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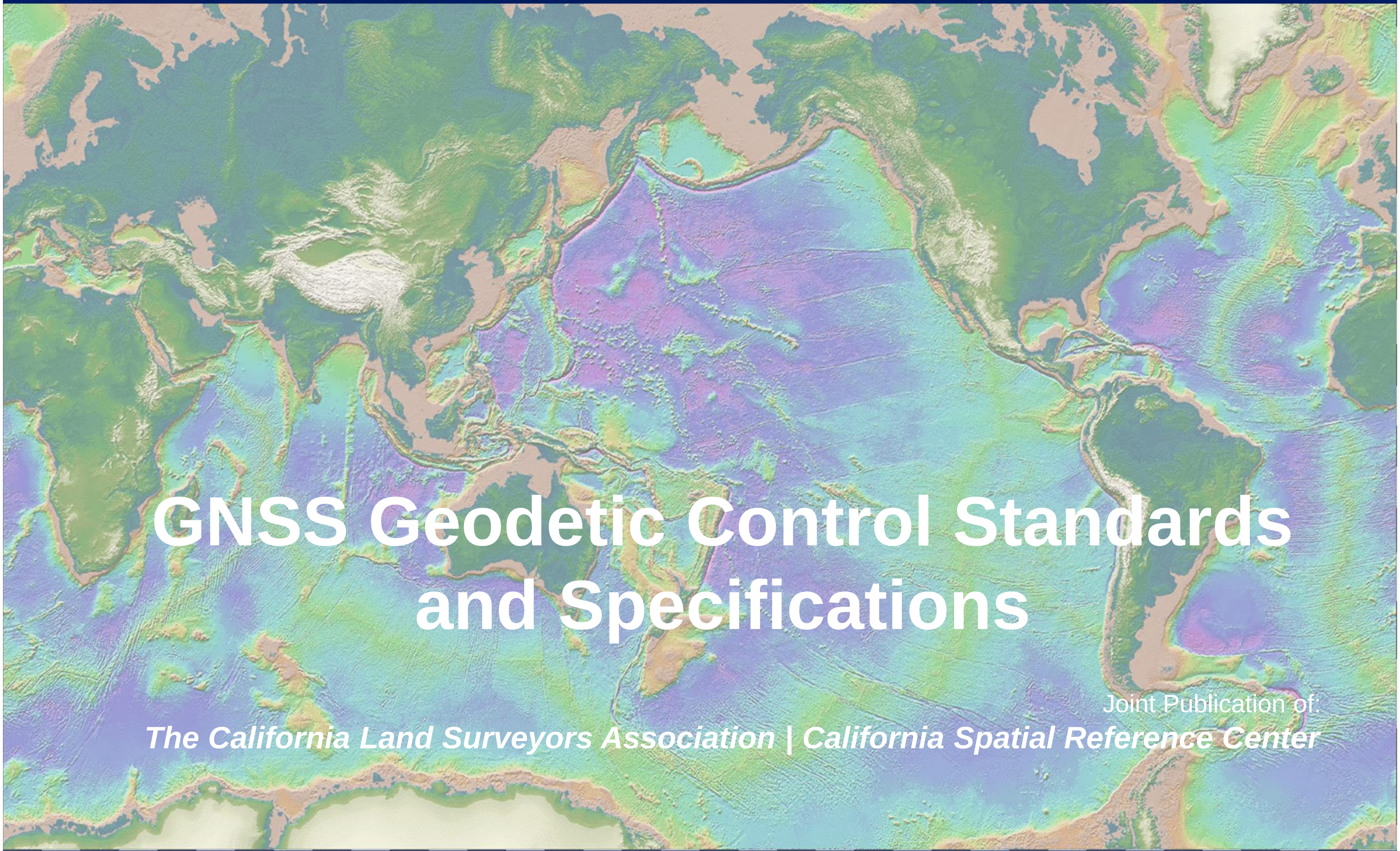

GNSS Geodetic Control Standards and Specifications

Joint Publication of:

The California Land Surveyors Association | California Spatial Reference Center

RBF CONSULTING jma THE LPA GROUP KASEMAN SALLYPORT

Presented by: *Gregory A. Helmer, PLS*

California Geodetic Control Committee

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SPECIFICATIONS FOR GEODETIC CONTROL NETWORKS USING HIGH-PRODUCTION GPS SURVEYING TECHNIQUES

Version 2.0, July 1996
(HTML Version)

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Specifications for Geodetic Control Networks Using
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Version 2.0, July 1995

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http://www.rbf.com/cgcc/hpgps21.htm

GNSS Surveying Standards and Specifications

California Land Surveyors Association
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CALIFORNIA LAND SURVEYORS ASSOCIATION 1966

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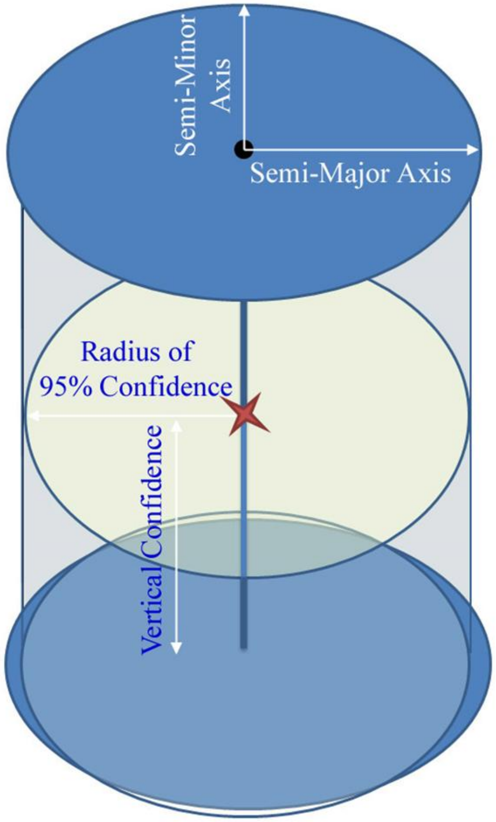
Positional Accuracy

