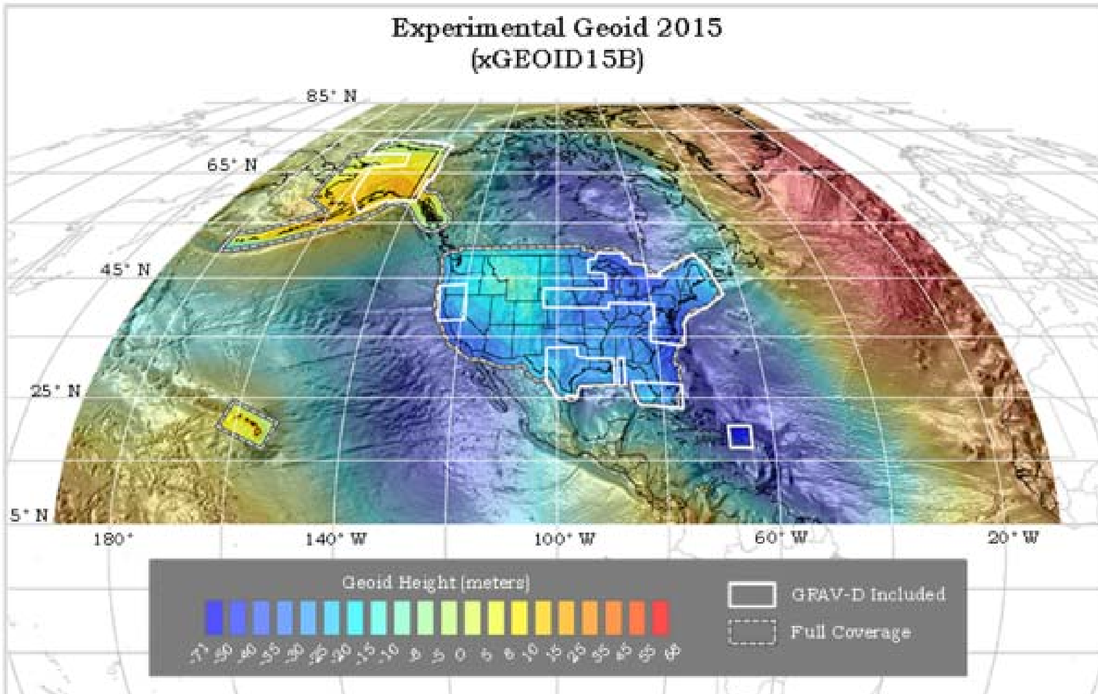


Fig. 1 shows the xGEOID15B model that covers the area from 5 to 85 degrees latitude and 170 to 350 degrees longitude. The white boxes correspond to the regions where GRAV-D airborne gravity data were included based on their suitability as of August, 2015

xGEOID15A: All available data and best methods EXCLUDING GRAV-D airborne gravity data.

xGEOID15B: All available data and best methods INCLUDING GRAV-D airborne gravity data.

Orthometric Heights from OPUS

Make geoid-based orthometric heights available via OPUS (NGS' Online Positioning User Service)

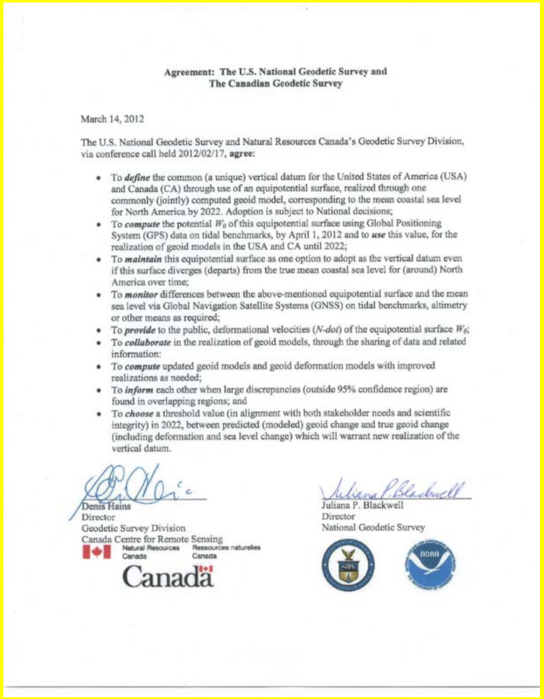
- **Done**, in the extended output

```
        ** Orthometric Heights Above Future Geopotential Datum.

Prototype orthometric heights are now being made available as a precursor to the completion
of GRAV-D and the replacement of NAVD 88 with a new geopotential reference system.  The
following height reflects the current best estimate of the true orthometric height, based on
the existing gravimetric geoid model.  This height is subject to change as data and modeling
for the gravimetric geoid change throughout the lifetime of the GRAV-D project, or as new
realizations of the ITRF are adopted.  However, at the completion of GRAV-D, these heights will
supersede the NAVD 88 heights

APPROX ORTHO HGT:      5.862 (m) [PROTOTYPE (Computed using USGG2012,GRS80,IGS08)]
```

