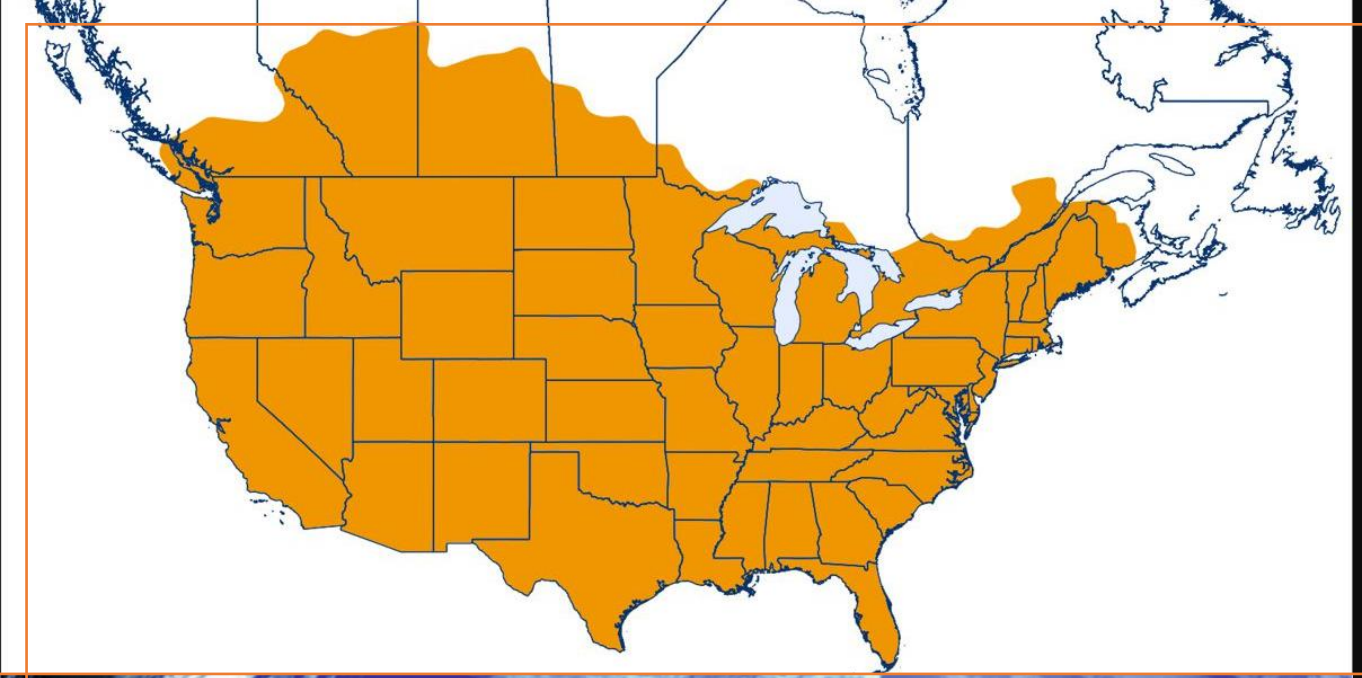


Are Satellite Based Correction Services The “Next Utility” For Surveyors? Continued!!

“The Future is Here”

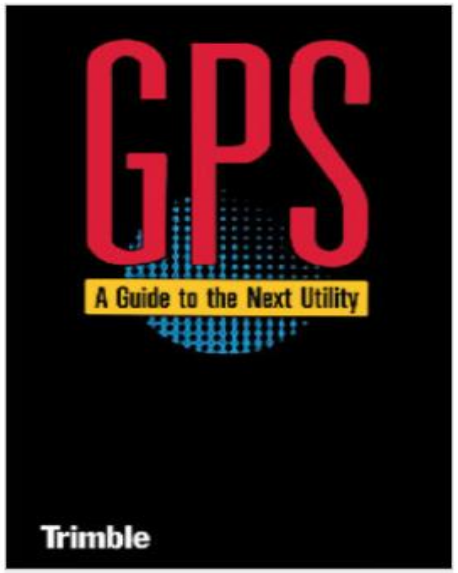
The American Surveyor

Are Satellite-Based Correction Services the "Next Utility"?

ROBERT L. GREEN, PS // 06.20.2021

GPS: The Original "Next Utility"

In the summer of 1978, I worked as a rodman/chainman for Boston Survey Consultant (now the BSC Group). My crew partnered with the engineering staff to conduct soil percolation tests for septic system design. At one point, our boss informed us he had just attended a meeting at our corporate office in Boston on the status of the GPS satellite constellation. Little was known about this technology as the first GPS satellite (NAVSTAR 1) had only been launched months earlier. He told us that within a few years you would be able to put a "magic black box" on the surface of the earth and obtain XYZ coordinates. As an 18-year-old kid, it was impossible for me to comprehend as we were in the process of locating the percolation test holes with a turn of the century K&E transit, a handheld magnifying glass to read the vernier, a Philly stadia rod for distance interpolation, and a machete for cutting line. As I reflect on this story, I realize how lucky I am to have witnessed all these measurement technology enhancements over the last four decades.



"GPS: A Guide to the Next Utility," by Jeff Hurn, published by Trimble in 1989.

LEARNING OBJECTIVES:

My Story and the History of "How did we get here?"

Technology Game Changers:

- Real Time Kinematic Positioning Solutions
- Real Time Networks (RTN's)
- Satellite Based Augmentation

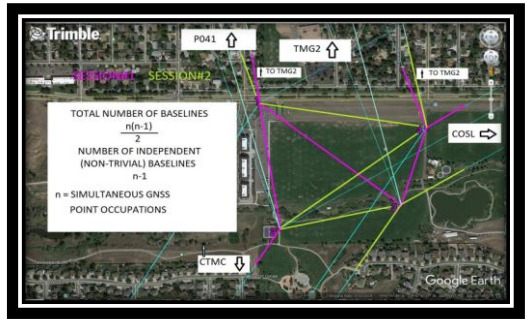
Publicly Available SBAS

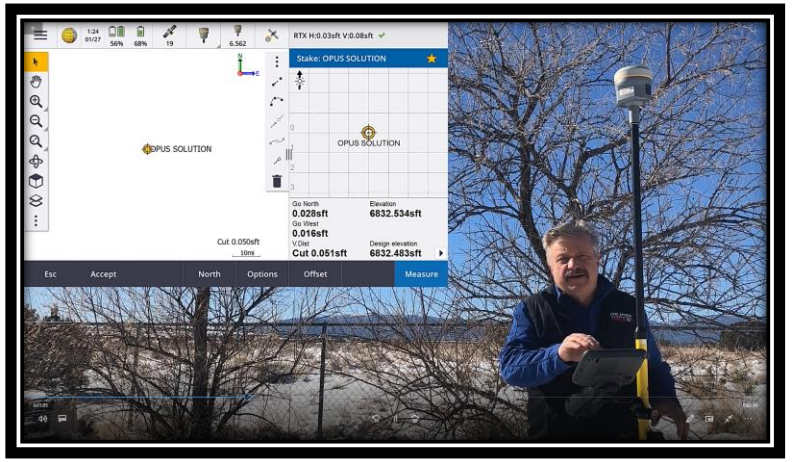
Private SBAS Solutions

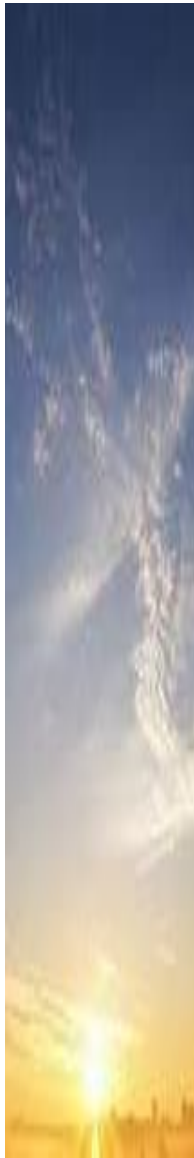
Precise Point Positioning (PPP):

- How does it work?
- Multiple Manufactures Solutions
- What's in it for me?

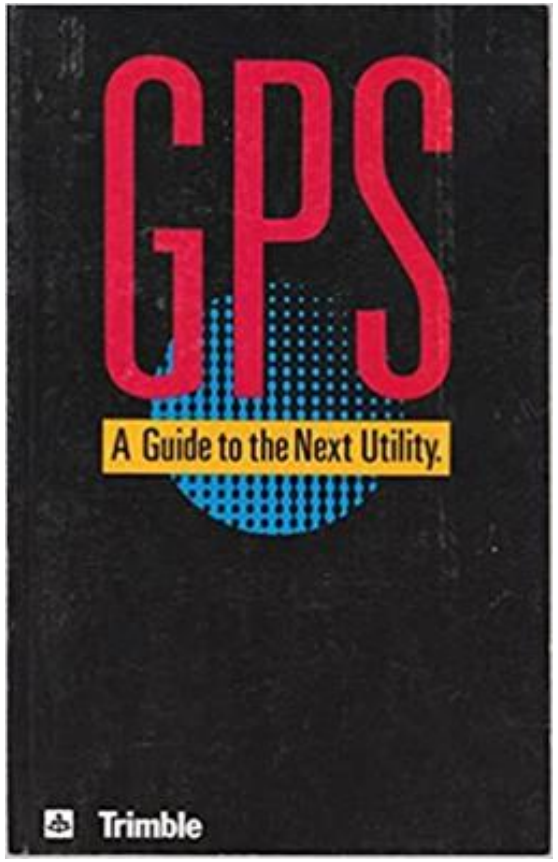
Experimentation and Testing Results







GPS the Original "NEXT UTILITY" and My Story



- First GPS Satellite Launch – February 22, 1978
  - NAVSTAR 1
  - 3 more launches that year!
    - May 13th, October 7th and December 11th
- I was working for Boston Survey Consultants (Later The BSC Group) as a Rodman/Chainman/Instrument Operator-in-Training
- GPS "Hype" was trickling into the industry

Instruments I Used in My Career
"The Past Predicts the Future"

Early 1980's

Mid 1990's

Instruments I Used in My Career
"The Past Predicts the Future"

Early to Mid 1990's

GPS
RTK "On a Stick"

PP - CLF

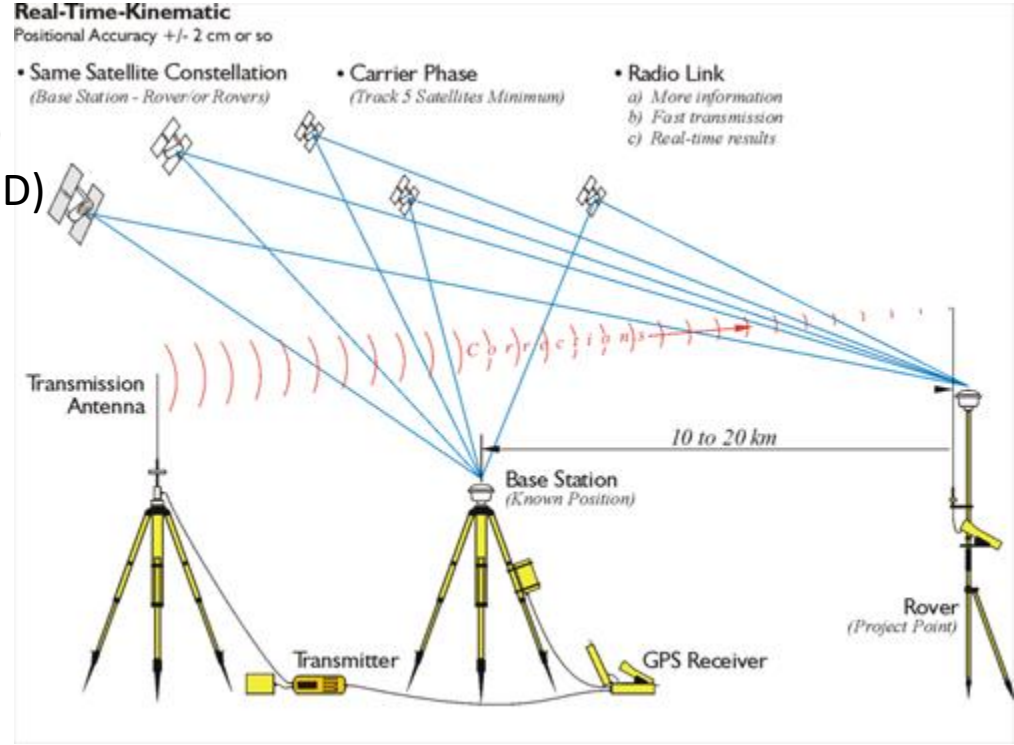
GPS
GLONASS

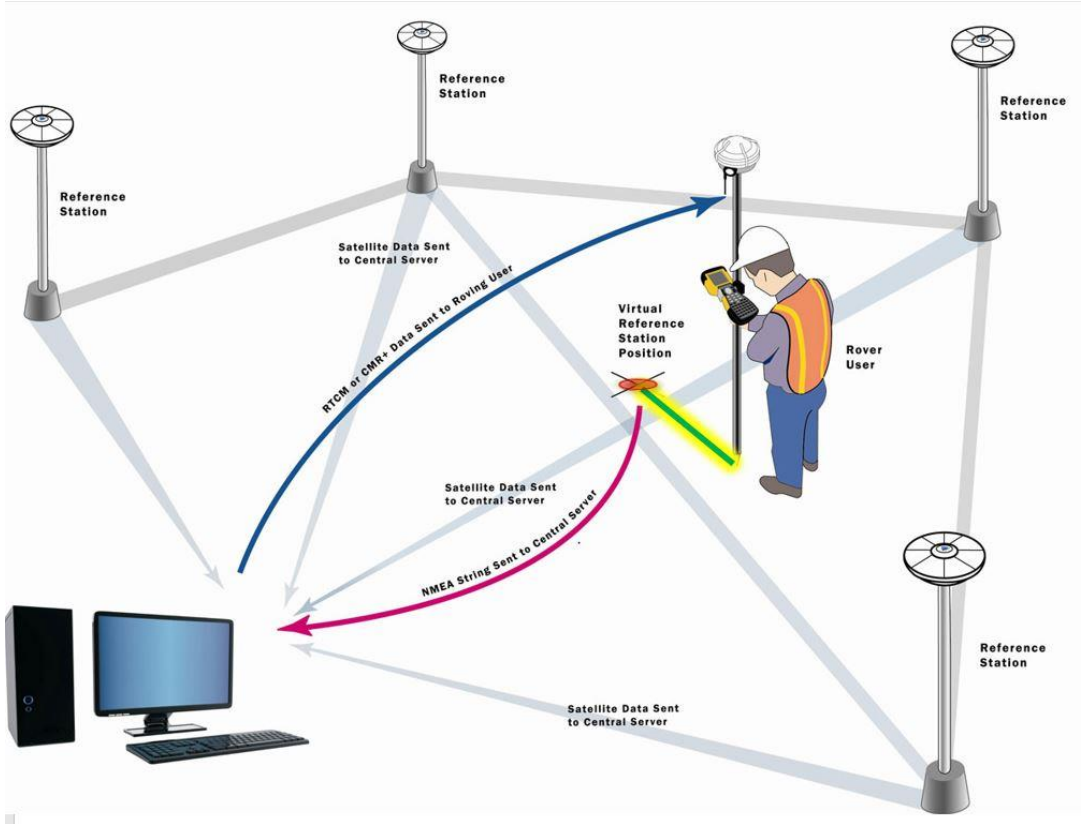
GPS
GNSS

Today

Game Changer #1 – Real Time Kinematic (RTK)

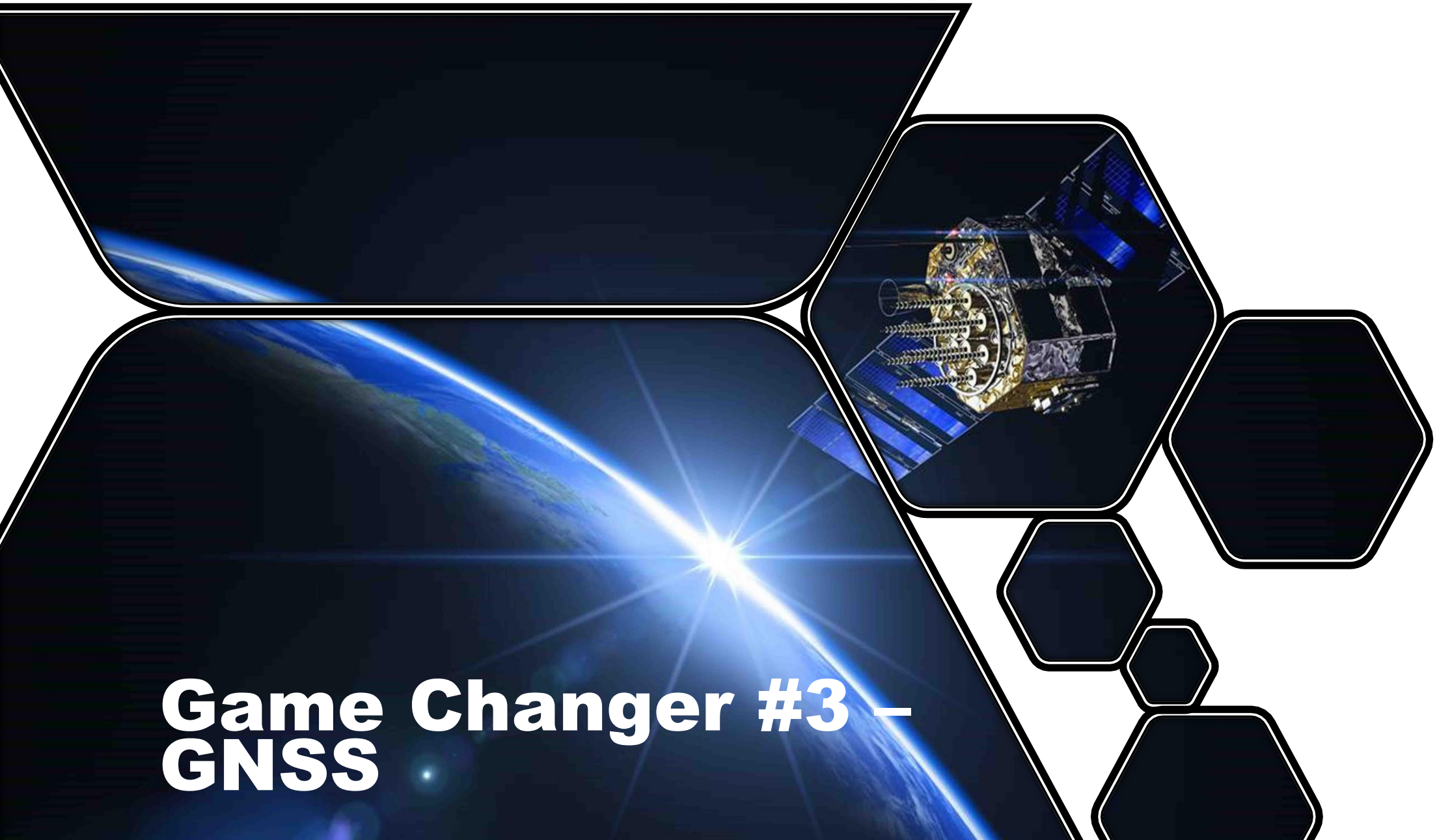
- Important Dates
  - December 8, 1993 GPS Initial Operational Capability (IOC) (DOD/DOT)
  - April 27, 1995, GPS Full Operational Capability (FOC) (USAF SPACE CMD)
- Mathematics ➡ Innovation ➡ Technology
  - Dr. Benjamin Remondi
  - Charlie Trimble
  - Javad Ashjaee
- Specifications
  - 1 cm + 1 **ppm** RMS HZ x 2 cm +2 **ppm** RMS VT
  - 6 miles (10 KM) 1990's
  - 12 miles (20 KM) 2000's