The volume space for positional accuracy is a simplified model representing horizontal and vertical confidence. It is centered on the adjusted point, scaled to 95% confidence, and bounded by upper and lower planes of vertical confidence of a given height component and the radius of the horizontal confidence.

<u>For most practical purposes, the semi-major axis of the error ellipse can be adopted as the horizontal radius of confidence.</u>

Since horizontal and vertical are correlated dimensions derived from the GNSS Cartesian coordinate frame, the cylindrical volume space is statistically conservative.

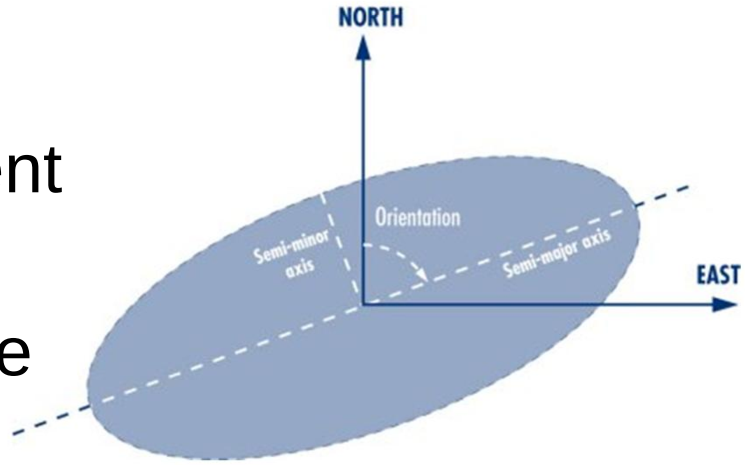


$$C.L. = \int_{-R}^{R} \int_{\sqrt{R^2-x^2}}^{\sqrt{R^2-x^2}} \frac{1}{2\pi\sigma_x\sigma_y(1-\rho^2)} \exp\left[\frac{-1}{2(1-\rho^2)}\left[\left(\frac{x-\mu_x}{\sigma_x}\right)^2 - 2\rho\left(\frac{x-\mu_x}{\sigma_x}\right)\left(\frac{y-\mu_y}{\sigma_y}\right) + \left(\frac{y-\mu_y}{\sigma_y}\right)^2\right]\right] dy\,dx$$

Proposed Accuracy Classifications

Classification	95% Confidence Region		Notes
	Meters	Feet	
1-Millimeter	≤ 0.001		Outside the scope of these specifications.
2-Millimeter	≤ 0.002		
0.5 cm	**≤ 0.005**	**≤ 0.016**	**Horizontal and vertical accuracy classifications included in these standards and specifications.**
1 cm	**≤ 0.01**	**≤ 0.033**	
2 cm	**≤ 0.02**	**≤ 0.066**	
5 cm	**≤ 0.05**	**≤ 0.164**	
10 cm	**≤ 0.1**	**≤ 0.328**	
2-Decimeter	≤ 0.2		Outside the scope of these specifications.
5-Decimeter	≤ 0.5		
1-Meter	≤ 1		
2-Meter	≤ 2		
5-Meter	≤ 5		

Network Accuracy is intended to measure the relationship between the control point in question, and the datum.
Local Accuracy measures the positional accuracy relative to other points within the same network.



- Constrained Network Adjustment
- Weighted Constraints
- Adopt Major Axis of 95% Ellipse
- 95% Confidence Error Bar
  (Augment for geoid model if applicable)

- The difference between the relative ellipse versus position ellipse is typically insignificant.
  Therefore: **Network Accuracy**

Independent testing from a source of higher accuracy is the preferred test for all forms of geospatial data

1. All observation errors must have been reduced to only random and normal uncertainties. Any systematic errors, blunders, or misclosures outside of a normal distribution, invalidate the statistical premise of least squares, and therefore must be eliminated.
2. The observations must have sufficient redundancy to trap outliers and distribute random errors. Care must be taken to insure that observations are truly independent in their redundancy, not merely in quantity.
3. A valid weighting strategy must be developed and applied to the observation data.

