Resilient High-Precision Positioning: From Mitigating Signal Interference to Modeling Complex Crustal Deformation

IGS Workshop 2026

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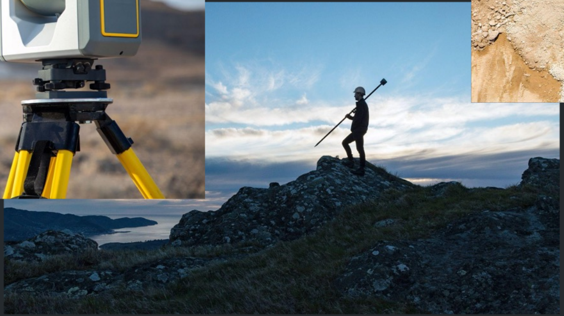
Introduction











Trimble®

GNSS Signal Interference Overview

01 Current Challenges

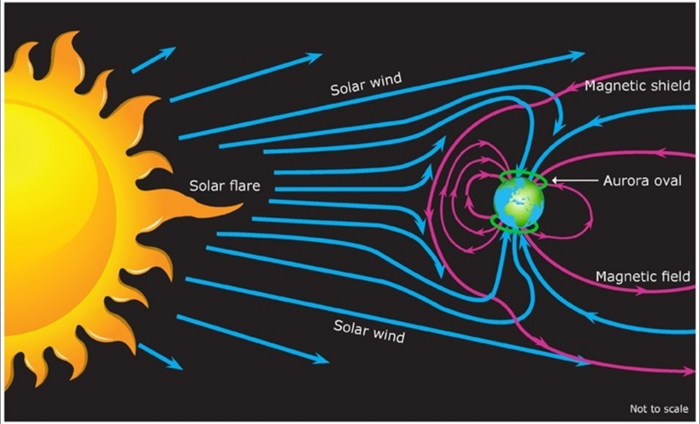
02 Ionoguard

03 Receiver Jamming & Spoofing threats

04 Pivot - Jamming and Spoofing Portal

Challenges in GNSS

- Solar activity:
  - The ionospheric threat has an 11-year cycle
  - Massive GNSS penetration during the low activity part of the cycle
- Jamming and Spoofing:
  - Transitions from a military threat / sophisticated lab threat to affecting civilian activity
  - Conflict regions: Baltic Sea, Black Sea, Red Sea, and Eastern Mediterranean
  - State sponsored jamming and spoofing impacting Civilian activity



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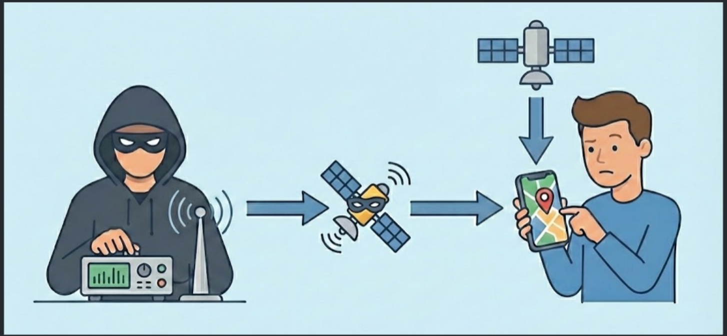
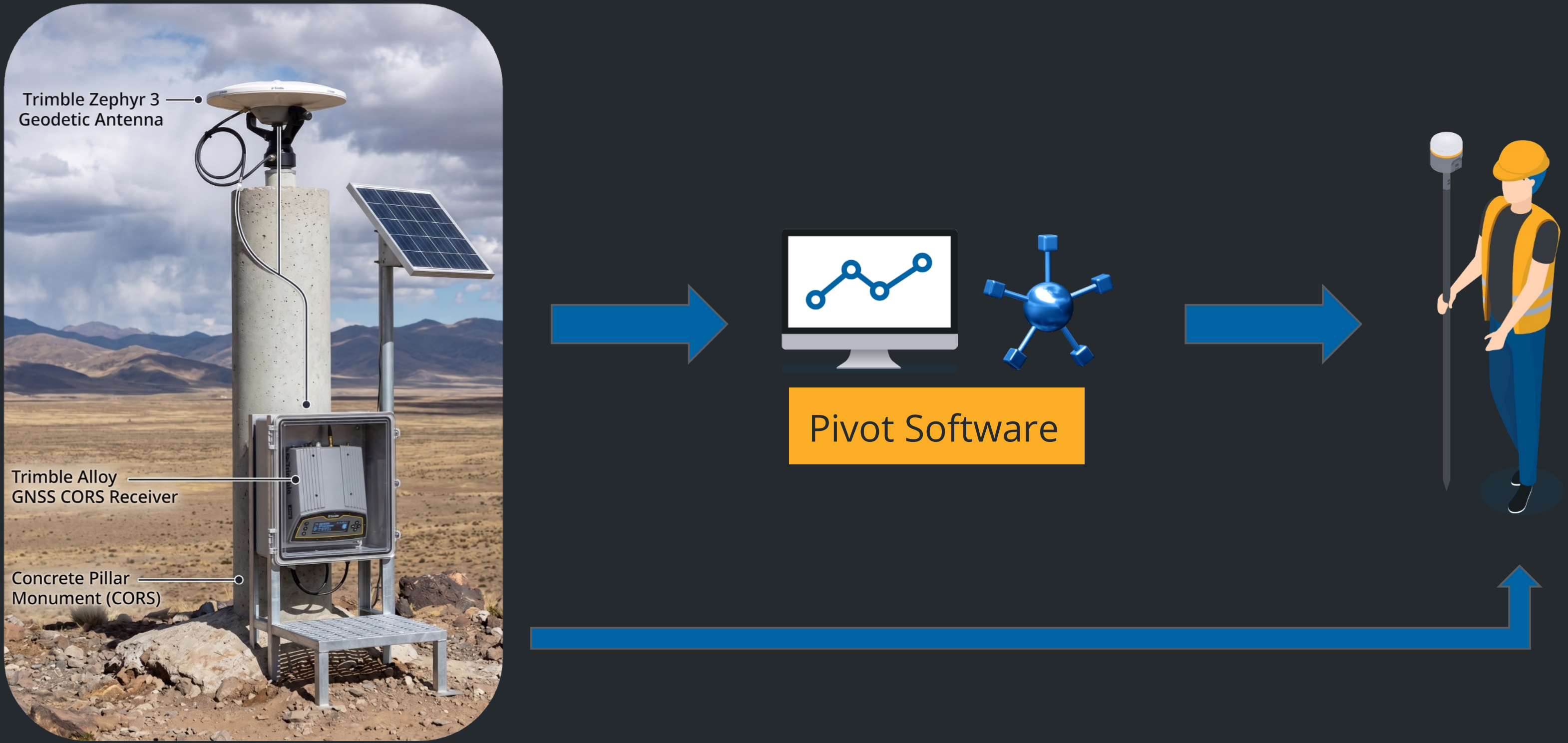


