Leveraging Global Navigation Satellite Systems Technology

NALMA's 13th National Gathering

Halifax, NS
October 21-23, 2025

Jason Bond, PhD, PEng, PSurv
Canadian Geodetic Survey, Natural Resources Canada

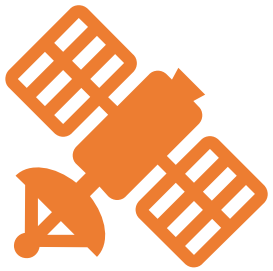
GNSS Positioning is enabling emerging technologies

https://www.yarbo.com/

https://www.yarbo.com/

https://www.navya.tech/

Objectives



Gain an understanding of how GNSS works

Gain an understanding of different methodologies for achieving high accuracy positioning

Be introduced to emerging GNSS technologies and applications

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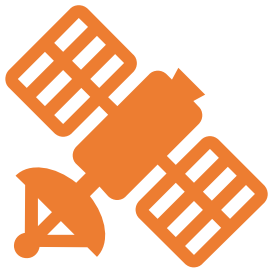

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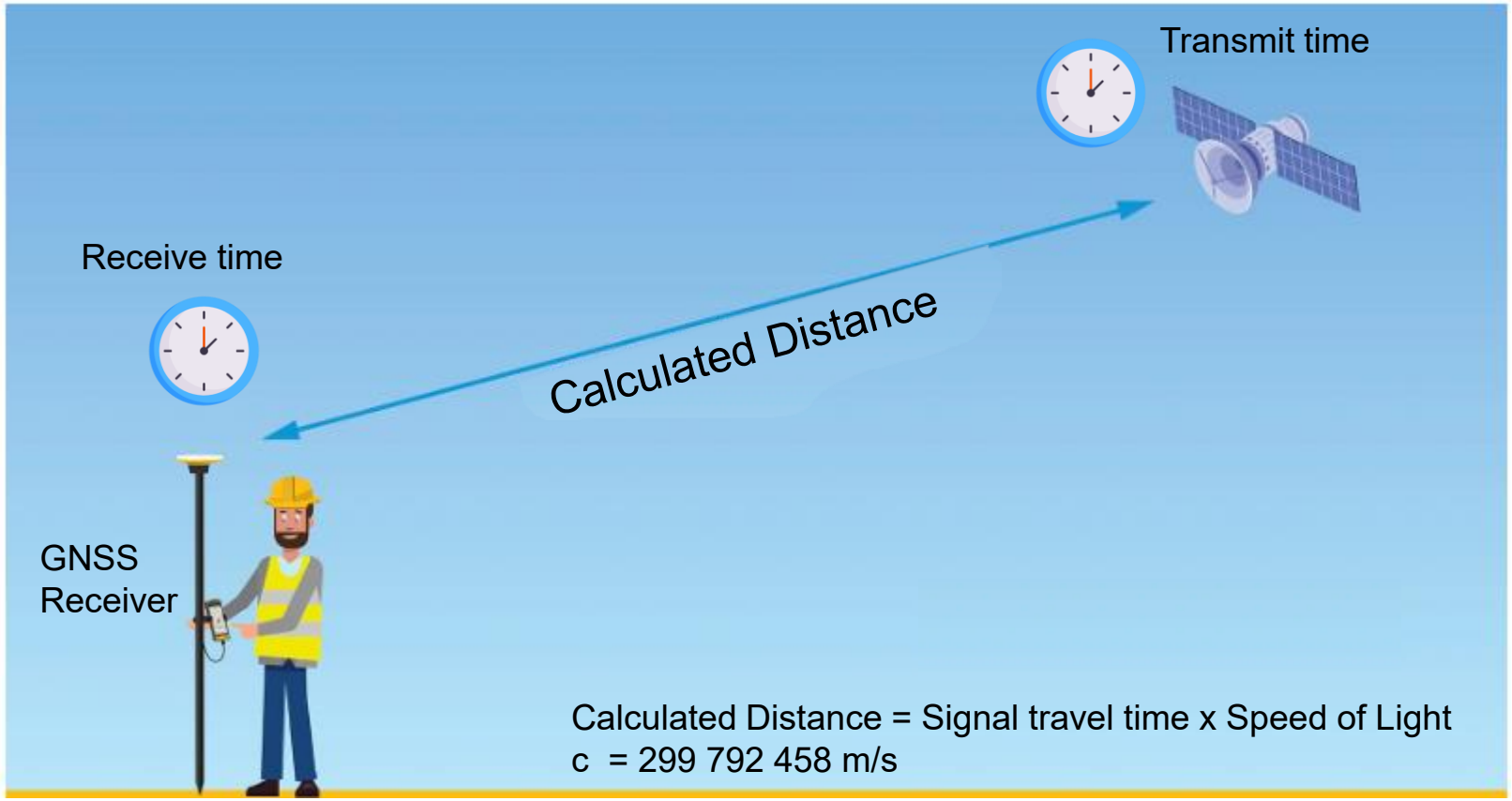
Determining Position using GNSS

GNSS is the umbrella term for all satellite positioning constellations

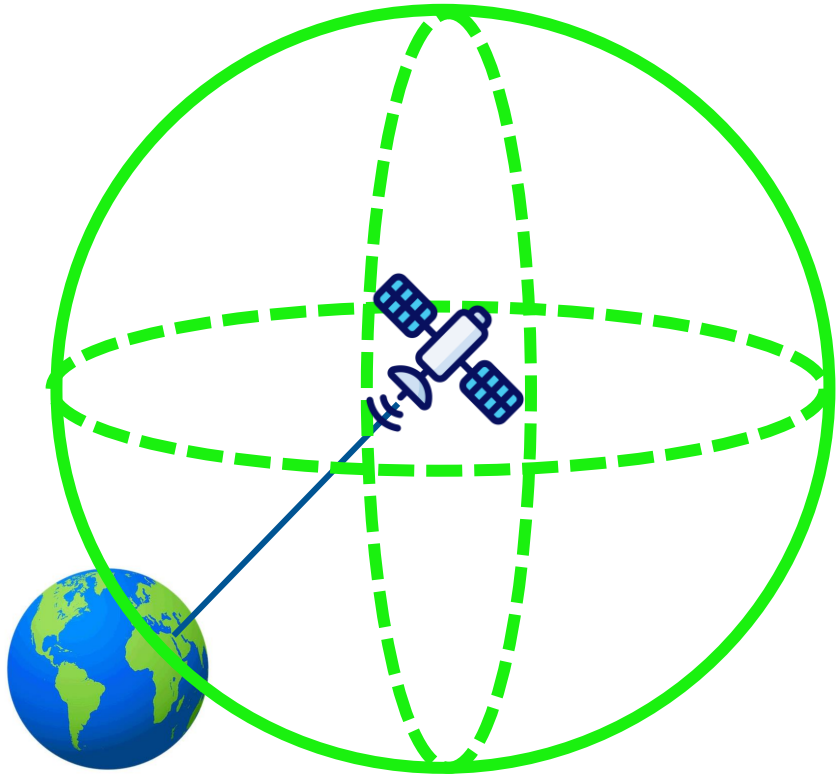
https://www.mobatime.com/

Calculating Distance from a Satellite

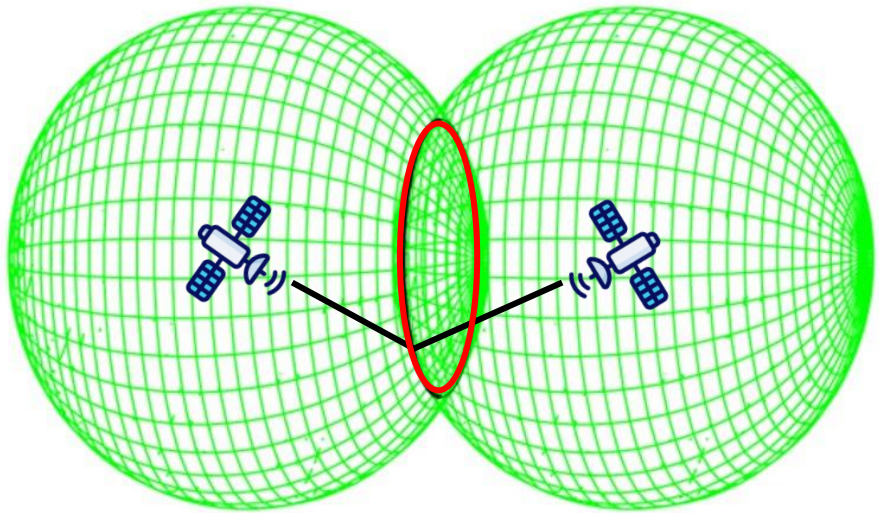


https://geospatial.trimble.com/

One known distance from a satellite places you on a sphere

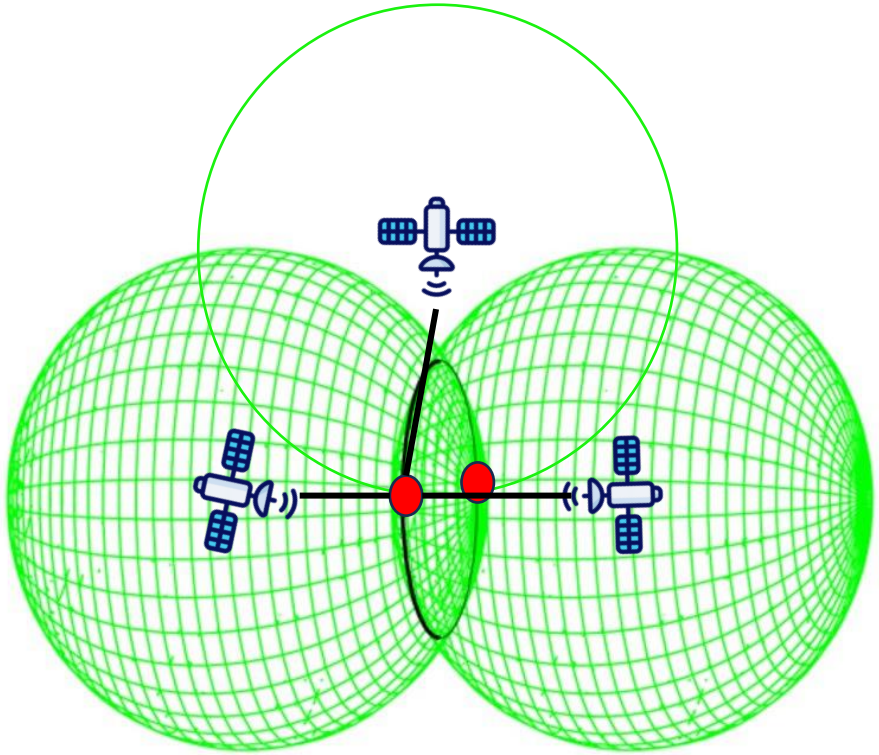


Two known distances from two satellites places you on a circle where the spheres intersect



https://www.researchgate.net/figure/Two-spheres-intersect-to-form-a-circle-1_fig5_329372402

Three known distances from three satellites narrows down the search to two points of intersection. One point is not on Earth