- Redundant Observations of Higher Quality
- Validate to Redundant Published Control
- Independent Solutions: Software, Satellite Constellations, Observable Frequencies

Signed and Sealed Project Report

- Geodetic control surveying is protected as the practice of Professional Land Surveying in California (Cal. BPC § Chapter 15, Article 3, 8726(f)
- A narrative description of the project
- Observation Campaign
- Processing Performed
- Summary of Results, Including Testing Performed
- Coordinate Listing Always Including Metadata
  Never issue only North,East,Elevation,Description

Best Practices - Guidelines

Network Applications

	Accuracy Classification	
	Horizontal	Vertical
Geographic Information Systems (GIS) and Asset Inventory	10 cm	10 cm
Planning-Level Photogrammetric Ground Control (5-foot contours)	5 cm	10 cm
Design-Level Photogrammetric Ground Control (1-foot contours)	2 cm	5 cm
Right of Way and Boundary Determination	1 cm	10 cm
Project Control for Design and Construction	1 cm	1 cm
Regional High-Precision Geodetic Horizontal Networks	1 cm	2 cm
Regional High-Precision Geodetic Vertical Networks	1 cm	1 cm
Ultra-High-Precision Networks and Deformation Monitoring	0.5 cm	0.5 cm

Goals and Objective Focused

- Existing Control and Geoid Slope
- Ionosphere and Troposphere Models
- Velocity Modeling
- Error Modeling or Error Distribution

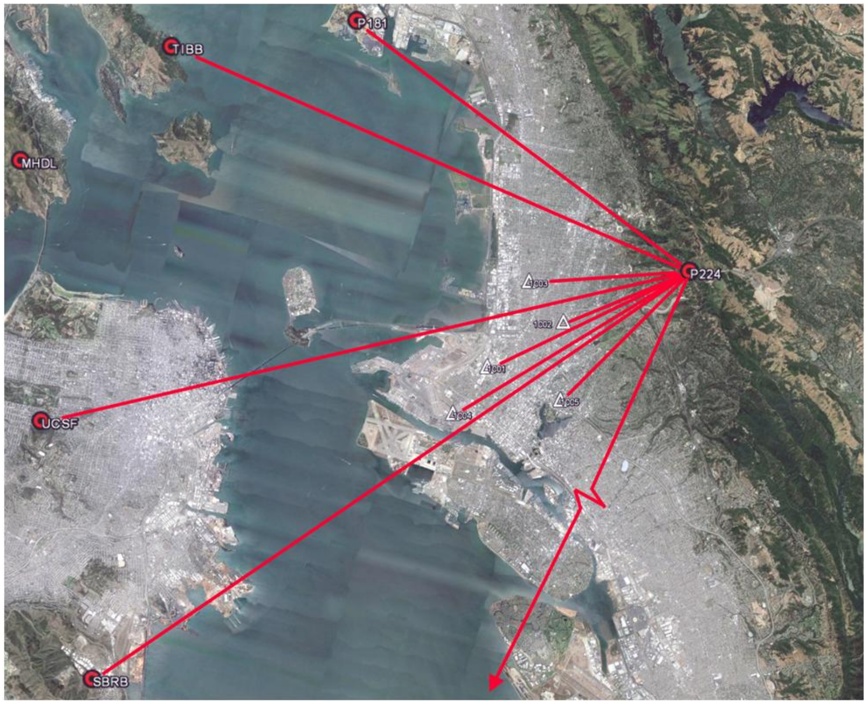
Gerald Mader's Guiding Principals
Arguments for: Hub Network Design

- "Precision is independent of baseline length"
- "Precision depends on observation span"
- "Session network designs must include both short and long baseline lengths"
- "GNSS measurement errors are independent, they do not propagate through a network"
- "Relative positions must be with respect to a single reference mark or reference network"

OPUS Projects

Loop vs. Hub Networks

Distributes (smears) observation and/or constraint errors across network.
Artificially imposes correlations between stations.



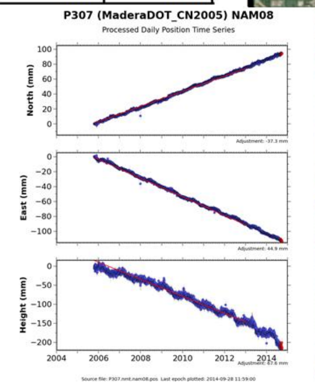
Preserves observation precision.
Short and long lines improve tropospheric modeling.
Bench mark errors lost in single vector.

Trivial vs. Non-Trivial Networks

Trival Vector Network (243 Degrees of Freedom)

