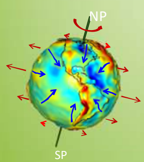
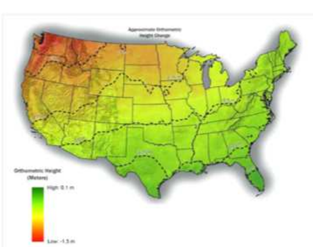
Datums Are A'Changin'



SLSI Workshop
09 January 2026
Jerry Mahun, PLS
Thrice-retired; Working on a Fourth
jerry.mahun@gmail.com
https://jerrymahun.com

Datums Are A'Changin'



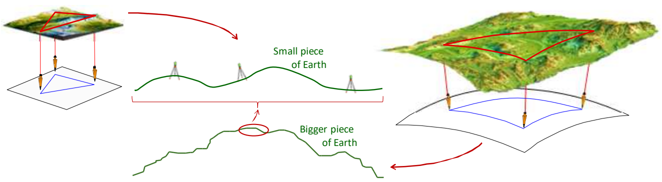
I. Introduction

I. Introduction

A. Physical Earth

The surface on which we measure.

- Not mathematical.
- Over small areas, we can assume a flat reference system – plane surveying
- Over larger areas, must account for earth's shape and dynamics – geodetic surveying



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I. Introduction

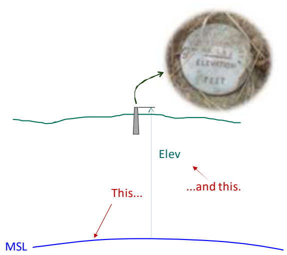
B. What's a datum?

Measurement reference surface.

Consists of a model and measurements referenced to the model.

Traditionally, Vertical and Horizontal datums separately defined because V & H measurements were different operations.

Contemporary 3D measurement platforms having impact on datum definition and refinement.



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II. Datums So Far...

II. Datums So Far…

A. Vertical datum

Gravitational force = f(mass, distance)

Earth: non-homogeneous; mass anomalies

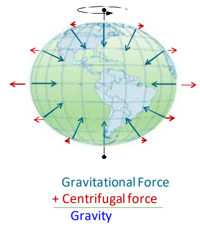
Centrifugal force = f(rotation, distance)

Minimum at Poles (dist=0),

Maximum at Equator (dist=R_E)

Gravity = Gravitational+Centrifugal forces

Oblate spheroid: Flattened at poles, enlarged around Equator



Slide 7/85

Society of Land Surveyors of Iowa

II. Datums So Far…

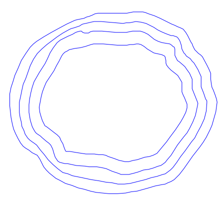
A. Vertical datum

Equipotential surface

A 3D surface along which (in+out) forces are uniform.

There are many equipotential surfaces. They are not mathematical.

Due to anomalies, nonhomogeneous mass, Earth wobble, varying Solar & Lunar forces, etc, equipotential surfaces are not smooth or perfectly parallel.



Slide 8/85

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II. Datums So Far…

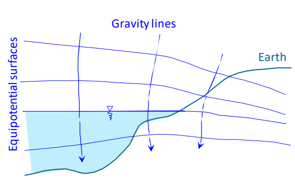
A. Vertical datum

Equipotential surface

Lines of gravity are perpendicular to equipotential surfaces

Because the surfaces are not parallel, gravity lines are not straight.

But they do all converge to the Earth's mass center.



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II. Datums So Far...

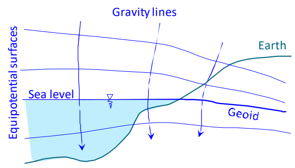
A. Vertical datum

Equipotential surface

The Geoid is the equipotential surface that *nominally* coincides with sea level under calm windless conditions.

Sea level still affected by atmospheric pressure, temperature, evaporation, Solar and Lunar gravity, etc.

Geoid best fits "average" sea level conditions.

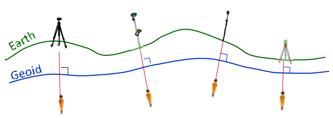


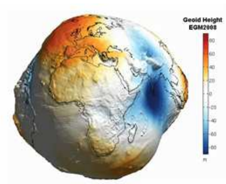
II. Datums So Far...

A. Vertical datum

A vertical line is the same as a line of gravity.

Centering a bubble or using a plumb bob orients equipment to the geoid.





Brian Shaw, NGS, Sept 2022

II. Datums So Far...

A. Vertical datum

Geoid coincides with Mean Sea Level (MSL) and is the vertical datum.

How to determine MSL?

27 tide stations monitoring water levels for multiple years.

19 yrs req'd for full tidal cycle

Heights transferred to tidal benchmark at each

Benchmarks connected via survey and networks adjusted.

II. Datums So Far…

A. Vertical datum

History

1899: 1st General Adjustment
1903: 2nd General Adjustment
1907: 3rd General Adjustment
1912: 4th General Adjustment
Sea Level Datum of 1929

Between adjustments, additional water level measurements recorded and network expanded.

First-order level networks by 1929 adjustment *(NGS)*

II. Datums So Far…

A. Vertical datum

Since 1929

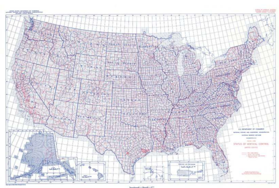
- network expanded
- higher quality measurements forced to fit less accurate control network

Sea Level Datum of 1929 wasn't sea level or the geoid.

Needed new adjustment.

Constraints for new datum:

FEMA Flood maps
USGS 7-1/2 min topoquads.


Vertical network by 1984 *(NGS)*

II. Datums So Far…

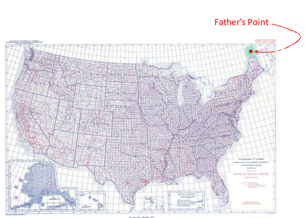
A. Vertical datum

Held Father's Point (Rimouski, NSRS PID TY5255)

North American Datum of 1988 (NAVD88).