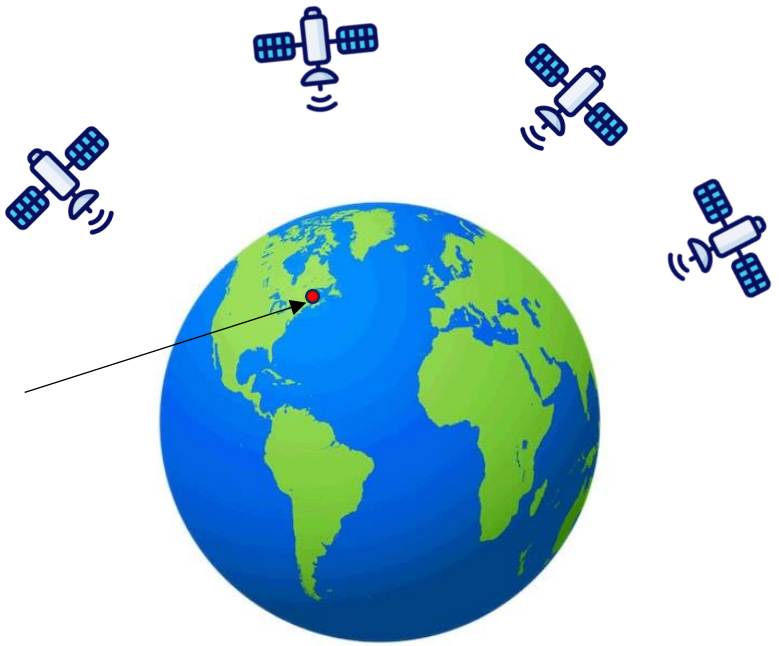


https://www.researchgate.net/figure/Two-spheres-intersect-to-form-a-circle-1_fig5_329372402

In practice, a **fourth** satellite measurement is needed, which allows the clock error in the GNSS receiver to be estimated

GNSS solves:

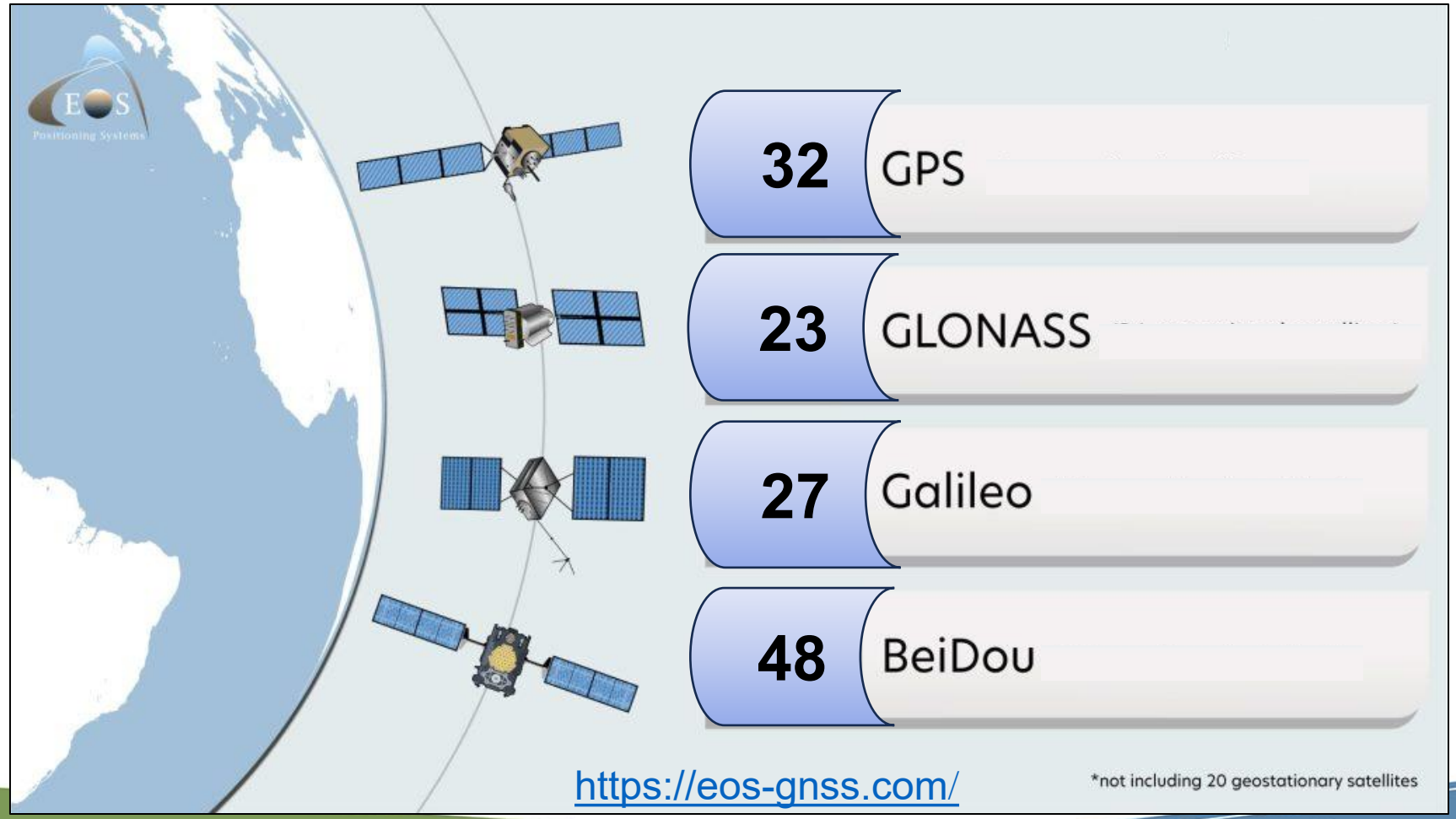
1. latitude
2. longitude
3. height
4. time error



It is too expensive to have atomic clocks in user receivers.

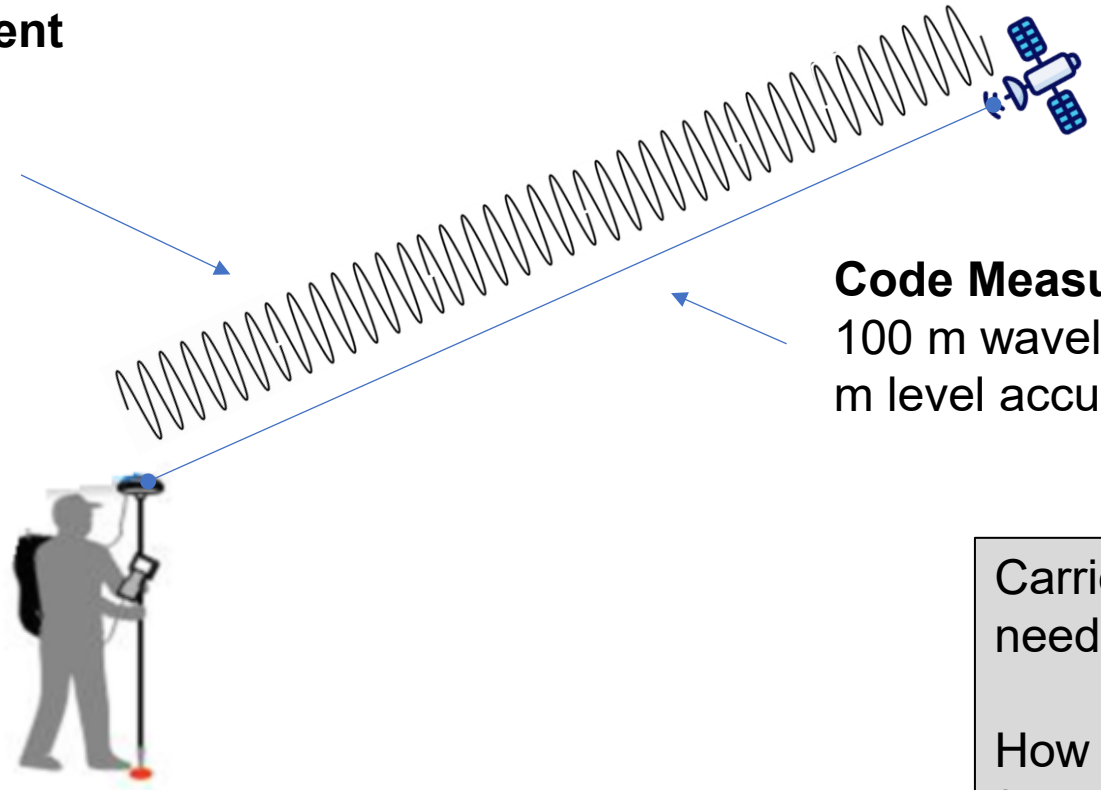
There are over 100 operational GNSS satellites

https://qzss.go.jp/en/technical/satellites/index.html



GNSS receivers track different types of measurements at different frequencies

Carrier Measurement
0.1 m wavelength
mm level accuracy



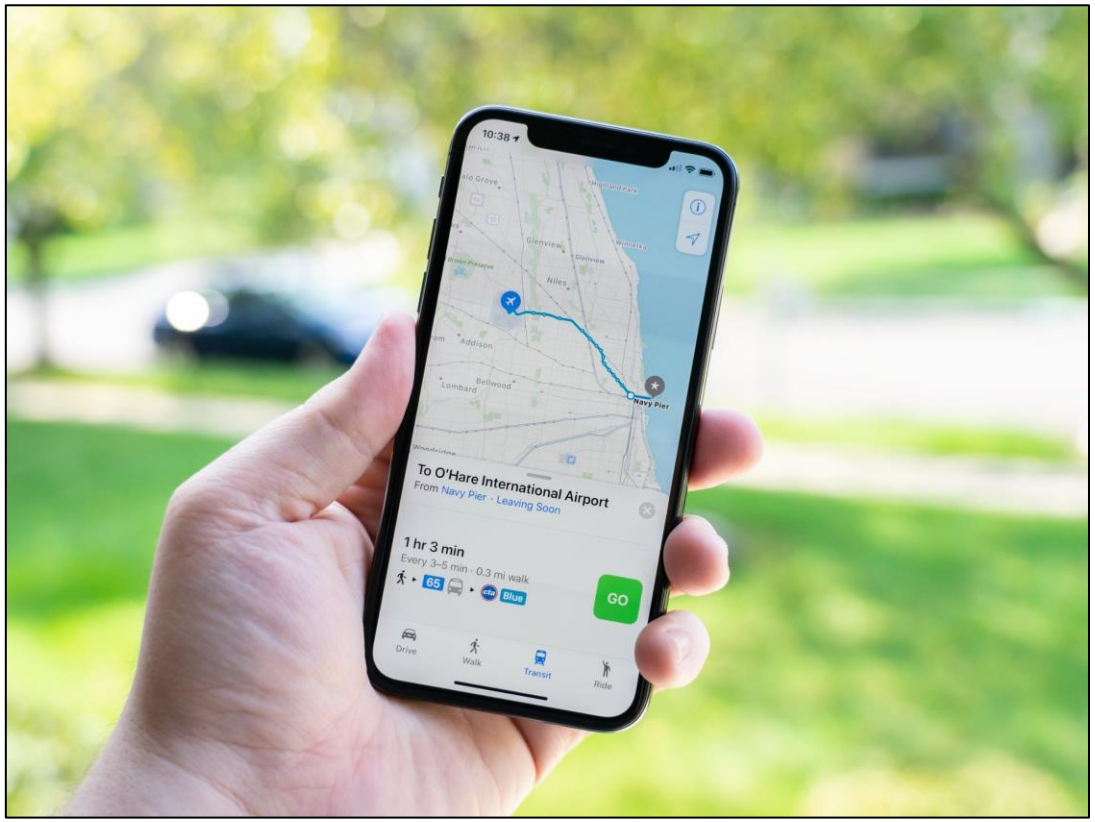
Code Measurement
100 m wavelength
m level accuracy

Carrier measurements are needed for high accuracy

How well can the receiver solve for the number of wavelengths?