Jamming and Spoofing

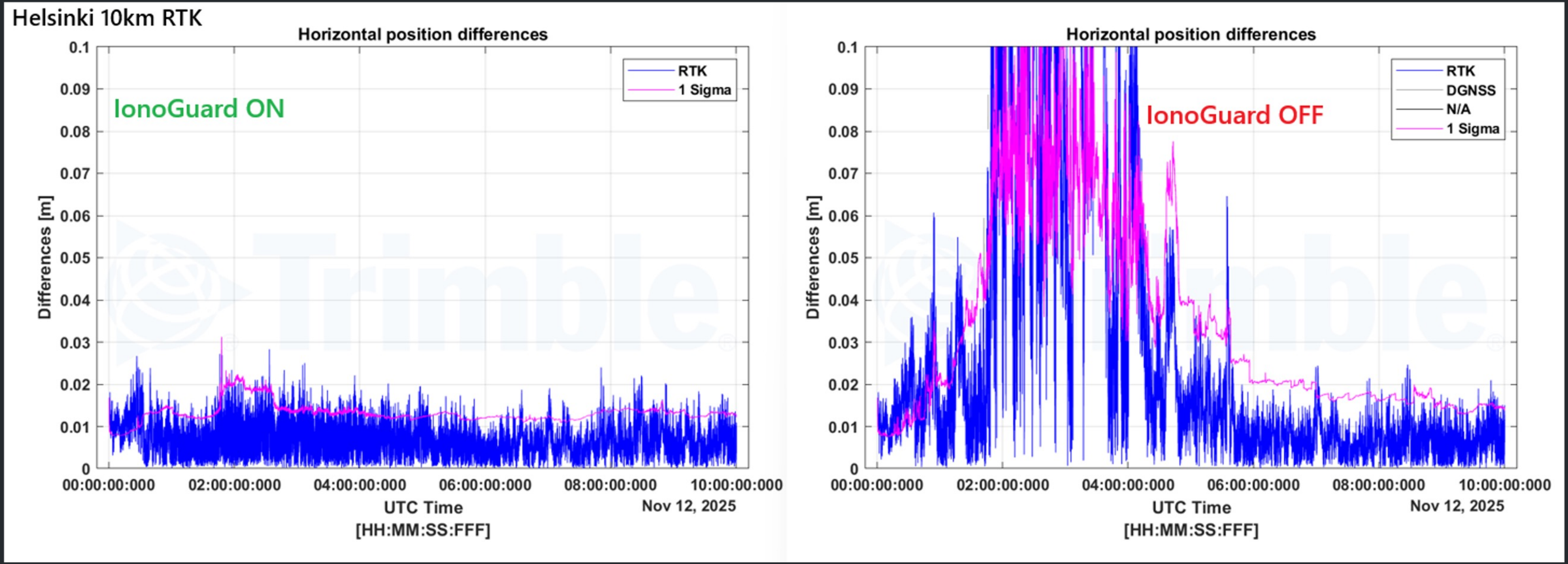
- Jamming (Denial of Service)
    - Definition: Jamming is the broadcasting of strong, competing radio signals on the same frequency as the GNSS satellites. Because satellite signals are incredibly weak by the time they reach Earth, it doesn't take much power to drown them out.
    - The Result: The receiver is overwhelmed by "noise" and loses its connection to the satellites. It simply stops working and cannot calculate a position or time or store correct data for post processing.
- Spoofing (Deception)
    - Definition: Spoofing is a more sophisticated and malicious attack where a transmitter broadcasts counterfeit GNSS signals that perfectly mimic real satellite signals. The attacker gradually increases the power of these fake signals until the receiver drops the real satellites and locks onto the fake ones.
    - The Result: The receiver still thinks it is working perfectly fine, but it is now calculating a false location or a false time chosen by the attacker.