Game Changer #2 – Real Time Networks (RTN's)

- My Introduction to RTN's (2000)
  - Grand Junction, CO
  - UHF Data Transmission from Multiple Reference Stations
    - Helped to find the body of Jennifer Blagg at County Landfill (2002)
    - Became one of the longest operational RTN's in the Country
- Internet Protocal
  - Voids the "Weak Link" of UHF Radio
  - Drastically Minimizes PPM Error
    - Localized Corrections
- Drawbacks
  - Internet Connection Required
    - RTK Bridges
  - Specific to a Geographical Area



Game Changer #3 – GNSS

GNSS Constellations

- **G**lobal **P**ositioning **S**ystem (GPS)
- **Gl**obal **O**rbiting **N**avigation **S**atellite **S**ystem (GLONASS)
- Galileo Satellite Navigation System
- **B**ei**D**ou 3 (BDS)
- **Q**uasi-**Z**enith **S**atellite **S**ystem (QZSS)
- **I**ndian **R**egional **N**avigation **S**atellite **S**ystem (IRNSS)

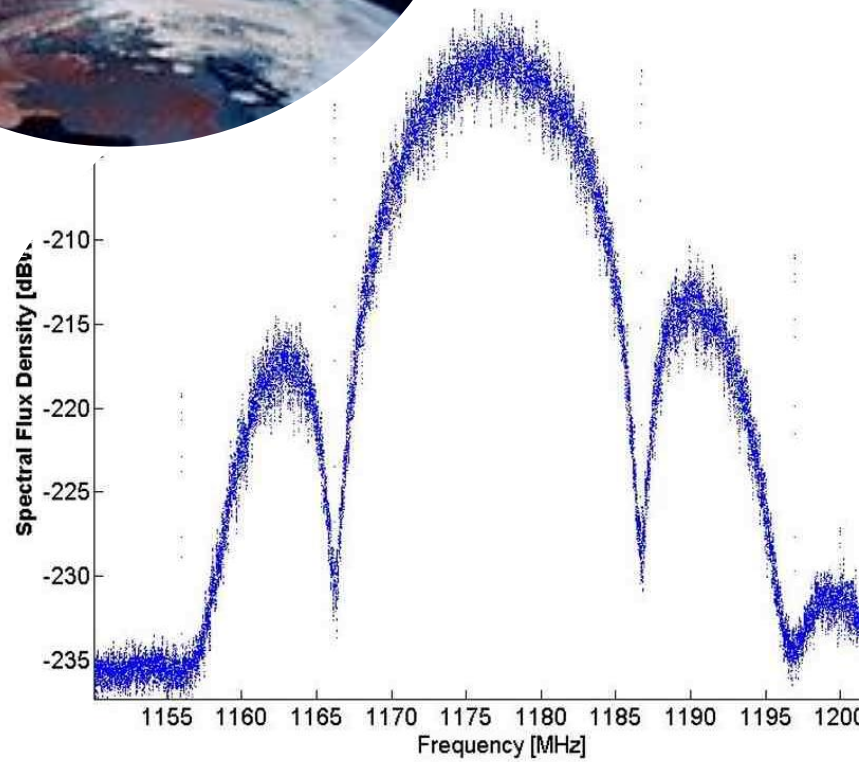
GNSS

GPS

- US Department of Defense Satellite System
  - 31 Current Operational Satellites
    - GPS Block III Satellites Continue to be Launched
      - First GPS III tracked January 13th, 2020 (SVN 74)
      - 10 GPS Block III's Developed and Manufactured by Lockheed Martin, Waterton Canyon, Littleton, CO
      - Future: GPS Block IIIF (Follow On), will include 22 SV's being developed by Lockheed Martin
  - Discontinuation of Codeless/Semi-Codeless GPS Access (**2019 Federal Radionavigation Plan)**
    - Legacy L1/L2 Receivers – Plan to update
    - https://www.gps.gov/technical/codeless/

GNSS

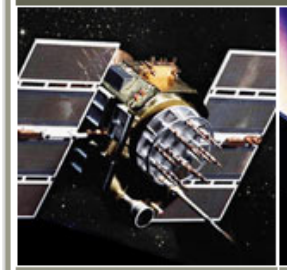
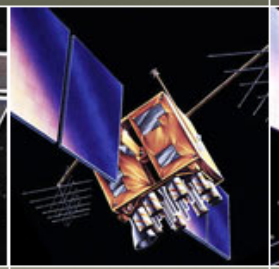
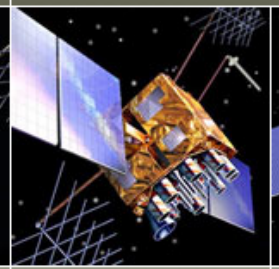
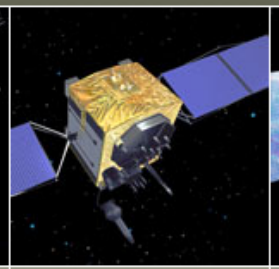
- **GPS**
  - L5 – 1176.45Mhz
    - Currently satellites broadcasting L5 = 12 IIF's + 4 Block III's
    - 3rd Carrier Observable
    - Positive impact for surveying
      - Due to wide bandwidth and comparatively longer spreading codes, the L5 signal is giving a high processing gain
      - Improved Ionospheric Modeling
      - Will enhance RTK vector lengths



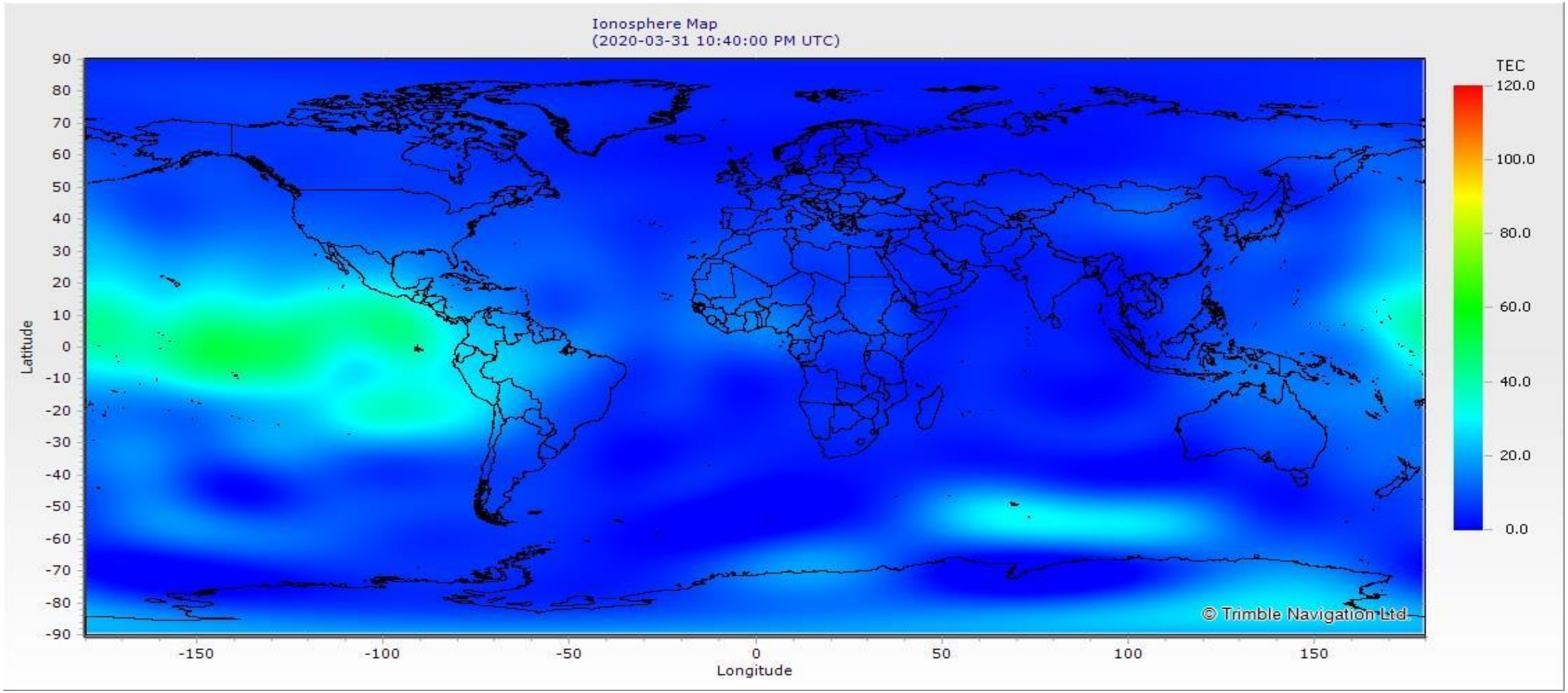
GNSS

GPS

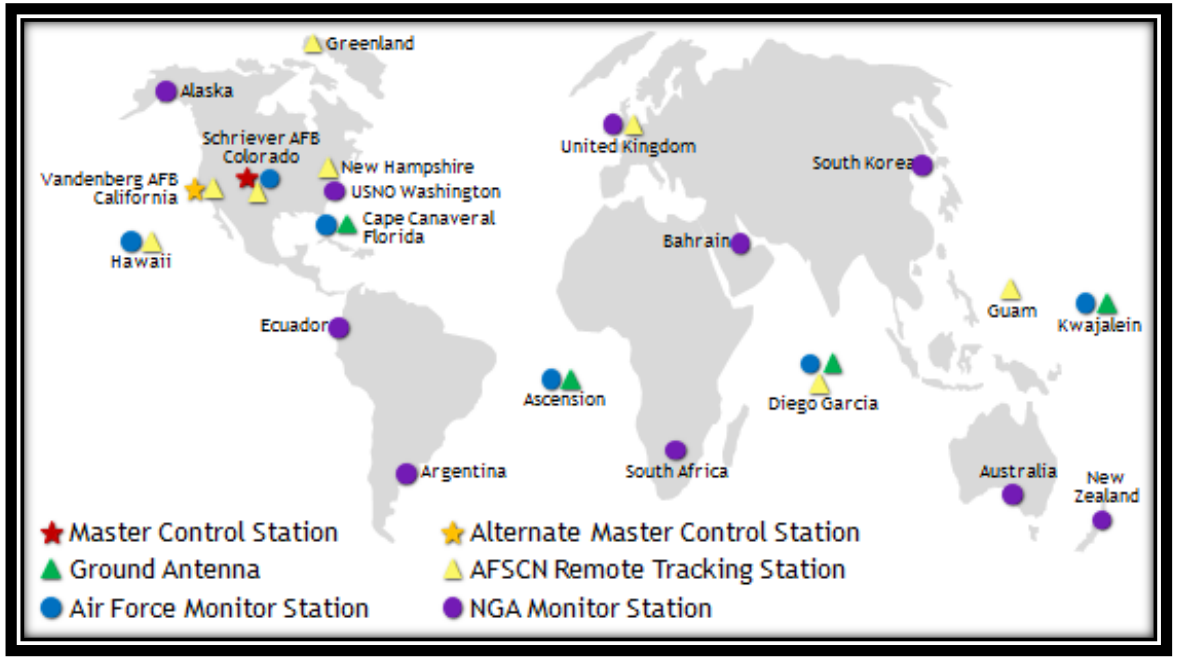
- High Precision Benefits
  - Ionospheric Errors
    - Reduced by Enhanced Ionospheric Modeling
    - Combining Signals from at least 2 frequency bands that are sufficiently apart from each other
    - Traditional L1 at 1575.42 and L2 at 1227.60
    - L1C at 1575.42 and L5 at 1176.45

LEGACY SATELLITES		MODERNIZED SATELLITES		
				
BLOCK IIA	**BLOCK IIR**	**BLOCK IIR-M**	**BLOCK IIF**	**GPS III/IIIF**
0 operational	8 operational	7 operational	12 operational	4 operational
▪ Coarse Acquisition (C/A) code on L1 frequency for civil users ▪ Precise P(Y) code on L1 & L2 frequencies for military users ▪ 7.5-year design lifespan ▪ Launched in 1990-1997 ▪ Last one decommissioned in 2019	▪ C/A code on L1 ▪ P(Y) code on L1 & L2 ▪ On-board clock monitoring ▪ 7.5-year design lifespan ▪ Launched in 1997-2004 *LEARN MORE ABOUT GPS IIR AT AF.MIL* ➡	▪ All legacy signals ▪ 2nd civil signal on L2 (L2C) *LEARN MORE* ➡ ▪ New military M code signals for enhanced jam resistance ▪ Flexible power levels for military signals ▪ 7.5-year design lifespan ▪ Launched in 2005-2009 *LEARN MORE ABOUT GPS IIR-M AT AF.MIL* ➡	▪ All Block IIR-M signals ▪ 3rd civil signal on L5 frequency (L5) *LEARN MORE* ➡ ▪ Advanced atomic clocks ▪ Improved accuracy, signal strength, and quality ▪ 12-year design lifespan ▪ Launched in 2010-2016 *LEARN MORE ABOUT GPS IIF AT AF.MIL* ➡	▪ All Block IIF signals ▪ 4th civil signal on L1 (L1C) *LEARN MORE* ➡ ▪ Enhanced signal reliability, accuracy, and integrity ▪ No Selective Availability *LEARN MORE* ➡ ▪ 15-year design lifespan ▪ IIIF: laser reflectors; search & rescue payload ▪ First launch in 2018 *LEARN MORE ABOUT GPS III AT AF.MIL* ➡

IONOSPHERE MAP/TEC



http://www.trimbleionoinfo.com/Images.svc/TEC



GPS Modernization

- **Control Segment**
  - Legacy Accuracy Improvement Initiative
    - Completed in 2008
    - Expanded monitor stations from 6 to 16
    - GPS Intrusion Protection Reinforcement – Nov ‘15
  - Operational Control System (OCX)
    - Dedicated Monitor Stations
    - Improved Cyber Security

trimble online GNSS planning to | Trimble GNSS Planning

gnssplanning.com/#/skyplot

Apps | Microsoft Office Ho... | Zoho CRM - Home... | A-Z Index of U.S. G... | Session Submissions | how to install SP Su... | how to fix the syste... | New Tab | Statistics and its rel... | Other bookmarks