“Ambiguity Resolution”

Typically code only measurements, 1 or 2 constellations tracked
$

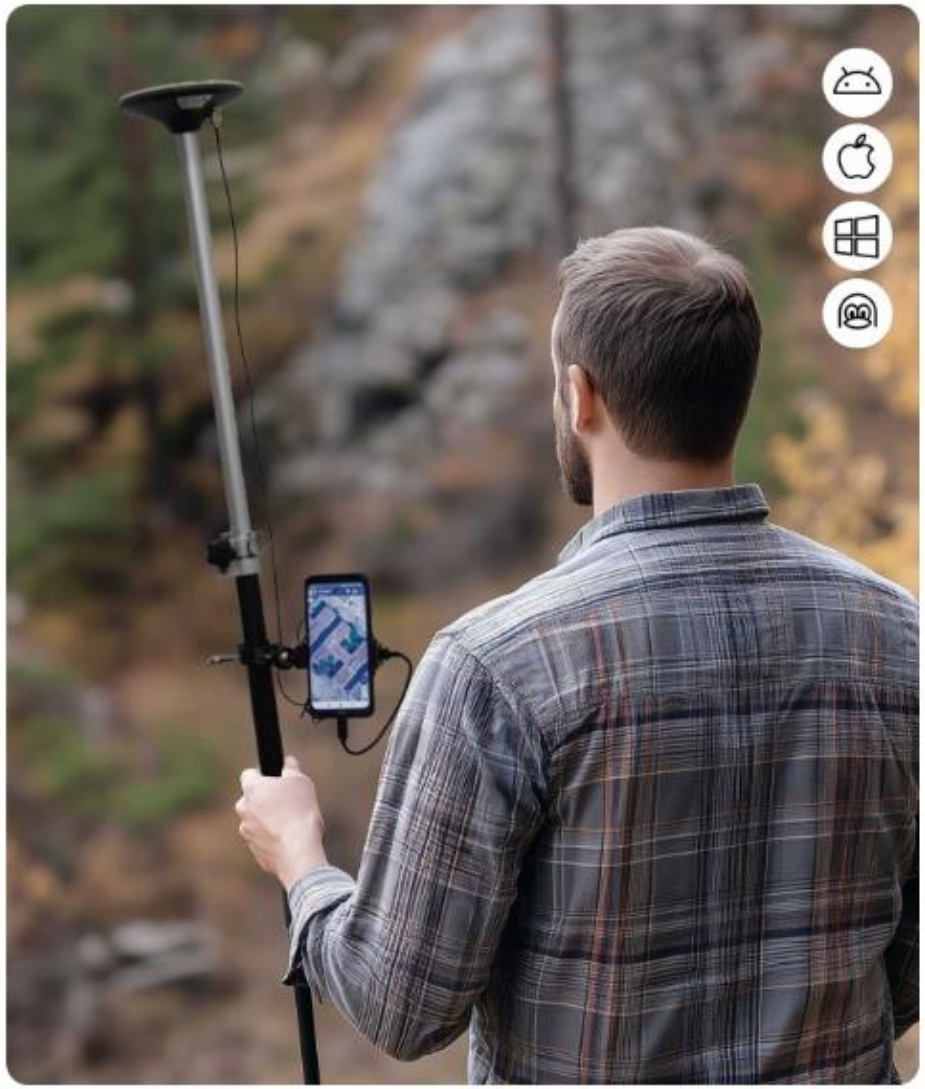


Typically code and carrier measurements, multiple constellations tracked
$$$

What to look for in a High-Performance, GNSS System

- High quality GNSS antenna
- Quality of ambiguity resolution capabilities
- Multi-frequency
- Multi-constellation
- Interference mitigation capabilities
- RT PPP capabilities
- Communication capabilities (wifi, cellular)

Some smartphones now have survey grade GNSS chips



Made in Europe

Professional

RTK Calibrated Surveyor Kit

Ready to work

Traditional survey performance at affordable cost.
Includes accessories.

Surveying job

High precision geolocation

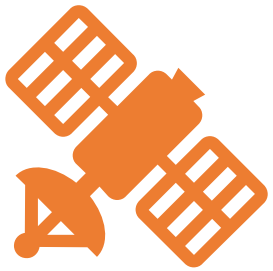
$1K

Select options

Best possible accuracy	GNSS module options	Bands	Constellations	How to enable RTK mode
1 centimeter	ZED-F9P Mosaic-X5 (optional)	L1/L2	GPS, GLONASS, BeiDou, Galileo, QZSS, SBAS Navic (optional)	internet (NTRIP)

Canada

Objectives



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GNSS Measurement Error Sources

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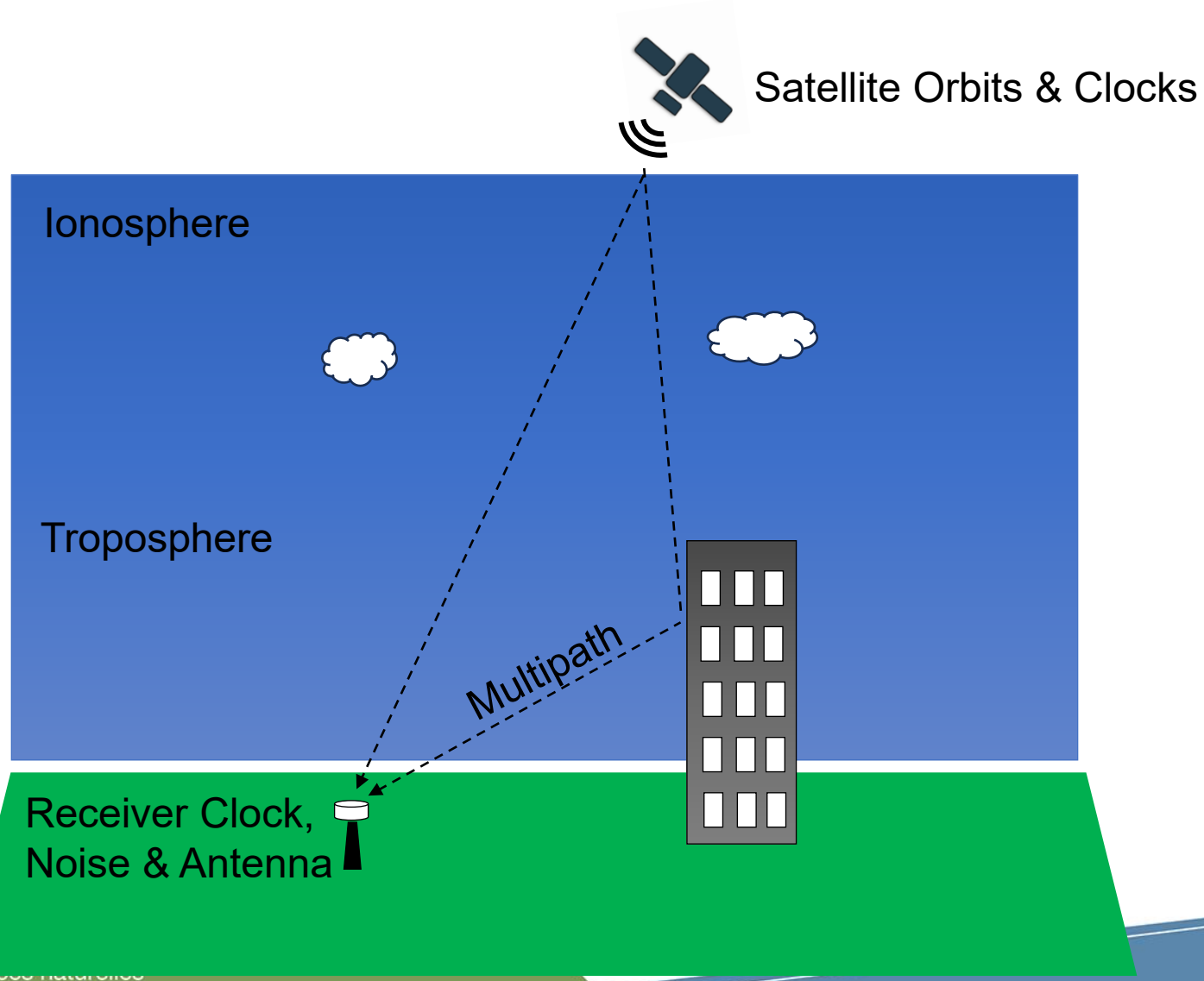


GNSS Measurement Error Sources

Error Source	Absolute Effect
Satellite Clock (atomic)	2 – 50 m
Satellite Orbit	2 – 100 m
Receiver Clock (quartz)	10 ms = 3,000,000 m
Ionosphere	0.5 – 100 m
Troposphere	0.01 – 0.5 m
Multipath Code	m
Multipath Carrier	mm - cm
Antenna	mm - cm

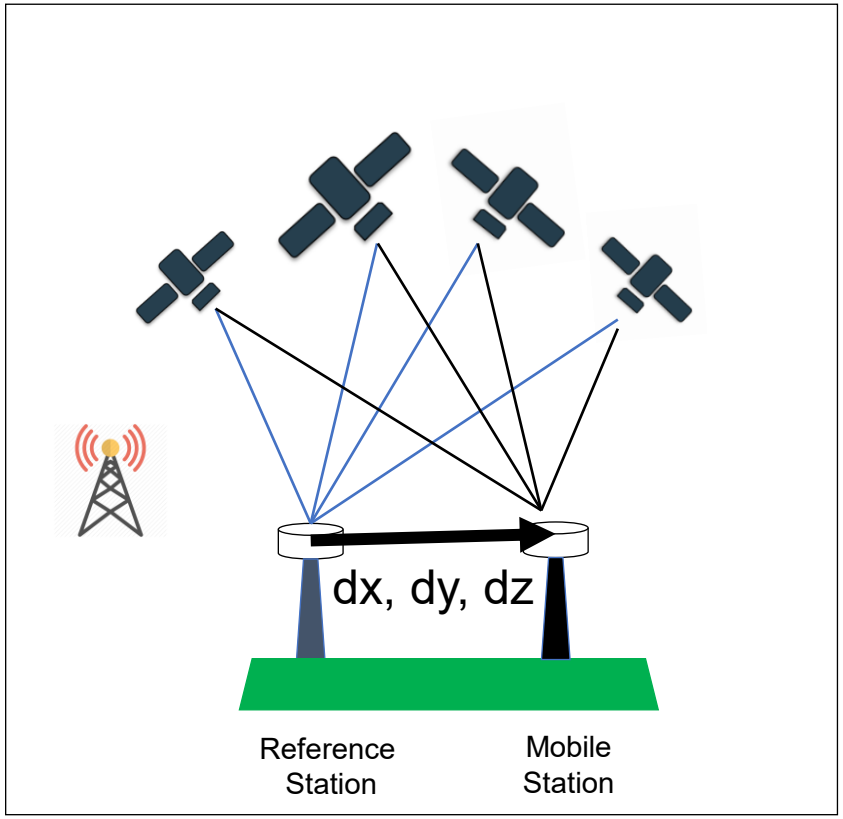
Different ways of minimizing the impact of error sources…

Combating GNSS Measurement Error Sources To Achieve High Accuracy

Relative / Differential Processing:

Corrections can be calculated for a known point and broadcast to nearby stations

"Observation Space Representation-OSR"



Error Source	Impact
Satellite Clock	Removed
Satellite Orbit	Removed
Receiver Clock	Removed
Ionosphere	Increases with distance from Reference (1 ppm)
Troposphere	Increases with distance from Reference (1 ppm)
Multipath	Up to 5/6 cm L1/L2

Multipath:
- Avoid reflective objects when possible
- Antenna choice
- Use longer session lengths

Real-time Kinematic (RTK) Positioning

- Surveyor's staff is like a positioning wand – it tells you where you are at cm level in real-time
- Corrections are broadcast using cellular connection or UHF radio

By building a polygon of stations, you can cut the distance dependent error in half- “**Network RTK**”

Corrections are calculated on a server.