Sea Level Datum of 1929 was retroactively renamed National Geodetic Vertical Datum of 1929 (NGVD29)

NAVD88 is refinement of NGVD29 and is not the geoid either.



Vertical network by 1984 *(NGS)*

II. Datums So Far...

A. Vertical datum

There is no exact conversion between NGVD29 and NAVD88.

Use *NGS Coordinate Conversion and Transformation Tool* (NCAT) on NGS website.

Since NAVD88 adoption, airborne and satellite gravity measurement platforms have been developed, facilitating better geoid modelling.

Approximate NAVD88 Error Based on Satellite Gravity Measurements

II. Datums So Far...

B. Pre-GPS Horizontal datum

1. Ellipsoid

A mathematical surface is needed to define a datum.

Positions must be referenced to it.

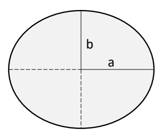
An ellipsoid is used.

Ellipsoid parameters

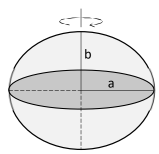
- a: semi-major axis
- b: semi-minor axis
- e: eccentricity
- f: flattening

$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

$$f = \frac{a-b}{a}$$



Ellipse



Ellipsoid: Ellipse rotated about the semi-minor axis

II. Datums So Far...

B. Pre-GPS Horizontal datum

2. Position reference

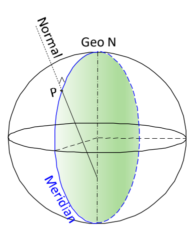
In addition to the ellipsoid, datum definition includes a 3D position reference system.

Normal: A line from a point perpendicular to the ellipsoid

Meridian: An elliptical section containing the normal and semi-minor axis.

Defines Geodetic N at a point.

Meridians converge



II. Datums So Far...

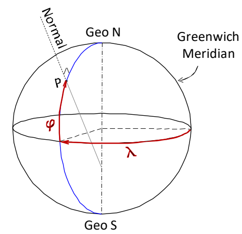
B. Pre-GPS Horizontal datum

2. Position reference

Geodetic Coordinates

Longitude (λ) - Angle in the semi-major axis plane E or W from Greenwich Meridian to point meridian
0°-180°W; 0°-180°E

Latitude (Φ) - Angle in point meridian N or S of the semi-major axis plane to the normal
0°-90°N; 0°-90°S



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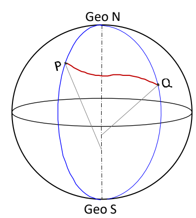
II. Datums So Far...

B. Pre-GPS Horizontal datum

2. Position reference

Geodetic Coordinates

Disadvantages:
- Positions are expressed in angular values
- Distances are in angular values
- Elliptical geometry
  - Shortest distance between two points is a *geodesic* - shallow s-shape curve.



Slide 20/85 — Society of Land Surveyors of Iowa

II. Datums So Far...

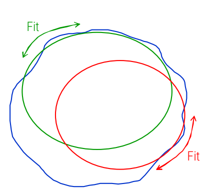
B. Pre-GPS Horizontal datum

3. Fitting

Prior to satellite measurement systems, it was typical to fit an ellipsoid regionally

A centrally located point is used as the origin.
- Ellipsoid and geoid coincide at this point

Fixed parameters:
- Origin's geodetic latitude and longitude
- Azimuth of a line from the origin
- Two ellipsoid parameters



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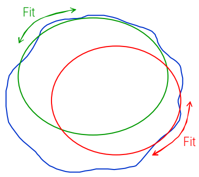
II. Datums So Far…

B. Pre-GPS Horizontal datum

3. Fitting

- Making the geoid and ellipsoid coincide assumes the two surfaces do not separate significantly throughout the area.
- Reasonable assumption for an early datum definition before a good mathematical geoid model was available.
- The error introduced wasn't significant for most surveys.



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Society of Land Surveyors of Iowa

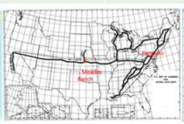
II. Datums So Far…

B. Pre-GPS Horizontal datum

4. North American – Regional Fit

Datum	Ellipsoid	Origin	Comments
New England Datum - 1879	Clarke 1866	Principio	Eastern coast and NE states
US Standard Datum - 1901	Clarke 1866	Meades Ranch	Transcontinental & Pacific arcs; 5000 pts
North American Datum - 1913	Clarke 1866	Meades Ranch	Canada & Mexico tied in
North American Datum - 1927	Clarke 1866	Meades Ranch	25,000 points


1879 Network


1901 Network


1927 Network


Meades Ranch, KS

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Society of Land Surveyors of Iowa

II. Datums So Far…

B. Pre-GPS Horizontal datum

5. North American – Global Fit

- By the 1970s
  - Network increased to over 270,000 points
  - Newer more accurate measurements were forced to fit less accurate control network.
  - VLBI and early satellite systems (eg, TRANSIT) required global perspective.


Horizontal Network, 1980

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Society of Land Surveyors of Iowa

II. Datums So Far…

B. Pre-GPS Horizontal datum

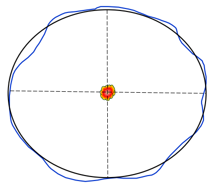
5. North American – Global Fit

A new ellipsoid, GRS80, was fit to the Earth's mass center.

- Ellipsoid and geoid not forced to coincide anywhere.

Semi-major axis in equatorial plane.

Semi-minor axis coincides with polar axis.



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II. Datums So Far…

B. Pre-GPS Horizontal datum

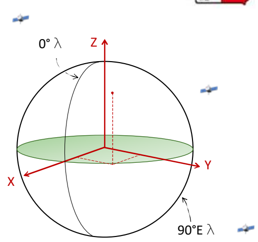
5. North American – Global Fit

Terrestrial Coordinate System - TCS

- A new 3D coordinate system introduced
- Used by early satellite systems

Three axis rectangular system

- Origin at Earth's mass center
- X-Axis in Equatorial plane through 0° Longitude (Greenwich Meridian).
- Y-Axis in Equatorial plane through 90° East Longitude
- Z-axis is perpendicular to equatorial plane in direction of N pole and coincident with rotational axis.