Trimble GNSS Planning Online

Settings | Satellite Library | Charts | Sky Plot | World View | EN

Local Time:
2021-02-25 00:00 UTC +00:00

Satellite Selection

Change selection

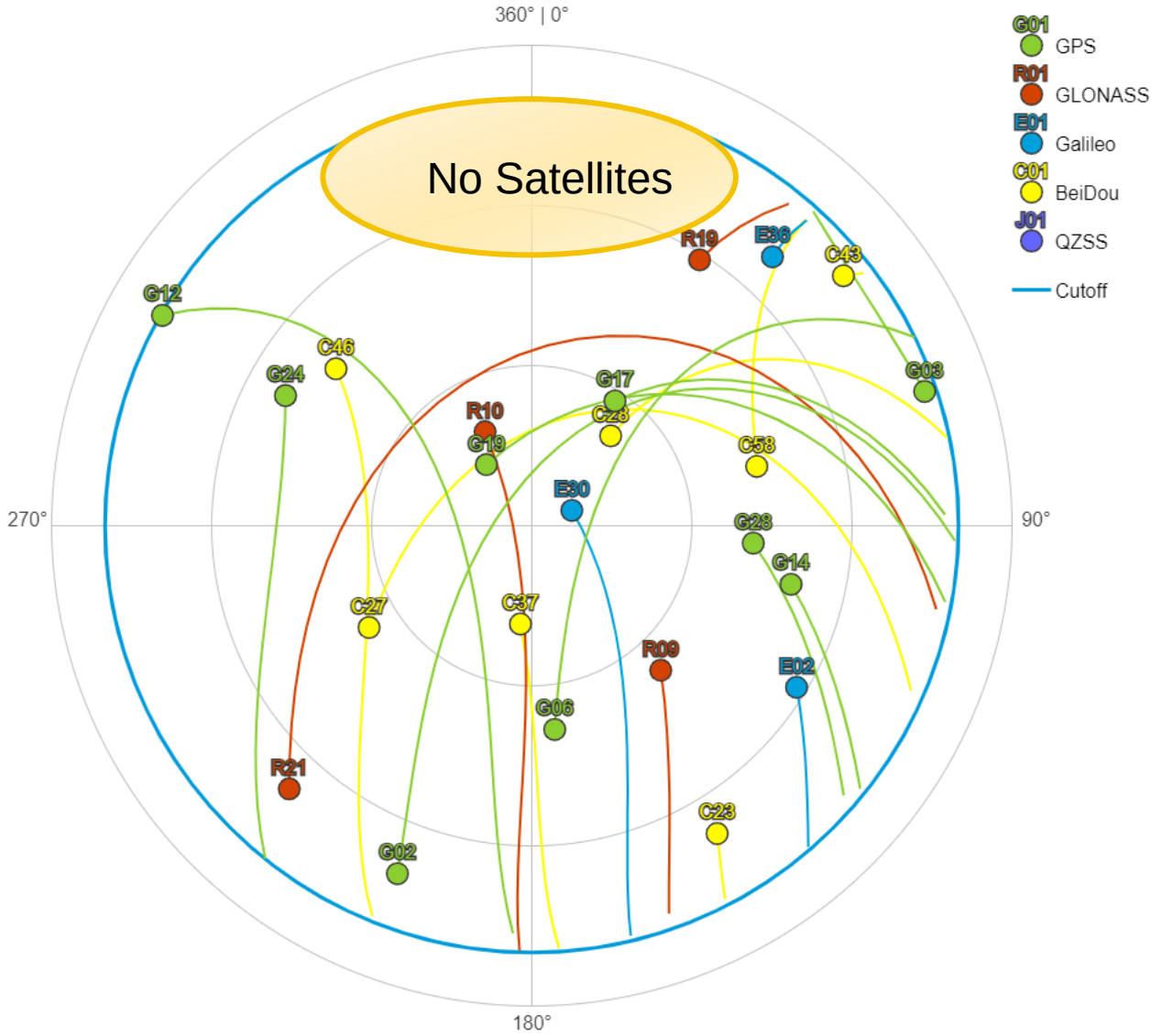
Satellites: **122/130**

System: active	Satellites	
	Selected	Healthy
GPS ✔	31	31
GLONASS ✔	22	22
Galileo ✔	16	16
BeiDou ✔	49	49
QZSS ✔	4	4

My Settings

Change settings

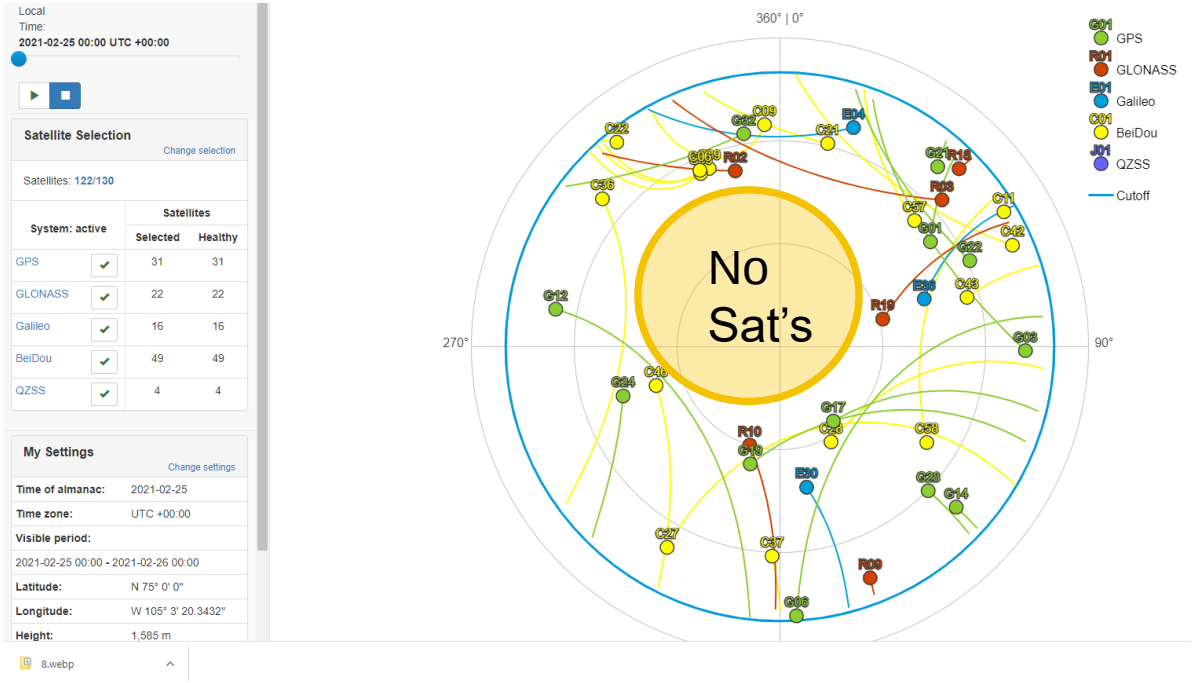
Time of almanac:	2021-02-25
Time zone:	UTC +00:00
Visible period:	
2021-02-25 00:00 - 2021-02-26 00:00	
Latitude:	N 39° 48' 18.5386"
Longitude:	W 105° 3' 20.3432"
Height:	1,585 m
Elevation cutoff:	10 °



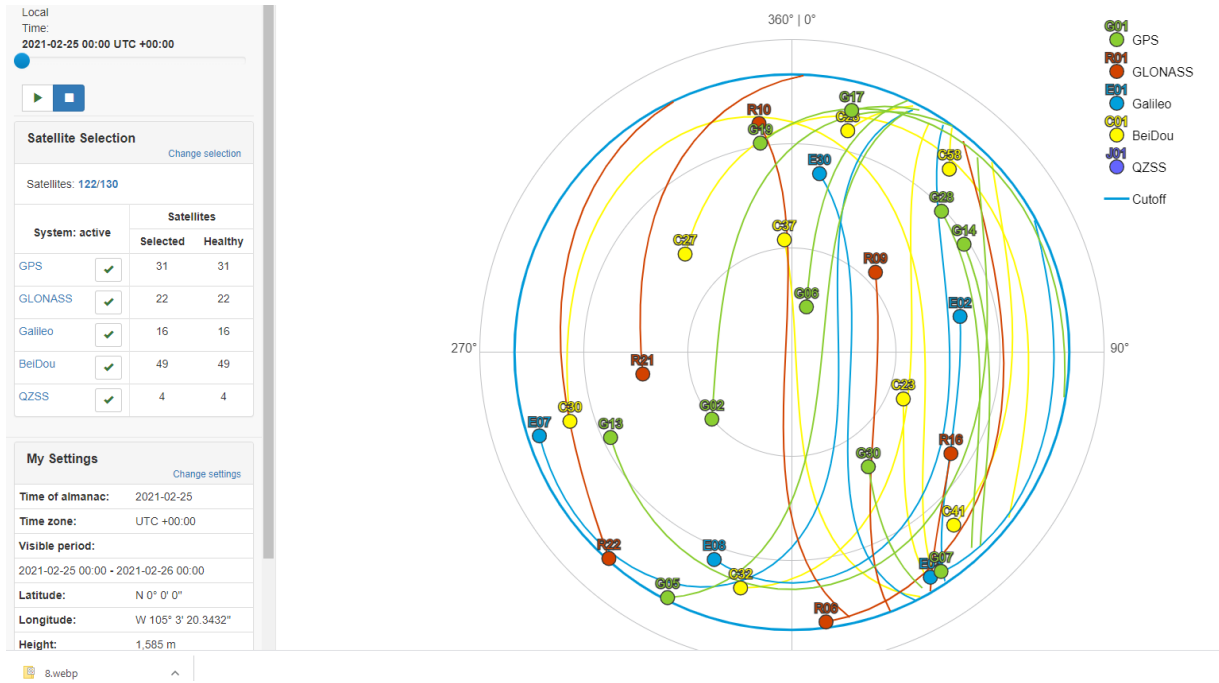
Type here to search

2:12 PM 2/25/2021

Additional “Sky Plots”



75 Degrees North Latitude

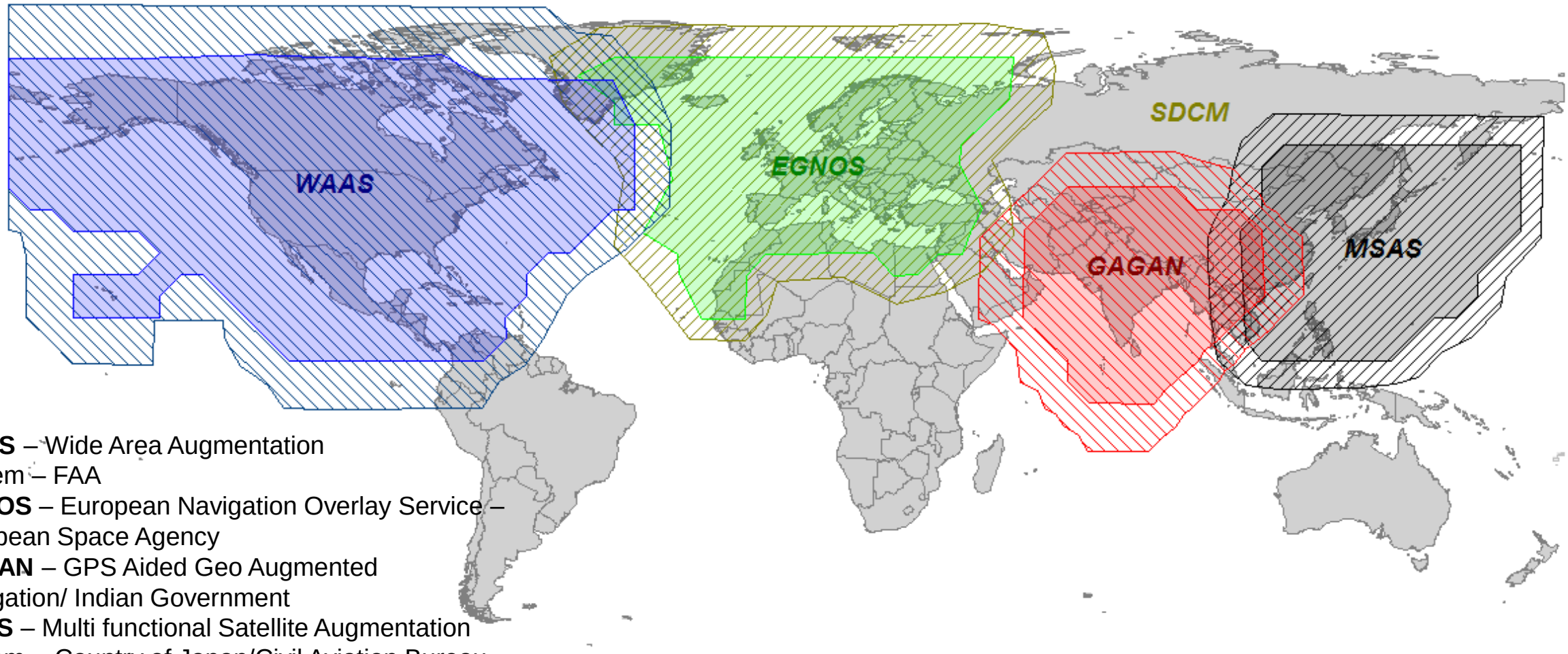


On the Equator

SBAS

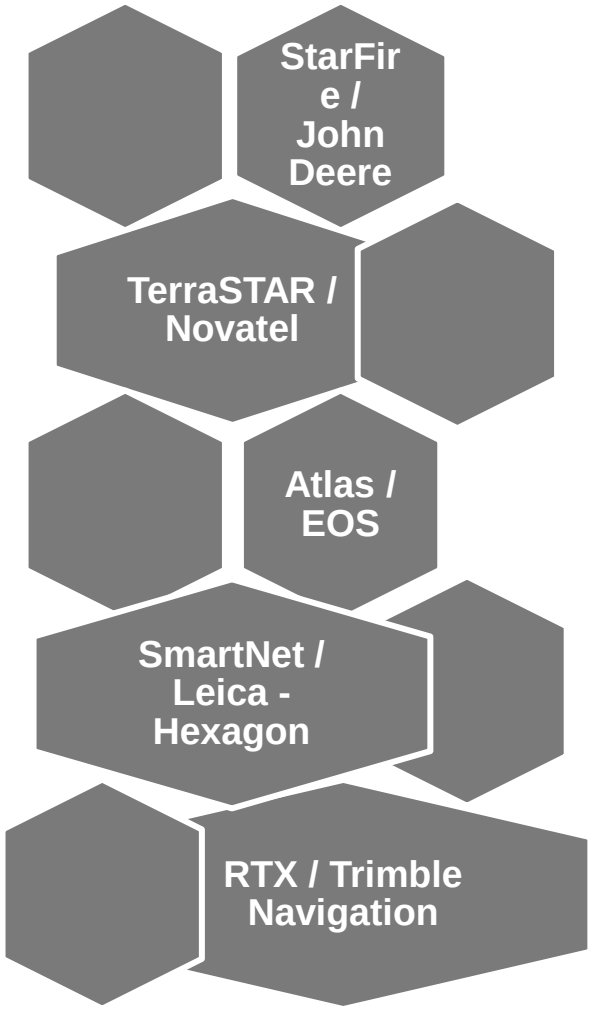
Satellite Based Augmentation System

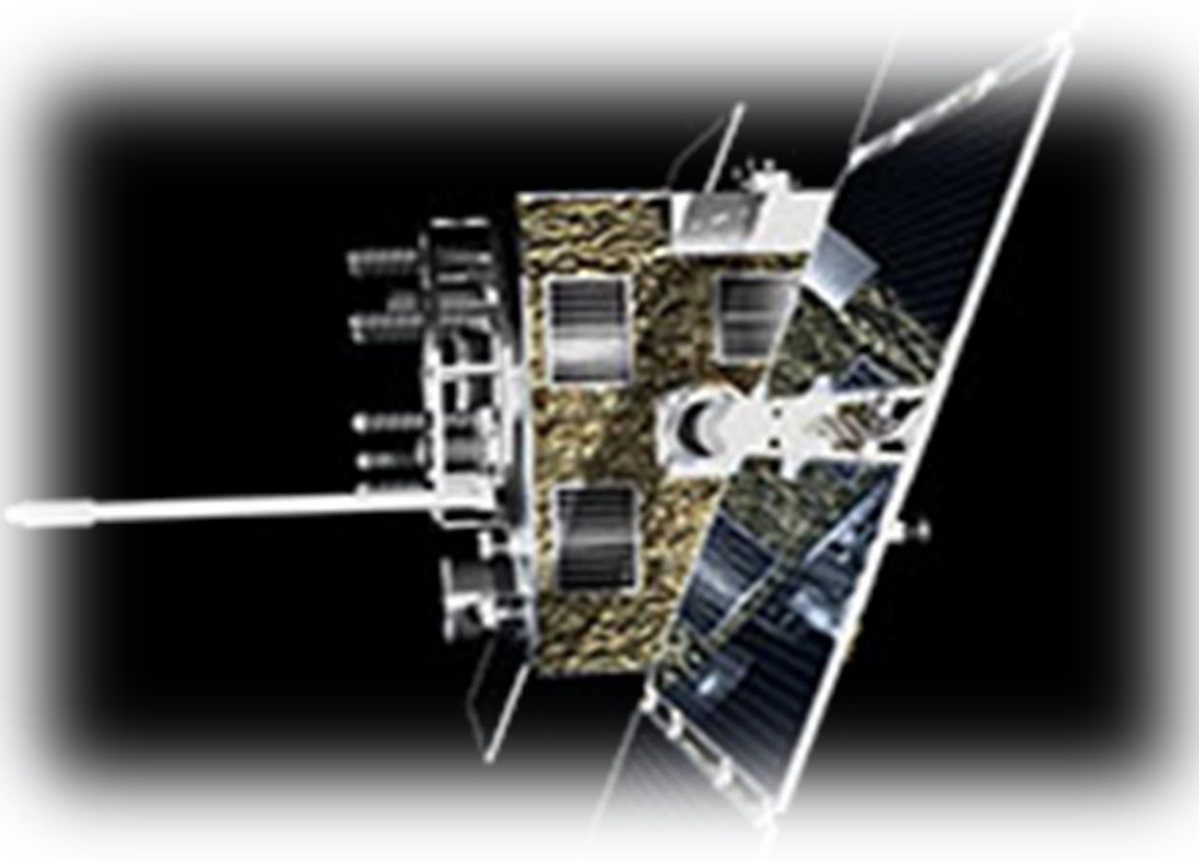
PUBLIC GLOBAL SBAS COVERAGE



WAAS – Wide Area Augmentation System – FAA
EGNOS – European Navigation Overlay Service – European Space Agency
GAGAN – GPS Aided Geo Augmented Navigation/ Indian Government
MSAS – Multi functional Satellite Augmentation System - Country of Japan/Civil Aviation Bureau

PRIVATE GLOBAL SBAS SERVICES





** (PPP) Precise Point Positioning Technology

TerraStar Correction Services / Novatel

WHAT IS TRIMBLE® RTX™

Trimble RTX (Real-Time eXtended) is a different type of correction technology known as Precise Point Positioning (PPP).