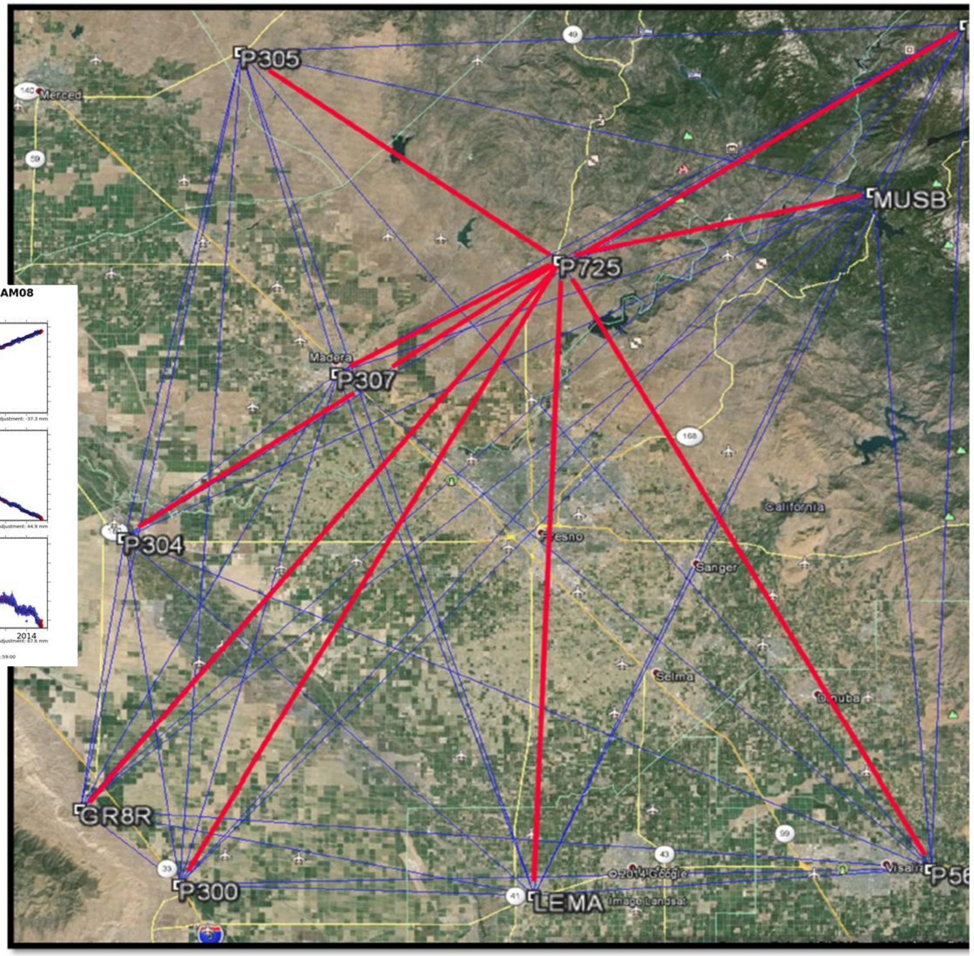
Station	North	East	Height	Maj(95%)	Min(95%)	Hgt(95%)
GR8R	4033628.989	193652.410	206.008	0.001	0.001	0.003
LEMA	4019931.806	250128.013	34.255	0.001	0.001	0.003
MUSB	4116222.000	294966.062	2042.520	0.001	0.001	0.003
P300	4022700.121	205744.443	137.280	0.001	0.001	0.003
P304	4071174.967	200276.121	17.050	0.001	0.001	0.003
P305	4138741.175	216843.150	96.052	0.001	0.001	0.003
P307	4093393.068	227694.322	49.277	0.001	0.001	0.003
P566	4022242.867	299890.656	78.119	0.001	0.001	0.003
P629	4138798.187	307034.263	2725.668	0.001	0.001	0.003
P725	4108261.474	255965.708	330.940	0.000	0.000	0.000

Station	ΔN	ΔE	Δh
GR8R	-0.001	-0.001	0.000
LEMA	-0.001	0.000	0.001
MUSB	0.000	-0.001	0.001
P300	-0.001	0.000	0.000
P304	0.001	0.000	-0.001
P305	0.001	0.002	-0.002
P307	0.001	0.002	0.000
P566	0.001	0.000	0.000
P629	-0.001	-0.001	0.001
P725	0.000	0.000	0.000



Hub Network (63 Degrees of Freedom)

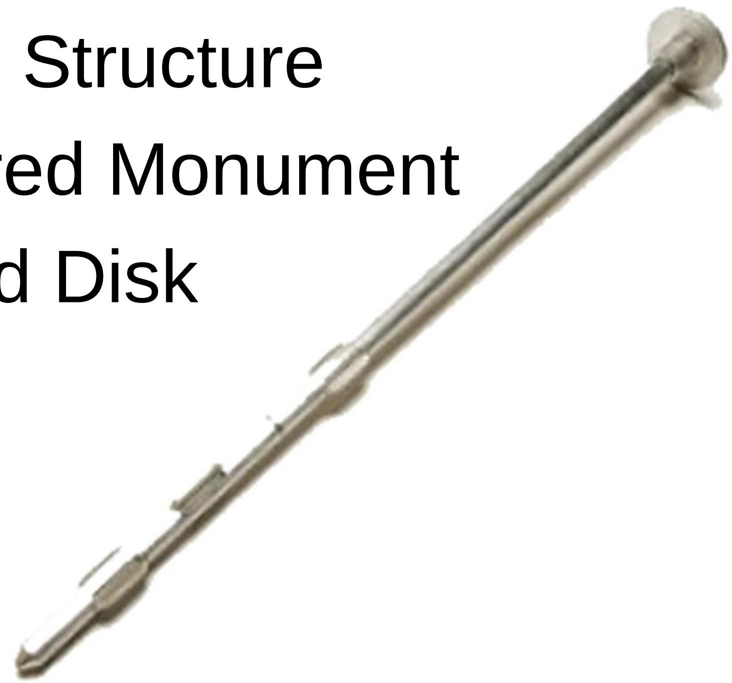
Station	North	East	Height	Maj(95%)	Min(95%)	Hgt(95%)
GR8R	4033628.988	193652.409	206.008	0.003	0.002	0.007
LEMA	4019931.805	250128.013	34.256	0.003	0.002	0.006
MUSB	4116222.000	294966.061	2042.521	0.003	0.002	0.007
P300	4022700.120	205744.443	137.280	0.003	0.002	0.006
P304	4071174.968	200276.121	17.049	0.003	0.002	0.007
P305	4138741.176	216843.152	96.050	0.003	0.001	0.006
P307	4093393.069	227694.324	49.277	0.003	0.002	0.007
P566	4022242.868	299890.656	78.119	0.003	0.002	0.006
P629	4138798.186	307034.262	2725.669	0.003	0.002	0.006
P725	4108261.474	255965.708	330.940	0.000	0.000	0.000