Values depend on location

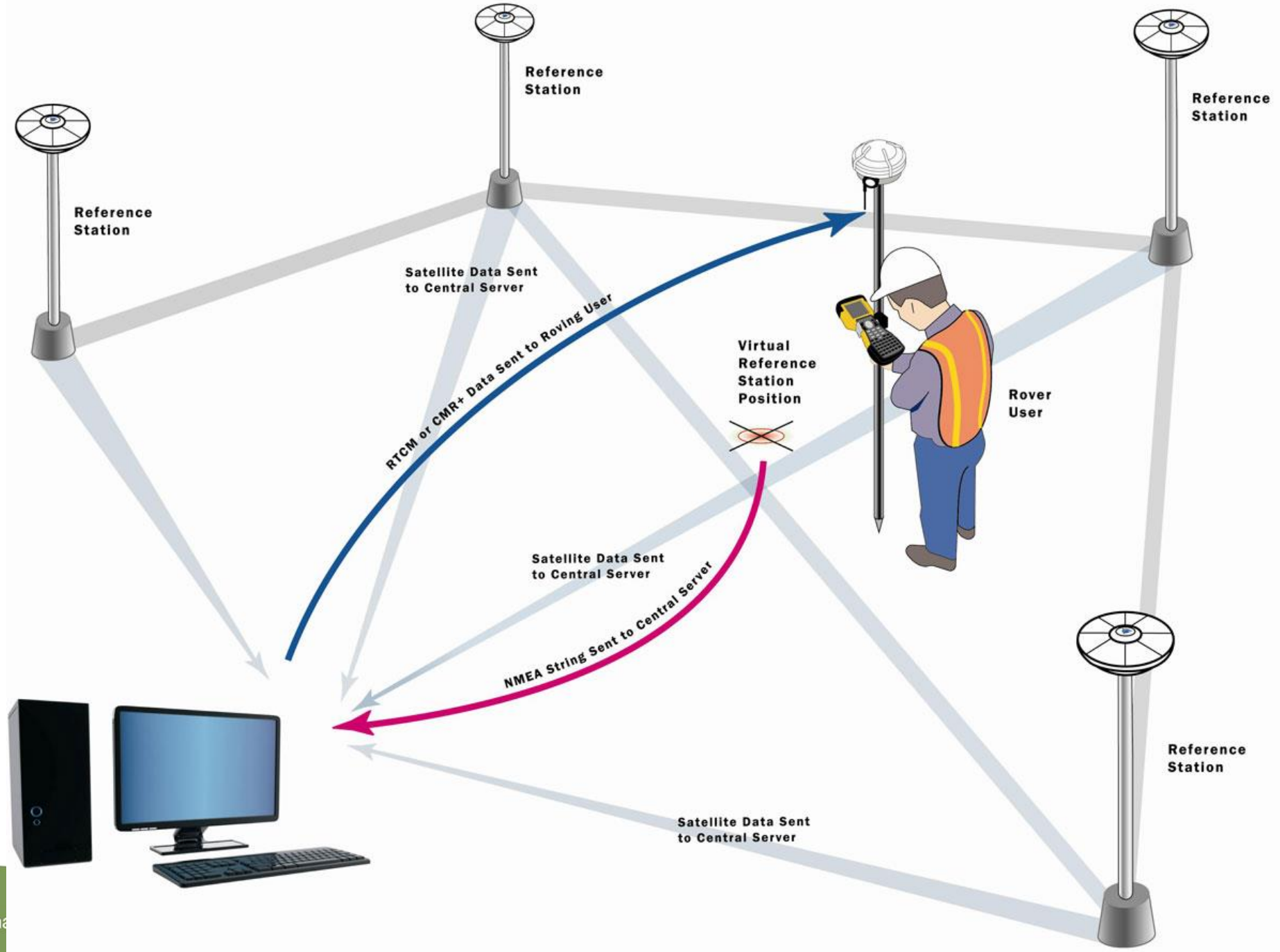


Image courtesy of Trimble

GNSS Active Control Stations

- Tracks GNSS signals from all satellites in view
- Enables corrections to be generated
- Should be stable – attached to bedrock when possible
- “Active” - continuously running
- “Control” – positioned with high accuracy, used to position other points

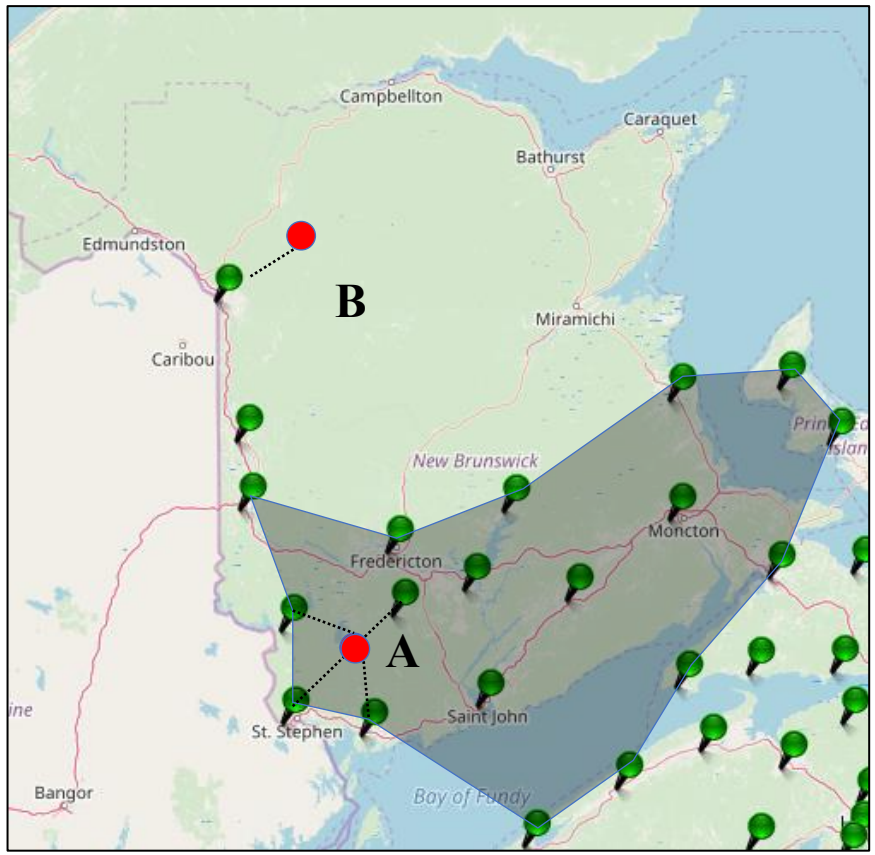
GNSS Active Control Stations

Network RTK

- 0.5 ppm (0.5 mm / km) vs 1 ppm for single baseline
- Example (assumes ± 20 mm horizontal RMS):
  - **NRTK:** At 25 km from nearest reference, expected horizontal accuracy is: ± (20 mm + 12.5 mm) 32.5 mm
  - **RTK:** At 25 km from reference, expected horizontal accuracy is ± (20 mm + 25 mm) 45 mm

Distance	5 km	10 km	15 km	20 km	25 km	30 km	35 km	40 km	45 km	50 km
RTK Error - mm	25	30	35	40	45	-	-	-	-	-
NRTK Error - mm	22.5	25	27.5	30	32.5	35	37.5	40	42.5	45

Example RTK & NRTK Scenarios

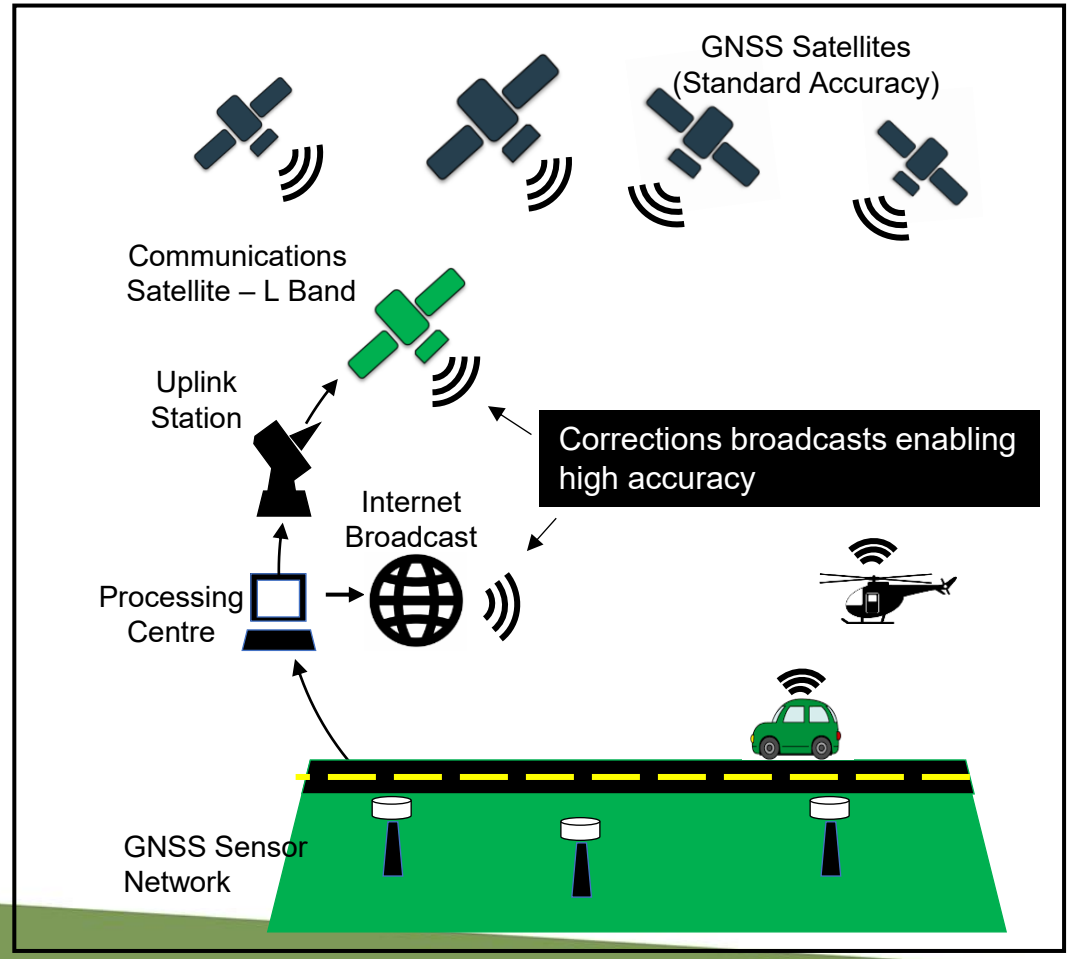


- **Surveyor A** has the benefit of working within a network of ACSs
- Corrections are interpolated and smaller

- **Surveyor B** is assuming that errors are the same at the nearest ACS
- Corrections are extrapolated and larger

Absolute, Precise Point Positioning
Corrections are estimated using a global network

"State Space Representation-SSR"



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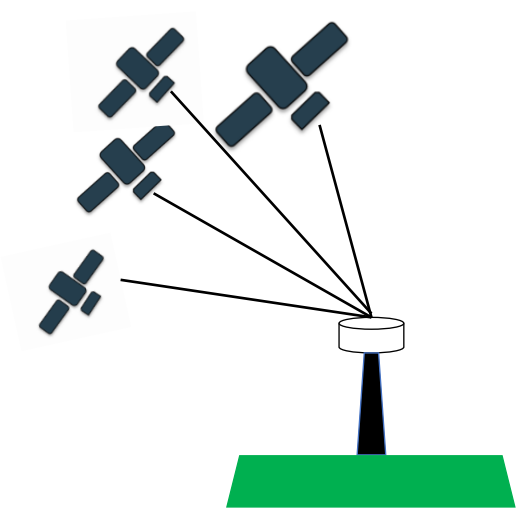
Satellite Clock	Estimated
Satellite Orbit	Estimated
Receiver Clock	Estimated
Ionosphere	Estimated / Dual frequency removes
Troposphere	Estimated
Multipath	Up to 5/6 cm L1/L2