A true global positioning technology

Multi-GNSS positioning system

Symbiosis with existing RTK technology

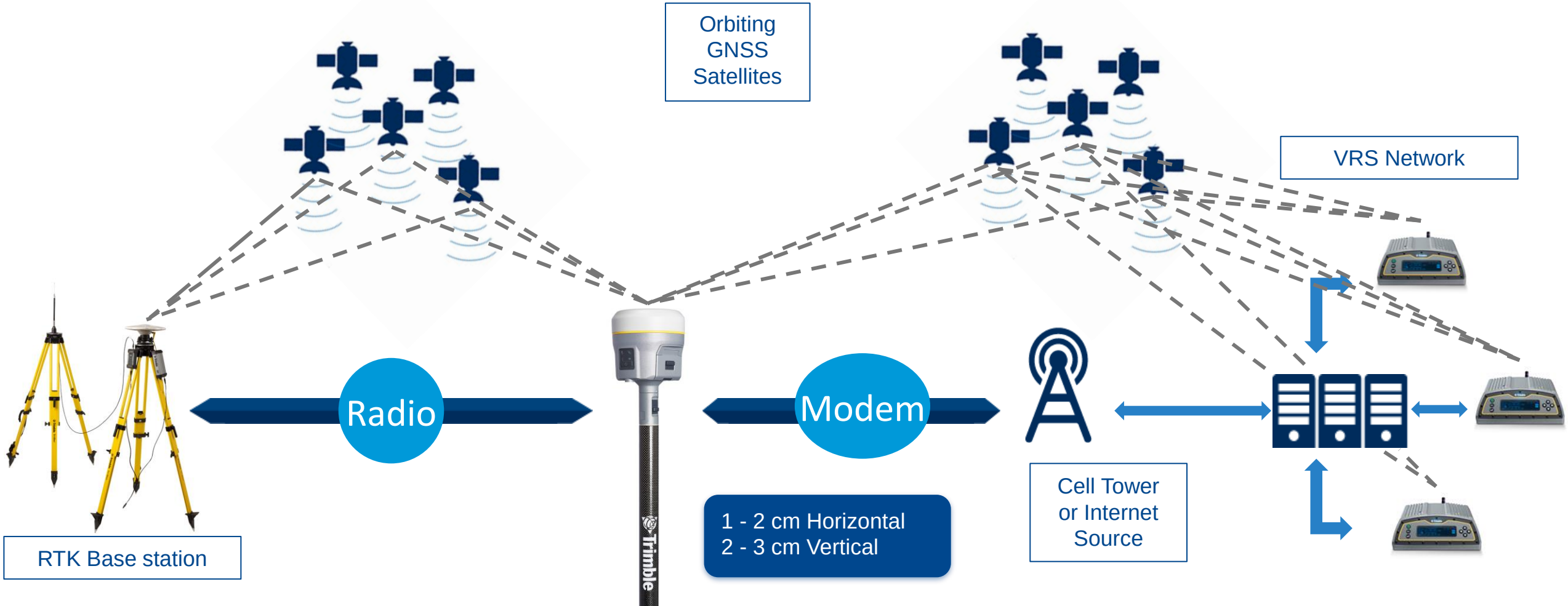
Introduced in 2011
Evolution of Infrastructure Pivot Software
Used by Agricultural, Geospatial, Construction

Updated CenterPoint RTX Performance in 2018
+/- 2cm RMS Horizontal Precision!

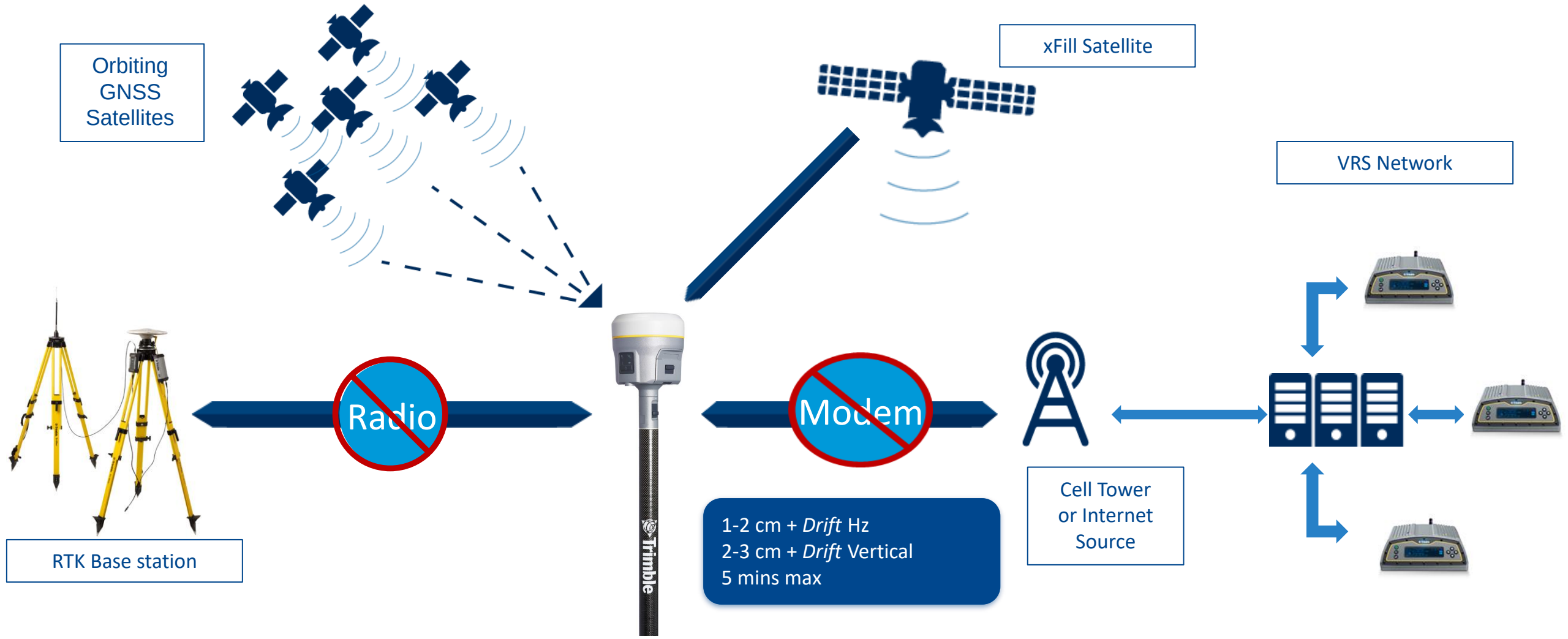
WHAT CORRECTION SERVICES ARE AVAILABLE?

	Horizontal Accuracy (cm)	Vertical Accuracy (cm)	Initialization (mins)[1] Fast / Standard
CenterPoint® RTX			
RMS	2 cm	5 cm	<1 / <15
95%	2.5 cm	-	<2 / <20
FieldPoint RTX™			
RMS	10 cm	-	<1 and <15
95%	20 cm	-	
ViewPoint RTX™			
RMS	50 cm	-	<5
95%	100 cm	-	

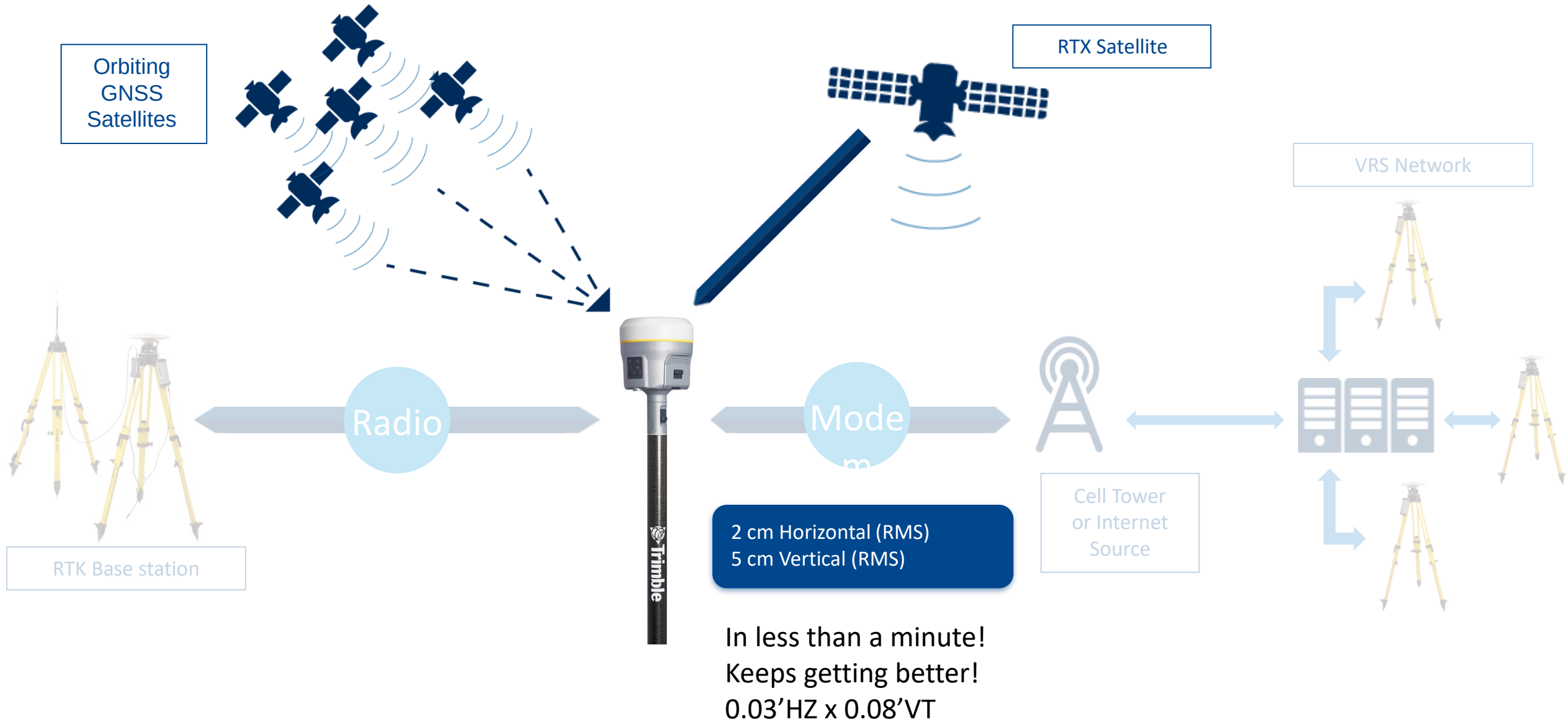
High-accuracy GNSS/GPS positioning - RTK/VRS