Agreement on W_0 value for the equipotential surface



Agreement: The U.S. National Geodetic Survey and The Canadian Geodetic Survey

March 14, 2012

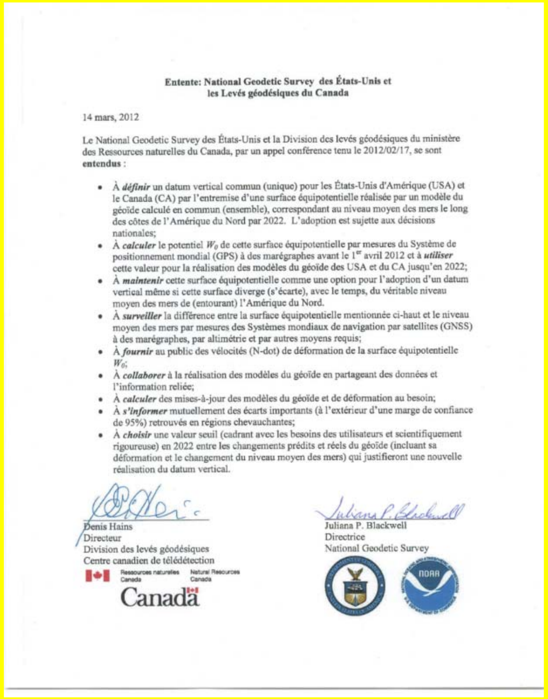
The U.S. National Geodetic Survey and Natural Resources Canada's Geodetic Survey Division, via conference call held 2012/02/17, **agree:**

- To ***define*** the common (a unique) vertical datum for the United States of America (USA) and Canada (CA) through use of an equipotential surface, realized through one commonly (jointly) computed geoid model, corresponding to the mean coastal sea level for North America by 2022. Adoption is subject to National decisions;
- To ***compute*** the potential W_0 of this equipotential surface using Global Positioning System (GPS) data on tidal benchmarks, by April 1, 2012 and to ***use*** this value, for the realization of geoid models in the USA and CA until 2022;
- To ***maintain*** this equipotential surface as one option to adopt as the vertical datum even if this surface diverges (departs) from the true mean coastal sea level for (around) North America over time;
- To ***monitor*** differences between the above-mentioned equipotential surface and the mean sea level via Global Navigation Satellite Systems (GNSS) on tidal benchmarks, altimetry or other means as required;
- To ***provide*** to the public, deformational velocities (*N-dot*) of the equipotential surface W_0;
- To ***collaborate*** in the realization of geoid models, through the sharing of data and related information:
- To ***compute*** updated geoid models and geoid deformation models with improved realizations as needed;
- To ***inform*** each other when large discrepancies (outside 95% confidence region) are found in overlapping regions; and
- To ***choose*** a threshold value (in alignment with both stakeholder needs and scientific integrity) in 2022, between predicted (modeled) geoid change and true geoid change (including deformation and sea level change) which will warrant new realization of the vertical datum.

Denis Hains
Director
Geodetic Survey Division
Canada Centre for Remote Sensing
Natural Resources Canada / Ressources naturelles Canada
Canada

Juliana P. Blackwell
Director
National Geodetic Survey

The geoid is one of the infinitely equipotential surfaces surrounding the Earth, with some (true) potential value of W_0.