GNSS Workflow



Ionoguard

- Trimble developed IonoGuard which act as a digital shield aiming to maintain the accuracy when there are high activity in the ionosphere.
- Independent Signal Tracking: Processes GNSS signals across multiple frequencies independently to ensure redundancy when specific bands are compromised.
- Rover RTK engine adjusts based on a per satellite basis.



Ionoguard

Colorado - October 2024 Storm

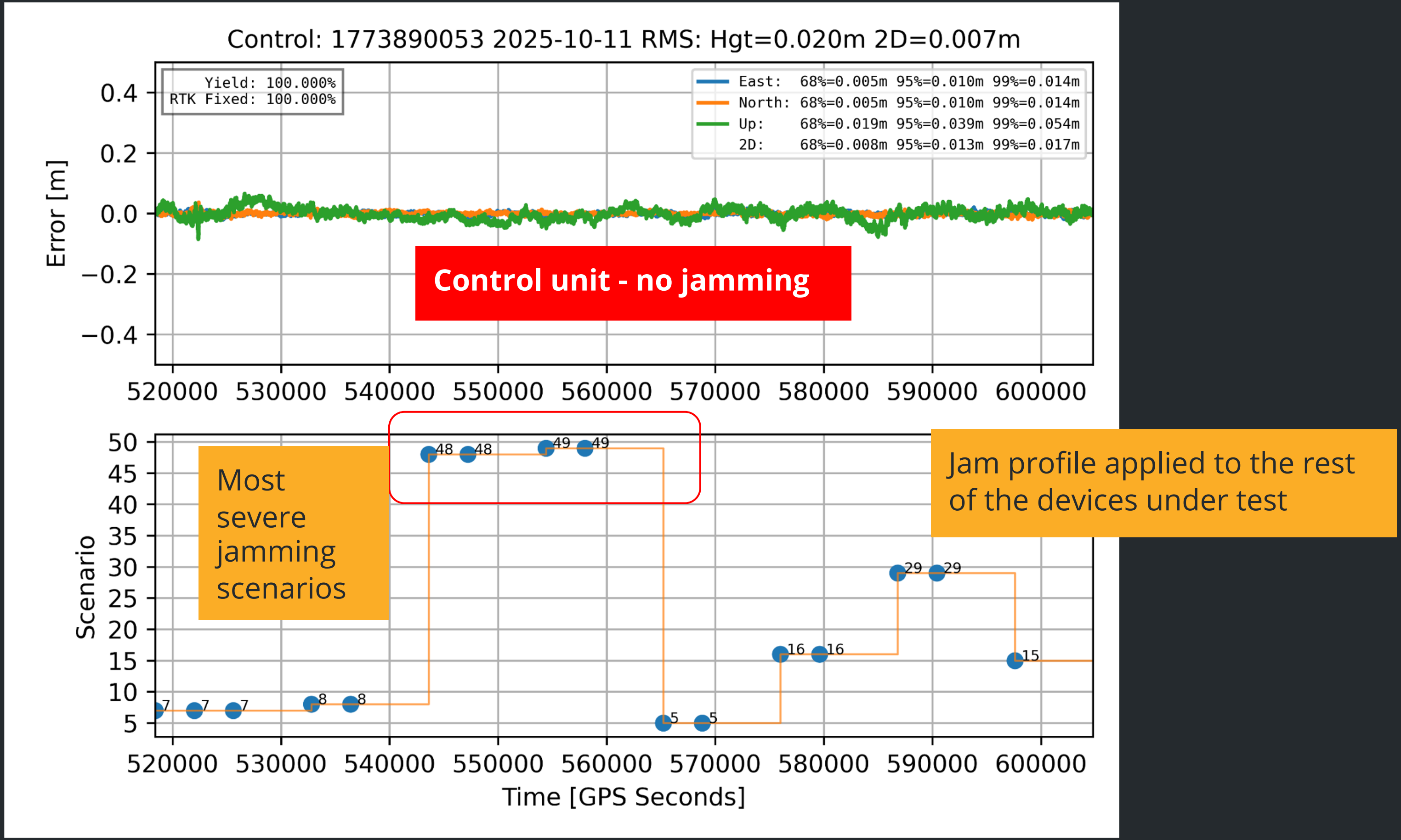
ALL | GPS | GLONASS | Galileo | BeiDou | QZSS | NavIC | SBAS | MSS