Stable Control Survey Monuments

**** Usability and Permanence ****

- 3D Deep Rod Monuments
- Disk in Rock or Concrete Structure
- 30" Minimum Manufactured Monument
- 2" Minimum Iron Pipe and Disk



Stable Control Survey Monuments

Table 3	Horizontal	Horizontal	Horizontal	Vertical	Vertical	Vertical
Spatial Accuracy Classification	.5 cm-2 cm	2 cm-5 cm	5 cm-10 cm	.5 cm-2 cm	2 cm-5 cm	5 cm-10 cm
Repeat Station Observations percent of number of stations						
Two times:	100%	100%	80%	100%	100%	80%
Three or more times:	10%	10%	0%	50%	25%	0%
Sidereal time displacement between occupations (start time to next start):	60 min.	45 min.	20 min.	120 min.	60 min.	45 min.
Satellite Constellation Mask						
Minimum number of satellites observed during 75% of occupation:	7	6	5	8	7	5
Maximum PDOP during 75% of occupation:	3	4	5	3	4	5
Antenna Setup						
Maximum centering error (measured and phase center):	3 mm	5 mm	7 mm	5 mm	5 mm	7 mm
Independent plumb point check required:	Y	Y	N	Y	N	N
Maximum height error (measured and phase center):	5 mm	5mm	5 mm	3 mm	5 mm	5 mm
Number of independent antenna height measurements per occupation:	2	2	2	2	2	2
Digital Photograph (location and close up) required for each mark occupation:	Y	Y	Y	Y	Y	Y
Fixed Height Tripod Recommended:	N	N	N	Y	Y	Y

Caltrans   Royal Institute of Chartered Surveyors

Traditional Differential GNSS Surveying

- Initial Position Accuracy
- GNSS Orbits and Clocks
- Atmosphere Error Reduction
- Baseline Processing
- Least Squares Processing
- Adjustment Analysis

Height Systems

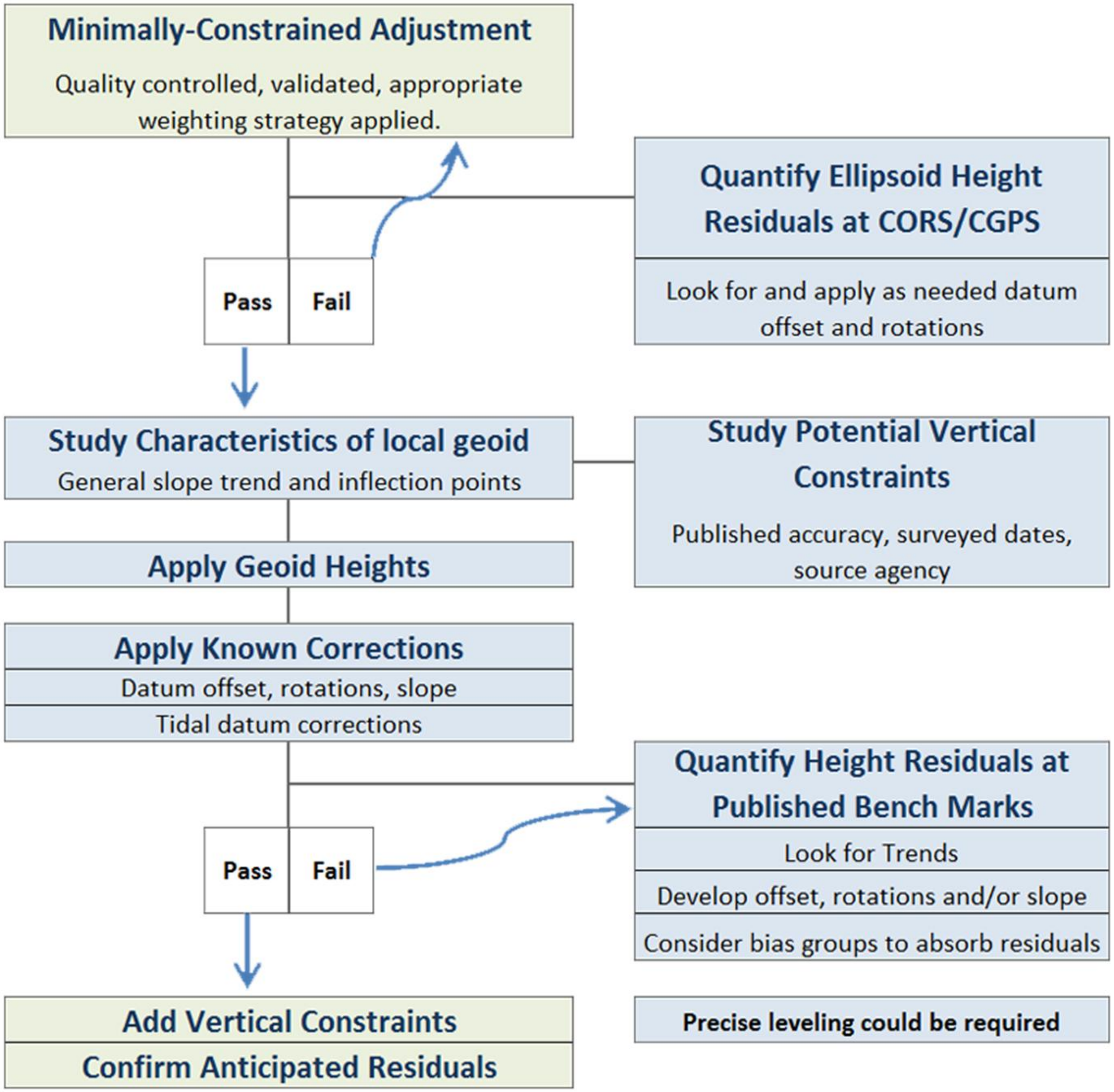
Ellipsoid Heights The direct expression of geodetic positions in terms of the chosen geodetic datum. California Geodetic Coordinates (CA Business and Professions Code).