Entente: National Geodetic Survey des États-Unis et les Levés géodésiques du Canada

14 mars, 2012

Le National Geodetic Survey des États-Unis et la Division des levés géodésiques du ministère des Ressources naturelles du Canada, par un appel conférence tenu le 2012/02/17, se sont **entendus** :

- À ***définir*** un datum vertical commun (unique) pour les États-Unis d'Amérique (USA) et le Canada (CA) par l'entremise d'une surface équipotentielle réalisée par un modèle du géoïde calculé en commun (ensemble), correspondant au niveau moyen des mers le long des côtes de l'Amérique du Nord par 2022. L'adoption est sujette aux décisions nationales;
- À ***calculer*** le potentiel W_0 de cette surface équipotentielle par mesures du Système de positionnement mondial (GPS) à des marégraphes avant le 1er avril 2012 et à ***utiliser*** cette valeur pour la réalisation des modèles du géoïde des USA et du CA jusqu'en 2022;
- À ***maintenir*** cette surface équipotentielle comme une option pour l'adoption d'un datum vertical même si cette surface diverge (s'écarte), avec le temps, du véritable niveau moyen des mers de (entourant) l'Amérique du Nord.
- À ***surveiller*** la différence entre la surface équipotentielle mentionnée ci-haut et le niveau moyen des mers par mesures des Systèmes mondiaux de navigation par satellites (GNSS) à des marégraphes, par altimétrie et par autres moyens requis;
- À ***fournir*** au public des vélocités (N-dot) de déformation de la surface équipotentielle W_0;
- À ***collaborer*** à la réalisation des modèles du géoïde en partageant des données et l'information reliée;
- À ***calculer*** des mises-à-jour des modèles du géoïde et de déformation au besoin;
- À ***s'informer*** mutuellement des écarts importants (à l'extérieur d'une marge de confiance de 95%) retrouvés en régions chevauchantes;
- À ***choisir*** une valeur seuil (cadrant avec les besoins des utilisateurs et scientifiquement rigoureuse) en 2022 entre les changements prédits et réels du géoïde (incluant sa déformation et le changement du niveau moyen des mers) qui justifieront une nouvelle réalisation du datum vertical.

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To choose a threshold value (in alignment with both stakeholder needs and scientific integrity) in 2022, between predicted (modeled) geoid change and true geoid change (including deformation and sea level change) which will warrant new realization of the vertical datum.