Local Atmosphere Estimates:
- Dense infrastructure required to obtain RTK like performance (50 km)
- Absolute and Differential infrastructure / performance levels begin to blur

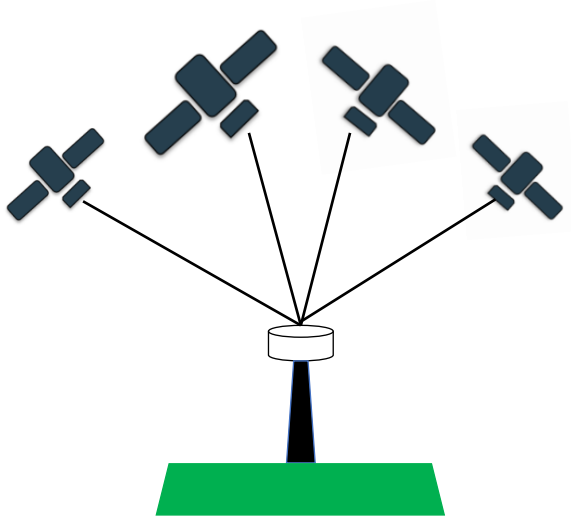
	RTK	RTK-PPP	RT-PPP
Accuracy after initialization	~1 cm	2 - 8 cm	3 - 10 cm
Initialization time	Immediate	Fast (< 1 min)	Slow (~20 min)
Coverage	Local	Regional	Global
Bandwidth requirements	High	Moderate	Low
Infrastructure density	~10 km	~100 km	~1000 km

https://www.septentrio.com/en/learn-more/insights/gnss-corrections-demystified

We can't forget that GNSS Position Quality Relies on Satellite Geometry and Visibility



Good visibility
Poor geometry



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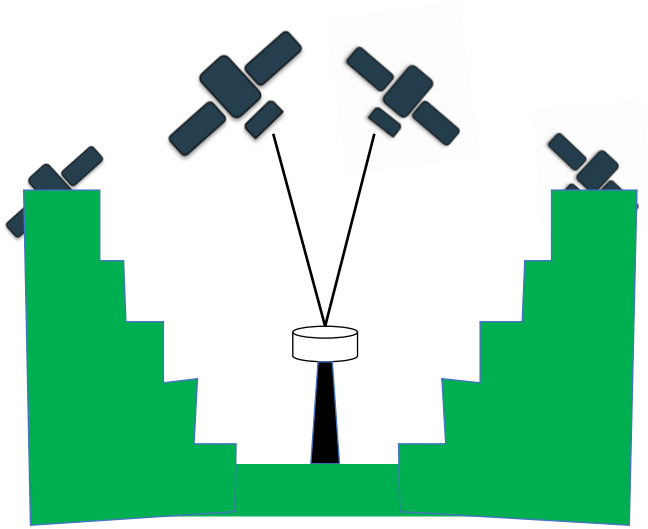

Poor visibility
Poor geometry

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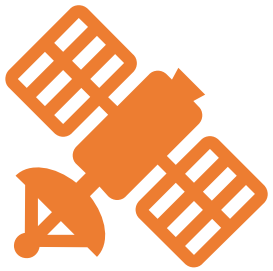

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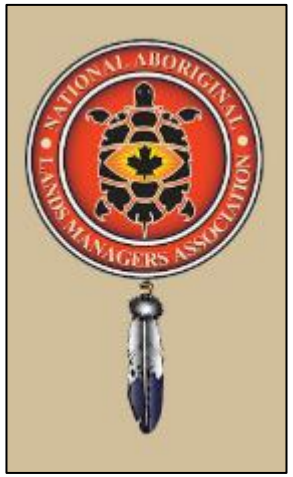
Applications

Reserve Land and Environment Management Program (RLEMP)

- The RLEMP is a comprehensive land management program that funds First Nations to manage all aspects of land, natural resources and the environment on reserve

- **Five Key Functions** of RLEMP:
  - Land use planning (community-based)
  - Lands management
  - Natural resources management
  - Environmental management
  - Compliance management (promotion, monitoring & enforcement)

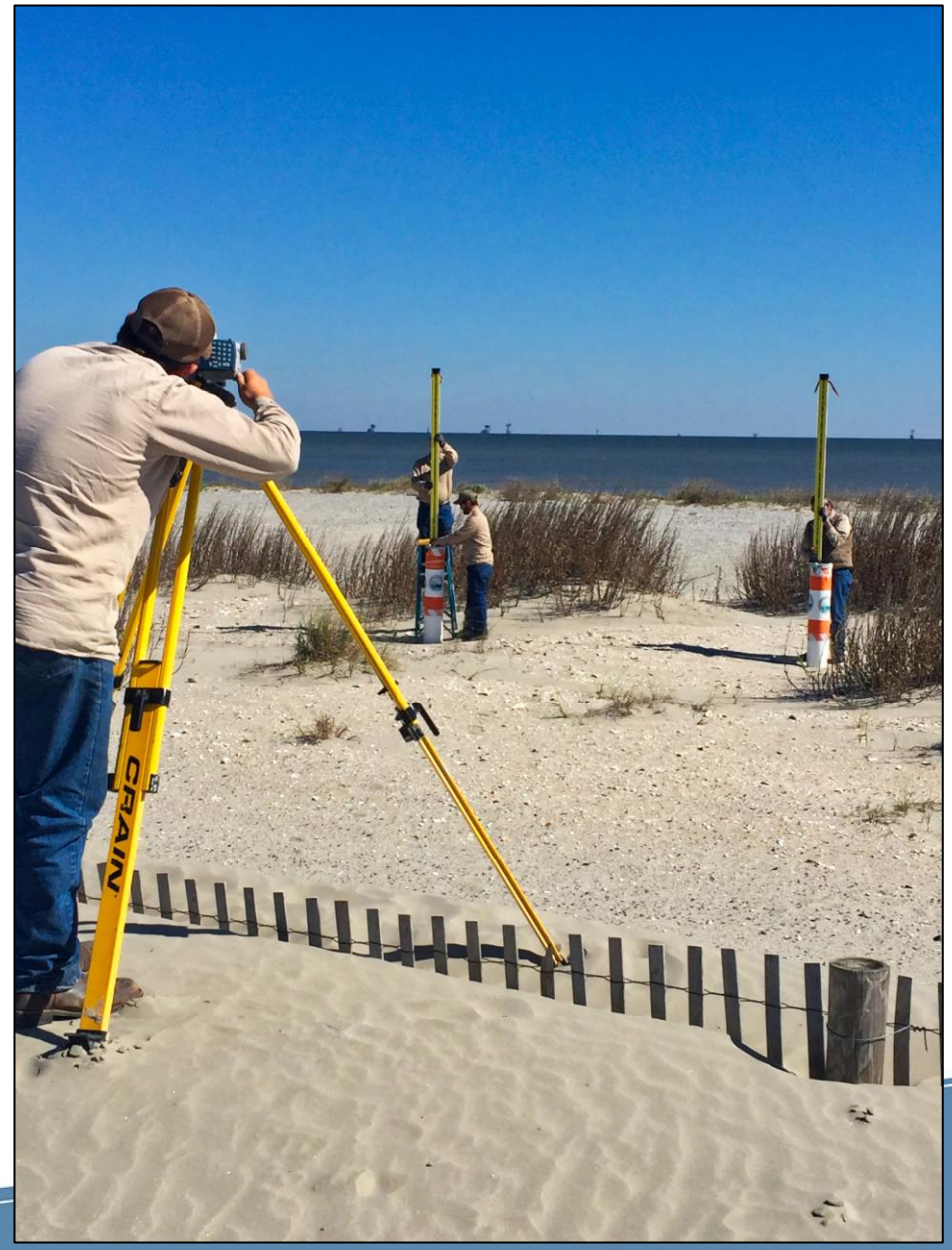


NALMA What is Land Management

Compliance surveys

- GNSS can be used to determine if environmental and building regulations are being followed:
  - Offsets from coastlines
  - Avoiding building on floodplains and environmentally sensitive areas

https://www.fenstermaker.com/



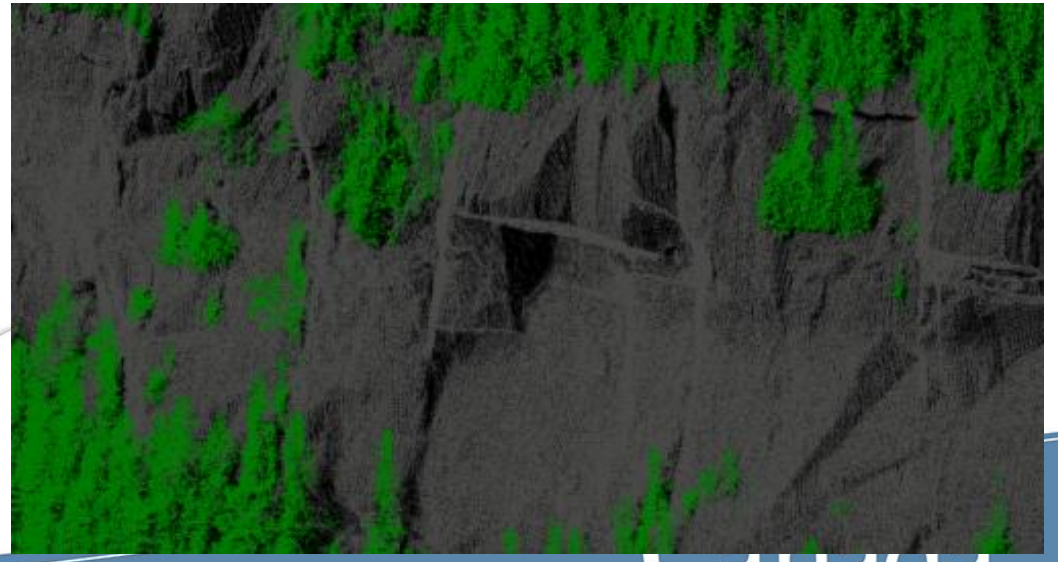
Environmental studies using drone mounted LiDAR