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II. Datums So Far…

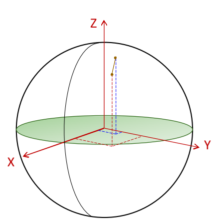
B. Pre-GPS Horizontal datum

5. North American – Global Fit

Terrestrial Coordinate System - TCS

Disadvantages:

- Huge coordinate values.
- Negative coordinates
- No "up" (vertical direction)
  - Top and bottom of vertical structures have different 3D coordinates.



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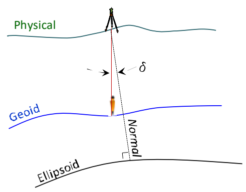
B. Pre-GPS Horizontal datum

5. North American – Global Fit

Geoid-Ellipsoid relationship is a function of Skewness and Vertical separation.

Skewness - Deflection of the vertical, δ

Angle between directions of gravity and ellipsoid *normal*.



B. Pre-GPS Horizontal datum

5. North American – Global Fit

Geoid-Ellipsoid relationship is a function of Skewness and Vertical separation.

Vertical separation

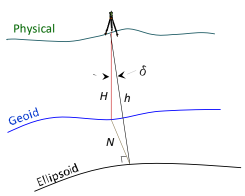
Heights between the surfaces

H - Orthometric: geoid to ground

N - Geoid: ellipsoid to geoid

h - Ellipsoidal: ellipsoid to ground

h = H+N



B. Pre-GPS Horizontal datum

5. North American – Global Fit

Geoid-Ellipsoid relationship is a function of Skewness and Vertical separation.

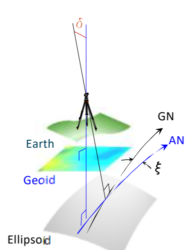
LaPlace Corr'n, ξ

The component of δ that relates Geodetic N (GN) and Astronomic N (AN) at a particular latitude.

Was a common correction applied when performing astro obs for meridian determination.

See Sec 2-27 & -28, *2009 Manual*

☆



II. Datums So Far...

C. Post-GPS Horizontal Datum

NAD83 was completed in 1986; referred to as NAD83 (86): *First realization*

GPS was not operational so was not included in NAD83 (86)

Many states created their own HPGN/HARN and tied them to the national network via GPS.

Found distortions in NAD83 (86) so NGS did state-by-state readjustments creating an updated NAD83 (xx) for each, xx being the year.

NGS did a national readjustment including state HARNs - NAD83 (HARN): *Second realization*

Two more realizations followed:

NAD83 (NSRS2007)	CORS added; GPS observed points only
NAD83 (2011)	Additional CORS & GPS observations. Current reference.

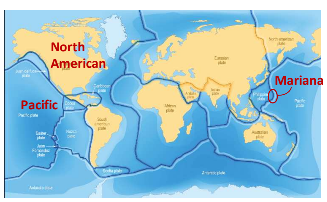
II. Datums So Far...

C. Post-GPS Horizontal Datum

Geologic tectonic plates

NAD83 (2011) Has three regions:

Plate	Realization
North American	NAD 83 (2011)
Pacific	NAD 83 (PA11)
Mariana	NAD 83 (MA11)



II. Datums So Far...

D. Epochs

Dynamic nature of Earth

Tectonics plates move wrt each other

Movements within plates (eg, fault lines)

Lunar and Solar gravitational attraction

Control points move, they have velocity.

Datum tagged with an Epoch: timestamp

NAD 83 (2011) Epoch 2010.00

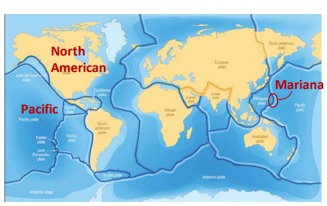
Format: Year.DayOfYear/365

(366 for Leap Year)

01/01/2010: 1/365=0.00 ⇨ 2010.00

02/15/2016:

(31+15)/366=0.126 ⇨ 2016.126



II. Datums So Far…

E. Reference Frameworks & Ellipsoids

NAD83 (xx) uses Geodetic Reference System of 1980 (GRS 80)

National Imagery and Mapping Agency (NIMA, formerly Defense Mapping Agency) uses the World Geodetic Reference System of 1984 (WGS 84)

GPS reference system

International Terrestrial Reference System (ITRS) uses its own ellipsoid.

All are intended to be geocentric, although GRS80 is off ~2 meters.

Associated 3D XYZ coordinate axes are located slightly differently.

	Semi-minor axis, m	Flattening
GRS 80	6,378,137.0	1/298.25722 2101
WGS 84	6,378,137.0	1/298.25722 3563
ITRS	6,378,136.49	1/298.25645

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II. Datums So Far…

E. Reference Frameworks & Ellipsoids

Example: OPUS Adjustment Results

```
REF FRAME:   NAD_83(2011)(EPOCH:2010.0000)     ITRF2020 (EPOCH:2025.96134)
        X:      -35265.046(m)  0.004(m)            -35266.058(m)  0.004(m)
        Y:    -4701349.893(m)  0.007(m)          -4701348.550(m)  0.007(m)
        Z:     4296015.495(m)  0.009(m)           4296015.409(m)  0.009(m)

      LAT:   42 36 41.18389      0.006(m)       42 36 41.21114      0.006(m)
    E LON:  269 34 12.82703      0.004(m)      269 34 12.78221      0.004(m)
    W LON:   90 25 47.17297      0.004(m)       90 25 47.21779      0.004(m)
   EL HGT:        268.817(m)     0.009(m)            267.776(m)     0.009(m)
ORTHO HGT:        301.690(m)     0.018(m)    [NAVD88 (Computed using GEOID18)]
```

Note: 1" Lat ~100 ft, 1" Long ~75 ft

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II. Datums So Far…

F. NSRS

National Spatial Reference System

1. Evolved from pre-NAD83 control network and datasheets
   - Physical Marks
   - Spatial information
   - Historical lineage

c1980s NGS no longer had mark maintenance budget.