SV	Type	Elev. [°]	Azim. [°]	L1-C/No Pos Ant [dBHz]	L1	L2-C/No Pos Ant [dBHz]	L2	L5-C/No Pos Ant [dBHz]	L5	L6-C/No Pos Ant [dBHz]	L6	Iono	IODE	URA [m]	Type
19	Galileo	73.20	128.02	45.0	CBOC	-	-	47.6	Alt	50.7	E6	🟡	78	3.12	-
9	GPS	72.06	304.51	48.0	CA	48.1	CM+CL	50.9	I+Q	-	-	🟢	46	2	IIF
4/6	GLONASS	71.87	182.41	48.1	CA	48.1	CA	-	-	-	-	🟠	9	5	M
4	GPS	71.25	133.78	44.7/48.4	CA/BOC	49.5	CM+CL	50.9	I+Q	-	-	🟡	149	2	III
21	Galileo	67.57	61.68	49.2	CBOC	-	-	50.3	Alt	56.1	E6	🔴	78	3.12	-
37	BeiDou	60.96	267.13	48.2/49.9	B1I/B1C	-	-	49.2	B2A	48.4	B3I	🔴	1	2.4	MEO
14/-7	GLONASS	59.92	16.50	50.2	CA	47.5	CA	-	-	-	-	🔴	9	2.5	M
23	BeiDou	57.79	45.14	47.5/49.9	B1I/B1C	-	-	48.2	B2A	48.5	B3I	🔴	1	2.4	MEO
32	BeiDou	57.18	201.63	47.8/50.7	B1I/B1C	-	-	48.8	B2A	49.2	B3I	🟡	1	2.4	MEO
15/0	GLONASS	52.12	258.40	48.6	CA	46.0	CA	-	-	-	-	🟠	9	2	M
5/1	GLONASS	49.19	322.14	48.8	CA	47.8	CA	-	-	-	-	🟢	9	4	M
16	GPS	44.57	50.51	45.5	CA	33.0	E	-	-	-	-	🔴	7	2	IIR
20	BeiDou	43.87	303.00	49.2/48.5	B1I/B1C	-	-	46.3	B2A	45.3	B3I	🟠	1	2.4	MEO
4	Galileo	43.68	311.88	47.8	CBOC	-	-	48.3	Alt	51.9	E6	🟠	70	3.12	-
RTXNA	MSS	43.67	173.59	50.8	-	-	-	-	-	-	-	-	-	-	-
7	GPS	42.52	287.59	45.8	CA	43.3	CM+CL	-	-	-	-	🔴	90	2	IIR-M
131	SBAS	42.25	198.16	45.0	CA	-	-	-	-	-	-	-	151	16	-
135	SBAS	39.51	209.40	44.5	CA	-	-	-	-	-	-	-	116	16	-
133	SBAS	37.62	214.83	45.4	CA	-	-	-	-	-	-	-	234	16	-
27	GPS	33.73	105.41	42.6	CA	42.8	CM+CL	47.9	I+Q	-	-	🟠	11	2	IIF
57	BeiDou	27.03	95.51	-	B1I	-	-	-	B2A	-	B3I	-	-	-	MEO
8	GPS	26.80	143.20	39.9	CA	39.6	CM+CL	44.6	I+Q	-	-	🟢	41	2	IIF
29	Galileo	26.24	130.90	45.7	CBOC	-	-	46.8	Alt	47.5	E6	🟢	63	3.12	-
3/5	GLONASS	21.76	158.59	44.6	CA	40.5	CA	-	-	-	-	🟢	9	4	M
6	Galileo	18.29	311.14	41.2	CBOC	-	-	44.0	Alt	43.9	E6	🟠	78	3.12	-
27	Galileo	15.67	44.01	42.7	CBOC	-	-	41.5	Alt	43.9	E6	🟢	78	3.12	-
3	GPS	13.58	191.86	36.6	CA	37.5	CM+CL	41.2	I+Q	-	-	🟢	31	2	IIF
30	GPS	13.35	274.96	36.3	CA	38.4	CM+CL	42.6	I+Q	-	-	🟡	147	2	IIF
26	GPS	12.34	48.68	37.9	CA	34.8	CM+CL	37.7	I+Q	-	-	🟢	39	2	IIF
41	BeiDou	12.31	161.82	36.8/37.6	B1I/B1C	-	-	39.4	B2A	38.7	B3I	🟢	1	2.4	MEO
43	BeiDou	11.35	93.68	37.2/38.8	B1I/B1C	-	-	36.9	B2A	38.2	B3I	🔴	1	2.4	MEO