High-accuracy GNSS/GPS positioning - xFill

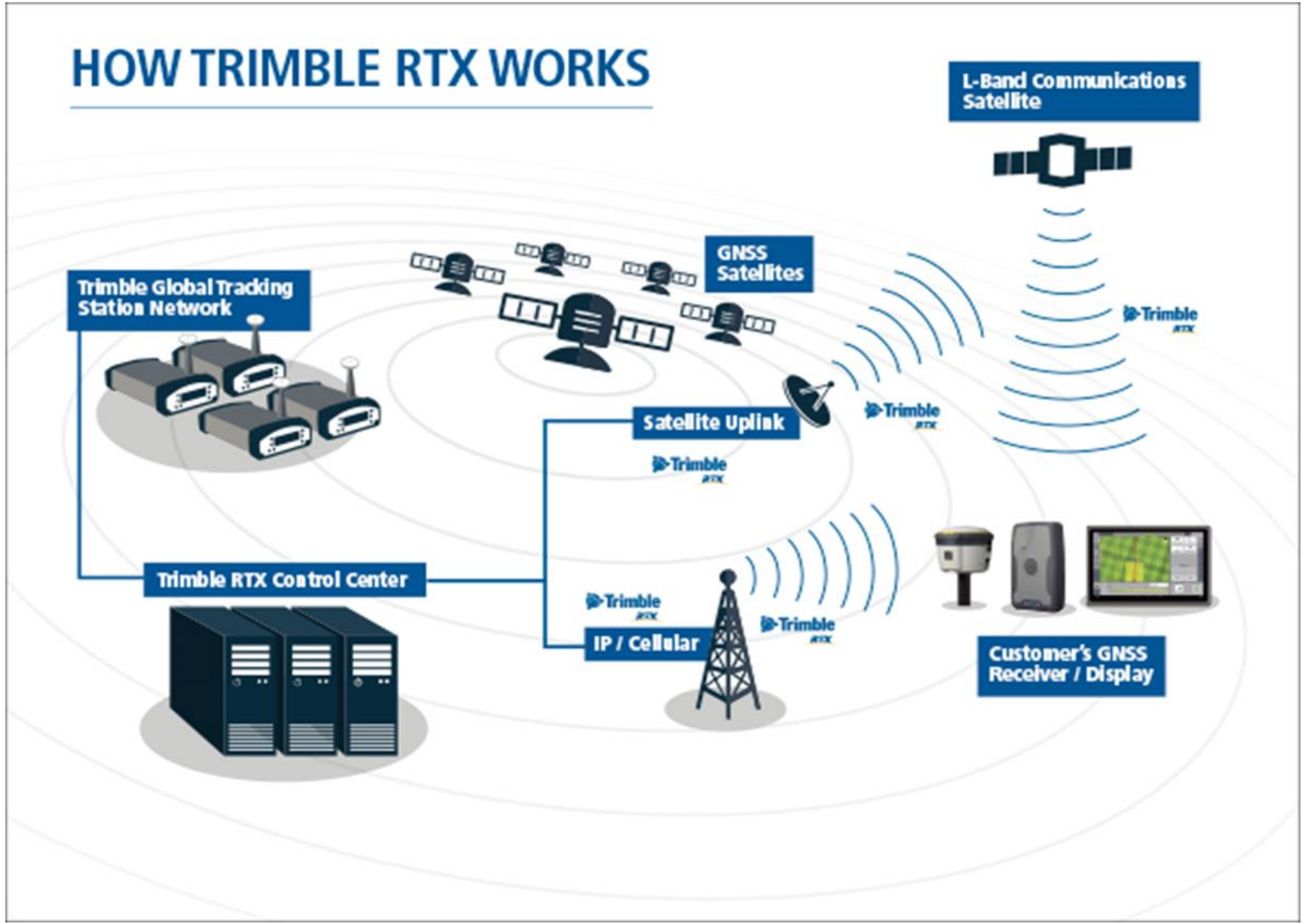


High-accuracy GNSS/GPS positioning - RTX

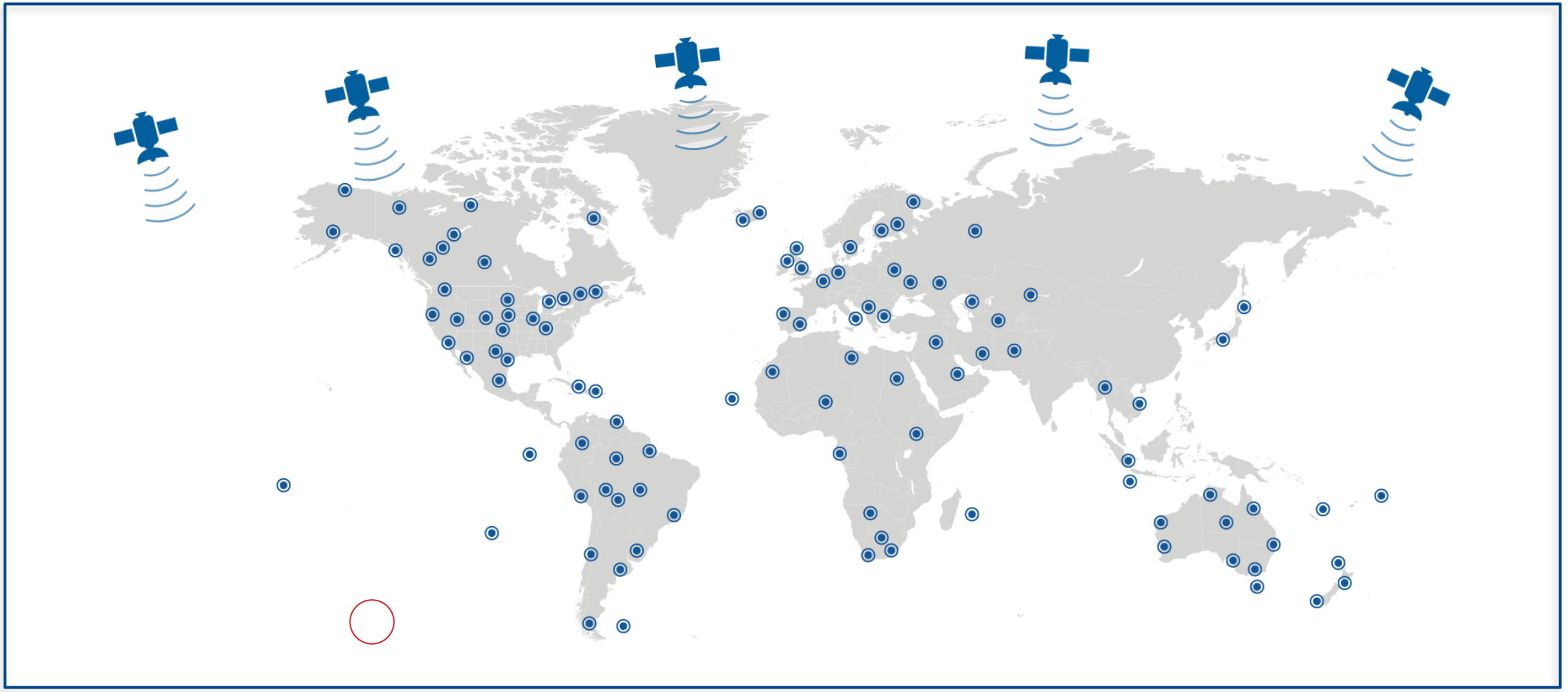


In less than a minute!
Keeps getting better!
0.03’HZ x 0.08’VT

High-accuracy GNSS/GPS positioning - RTX



RTX TRACKING NETWORK OF GNSS RECEIVERS



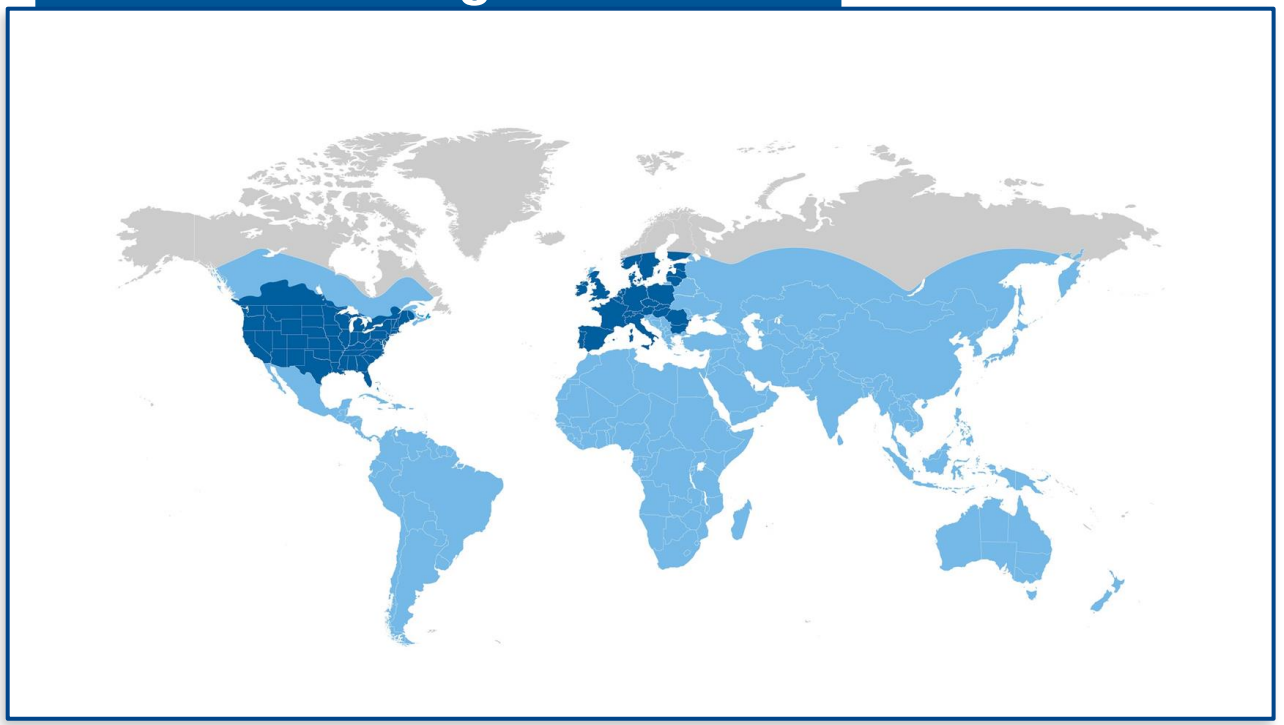
● Trimble receivers tracking GPS, GLN, GAL, BDS, QZS

CENTERPOINT RTX REVIEW

Satellite delivered high-accurac GNSS corrections

- 2 cm (RMS) (< 1 in.) Horizontal
- 5 cm (RMS) (< 2 in.) Vertical
- Convergence < 1 minute in Fast Regions, or < 15 minutes elsewhere
- Delivery via satellite or cellular/IP
- Available globally

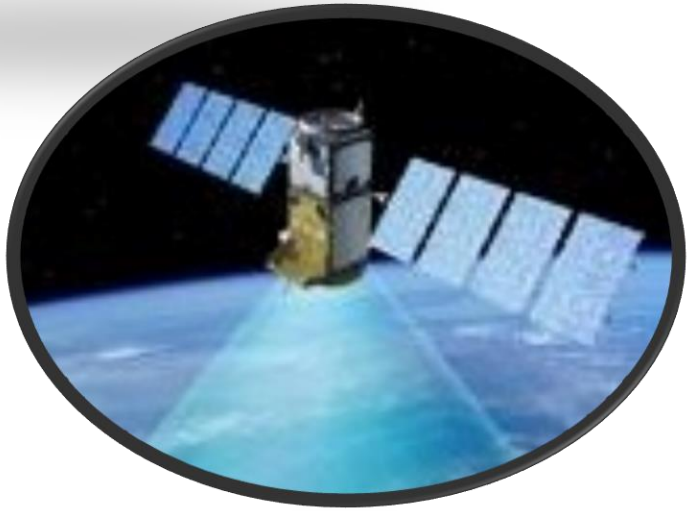
Global Coverage



RTX Fast RTX standard

Topography, boundary work, stakeout or as-built

Large Boundaries & Asset Mapping, Cadastral Mapping

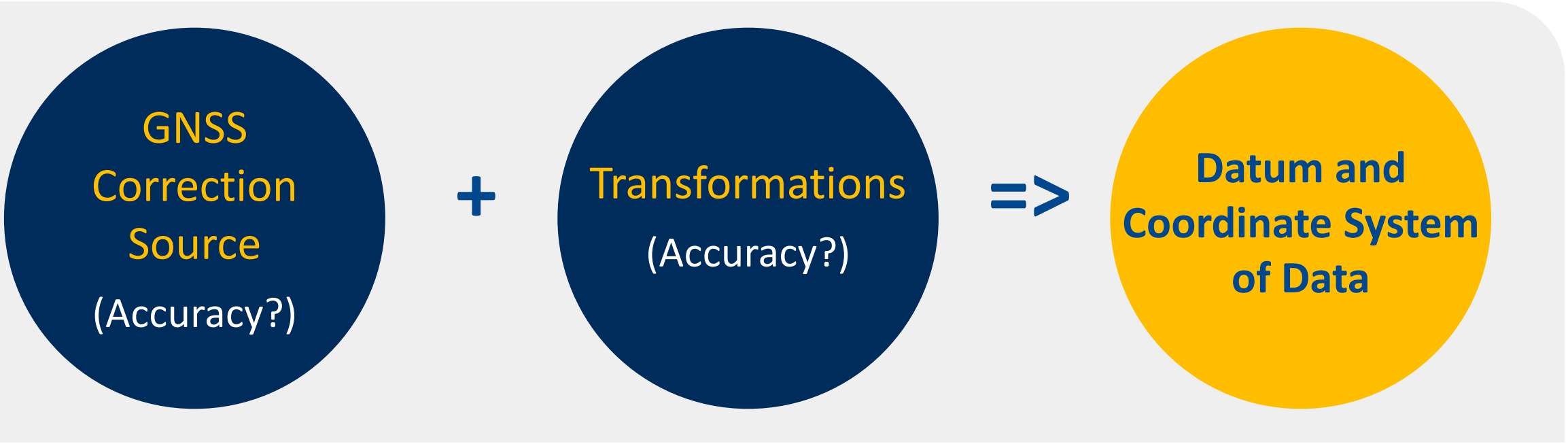


NO BASE STATION, RTN/VRS OR CELL REQUIRED

- RTX Requirements
  - Good GNSS visibility
  - Good view of the southern sky (where the L-band satellites are)
  - RTX Compliant GNSS Receiver
  - Mission Planning
  - Be Careful working around Obstrucations
    - Tall Buildings, Canyons and Heavy Canopy

WHAT DATUM AND COORDINATE SYSTEM IS MY GNSS DATA IN?

The correction source, along with any transformations taking place, determine the datum and coordinate system of the GNSS data

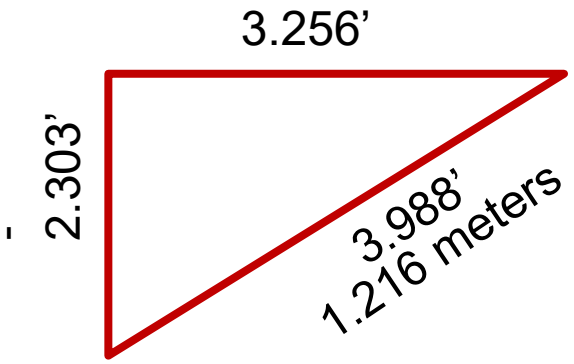


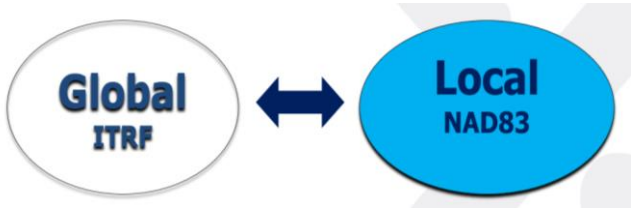
ITRF VS NAD83

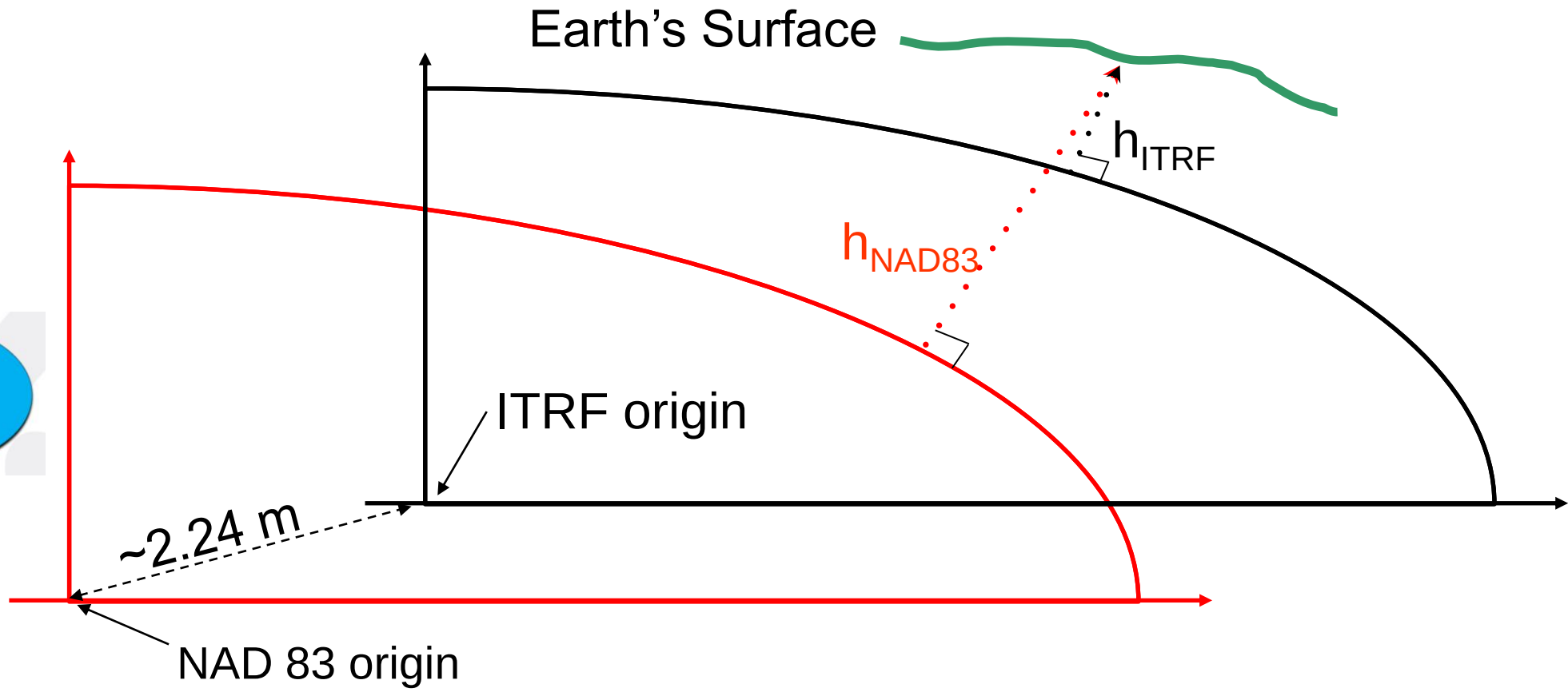
LOCALIZATION/CALIBRATION OR RTK TO RTX OFFSET REQUIRED

Horizontal adjustment

Origin north	1716489.618
Origin east	3104469.462
Translation north	-2.303
Translation east	3.256
Rotation	0°00'00.0000"
Scale factor	1.00000000



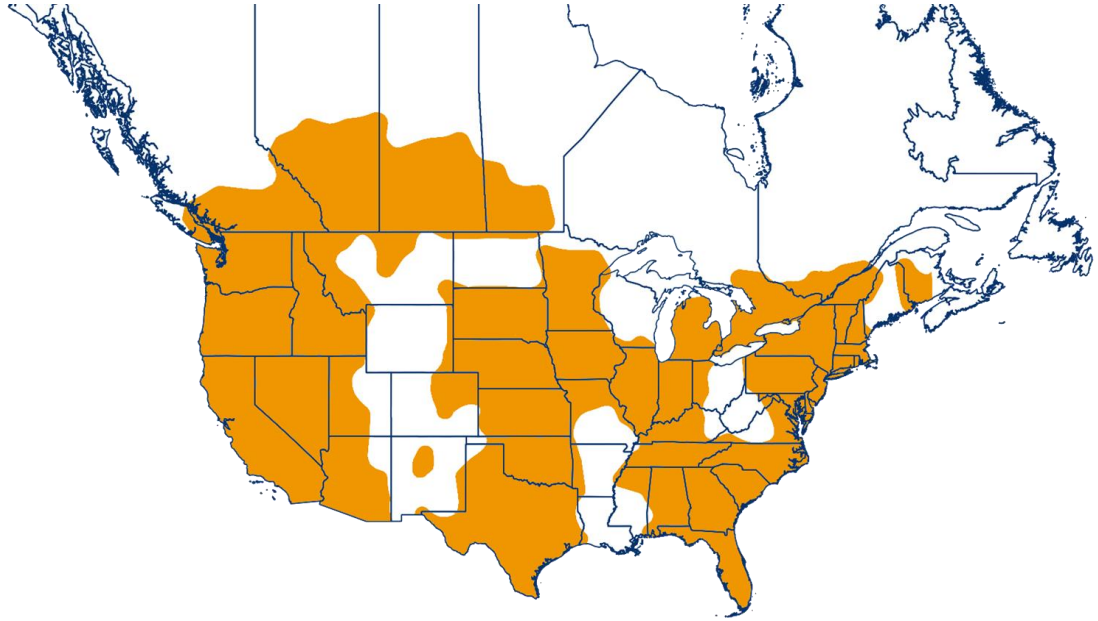




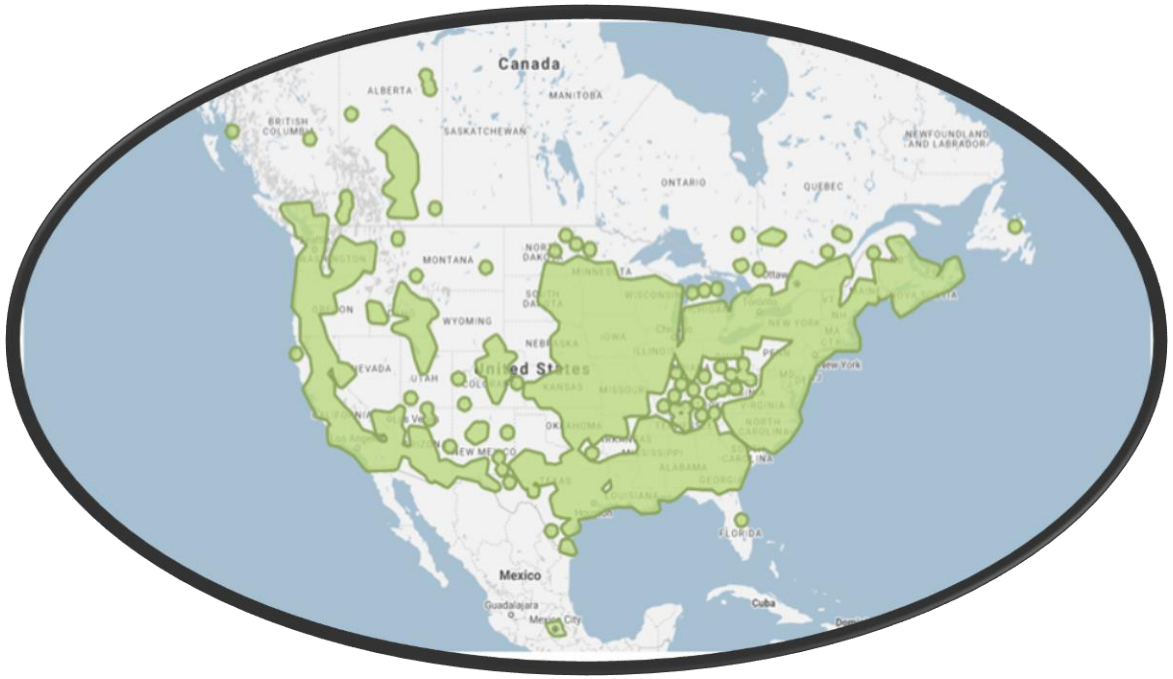
CenterPoint RTX Recent Technical Enhancements

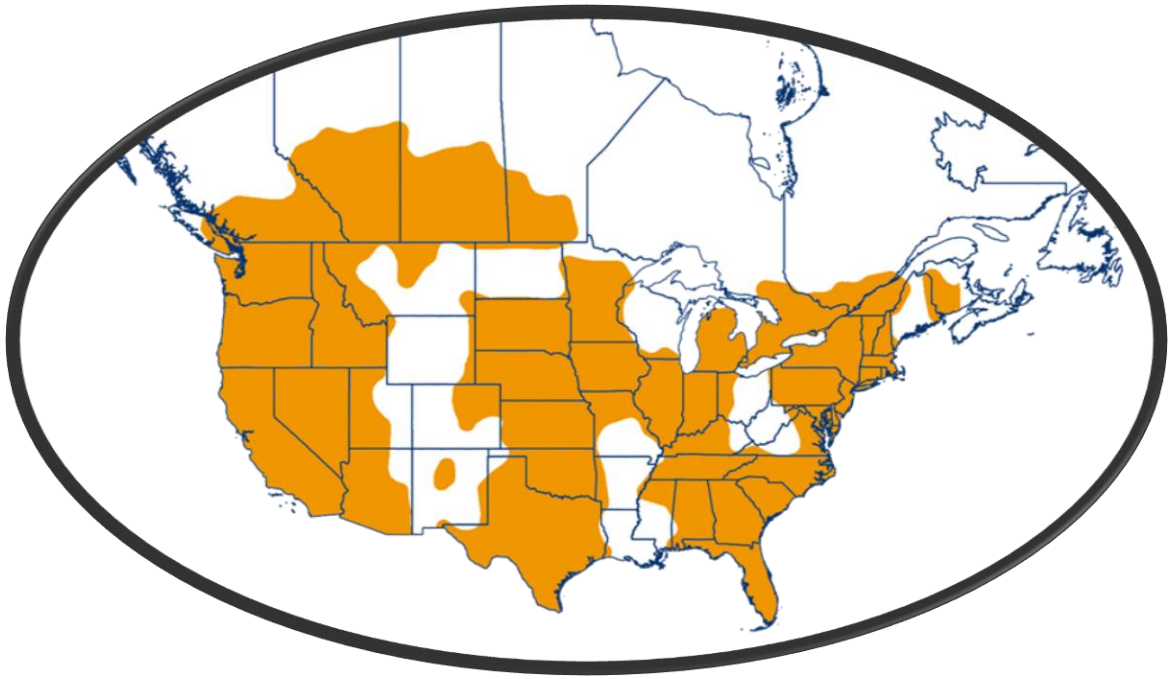
ENHANCEMENT 1: RTX "FAST" CONUS COVERAGE

Prior to May 5, 2020 → **Today**



Seven States
One Virtual Conference
Magnificent Opportunities





Similarities!!!