https://balkotechnologies.com/en/applications/lidar-drone-for-environment

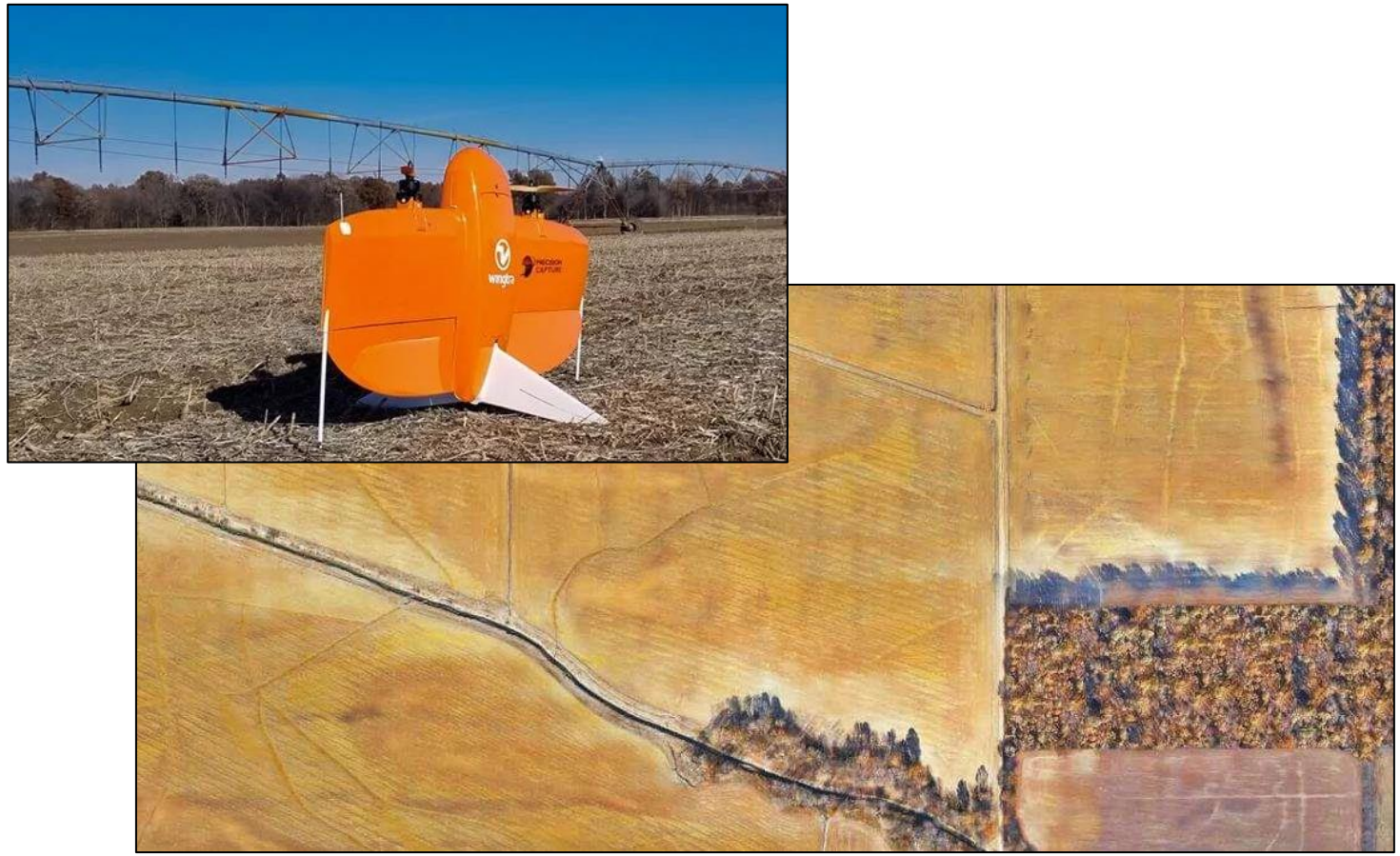
- Coastal erosion, deforestation, vegetation growth and changes in waterways can be accurately monitored using LiDAR

- Develop informed regulations

- Drones positioned with high accuracy GNSS can have LiDAR sensors attached to collect 3D data



Mapping floodplains with high-accuracy survey drone



- Building solar farm near the Mississippi River
- Needed accurate elevation information and digital terrain models
- Photos are time stamped and positioned with cm accuracy
- Solar panels located to avoid flooding damage

https://www.septentrio.com/en/learn-more/customer-stories/mapping-floodplains-high-accuracy-survey-drone

GNSS is used in Agriculture to automatically guide farming machinery operations

Seeding: Guidance lines used to vary seeding locations: improved germination, better plant stand, better root development, improved resistance to disease and ultimately better crop yield.

Spraying: Boundary lines created and used to turn off equipment in ditches or over fence lines, preventing over spraying. Avoid spray overlap

Harvesting: Guidance lines exchanged amongst different machines, so that harvesting work lines up

http://www.deutz-fahr.com

Benefits to Agriculture

http://www.deutz-fahr.com

- Reduced fuel consumption with less overlap
- Continued operations at night or during fog
- Reduced costs by using less seeds, fertilizers
- Reduction in soil compaction by following the same paths
- Less operator fatigue
- Less environmental impact through less agrichemical run-off
- Less water waste with better spraying

GNSS enables Asset Management

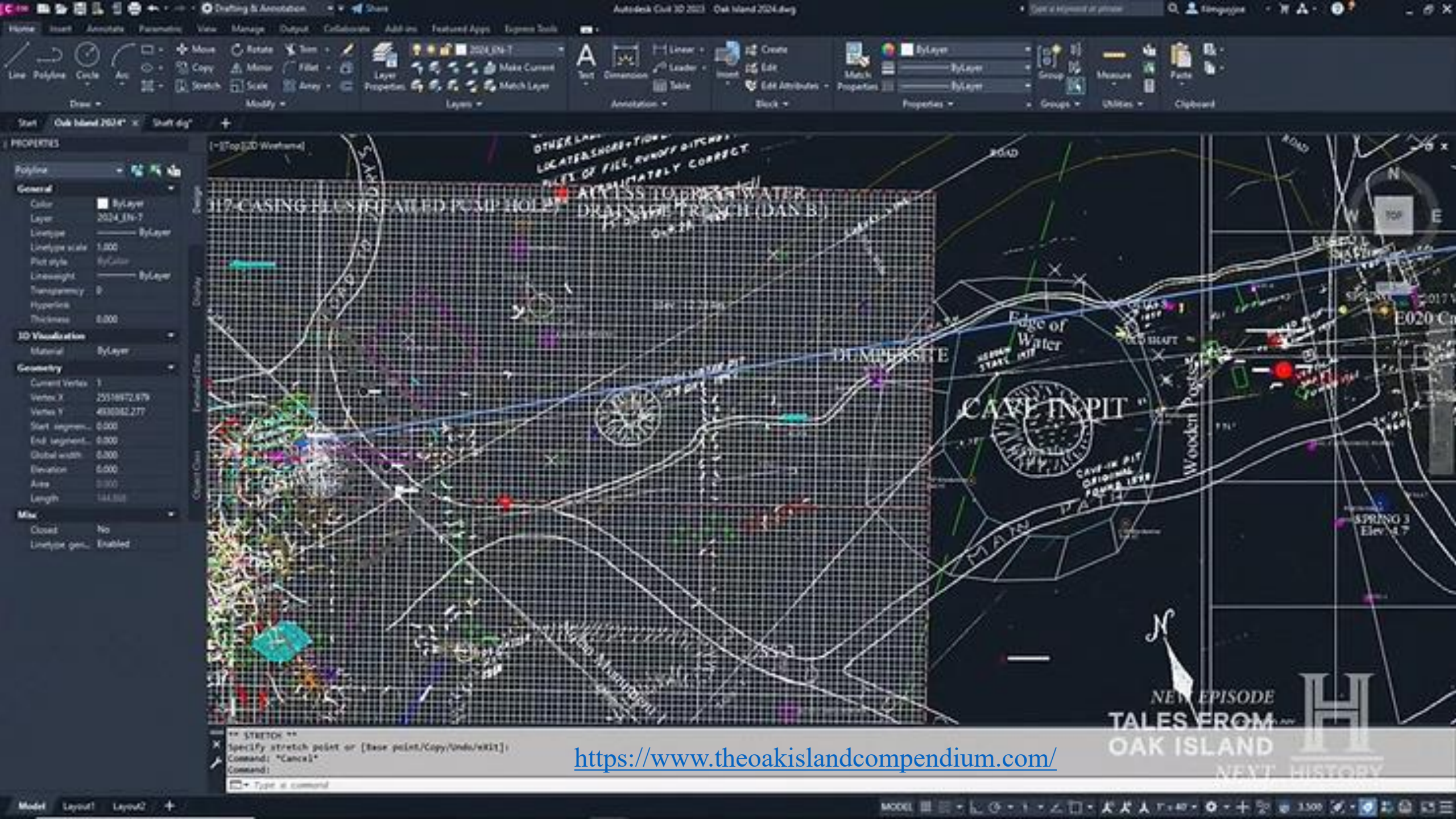
https://leica-geosystems.com

- Monitor and identifying optimal times to upgrade infrastructure
- Often more cost effective to repair infrastructure at regular intervals than to have to fully replace it prematurely
- Applies to waste and storm water systems, bridges, and buildings…etc
- GNSS enables asset management in a Geographic Information System (GIS) environment
- Precise height data on infrastructure allows for flood planning

Several Canadian Provinces and Cities have invested in GNSS infrastructure to support governance and asset management

- Cities: Montreal, Calgary, Moncton, Victoria, Vancouver
- Provinces: NS, PE, QC, BC
- Montreal uses RTK for monitoring flood levels, locating park infrastructure, legal surveys and emergency vehicle guidance
- Bringing asset information together in one Geographic Information System allows for better planning and decision making

https://leica-geosystems.com/


Edge of Water
CAVE-IN PIT
Wooden Post
MAIN PATH
SPRING 3
NEW EPISODE
TALES FROM
OAK ISLAND
NEXT HISTORY
https://www.theoakislandcompendium.com/

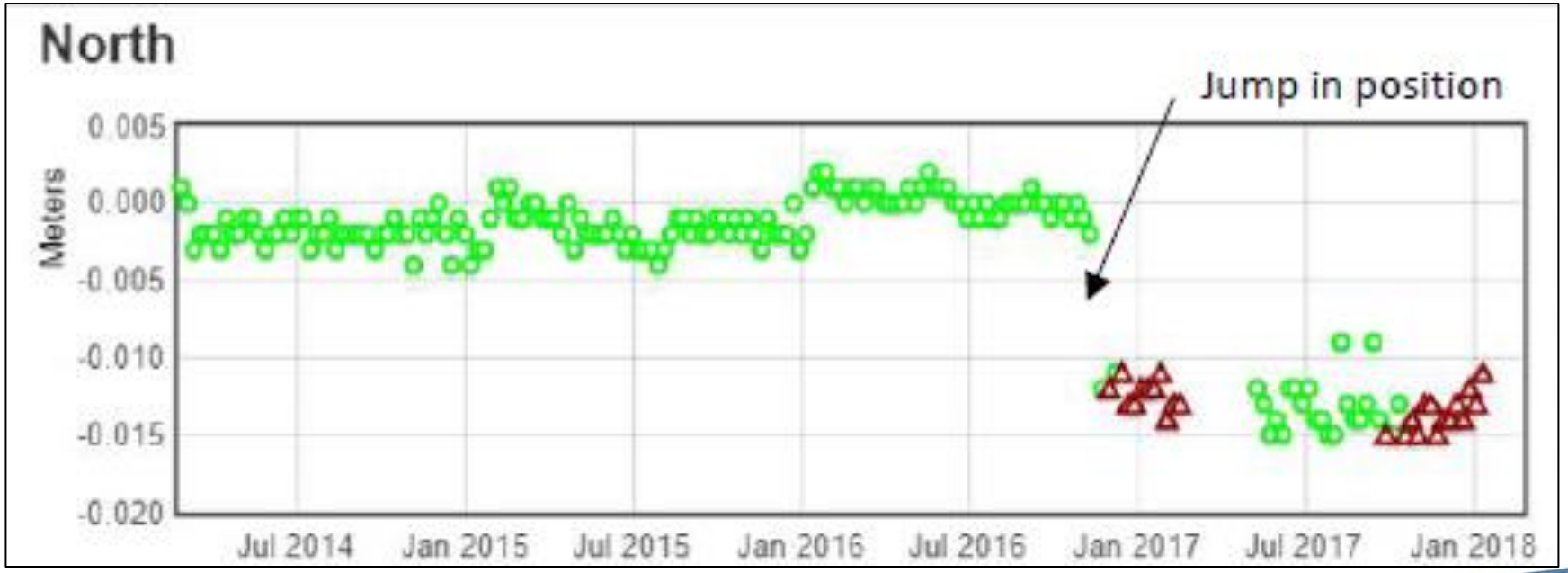
High Accuracy GNSS Positioning can provide advance warning of emergency situations

http://www.news1130.com

- Highly accurate, GNSS positions can be used to detect out of the ordinary circumstances which may represent an emergency situation.
- By monitoring position information over time, variance from normal trends can be detected and reported.
- If the abnormality is deemed significant, measures can be taken for emergency preparedness.