Jamming

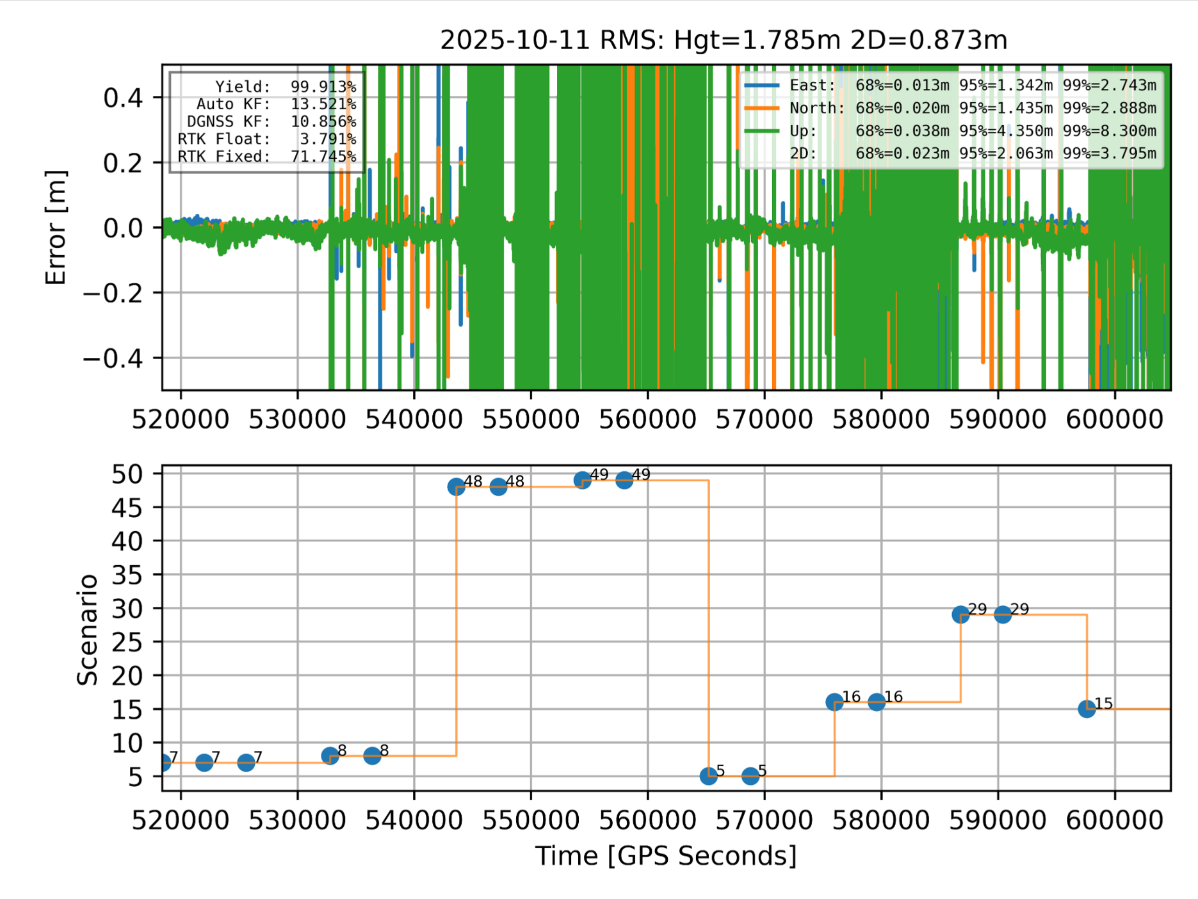
- Created over 50 jam scenarios
  - Measured threats
  - Theoretical threats
  - Combinations (CW, Chirp, Broadband, one or more bands, pulsed variants, …)
  - Couple the jam source on to a cabled live sky feed (no broadcast)
  - Each scenario at least 3 hours
  - Continually loop through all scenarios and automatically test
    - Collect various KPIs
- Trimble systems attempt to maintain lock through jamming
  - PVT is system agnostics and uses whatever is available

Jamming Test



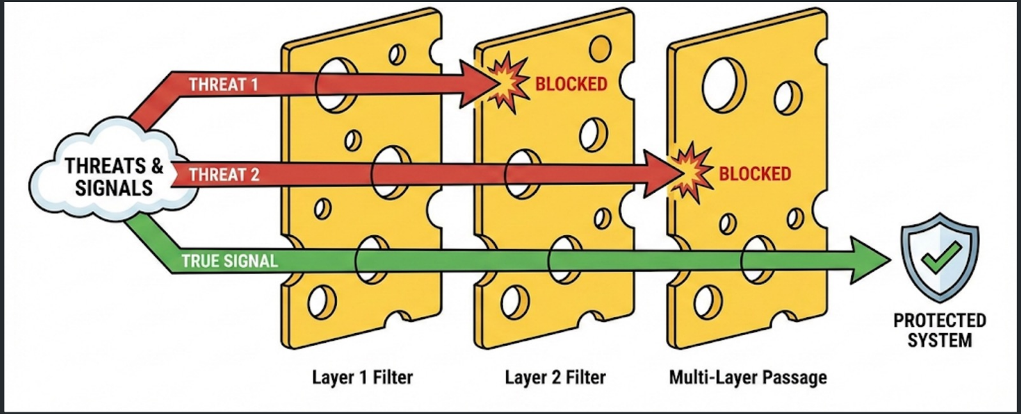
Jamming Test

Competitive system with good anti-jam, but the PVT performance degrades with more complex jamming



Spoofing

- Attempt to prevent the spoofer “capturing” the channels
  - But accept that signals will get spoofed
- Implement a “Swiss Cheese” layer approach to anti-spoofing
  - Cross check between signals (L1, L2, L5) etc
  - Signals from the same satellite on the same band (L1 C/A to L1C)
  - Review residuals / form sub-system solutions
  - Review the spectrum (Trimble receivers have access to the FFT)
  - Navigation Message Authentication (NMA)