Many marks destroyed or disturbed.

Poor locations for GPS obs.

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II. Datums So Far...

F. NSRS

National Spatial Reference System

2. NAD 83

Datasheets converted to digital database

All points made 3D

- Scaled elev added to horizontal points
- Approx Lat/Long added to BMs

Some points:

- Measured gravity
- Local/Network accuracy
- Point velocities

Modeled information

- Geoid ht
- Ellipsoid ht
- LaPLace Corr'n

Updated to-reach and condition info.

Easier to contribute condition information, incl photos

Points added as developed and between realizations

- CORS
- Height Modernization

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Society of Land Surveyors of Iowa

II. Datums So Far...

F. NSRS

```
AJ8303 ***********************************************************************
AJ8303  SACS          -  This is a Secondary Airport Control Station.
AJ8303  DESIGNATION -  AMW F
AJ8303  PID         -  AJ8303
AJ8303  STATE/COUNTY-  IA/STORY
AJ8303  COUNTRY     -  US
AJ8303  USGS QUAD   -  SLATER (2018)
AJ8303
AJ8303                         *CURRENT SURVEY CONTROL
AJ8303  ______________________________________________________________________
AJ8303* NAD 83(2011) POSITION- 41 59 55.26242(N) 093 37 31.13374(W)   ADJUSTED
AJ8303* NAD 83(2011) ELLIP HT-   251.419 (meters)        (06/27/12)   ADJUSTED
AJ8303* NAD 83(2011) EPOCH   -  2010.00
AJ8303* NAVD 88 ORTHO HEIGHT -   281.00  (meters)      921.9   (feet) GPS OBS
AJ8303  ______________________________________________________________________
AJ8303  NAVD 88 orthometric height was determined with geoid model    GEOID99
AJ8303  GEOID HEIGHT    -        -29.528 (meters)                     GEOID99
AJ8303  GEOID HEIGHT    -        -29.661 (meters)                     GEOID18
AJ8303  NAD 83(2011) X  -   -300,177.724 (meters)                     COMP
AJ8303  NAD 83(2011) Y  - -4,737,783.775 (meters)                     COMP
AJ8303  NAD 83(2011) Z  -  4,245,663.436 (meters)                     COMP
AJ8303  LAPLACE CORR    -        -12.31  (seconds)                    DEFLEC18

AJ8301                        SUPERSEDED SURVEY CONTROL
AJ8301
AJ8301  NAD 83(2007)-  41 59 37.60879(N)    093 37 05.65529(W) AD(2002.00) 0
AJ8301  ELLIP H (02/10/07)  251.200  (m)                       GP(2002.00)
AJ8301  ELLIP H (06/15/04)  251.204  (m)                       GP(        ) 4 1
AJ8301  NAD 83(1996)-  41 59 37.60859(N)    093 37 05.65517(W) AD(        ) B
AJ8301  ELLIP H (11/27/02)  251.224  (m)                       GP(        ) 4 1
AJ8301  NAD 83(1996)-  41 59 37.60834(N)    093 37 05.65524(W) AD(        ) B
AJ8301  ELLIP H (03/18/02)  251.229  (m)                       GP(        ) 4 1
AJ8301  NAVD 88 (03/18/02)  280.83   (m)  GEOID99  model used  GPS OBS
```

```
***********************************************************************
MH0669  DESIGNATION -  LEE
MH0669  PID         -  MH0669
MH0669  STATE/COUNTY-  IA/STORY
MH0669  COUNTRY     -  US
MH0669  USGS QUAD   -  SLATER (2018)
MH0669
MH0669                         *CURRENT SURVEY CONTROL
MH0669  ______________________________________________________________________
MH0669* NAD 83(1996) POSITION- 41 53 30.92251(N) 093 37 42.31720(W)   ADJUSTED
MH0669* NAVD 88 ORTHO HEIGHT -   318.2   (meters)     1044.    (feet) VERTCON3
MH0669  ______________________________________________________________________
MH0669  GEOID HEIGHT    -        -30.417 (meters)                     GEOID18
MH0669  LAPLACE CORR    -         -8.04  (seconds)                    DEFLEC18
MH0669  HORZ ORDER      -  FIRST
MH0669
MH0669.The horizontal coordinates were established by classical geodetic methods
MH0669.and adjusted by the National Geodetic Survey in May 1999.
MH0669
MH0669.The NAVD 88 height was computed by applying the VERTCON shift value to
MH0669.the NGVD 29 height (displayed under SUPERSEDED SURVEY CONTROL.)

MH0669                        SUPERSEDED SURVEY CONTROL
MH0669
MH0669  NAD 83(1986)-  41 53 30.92279(N)    093 37 42.32219(W) AD(        ) 1
MH0669  NAD 27      -  41 53 30.96847(N)    093 37 41.53302(W) AD(        ) 1
MH0669  NGVD 29 (07/19/86)  318.1    (m)        1044.     (f) VERT ANG
```

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III. New Datums Ahead!

III. New Datums Ahead!

A. Why?

Why not?

NAVD 88 is offset and tilted relative to best current geoid model

NAD 83(2011) is misaligned by approx. 2.2 meters from Earth's center

Correcting both will change point horizontal and vertical positions up to 4 meters

Modernized NSRS will rely on GNSS stations:

- Improved horizontal accuracy
- Improved vertical accuracy
- Ease of maintenance and updates
- Responsiveness to significant geological events, like earthquakes

Slide 40/85 **Society of Land Surveyors of Iowa**

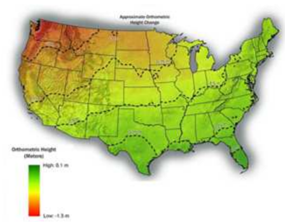
III. New Datums Ahead!