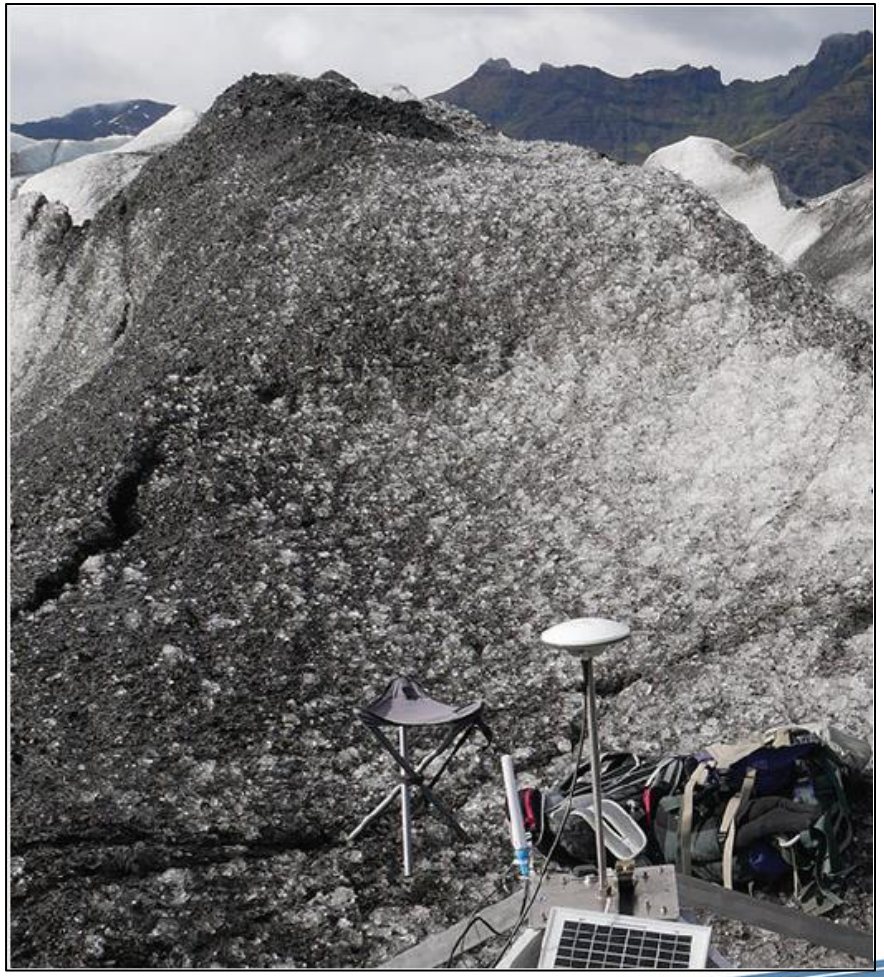
There are several applications in Canada where GNSS can and does play a key role in emergency preparedness

- Tsunami detection
- Earthquake early warning systems
- Landslide detection
- Avalanche detection
- Structural monitoring
- Subsidence monitoring



High accuracy, GNSS positioning enables Climate Change Studies

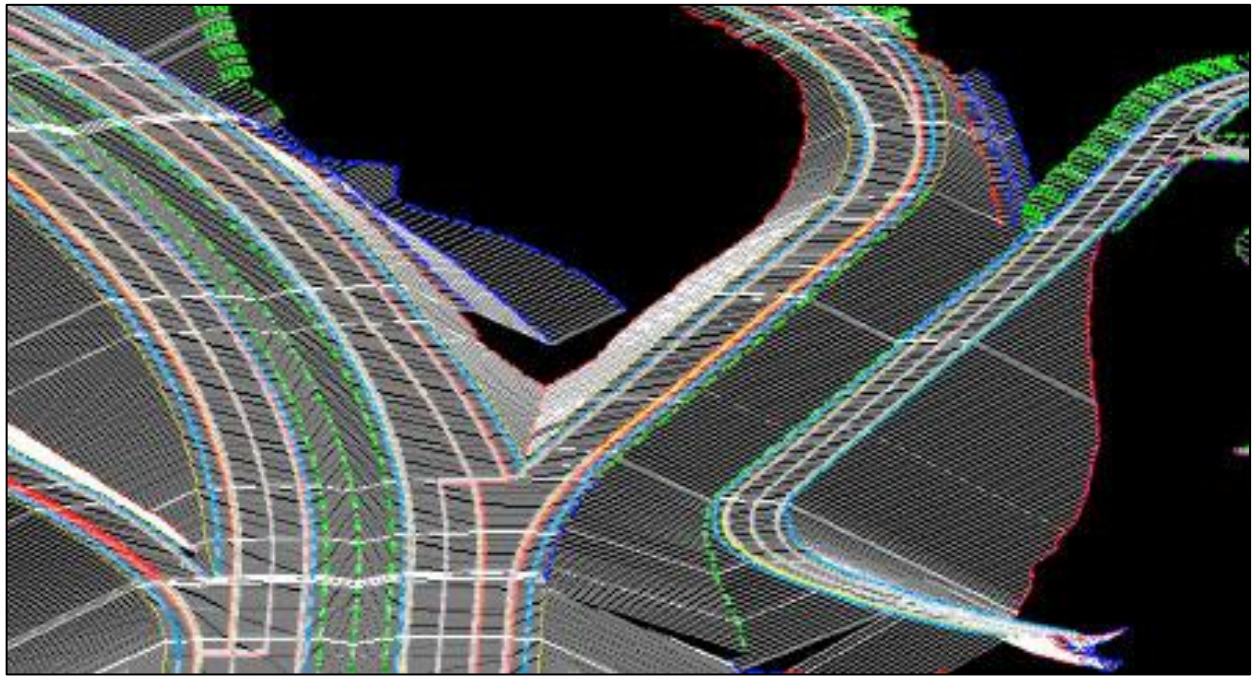
- Glacial monitoring
- Sea level rise and changes in other water levels
- Tracking and monitoring of endangered wildlife for conservation



https://www.swiftnav.com/survey

Precision GNSS enables efficient road construction

- Roads are designed in 3D before construction begins
- The 3D model is transferred to a computer onboard of the heavy machinery
- The heavy machinery's computer compares its blade/bucket position with the desired position from the 3D model
- The console screen indicates the required actions
- Efficiencies of 30% common
- Increased safety



https://www.fhwa.dot.gov/

Precision GNSS enables road construction

https://www.equipmentworld.com

https://www.topconpositioning.com

Available Technologies / Services

Network RTK Service Providers

Brandt

GEODNET

Leica Geosystems

Can-Net

lewis instruments ltd.

metacon

TOPCON

Example Real-time PPP Service Providers

TERRASTAR

Fugro Starfix®

ublox
PointPerfect Flex

Trimble Positioning Services

JAVAD
J-Star

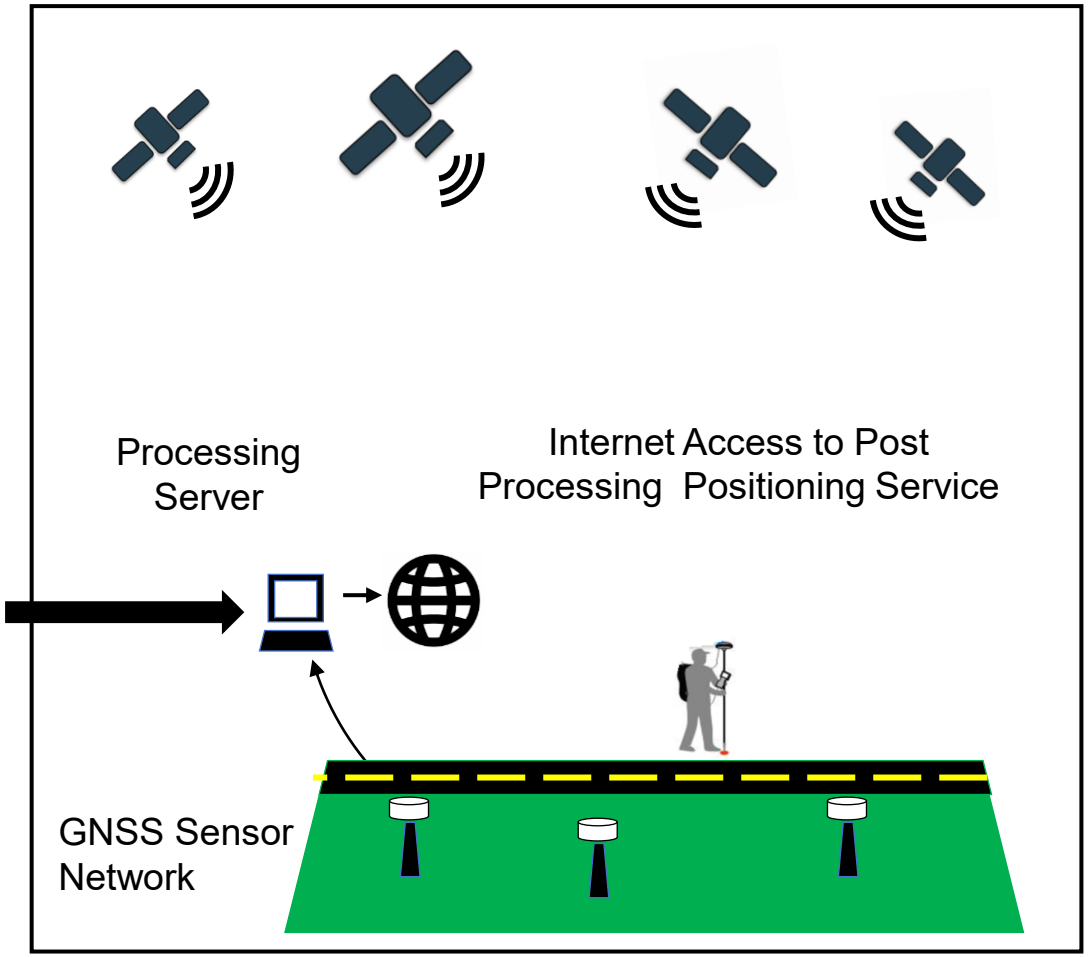
Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) service

Precise Point Positioning

- Absolute Positioning
- No user reference station required
- NRCan CSRS- PPP, free post processing service

NRCan's CSRS- PPP Service can be accessed online for post mission processing

Corrections calculated enabling high accuracy positioning:
- Satellite orbits
- Satellite clocks
- Satellite observation biases
- Atmospheric biases



CSRS (Post Processed) PPP is easy to use

Store raw GNSS data on receiver

Processing mode — CSRS-PPP

◉ Static ○ Kinematic

NAD83 | ITRF

Epoch (Adopted)

Vertical datum

CGVD2013

Contribute to passive control maintenance? (What is this?)

☐ Authorize the Canadian Geodetic Survey to archive and publish CSRS-PPP submission and solution

Official Canadian federal or provincial geodetic marker number

▶ More options

RINEX observation file(s), 300 MB max (.zip, .gz, .Z, .tar, .??O)

Note: You may submit multiple RINEX files in a single .zip or .tar archive

Choose File | No file chosen

☐ Remove plots from CSRS-PPP solution PDF report (Why?)