NAVD88 Orthometric Heights The realization on the ground of a national network of precise leveling and sophisticated (for the era) processing and analysis. Neither geocentric nor consistent in terms of geodetic science.

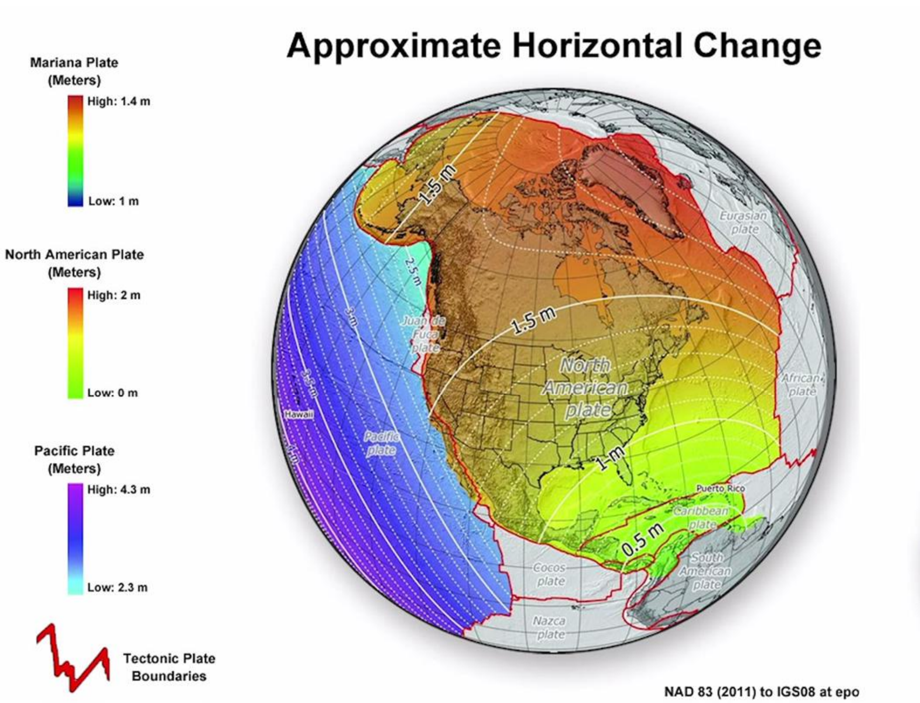
Geopotential Heights Future official system of elevations for North America, based exclusively upon a gravimetric geoid model and adopted zero datum equipotential surface.

Local Elevation Systems Include NGVD29, tidal datum (e.g. Mean Sea Level, Mean Lower Low Water, etc.), NGVD29, and some local-agency-maintained bench mark networks.