B. Vertical Datum

North American-Pacific Geopotential Datum of 2022 (NAPGD2022)

- New gravity-based geopotential datum based on a refined geoid model
- Will contain info to provide consistent orthometric heights, geoid variations, gravity anomalies, deflections of the vertical, and all other geodetic coordinates related to the gravity field.

Based on time-dependent GEOID2022



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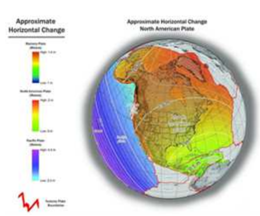
III. New Datums Ahead!

C. Horizontal Datum

Three NAD 83 reference frames replaced with four plate-fixed frames:

- North American Terrestrial Reference Frame of 2022 (NATRF2022)
- Pacific Terrestrial Reference Frame of 2022 (PATRF2022)
- Mariana Terrestrial Reference Frame of 2022 (MATRF2022)
- Caribbean Terrestrial Reference Frame of 2022 (CATRF2022)

Each frame will be identical to ITRF2020 at epoch 2020.00.



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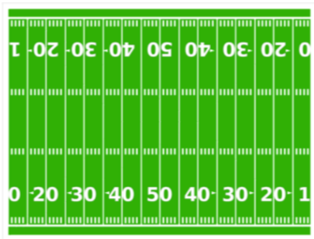


IV. Grid Systems

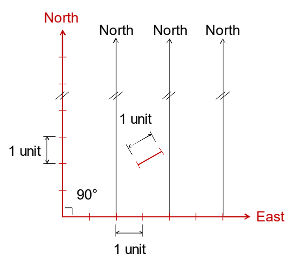
A. Two Dimensional

1. Planar

Desirable characteristics

a. Orthogonal
b. Parallel north lines
c. Uniform scale in all directions

Comps are simple.



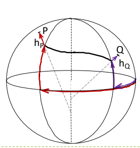
A. Two Dimensional

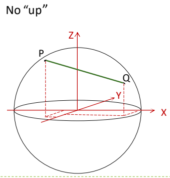
2. Why 2D not 3D?

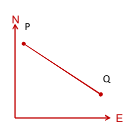
a. Geodetic Coordinates
- Must reduce points to ellipsoid
- Positions in angular values
- Ellipsoid geometry complex

b. Terrestrial Coord System
- 3D space vector
- Huge coordinates – cumbersome.
- No "up"

c. Grid Coordinates
- Must reduce ground to grid – simple math





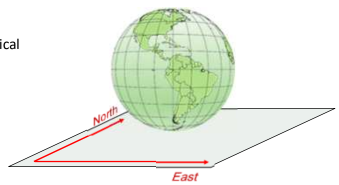


IV. Grid Systems

B. 3D to 2D

We're on a 3D surface

We want to put it in a 2D mathematical system

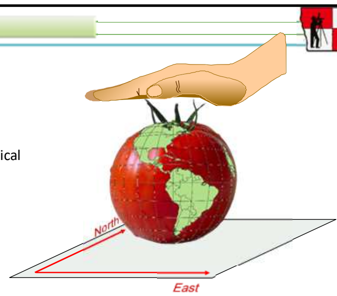


IV. Grid Systems

B. 3D to 2D

We're on a 3D surface

We want to put it in a 2D mathematical system



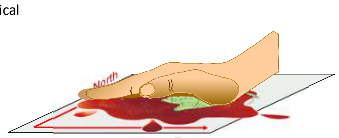
IV. Grid Systems

B. 3D to 2D

We're on a 3D surface

We want to put it in a 2D mathematical system

With a direct projection we get a distorted representation



IV. Grid Systems

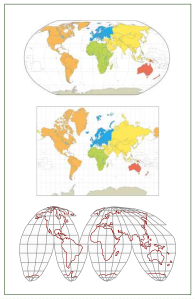
B. 3D to 2D

We're on a 3D surface

We want to put it in a 2D mathematical system

With a direct projection we get a distorted representation

Different mathematical projections distort different ways.



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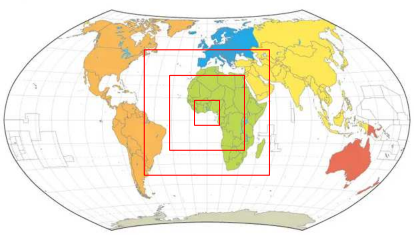
IV. Grid Systems

B. 3D to 2D

The smaller the area projected, the smaller the distortions.



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IV. Grid Systems

C. Distortions

The two distortions are

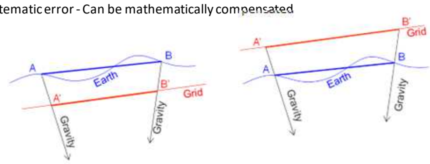
1. Distance

Ground points must be projected vertically to the 2D grid plane.

This moves them closer together or further apart, altering distance.

Distance distortion = f(heights, grid fit)

Systematic error - Can be mathematically compensated



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IV. Grid Systems

C. Distortions

The two distortions are

2. Direction

3D meridians converge, 2D Grid do not.

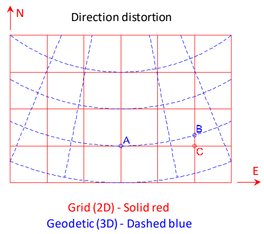
3D E/W lines are curved, 2D Grid are straight.

No distortion at center of projection

Increases moving E & W of center

Direction distortion = f(longitude)

Systematic error - Can be mathematically compensated



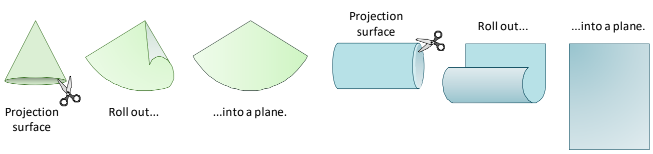
IV. Grid Systems

D. Projection Surfaces

To control or compensate distortions, we must project from a 3D mathematical surface to another mathematical surface that can be developed into a plane without introducing additional distortions.