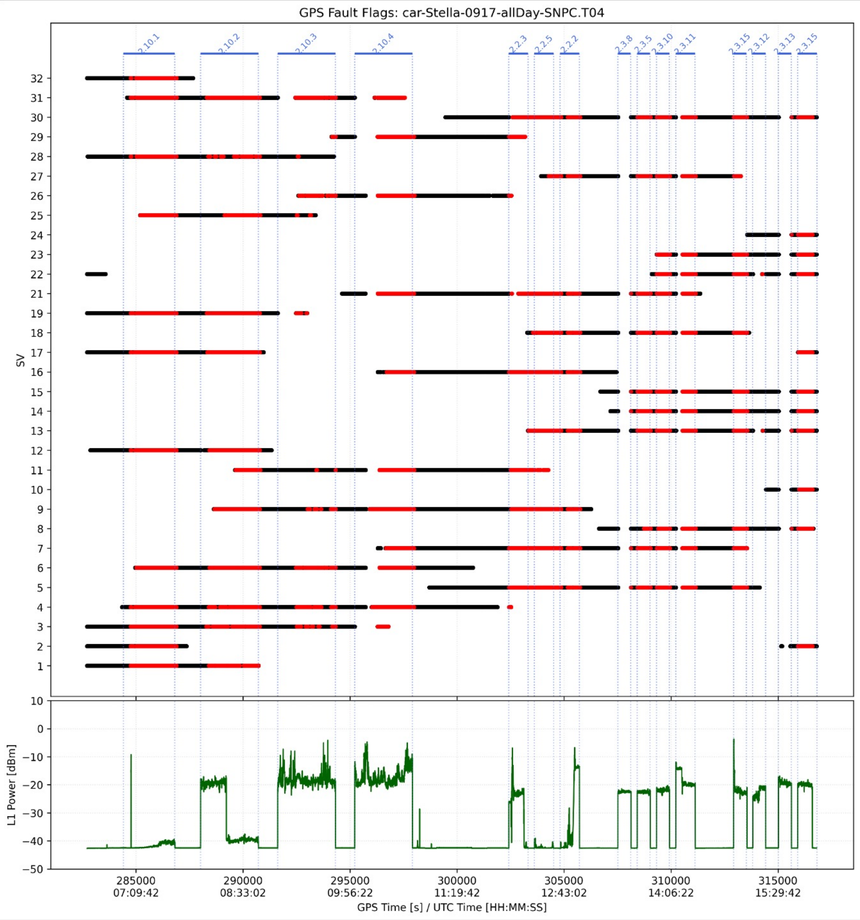


Test Scenario

- World’s largest civilian jamming/spoofing test
- Held annually in Northern Norway (Bleik)

Test Scenario - Receiver

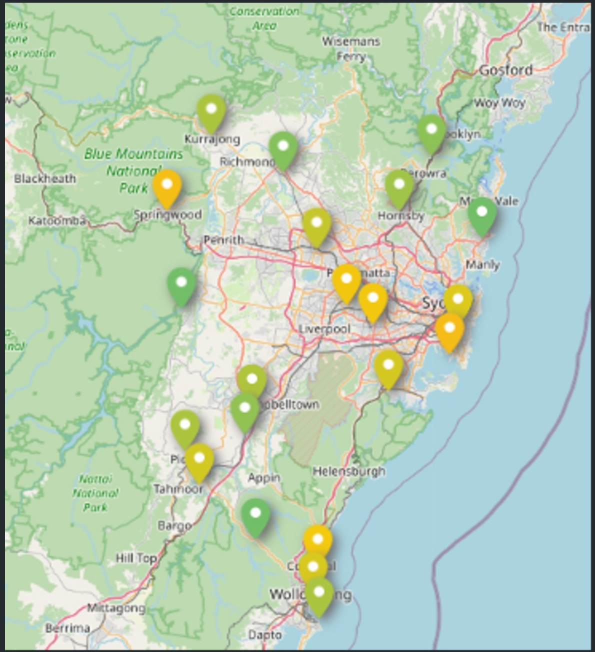
- GPS fault detection
- Red
  - One or more flags
  - On one or more signals
- Blue segments are spoofing tests



Pivot 5.3 - Jamming and Spoofing Portal

- Trimble hosted web applications
- Customers can only see their own data
- Analyze 4 KPIs per signal
- Provide a localized view of jamming and spoofing

Pivot provides a localized view



Jamming Detection

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Signal-to-Noise Ratio

Monitors the ratio of signal power to noise power; corrections are applied for satellite elevation and receiver type.

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Power Spectrum

Analyzes power distribution across frequency domains; L1/L2 monitoring via Trimble Alloy firmware.

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SNR Std. Deviation

Calculates the volatility of the signal quality to distinguish between natural noise and artificial interference.

loc
k

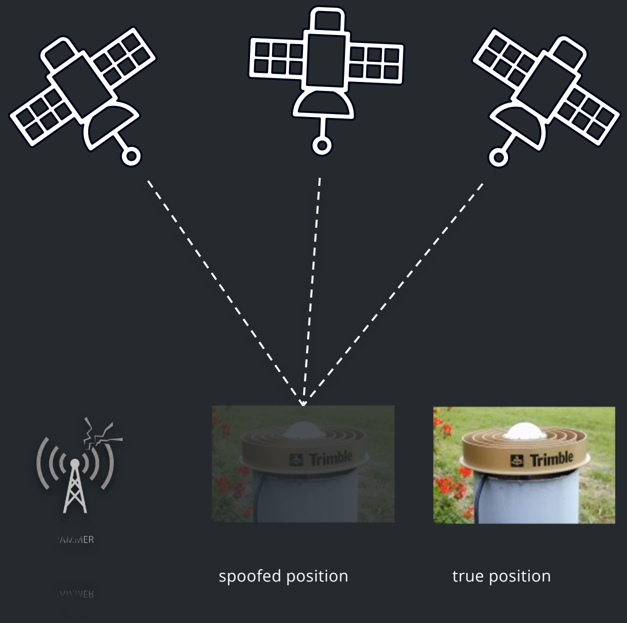
Loss-of-Lock (LLI)

Tracks frequency of disconnects between satellites and receivers as a primary indicator of denial-of-service.