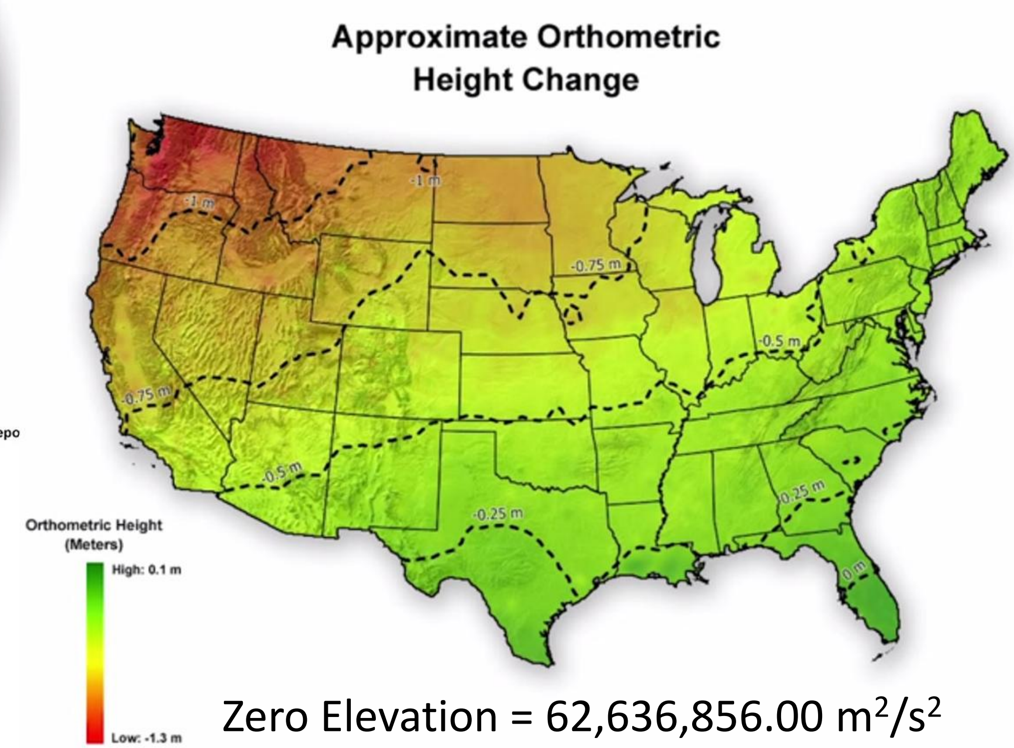
NAVD88 or Local Heights



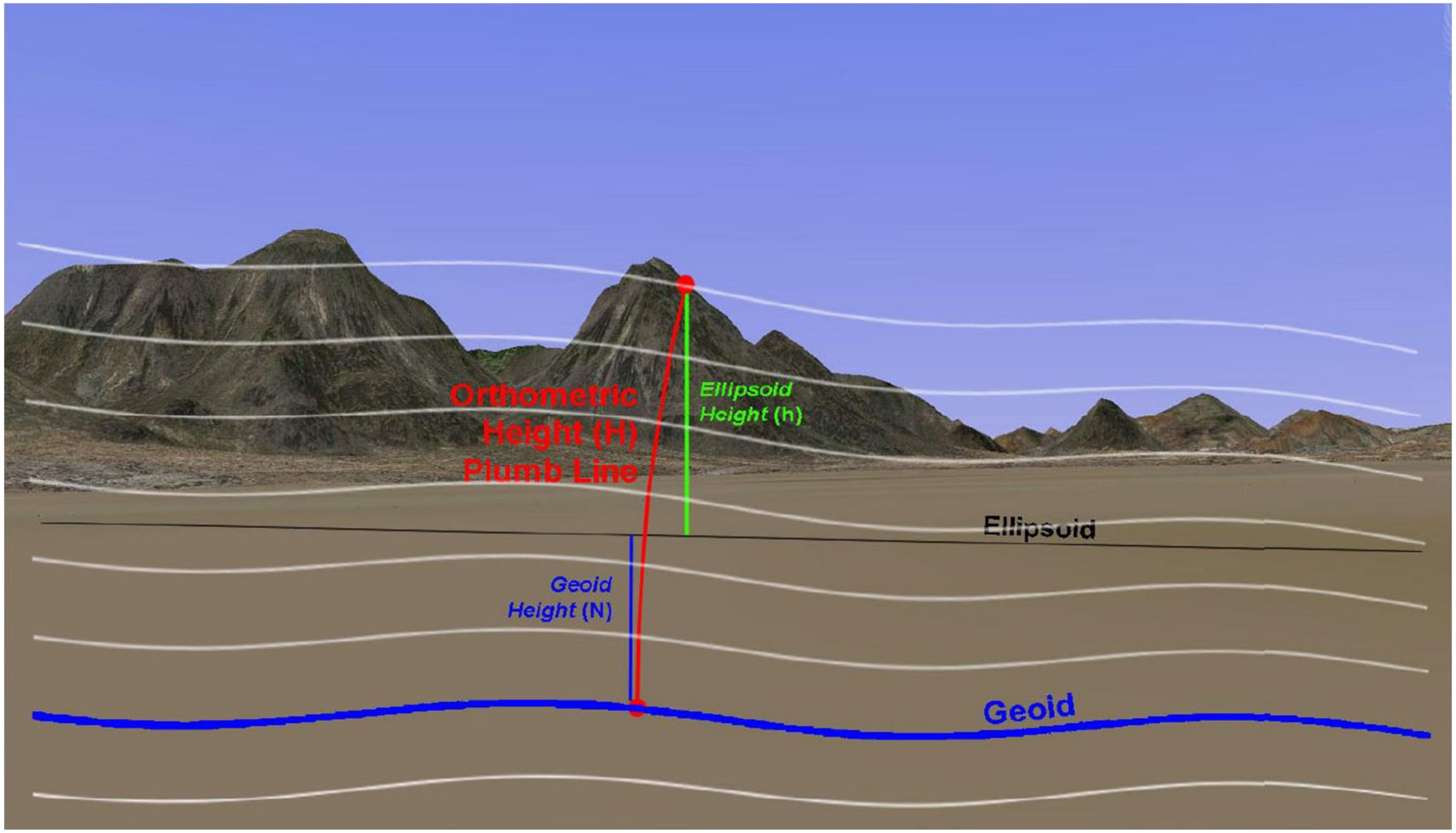
Earth-Centered, Geopotential Datum



ITRFxx → Velocity Model → Projection



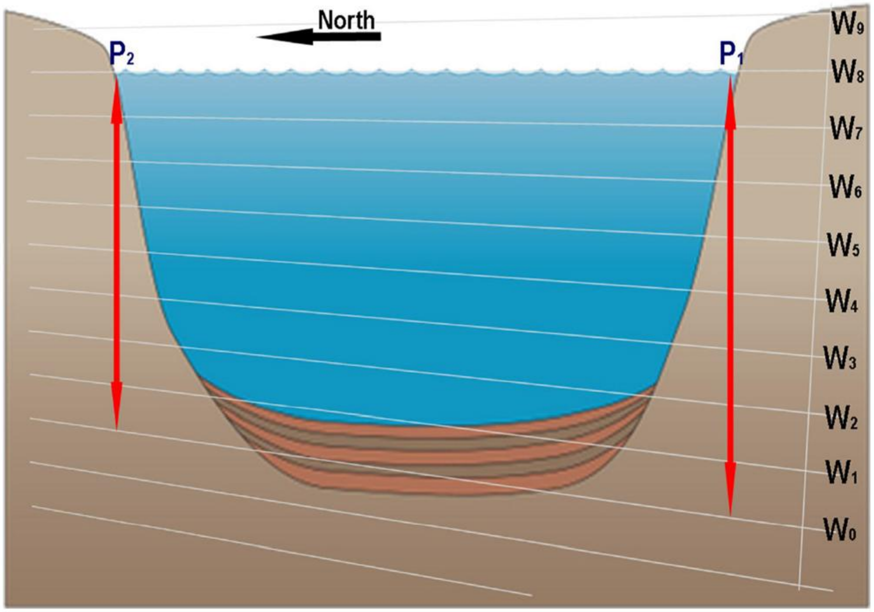
Zero Elevation = 62,636,856.00 m^2/s^2



Orthometric height is the distance from the geoid to a point along a line normal to the equipotential of the gravity field. Therefore the value is correctly computed along a curved plumb line. To do so requires knowledge of the potential gravity at every point along the plumb line.

Orthometric Height Conundrum

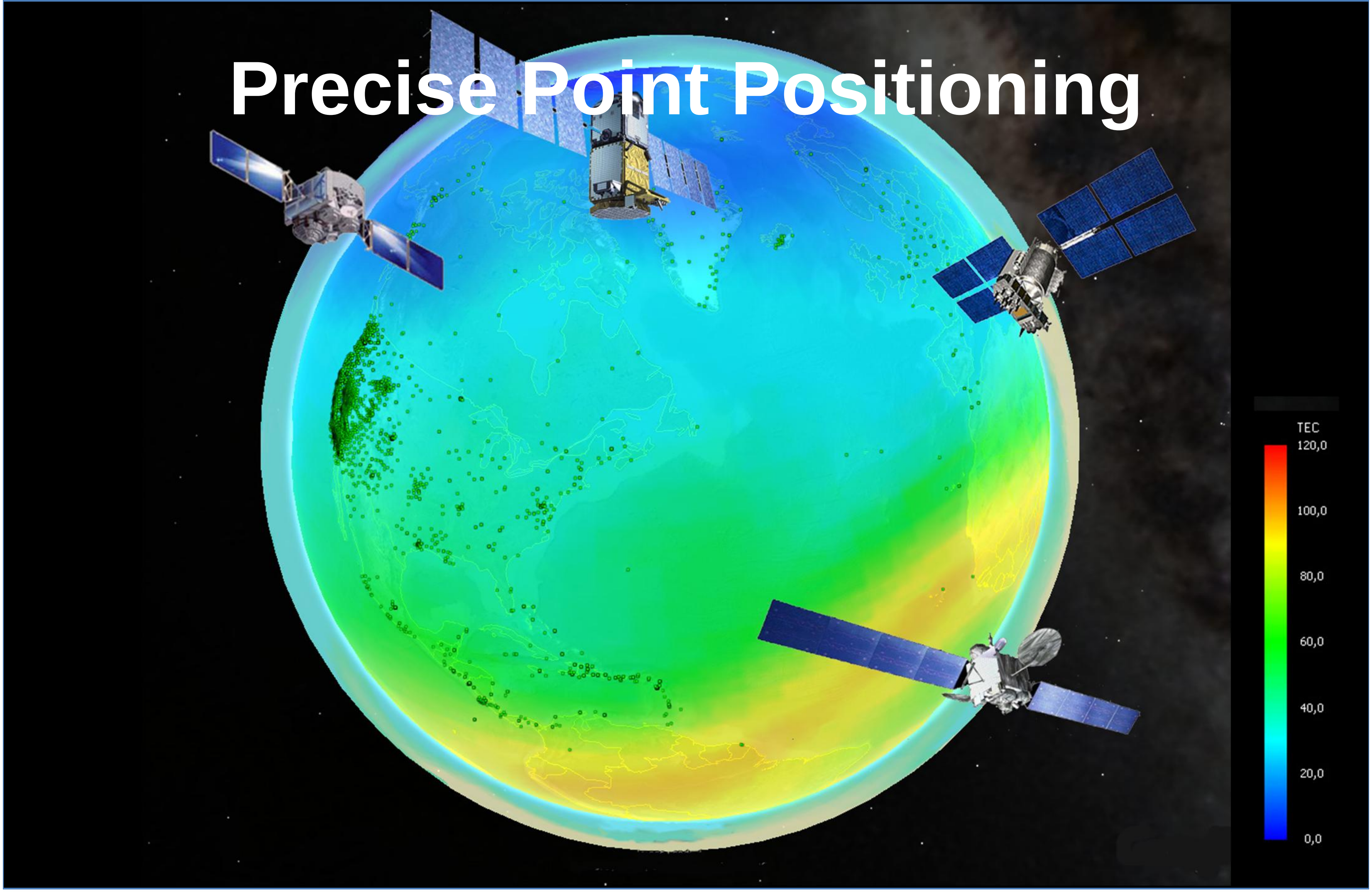
The lines W_i are equipotential surfaces with W_0 being the geoid or datum surface. The orthometric height at Points P_1 and P_2 are the distances along the plumb line between W_0 the datum and W_8 the equipotential surface of the lake, and are properly computed by the formula:



$H_1 = (W_8 – W_0) / g'_1$
$H_2 = (W_8 – W_0) / g'_2$
Where g'_i = the mean gravity along the respective plumb line

Since equipotential surfaces converge to the north in the northern hemisphere, due to the decrease in centrifugal force, $H_1 > H_2$.

Precise Point Positioning



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Questions & Answers

Statement of Qualifications
A Winning Approach