The ellipsoid is the 3D surface.

A cone or cylinder is the projection surface that can be rolled out flat.



IV. Grid Systems

D. Projection Surfaces

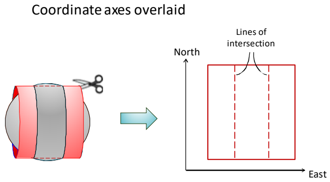
Secant projections are used

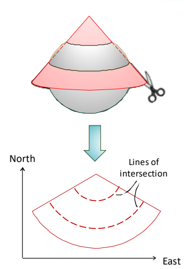
Cone or cylinder cuts through the ellipsoid.

Points are projected.

Projection is rolled out

Coordinate axes overlaid



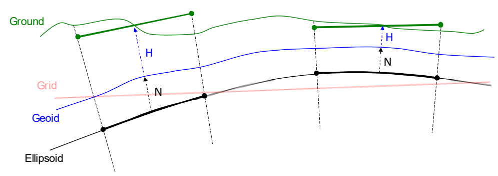


IV. Grid Systems

E. Distance Distortion

Distances are reduced from Ground to Grid in two steps:

1. Horizontal ground to geodetic on the ellipsoid = f(orthometric, geoid heights)

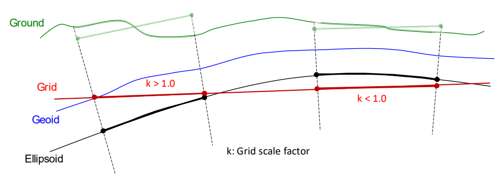


IV. Grid Systems

E. Distance Distortion

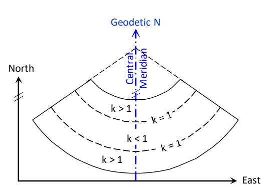
Distances are reduced from Ground to Grid in two steps:

1. Horizontal ground to geodetic on the ellipsoid = f(orthometric, geoid heights)
2. Geodetic to grid = f(grid scale factor)

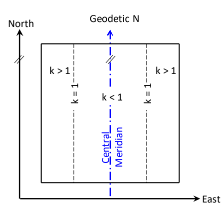


IV. Grid Systems

E. Distance Distortion



Conic: Scale varies N/S



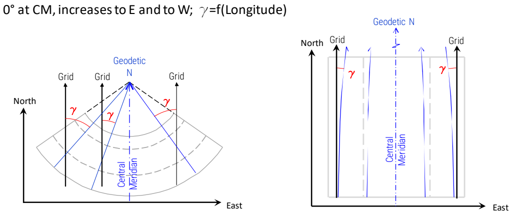
Cylindric: Scale varies E/W

IV. Grid Systems

F. Direction Distortion

Convergence, γ, is angle between Grid and Geodetic North.

0° at CM, increases to E and to W; γ=f(Longitude)



Conic Projection

Cylindric Projection

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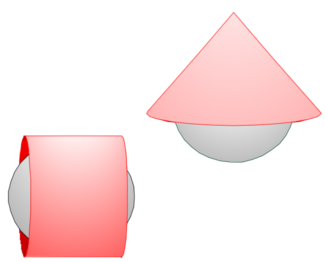
IV. Grid Systems

D. Low Distortion Projection (LDP)

A low distortion projection covers a smaller area and brings the grid closer to Earth surface.

Fitting projection closer to the ground. minimizes distance distortions.

Because the projection is close to ground level, it may not intersect the ellipsoid.



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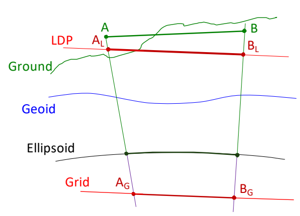
Society of Land Surveyors of Iowa

IV. Grid Systems

D. Low Distortion Projection (LDP)

A low distortion projection covers a smaller area and brings the grid closer to Earth surface.

Distortions, ground to grid, are generally in the 1/40,000-1/60,000 range.



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Society of Land Surveyors of Iowa

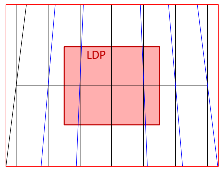
IV. Grid Systems

D. Low Distortion Projection (LDP)

A low distortion projection covers a smaller area and brings the grid closer to Earth surface.

Because it covers less area E-W, convergence angles are smaller and more consistent.

Ground and Grid values, except for control purposes, can be treated as the same.



Smaller Convergence Angles

V. Formal Coordinate Systems

V. Formal Coordinate Systems

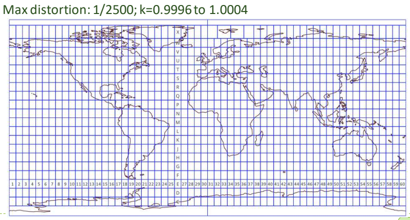
A. Universal Transverse Mercator (UTM)

60 adjacent cylindric projections circumventing the Earth

Each projection is 6° wide and runs from 80° S Lat to 84° N Lat.

Numbered 1 to 60 from west to east and lettered C to X south to north

Max distortion: 1/2500; k=0.9996 to 1.0004



Same zones used in NAD 27 and NAD 83(xx).

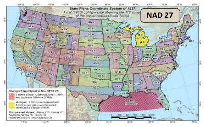
Not NGS designed, but are included in NSRS and supported in NCAT.