Spoofing Detection

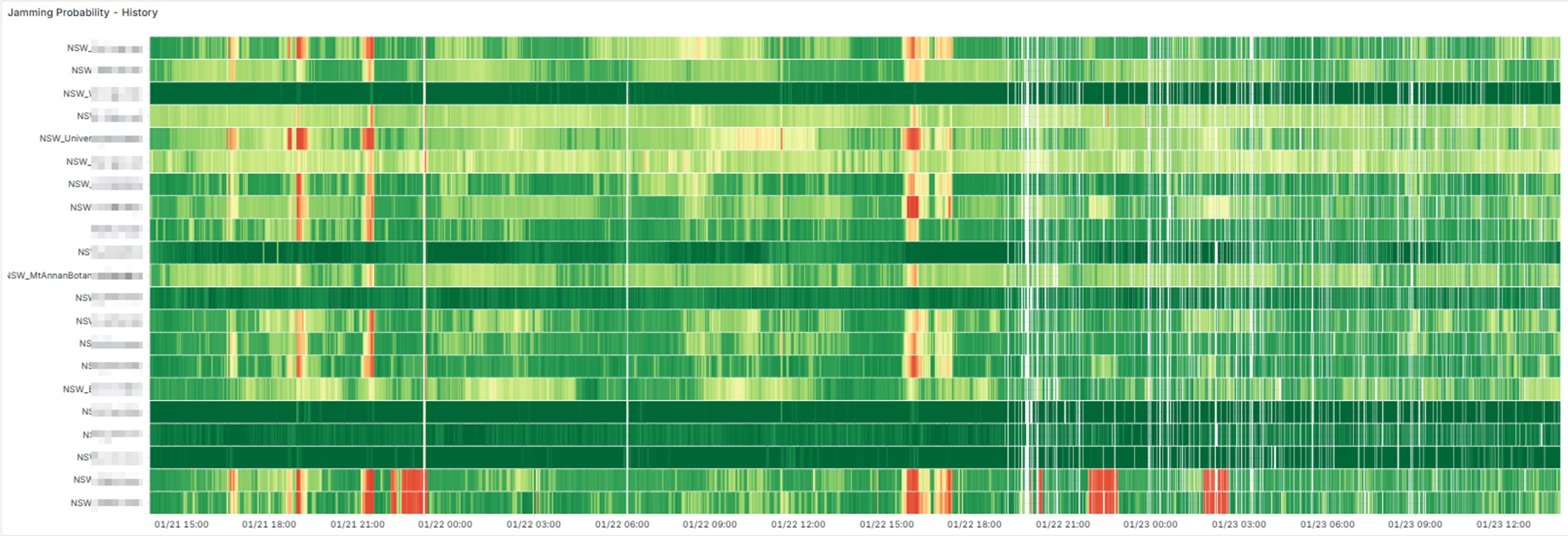
Spoofing affects an entire satellite system

- **Single Point Position (SPP)** calculated for each constellation individually
- **Offset [m] (3D, 2D, Height)** calculated based on station coordinate per satellite system
- **Alarming** if offset exceeds configured threshold
- Observation **before Raw Data Analysis (RDA)** used