RTK VS. RTX — DETERMINING COORDINATE SYSTEMS

RTX Satellite

NAD83(2011) 2010.0 vector dX dY dZ

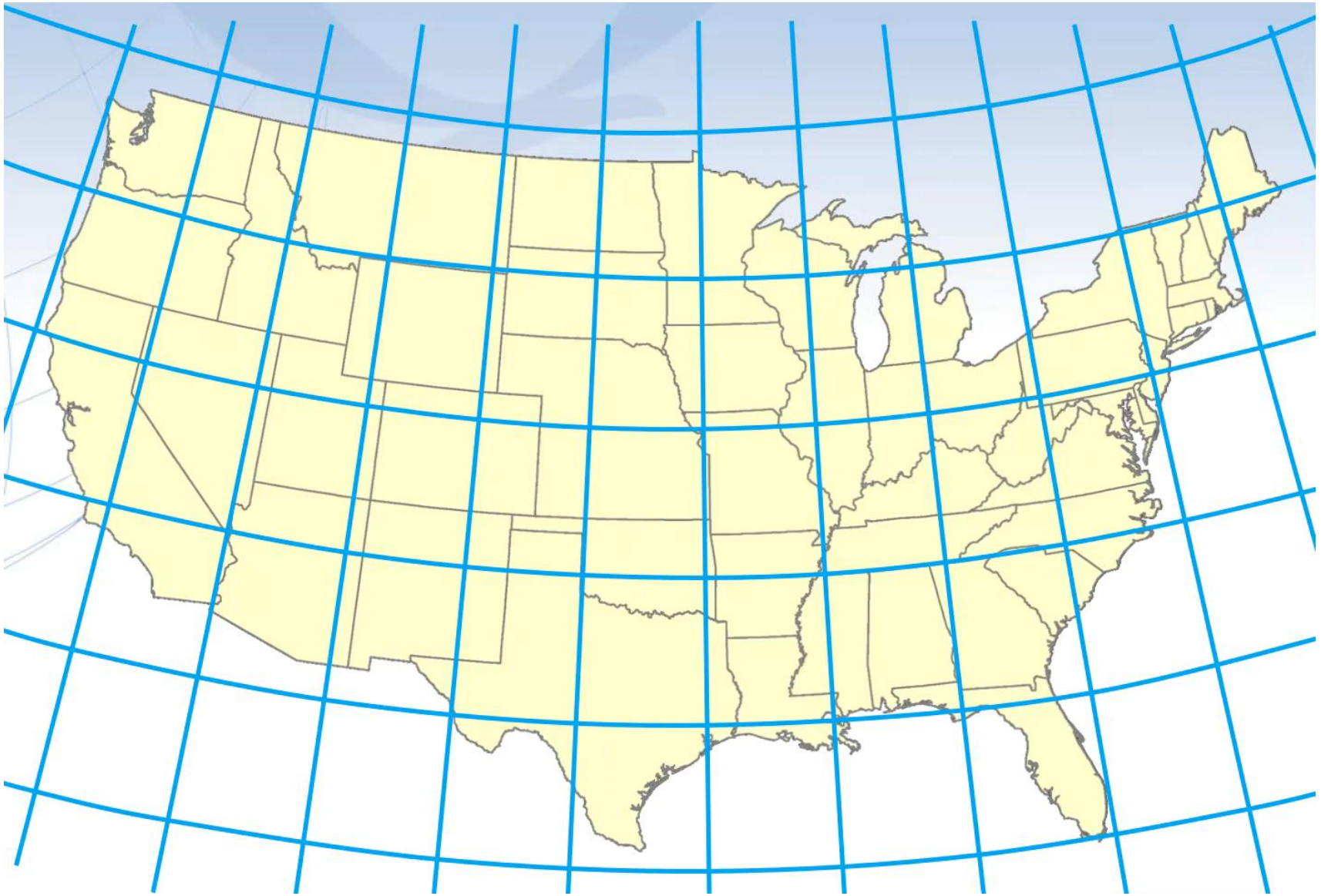
ITRF2014 Current Epoch Corrections

NAD83(2011) 2010.0
Local position at base

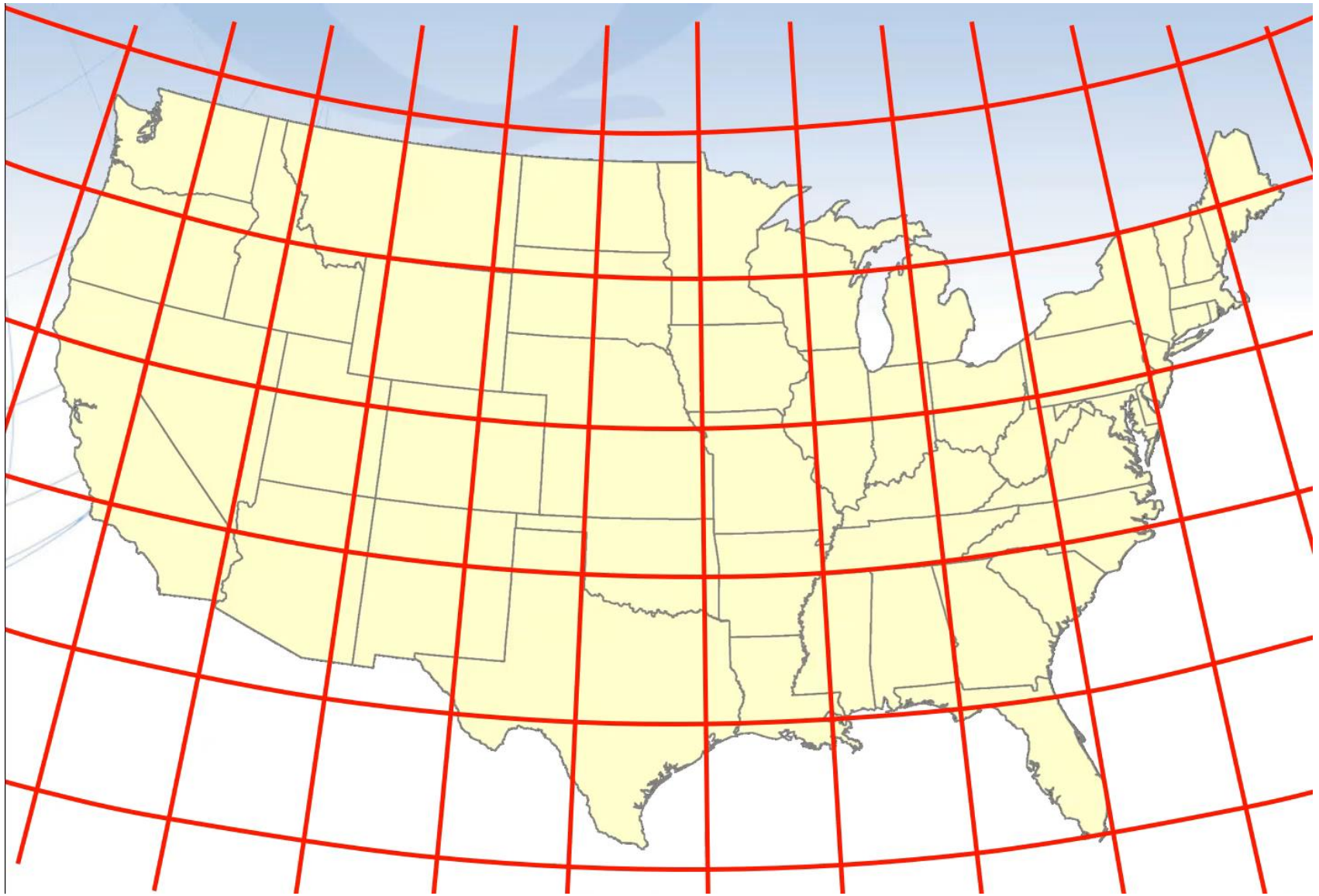
NAD83(2011) 2010.0
RTK position at rover

ITRF2014 @ Epoch of Measurement
automatically transformed to
NAD83(2011) 2010.0
RTX position at rover

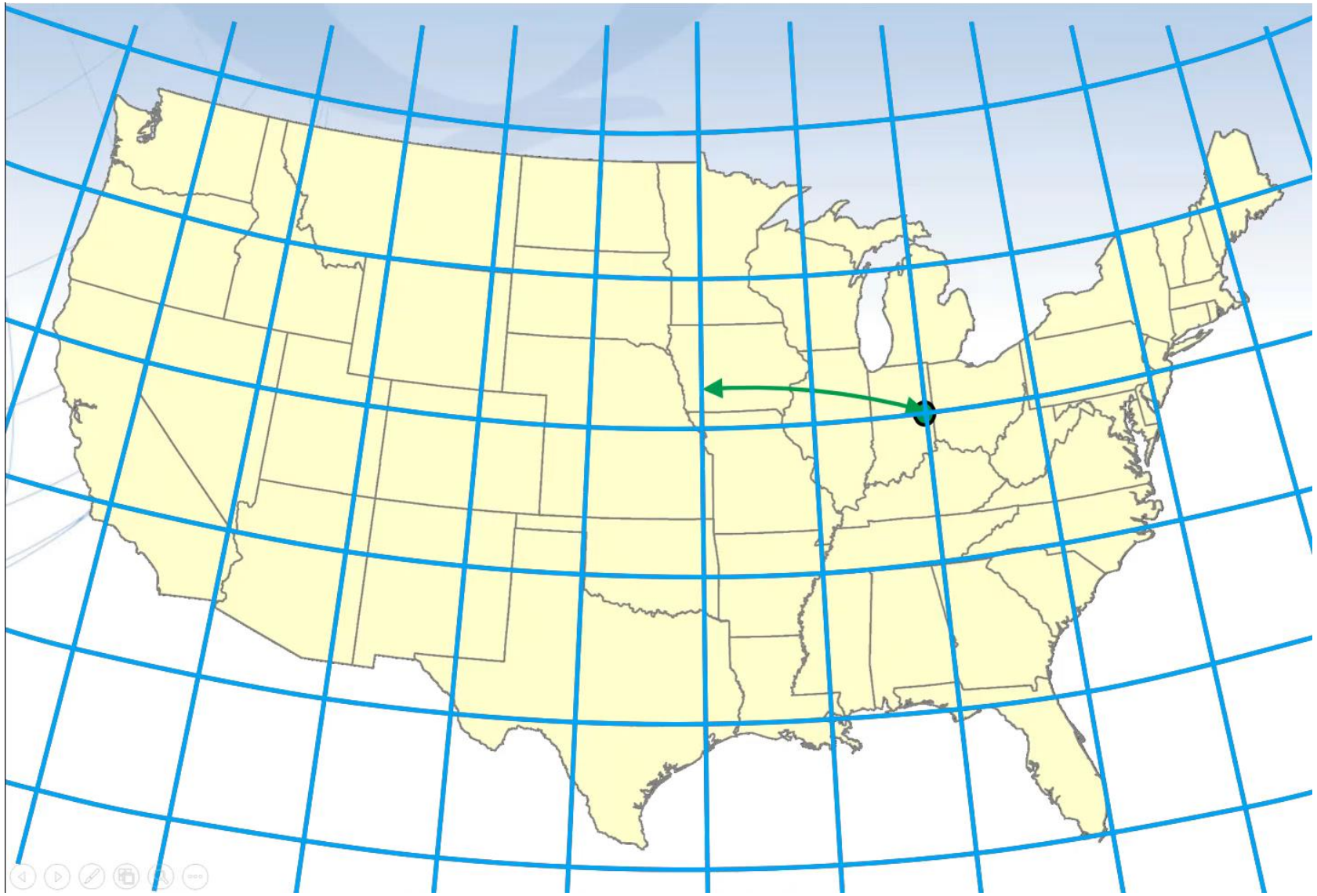
ITRF2014 – constant frame, rotating plate