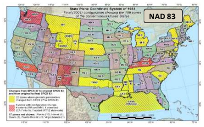
V. Formal Coordinate Systems

B. State Plane Coordinates (SPC)

Designed by NGS (C&GS), included in NSRS and supported in NCAT

1. NAD 27
   - Development began in 1930s
   - Maximum distance distortion 1/10,000 (ellipsoid to grid)
     - k = 0.9999 to 1.0001
     - →multiple zones in most states
2. NAD 83(xx)
   - Some zone reshuffling





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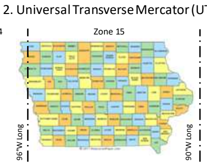
V. Formal Coordinate Systems

C. Current Iowa Systems

1. State Plane Coordinate (SPC) system

Projection	Conic
Zones	2
Max Distortion (ellipsoid to grid)	1/10,000

2. Universal Transverse Mercator (UTM)



Projection	Cylindric
Zones	1+
Max Distortion (ellipsoid to grid)	1/2500

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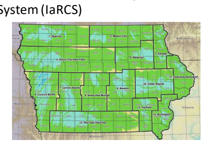
V. Formal Coordinate Systems

C. Current Iowa Systems

3. Low Distortion: Iowa Regional Coordinate System (IaRCS)



Projection	Cylindric & Conic
Zones	14
Max Distortion (ground to grid)	1/40,000

Because these are locally designed, they are not included in NSRS not supported in NCAT.

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V. Formal Coordinate Systems

D. State Plane Coordinate System of 2022 (SPCS2022)

Original plan: Three-level system for each state

1. Single state-wide zone
2. Up to three traditional-type SPC zones
3. Multi-zone areas covering less than an entire state (eg, LDPs)

All would be NCAT supported

Feedback from many states:

Local LDPs used more than traditional SPC systems

Petitioned NGS to include existing LDP systems in SPCS2022 for #2 & #3

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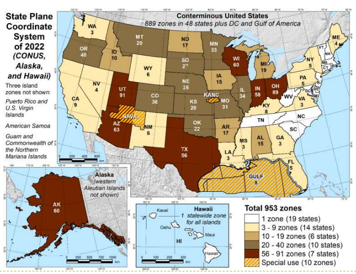
V. Formal Coordinate Systems

D. State Plane Coordinate System of 2022 (SPCS2022)

Current SPCS2022 plan



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VI. Ground and Grid

VI. Ground and Grid

A. Distortion Compensation

1. Distance

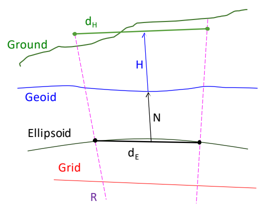
Two steps

a. Ground to ellipsoid

$$EF = \frac{R}{R + H + N}$$

$$d_L = d_H \times EF$$

d_H Horizontal ground distance
d_E Ellipsoidal (geodetic) distance
EF Elevation Factor
R Mean Earth radius
H Orthometric ht (elev)
N Geoid height



R = 20,902,000 ft = 6,371,000 m (approx.)

VI. Ground and Grid

A. Distortion Compensation

1. Distance

Two steps

b. Ellipsoidal to grid

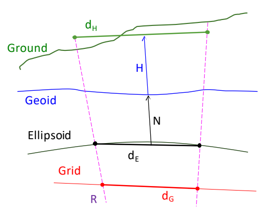
$$d_G = d_E \times k$$

d_G Grid distance
d_E Ellipsoidal (geodetic) distance
k Grid scale factor

c. Combined factor

$$CF = EF \times k$$

$$d_G = d_H \times CF$$



VI. Ground and Grid

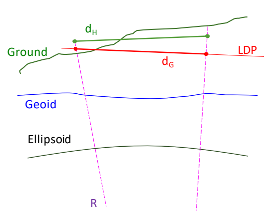
A. Distortion Compensation

1. Distance

d. LDP

Because a LDP grid is near-ground level, there may be no discernible difference between ground and grid distances.

This reduction can be ignored for IaRCS unless precision >1/40,000 needed.



VI. Ground and Grid

A. Distortion Compensation

2. Direction

The convergence angle, γ, is **from** Geodetic N **to** Grid N

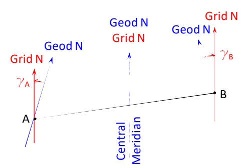
It is positive (cw) East of the CM, negative (ccw) West of the CM

To convert Geodetic (Ground) direction to Grid:

$$t = \alpha - \gamma$$

t	Grid azimuth
α	Geodetic azimuth
γ	Convergence

Might be significant for an LDP



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VI. Ground and Grid

B. Reduction Elements

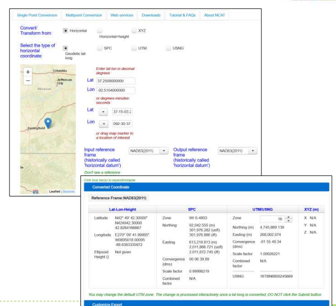
Where do we get the ortho and geoid heights, scale, and convergence angles?

NGS software (*Geodetic Tool Kit*):

NCAT[1]

GEOIDXX

Ortho heights from USGS topoquads



[1]*NCAT* does not currently support local LDPs. When NATRF2022 is adopted, *NCAT* will include NGS-accepted LDPs.

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VII. Moving Positions Between Systems

VII. Moving Positions Between Systems

A. Terms

1. Conversion: changing a number from one system to another without introducing error.

Used when there is an exact mathematical relationship between the two systems.

Example: Convert 24 inches to feet.

$$24in \times \frac{1ft}{12in} = 2ft \quad exactly$$

Exact

2. Transformation: using an approximate relationship to change between systems when there is no exact relationship between them.

Error is introduced; the amount depends on the model used for the approximation.

Example: a surveyor counted 42 paces on a 100 ft baseline. He then counted 73.5 paces along a parking lot. How long is the parking lot?

$$73.5paces \times \frac{100\ ft}{42paces} = 175ft \quad approx$$

Not Exact

VII. Moving Positions Between Systems

B. Changing Coordinates *Within* a Datum

SPC, UTM, and IARS are based on conic or cylindric projections connected to the ellipsoid.

These are based on rigorous (and complex) mathematical relationships.

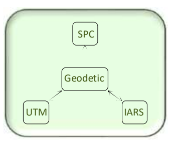
Going between grid and geodetic coordinates is a **conversion**.