Stay tuned to the NGS web page for new information, videos, and data

https://www.youtube.com/playlist?list=PLsyDl_aqUTdFY6eKURmiCBBk-mP4R10Dx

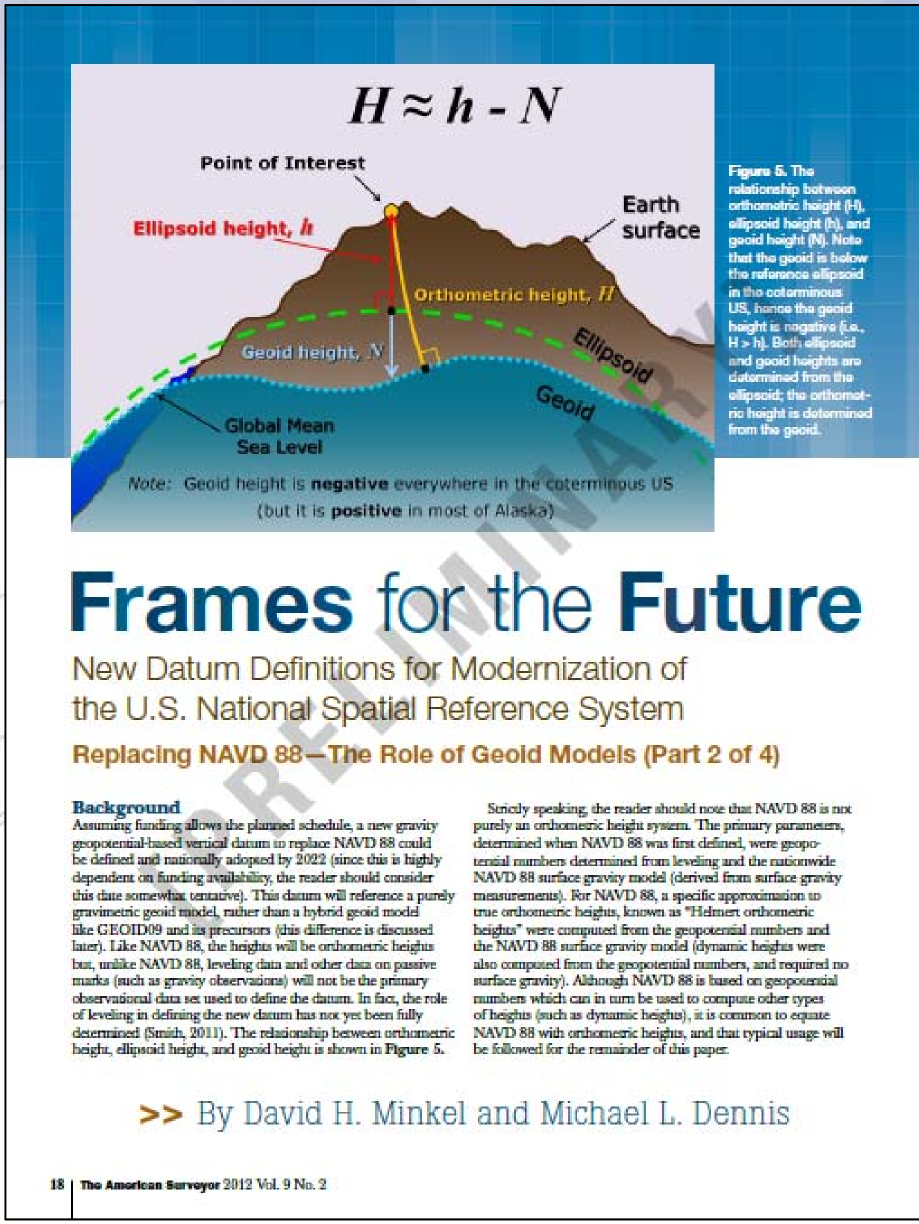

Figure 5. The relationship between orthometric height (H), ellipsoid height (h), and geoid height (N). Note that the geoid is below the reference ellipsoid in the coterminous US, hence the geoid height is negative (i.e., H > h). Both ellipsoid and geoid heights are determined from the ellipsoid; the orthometric height is determined from the geoid.

Frames for the Future

New Datum Definitions for Modernization of the U.S. National Spatial Reference System

Replacing NAVD 88—The Role of Geoid Models (Part 2 of 4)

Background

Assuming funding allows the planned schedule, a new gravity geopotential-based vertical datum to replace NAVD 88 could be defined and nationally adopted by 2022 (since this is highly dependent on funding availability, the reader should consider this date somewhat tentative). This datum will reference a purely gravimetric geoid model, rather than a hybrid geoid model like GEOID09 and its precursors (this difference is discussed later). Like NAVD 88, the heights will be orthometric heights but, unlike NAVD 88, leveling data and other data on passive marks (such as gravity observations) will not be the primary observational data set used to define the datum. In fact, the role of leveling in defining the new datum has not yet been fully determined (Smith, 2011). The relationship between orthometric height, ellipsoid height, and geoid height is shown in Figure 5.

Strictly speaking, the reader should note that NAVD 88 is not purely an orthometric height system. The primary parameters, determined when NAVD 88 was first defined, were geopotential numbers determined from leveling and the nationwide NAVD 88 surface gravity model (derived from surface gravity measurements). For NAVD 88, a specific approximation to true orthometric heights, known as "Helmert orthometric heights" were computed from the geopotential numbers and the NAVD 88 surface gravity model (dynamic heights were also computed from the geopotential numbers, and required no surface gravity). Although NAVD 88 is based on geopotential numbers which can in turn be used to compute other types of heights (such as dynamic heights), it is common to equate NAVD 88 with orthometric heights, and that typical usage will be followed for the remainder of this paper.

>> By David H. Minkel and Michael L. Dennis

THE American Surveyor
A Foot In The Past... An Eye To The Future

Find the article(s) in the Archives at: http://www.amerisurv.com

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Photo by Pat Barott