Submit to PPP

CSRS-PPP 5.11.0 (2025-05-05)

acht0320.24o
ACHT

Data Start	Data End	Duration of Observations
2024-02-01 00:00:00.00	2024-02-01 23:59:30.00	23:59:30
Processing Time	**Mode**	**Product Type**
15:28:07 UTC 2025/05/27	Static	Final

Observations

GPS : C1 C2 L1 L2 GLONASS : C1 C2 L1 L2

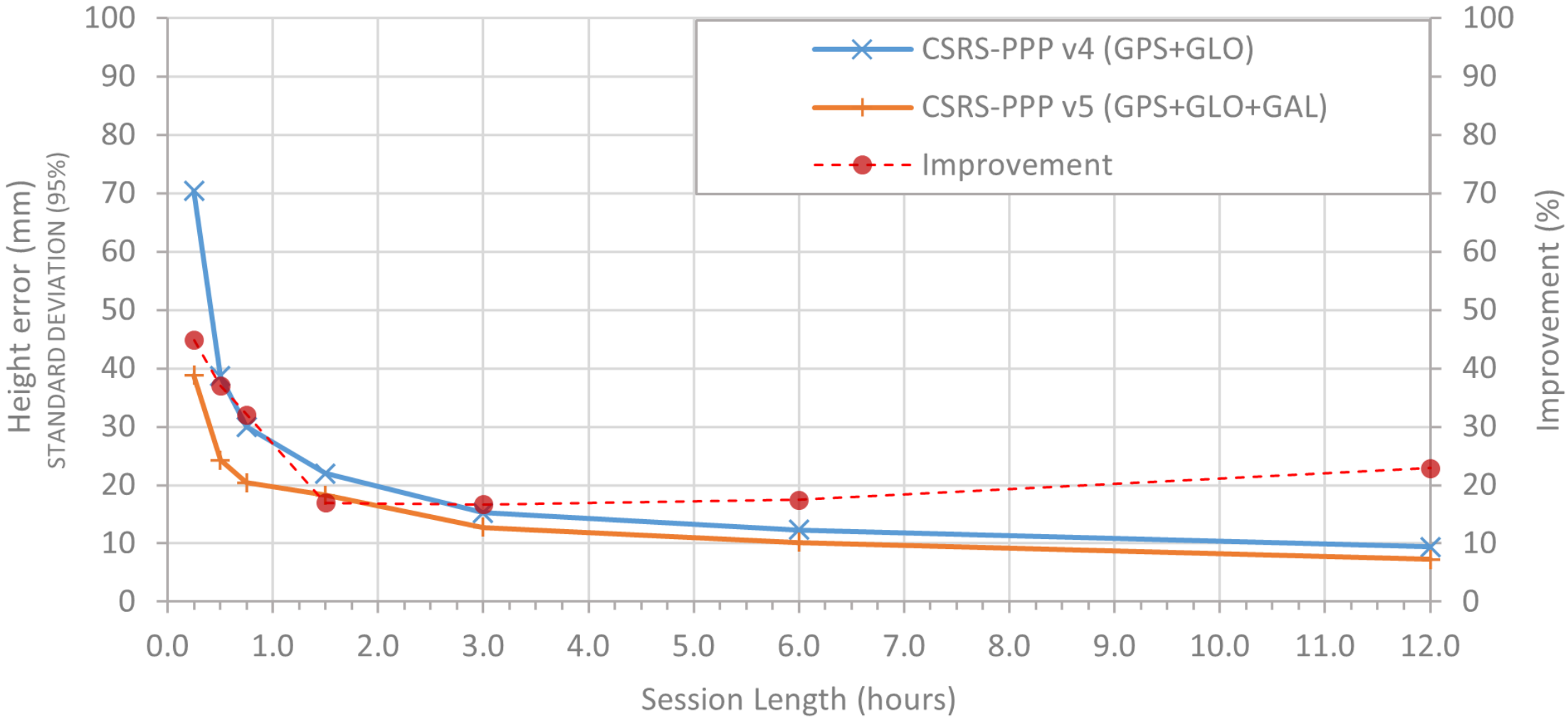
Elevation Cut-Off	Rejected Epochs	Fixed Ambiguities	Estimation Steps
7.5 degrees	0.00 %	98.65 %	30.00 sec
Antenna Model	**APC to ARP**	**ARP to Marker**	
TRM59900.00 NONE	REF PCO : GPS GLONASS	H:0.077m / E:0.000m / N:0.000m	

(APC = antenna phase center; ARP = antenna reference point; REF PCO = reference phase center offset)

Estimated Position for acht0320.24o

	Latitude (+n)	Longitude (+e)	Ell. Height
NAD83(CSRS) (2010.0)†	45° 30' 45.99029"	-61° 1' 35.81059"	22.149 m
SIG_PPP(95%)‡	0.002 m	0.002 m	0.007 m
SIG_TOT(95%)‡	0.007 m	0.005 m	0.009 m

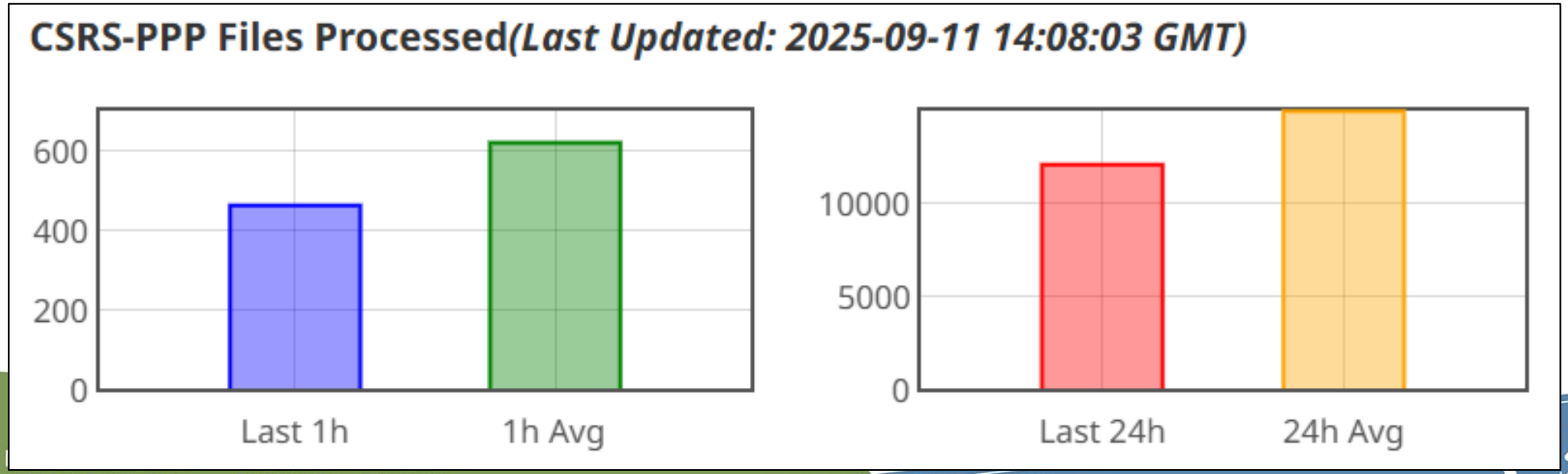
Support for Galileo improves convergence time and accuracy



CSRS-PPP Usage

- With 1 hour of GNSS observations, ±1 cm in horizontal components and ±2 cm in vertical at 95% confidence is possible

- 10 years ago: ±3 cm horizontal in 3 hours



Galileo High Accuracy Service (HAS)

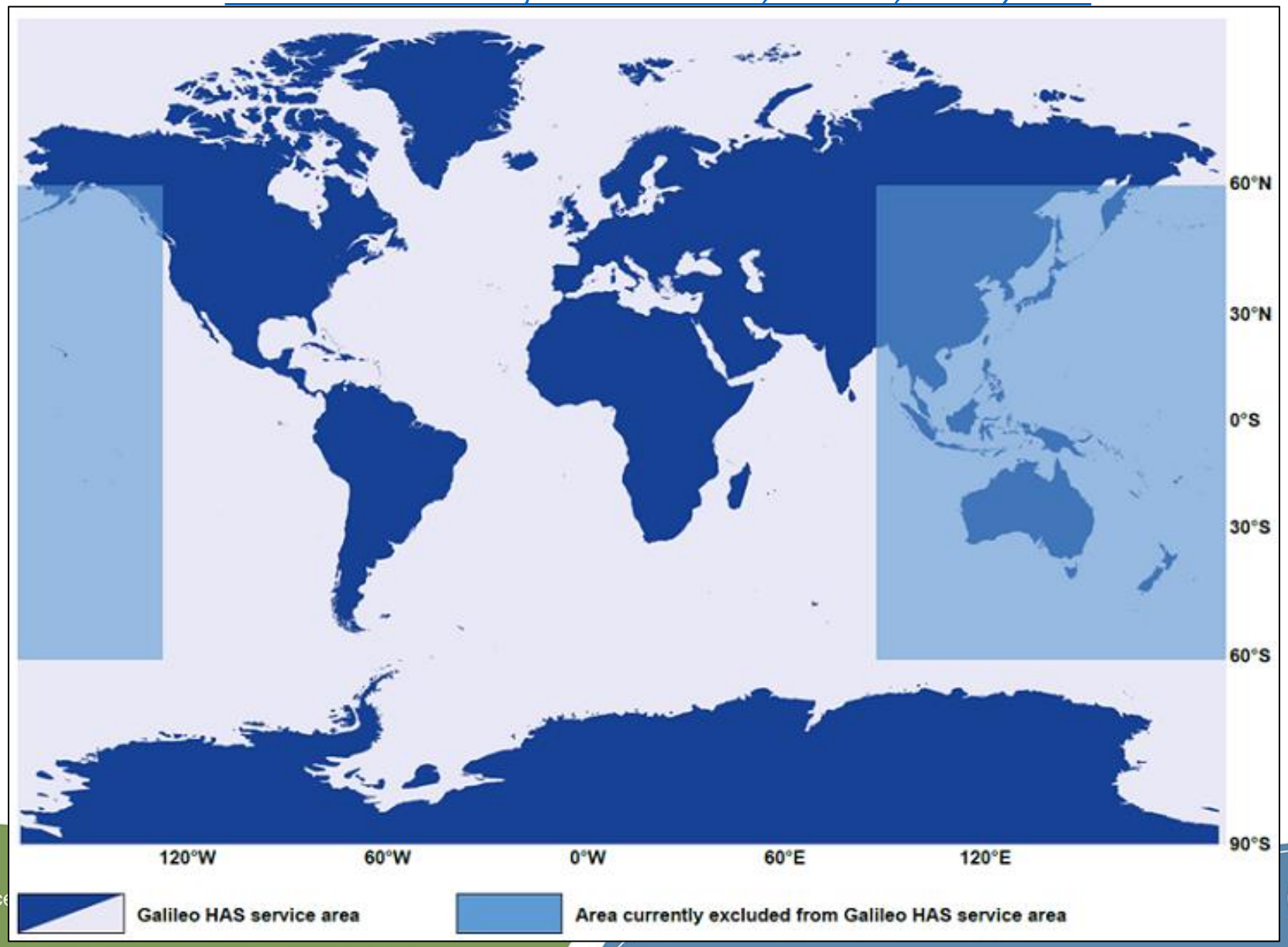
https://www.gsc-europa.eu/galileo/services/galileo-high-accuracy-service-has

Galileo High Accuracy Service (HAS)

- Free
- Corrections broadcast in the Galileo E6-B signal and over internet
- Corrections: satellite orbit, satellite clocks, satellite biases, (atmosphere?)
- Implemented in real-time PPP
- Better than 20 cm accuracy horizontal, 40 cm vertical

Galileo HAS Coverage

Galileo HAS Service Definition Document, Issue 1.0, January 2023



Example HAS-enabled receivers

- Spectra SP100
- Trimble R10/R12
- Topcon Hiper HR
- Hemisphere S631
- Geode GNS3H
- EOS Skadi Gold

Objectives

Gain an understanding of how GNSS works

4 satellites needed

Carrier tracking for high accuracy

Gain an understanding of different methodologies for achieving high accuracy positioning

RTK, NRTK, PPP

Be introduced to emerging GNSS technologies and applications

CSRS-PPP, HAS

Ag, Climate Change, Asset Management…

Summary

GNSS technology is enabling new technologies and applications including:

- Autonomous vehicles
- Climate change studies
- Asset management

The installation of GNSS stations can enable real-time positioning services (RTK / PPP) in underserved areas

Having accurate position information for data sets allows the data layers to be combined and enables for better decision making

Questions