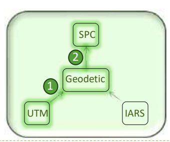
To go from one grid coordinate to another is two conversions

Example: from UTM to SPC

Convert UTM to Geodetic

Convert Geodetic to SPC





VII. Moving Positions Between Systems

C. Changing Coordinates *Between* Datums

There are no exact conversions between any of the horizontal datums.

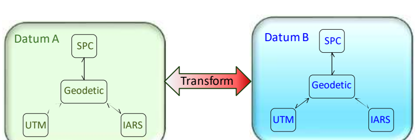
NAD 27 to NAD 83 (86) are largest position changes.

Changes between NAD 83 (xx) realizations are much smaller

NAD 83 (xx) to NATRF2022 is up to a few meters

Must use a mathematical model to transform positions in one datum to positions in another.

The better the model, the smaller the error.



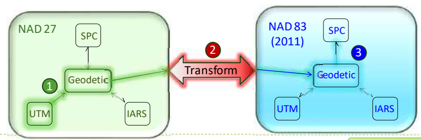
VII. Moving Positions Between Systems

C. Changing Coordinates *Between* Datums

Some datum-to-datum changes are combinations of conversions and transformations.

Example: determine NAD 83 (2011) SPC coordinates of NAD 27 UTM coordinates.

1. Convert NAD 27 UTM to NAD 27 Geodetic
2. Transform NAD 27 Geodetic to NAD 83 (2011) Geodetic
3. Convert NAD 83 (2011) Geodetic to NAD 83 (2011) SPC



VII. Moving Positions Between Systems

D. Changing a Point's Coordinates

NCAT (NGS Coordinate Transformation Tool)
https://geodesy.noaa.gov/NCAT/

Online coordinate conversion and transformation tool.

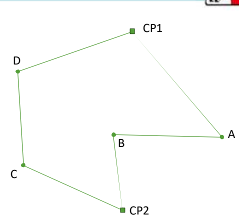
Current version does not support SPCS2022 nor current LDPs.
- Beta version does;
- Final NCAT will.

VII. Moving Positions Between Systems

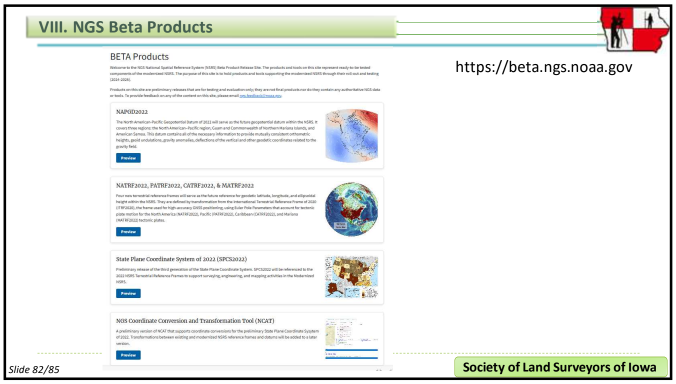
E. Best Way

Use original measurements
- Reduce to desired realization grid
- Use updated control coordinates
- Readjust measurements.

Example:
- Original traverse adjusted using NAD 83 (86) control points.
- To get NAD 83 (2011), readjust the traverse using updated coordinates of the control points.



CP1, CP2: control points


VIII. NGS Beta Products
BETA Products
https://beta.ngs.noaa.gov
NAPGD2022
Preview
NATRF2022, PATRF2022, CATRF2022, & MATRF2022
Preview
State Plane Coordinate System of 2022 (SPCS2022)
Preview
NGS Coordinate Conversion and Transformation Tool (NCAT)
Preview
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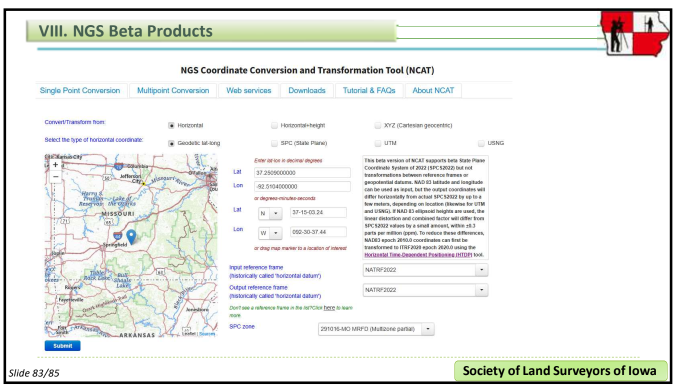
VIII. NGS Beta Products
NGS Coordinate Conversion and Transformation Tool (NCAT)
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Tutorial & FAQs
About NCAT
Convert/Transform from:
Horizontal
Horizontal+height
XYZ (Cartesian geocentric)
Select the type of horizontal coordinate:
Geodetic lat-long
SPC (State Plane)
UTM
USNG
Lat
Lon
Input reference frame
Output reference frame
NATRF2022
SPC zone
Submit
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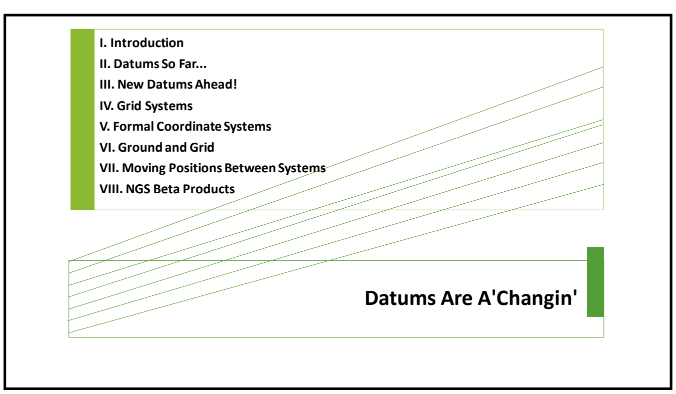
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II. Datums So Far...
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VIII. NGS Beta Products
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Questions?