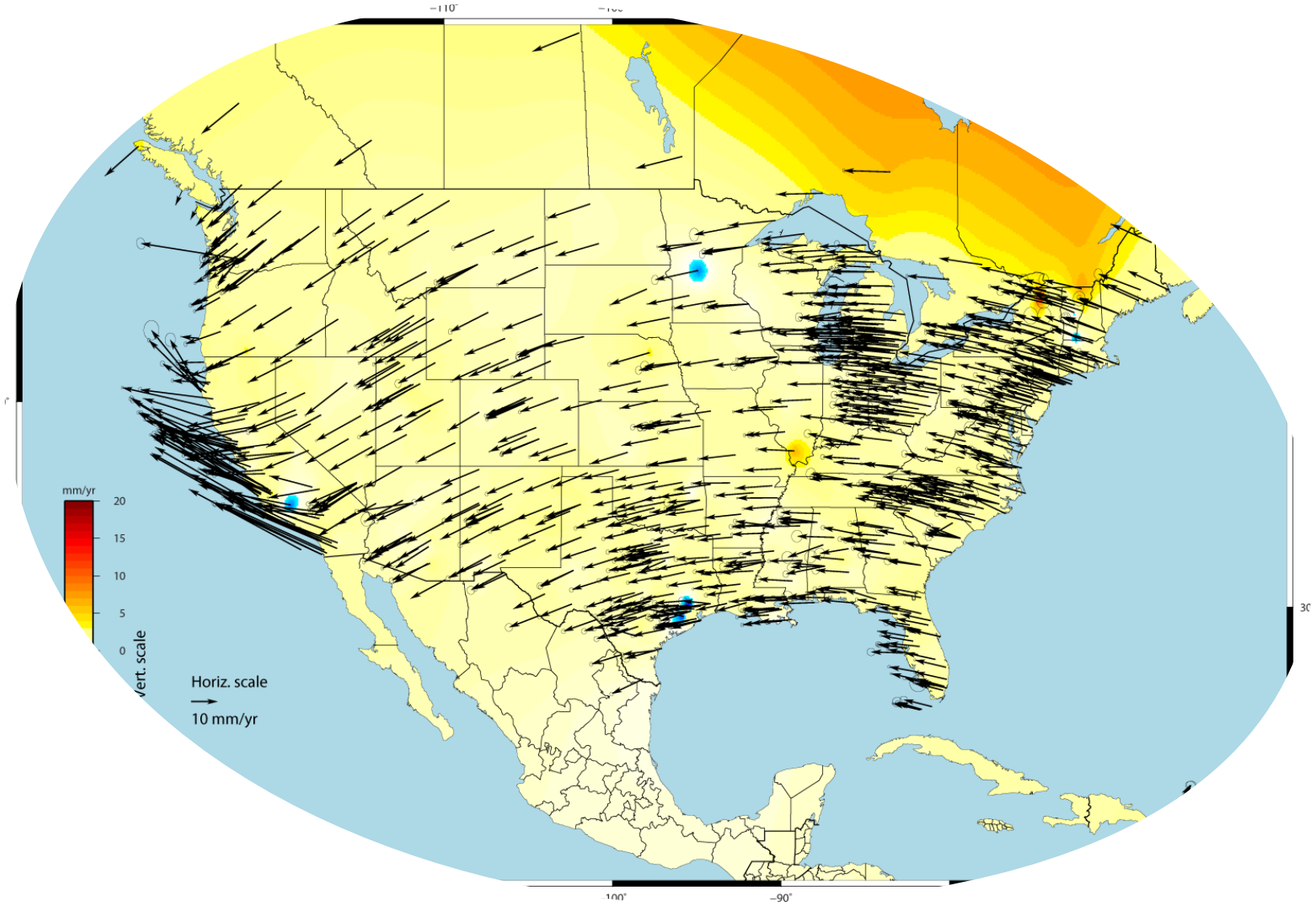


NAD83 – rotating frame, constant with plate



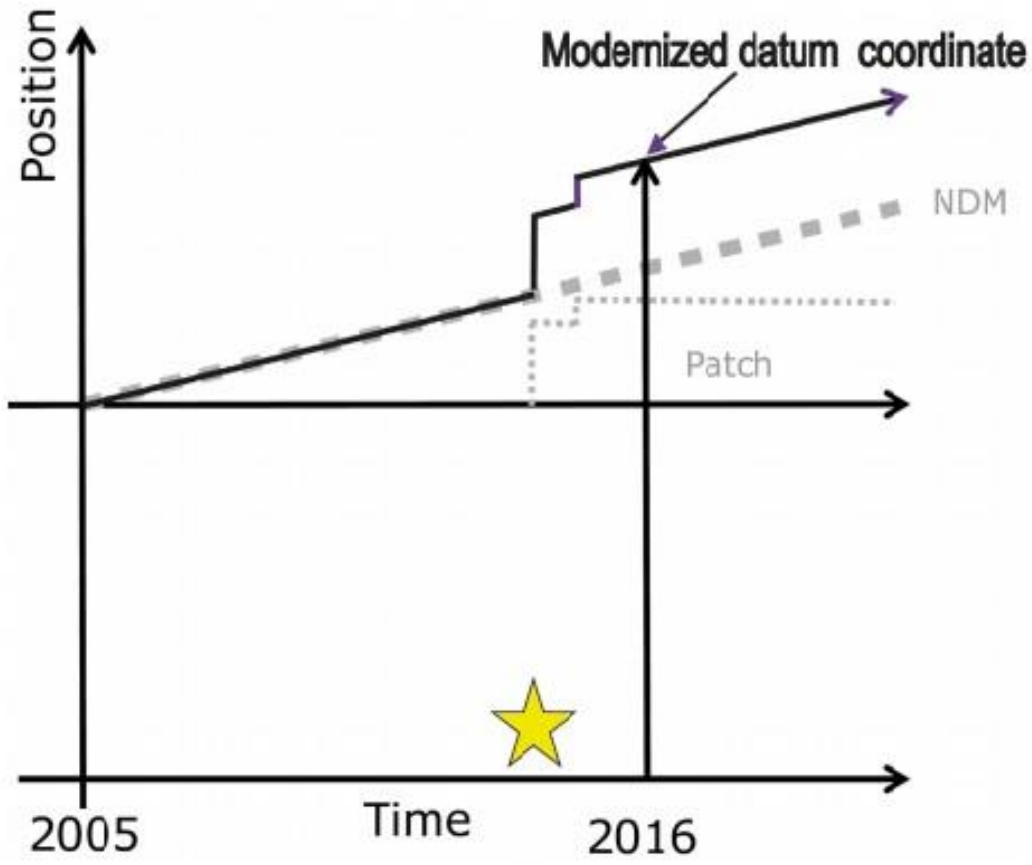
ITRF2014 to/from NAD83



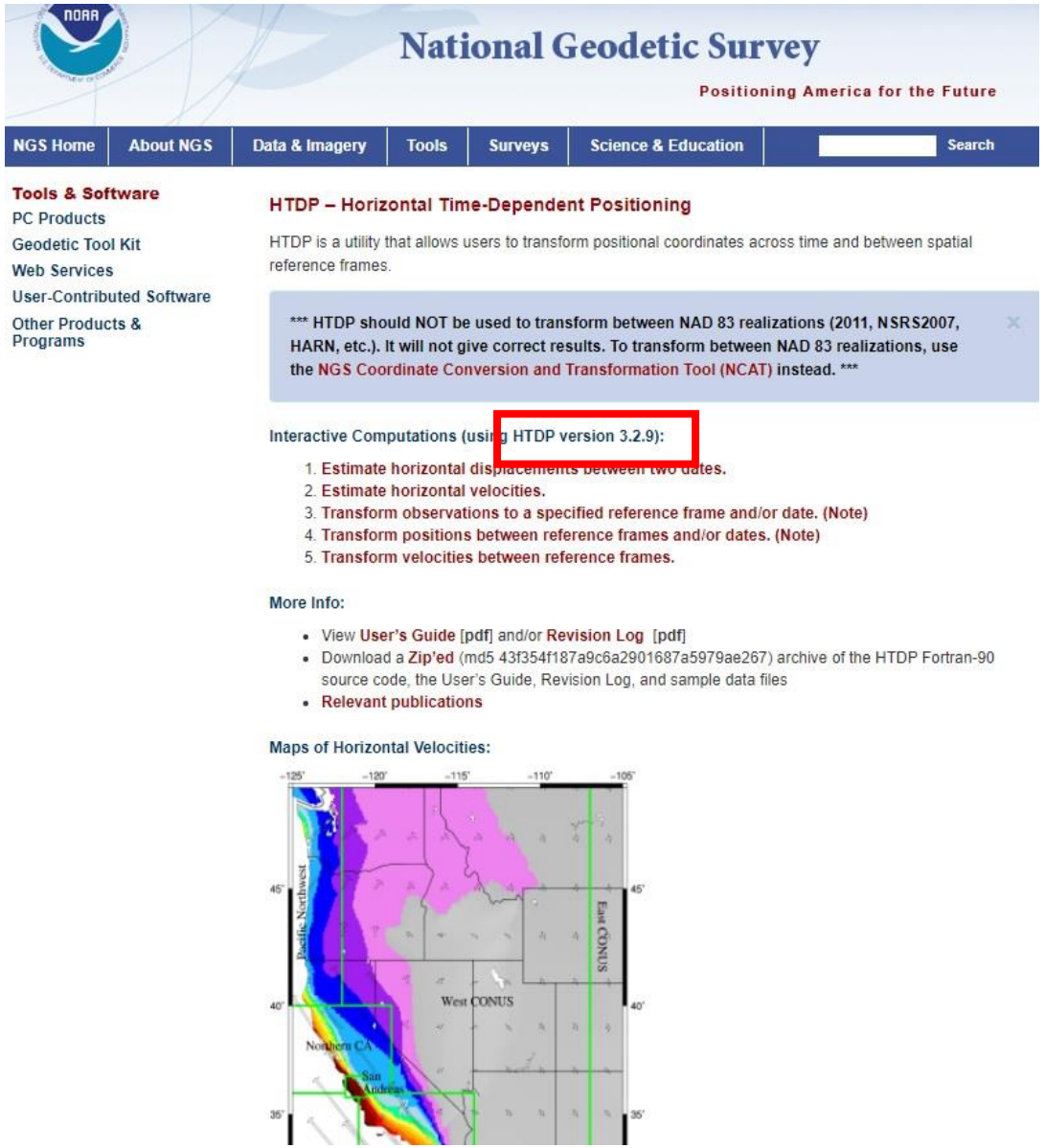


NORTH AMERICAN AND PACIFIC PLATE VELOCITIES

DISPLACEMENT MODELS: HTDP 3.2.9

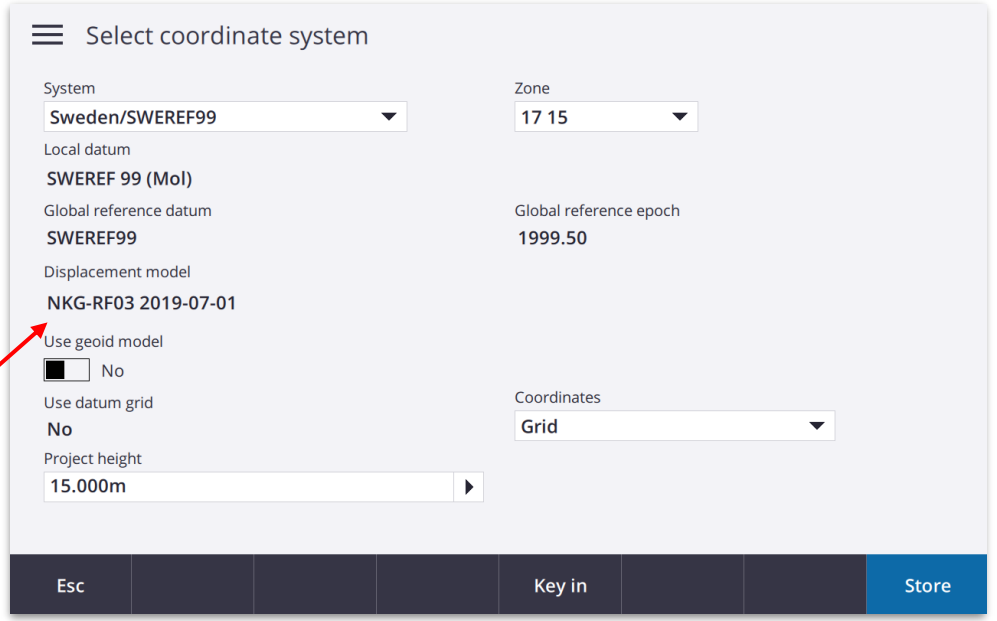


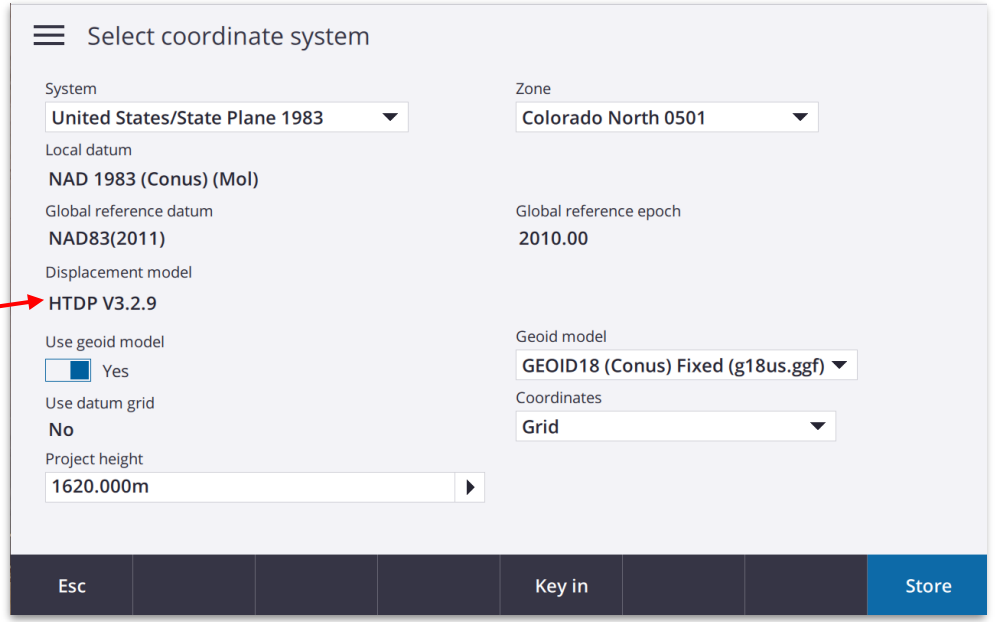
at https://frontierprecision.com/wp-content/uploads/Trimble-Def-Models.pdf



Local displacement models

Country	Reference frame	Local displacement model
Brazil	SIRGAS2000	VEMOS2009
Denmark	EUREF-DK94	NKG-RF03
Estonia	EST97	NKG-RF03
Finland	EUREF-FIN	NKG-RF03
Sweden	SWEREF99	NKG-RF03
Norway	EUREF89	NKG-RF03
Iceland	ISN2016	ISN2016
New Zealand	NZGD2000	NZGD2000 Deformation Model
USA	NAD83(2011)	HTDP V3.2.9
Canada	NAD83(CSRS)v7	CSRS Velocity Grid V7.0





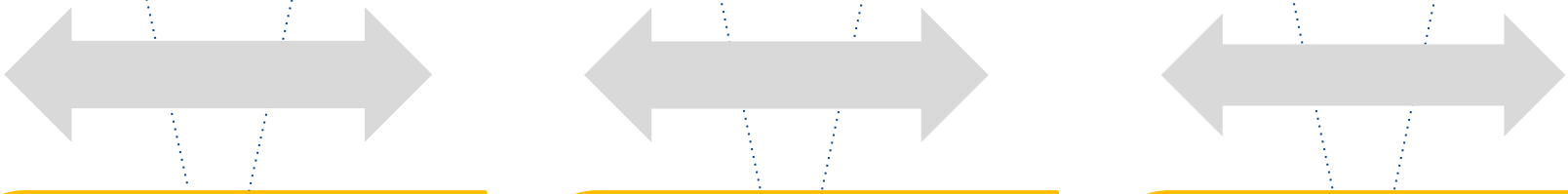
COORDINATE TRANSFORMATIONS

ITRF Global Coordinates
RTX Position
(Xecef, Yecef, Zecef)
ITRF2014 (epoch 2020.37)

Local coordinates
RTK Position
(Xecef, Yecef, Zecef)
NAD83 2011 (epoch 2010)

LOCAL coordinates
(Lat.,Long.,Height)
NAD83

GRID coordinates
(North, East)
Colorado North 0501
Derived Elevation Via Geoid



Time Dependent Datum Transformation

Fourteen parameter
+ displacement models
(ITRF2014 and local displacement)

Static Datum Transformations

Molodensky
Seven Parameter
Multiple Regression
Datum Grid
RTCM Datum

Projection & Site Calibration

Standard Projections
Projection Grid
Geoid Models
Ground Coordinates
Snake Grid
Horz.& Vert. adjustments

SURVEY REPORT OF RTX OBSERVATIONS

Covariance Matrix

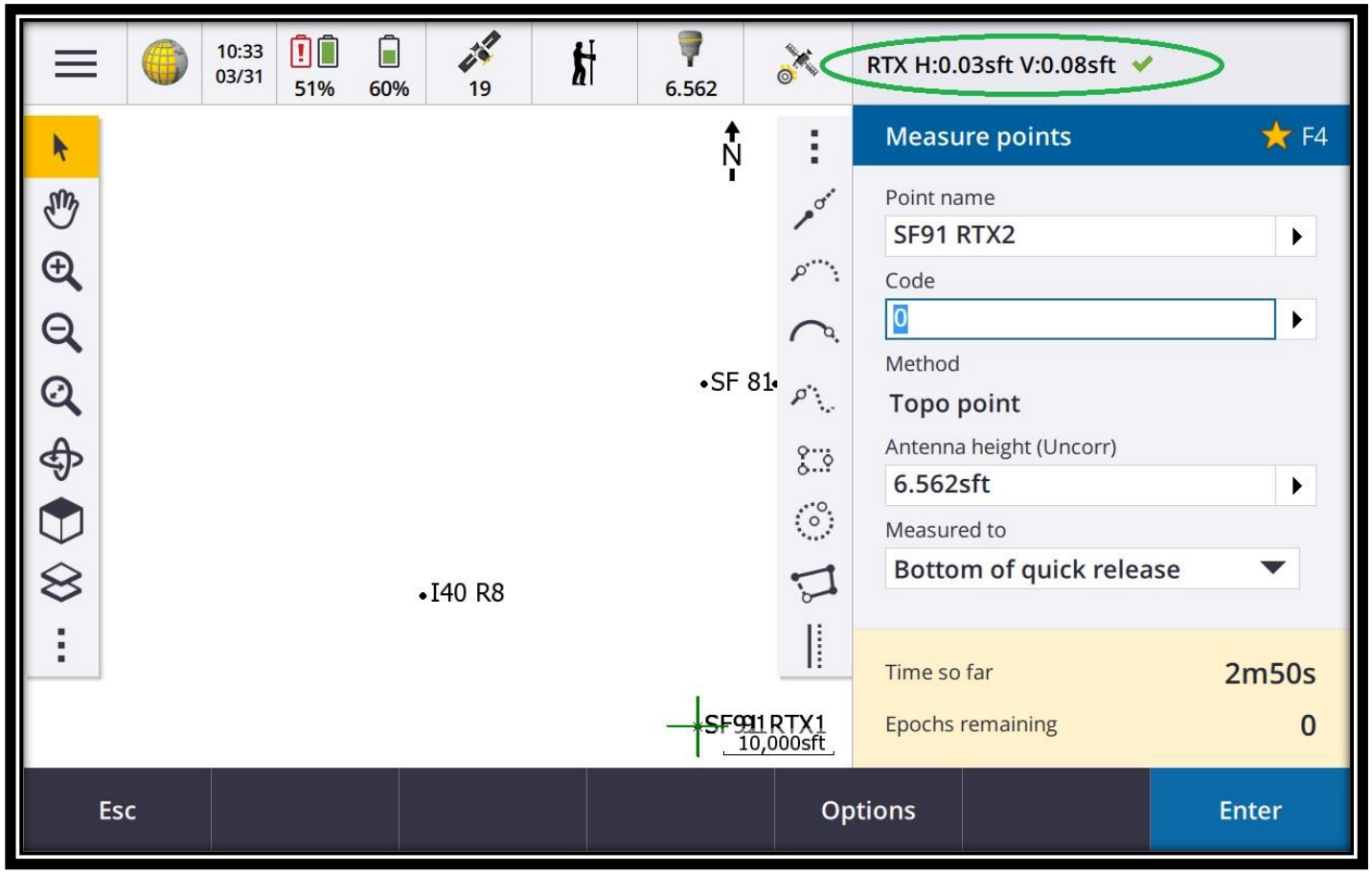
Point	1000	RTX X	-4788902.877	RTX Y	-16450235.363	RTX Z	11985522.610	Code	CORNER CONC
		Method	RTX	Type	Topo point	Search class	Normal		
Antenna height	6.562	Type	Uncorrected	Hz Prec	0.045	Vt Prec	0.194		
QC 1		PDOP	1.3	GDOP	1.9	HDOP	0.6	VDOP	1.1
		Base data age	7	Satellites	22	Positions used	11		
QC 2		VCV xx (m²)	0.000291	VCV xy (m²)	0.000706	VCV xz (m²)	-0.000453		
				VCV yy (m²)	0.002291	VCV yz (m²)	-0.001470		
						VCV zz (m²)	0.001094		
Point	1001	RTX X	-4788899.049	RTX Y	-16450222.435	RTX Z	11985541.915	Code	CORNER CONC
		Method	RTX	Type	Topo point	Search class	Normal		
Antenna height	6.562	Type	Uncorrected	Hz Prec	0.045	Vt Prec	0.166		
QC 1		PDOP	1.3	GDOP	1.9	HDOP	0.6	VDOP	1.1
		Base data age	6	Satellites	23	Positions used	3		
QC 2		VCV xx (m²)	0.000238	VCV xy (m²)	0.000528	VCV xz (m²)	-0.000333		
				VCV yy (m²)	0.001687	VCV yz (m²)	-0.001054		
						VCV zz (m²)	0.000813		
Point	1002	RTX X	-4788899.257	RTX Y	-16450222.325	RTX Z	11985542.150	Code	EDGE DRIVE
		Method	RTX	Type	Topo point	Search class	Normal		
Antenna height	6.562	Type	Uncorrected	Hz Prec	0.040	Vt Prec	0.147		
QC 1		PDOP	1.1	GDOP	1.6	HDOP	0.6	VDOP	1.0
		Base data age	7	Satellites	23	Positions used	3		
QC 2		VCV xx (m²)	0.000190	VCV xy (m²)	0.000417	VCV xz (m²)	-0.000260		
				VCV yy (m²)	0.001338	VCV yz (m²)	-0.000832		
						VCV zz (m²)	0.000641		
Point	1003	RTX X	-4788900.492	RTX Y	-16450222.063	RTX Z	11985542.207	Code	EDGE DRIVE
		Method	RTX	Type	Topo point	Search class	Normal		
Antenna height	6.562	Type	Uncorrected	Hz Prec	0.044	Vt Prec	0.150		
QC 1		PDOP	1.1	GDOP	1.6	HDOP	0.6	VDOP	1.0
		Base data age	6	Satellites	23	Positions used	3		
QC 2		VCV xx (m²)	0.000203	VCV xy (m²)	0.000429	VCV xz (m²)	-0.000268		
				VCV yy (m²)	0.001389	VCV yz (m²)	-0.000854		
						VCV zz (m²)	0.000673		
Point	1004	RTX X	-4788901.236	RTX Y	-16450220.313	RTX Z	11985544.258	Code	EDGE DRIVE
		Method	RTX	Type	Topo point	Search class	Normal		
Antenna height	6.562	Type	Uncorrected	Hz Prec	0.046	Vt Prec	0.153		
QC 1		PDOP	1.1	GDOP	1.6	HDOP	0.6	VDOP	1.0
		Base data age	8	Satellites	23	Positions used	3		
QC 2		VCV xx (m²)	0.000214	VCV xy (m²)	0.000445	VCV xz (m²)	-0.000277		
				VCV yy (m²)	0.001445	VCV yz (m²)	-0.000885		
						VCV zz (m²)	0.000705		

SURVEY REPORT OF RTX OBSERVATIONS

Covariance Matrix

Point	1001	RTX X	-4788899.049	RTX Y	-16450222.435	RTX Z	11985541.915	Code	CORNER CONC
		Method	RTX	Type	Topo point	Search class	Normal		
Antenna height	6.562	Type	Uncorrected	Hz Prec	0.045	Vt Prec	0.166		
QC 1		PDOP	1.3	GDOP	1.9	HDOP	0.6	VDOP	1.1
		Base data age	6	Satellites	23	Positions used	3		
QC 2		VCV xx (m²)	0.000238	VCV xy (m²)	0.000528	VCV xz (m²)	-0.000333		
				VCV yy (m²)	0.001687	VCV yz (m²)	-0.001054		
						VCV zz (m²)	0.000813		

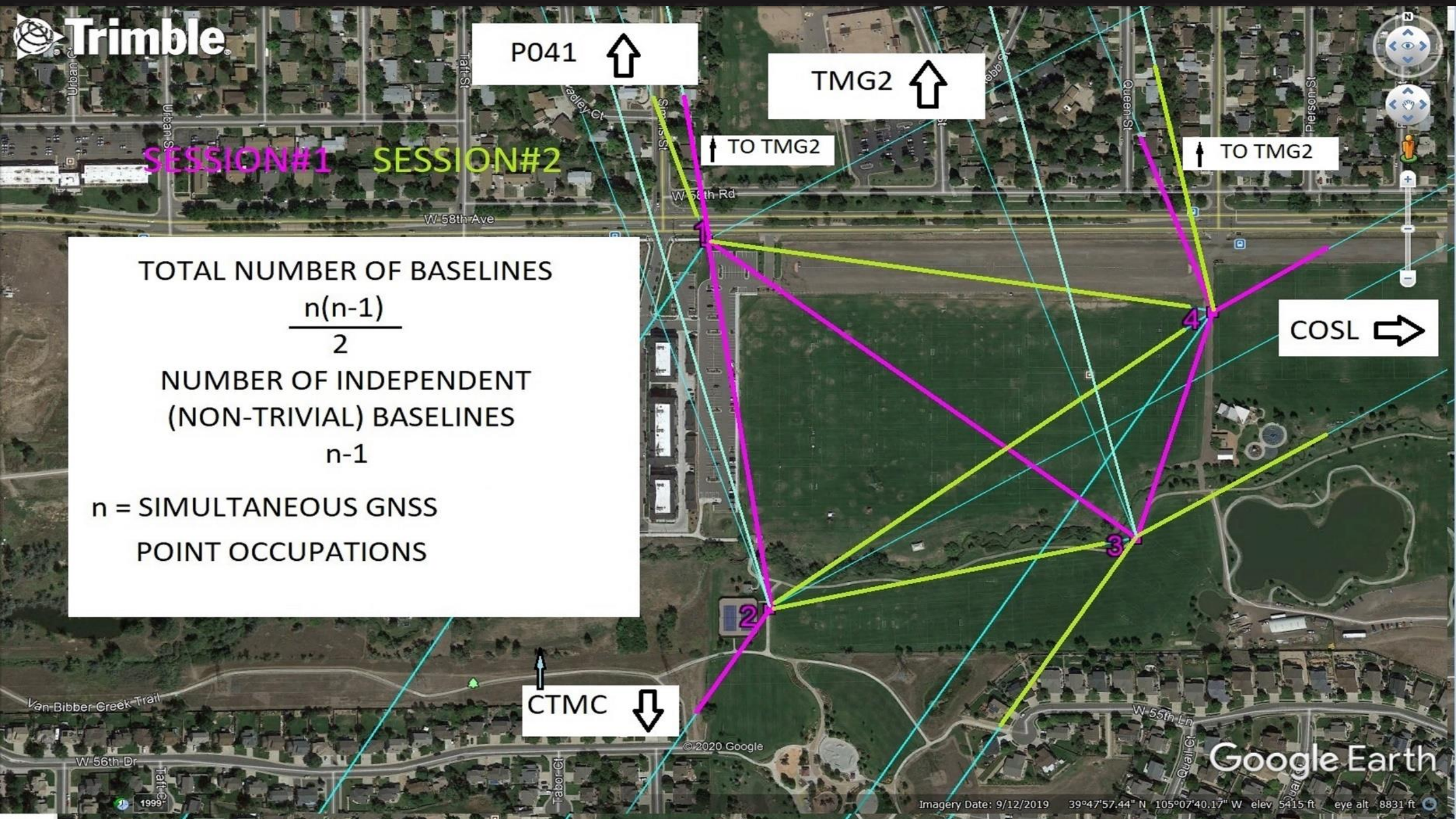
CENTERPOINT RTX / TRIMBLE ACCESS INTERFACE




FRONTIER

CENTERPOINT RTX / NGS OPUS TEST

REF FRAME: NAD_83(2011)(EPOCH:2010.0000)			ITRF2014 (EPOCH:2021.06850)	
X:	-1459667.152(m)	0.010(m)	-1459668.051(m)	0.010(m)
Y:	-5014041.367(m)	0.022(m)	-5014040.002(m)	0.022(m)
Z:	3653190.260(m)	0.018(m)	3653190.091(m)	0.018(m)
LAT:	35 9 20.48659	0.006(m)	35 9 20.50189	0.006(m)
E LON:	253 46 7.97628	0.006(m)	253 46 7.92714	0.006(m)
W LON:	106 13 52.02372	0.006(m)	106 13 52.07286	0.006(m)
EL HGT:	2063.060(m)	0.029(m)	2062.097(m)	0.029(m)
ORTHO HGT:	2082.545(m)	0.038(m)	[NAVD88 (Computed using GEOID18)]	


Trimble
P041
TMG2
TO TMG2
TO TMG2
SESSION#1
SESSION#2
W 58th Ave
W 58th Rd
COSL
CTMC
1
2
3
4
TOTAL NUMBER OF BASELINES
n(n-1)
2
NUMBER OF INDEPENDENT
(NON-TRIVIAL) BASELINES
n-1
n = SIMULTANEOUS GNSS
POINT OCCUPATIONS
Van Bibber Creek Trail
W 56th Dr
W 55th Ln
Quail Ct
Taft Ct
Tabor Ct
Urban Ct
Urban St
Taft St
Sheridan St
Queen St
Pierson St
© 2020 Google
Google Earth
Imagery Date: 9/12/2019 39°47'57.44" N 105°07'40.17" W elev 5415 ft eye alt 8831 ft

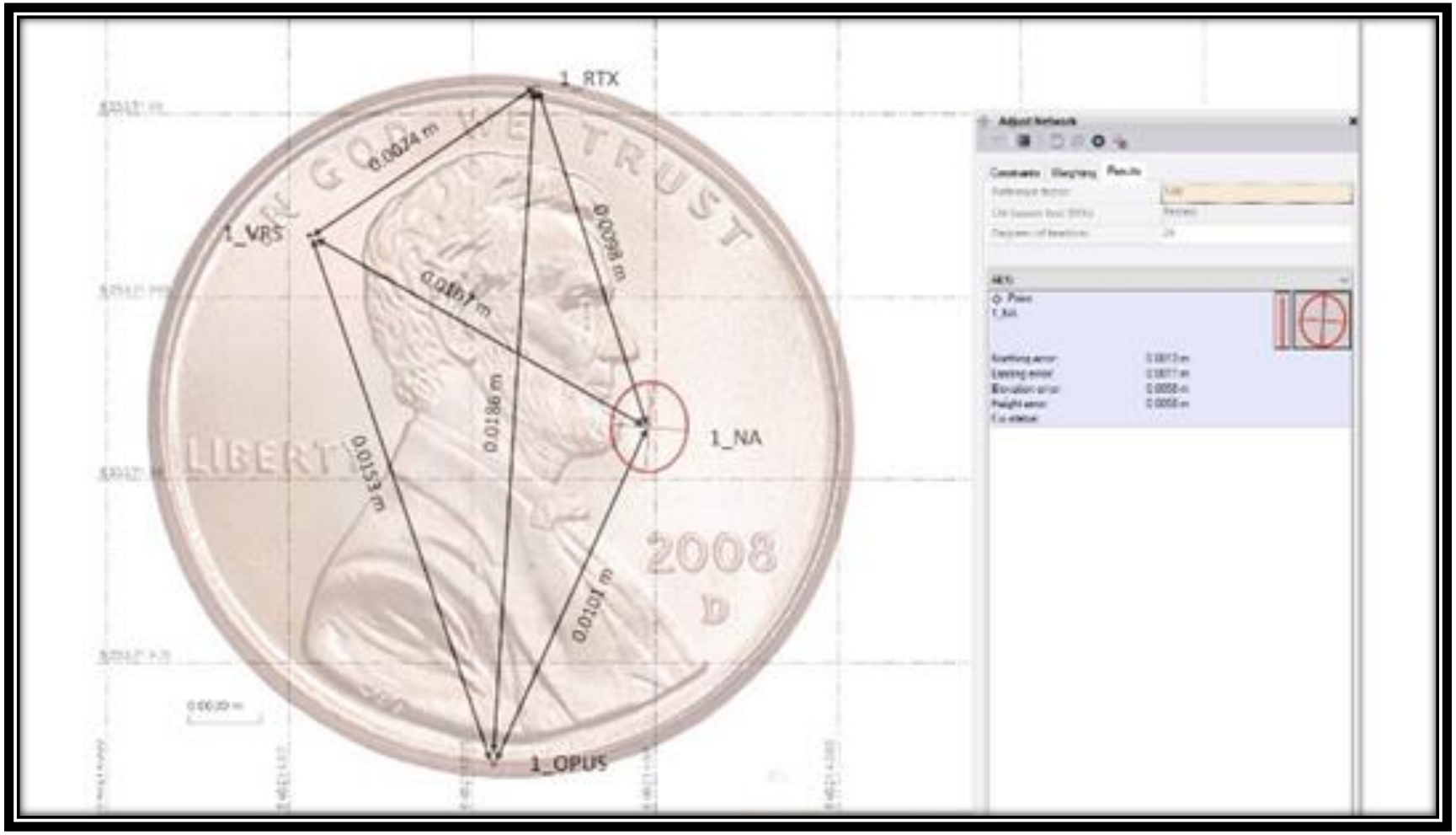
Adjusted Grid Coordinates

Point ID	Northing (US survey foot)	Northing Error (US survey foot)	Easting (US survey foot)	Easting Error (US survey foot)	Elevation (US survey foot)	Elevation Error (US survey foot)	Constraint
1_NA	1717096.242	0.004	3104372.662	0.004	5427.250	0.019	
2	1715997.043	0.004	3104540.845	0.004	5410.859	0.019	
3	1716204.615	0.004	3105542.951	0.004	5400.152	0.019	
4	1716886.171	0.004	3105755.624	0.004	5399.405	0.019	
COSL	2022933.107	?	3631331.548	?	3970.314	?	LLh
CTMC	1687841.271	?	3086394.057	?	6022.264	?	LLh
P041	1770881.433	?	3085725.381	?	5728.278	?	LLh
TMG2	1836593.954	?	3074653.207	?	5531.202	?	LLh

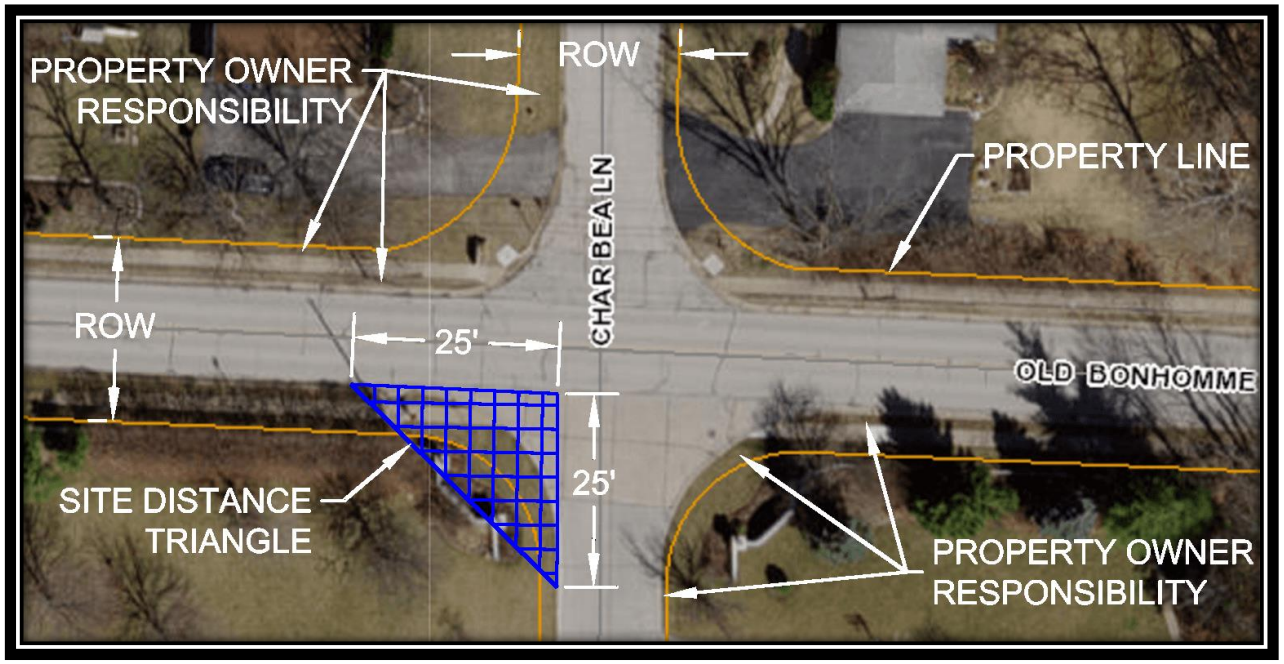
Error Ellipse Components

Point ID	Semi-major axis (US survey foot)	Semi-minor axis (US survey foot)	Azimuth
1_NA	0.004	0.004	6°
2	0.004	0.004	9°
3	0.004	0.004	7°
4	0.004	0.004	6°

TRIMBLE CENTERPOINT RTX VS NGS OPUS VS VRS VS NA TEST



Trimble RTX – My Career, It Would Have Been GREAT!!
Property Access and Emergencies



Trimble RTX – My Career, It Would Have Been GREAT!!
CAMP PENDELTON – DEL MAR- Amphibious Assault Vehicles

Trimble RTX – My Career, It Would Have Been GREAT!!

AC360: Drugs Tunnel

THANK YOU

FOR YOUR TIME
AND
ATTENTION!!

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