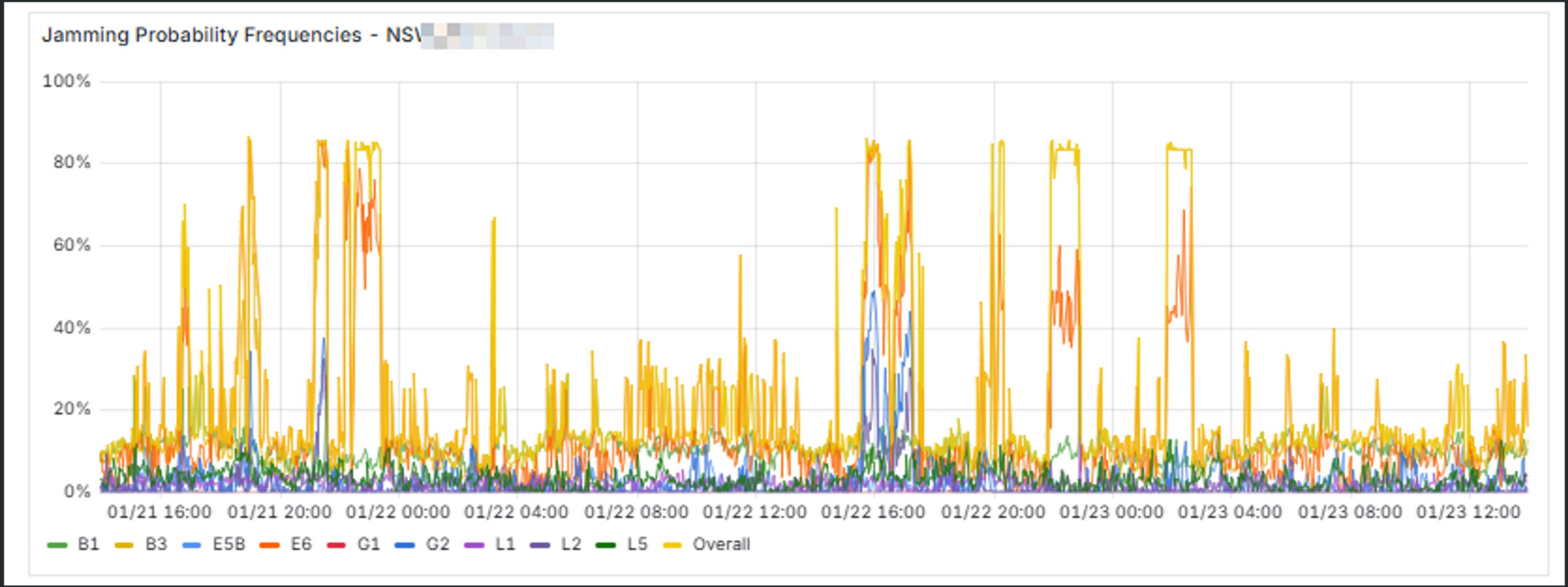
Pivot 5.3 - Jamming and Spoofing Portal

- 48 hours in the Sydney area
- Shows jamming on some stations

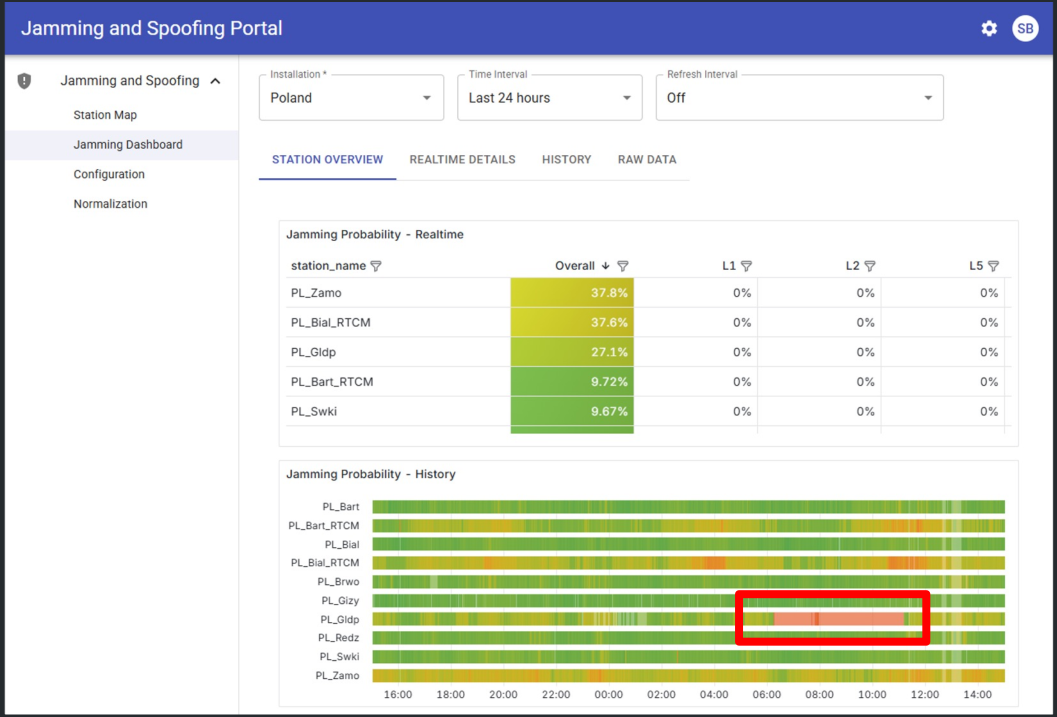


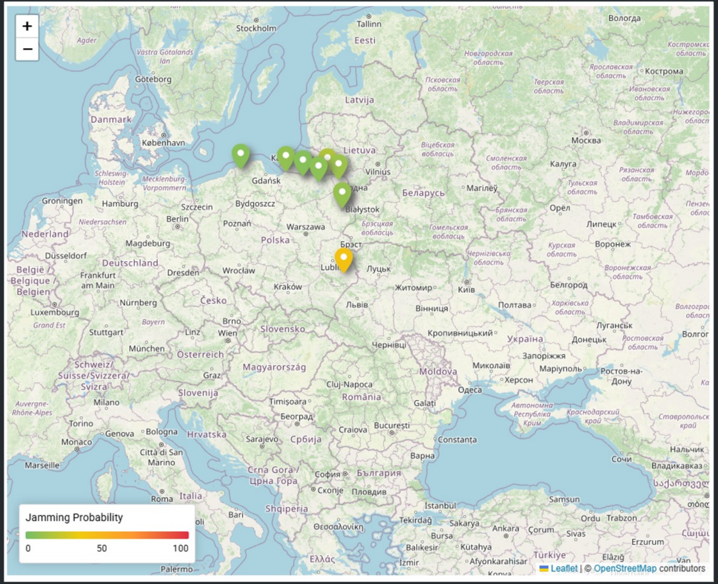
Pivot 5.3 - Jamming and Spoofing Portal

- Deep dive on stations
  - In this case most of the impact is in E6 and B3



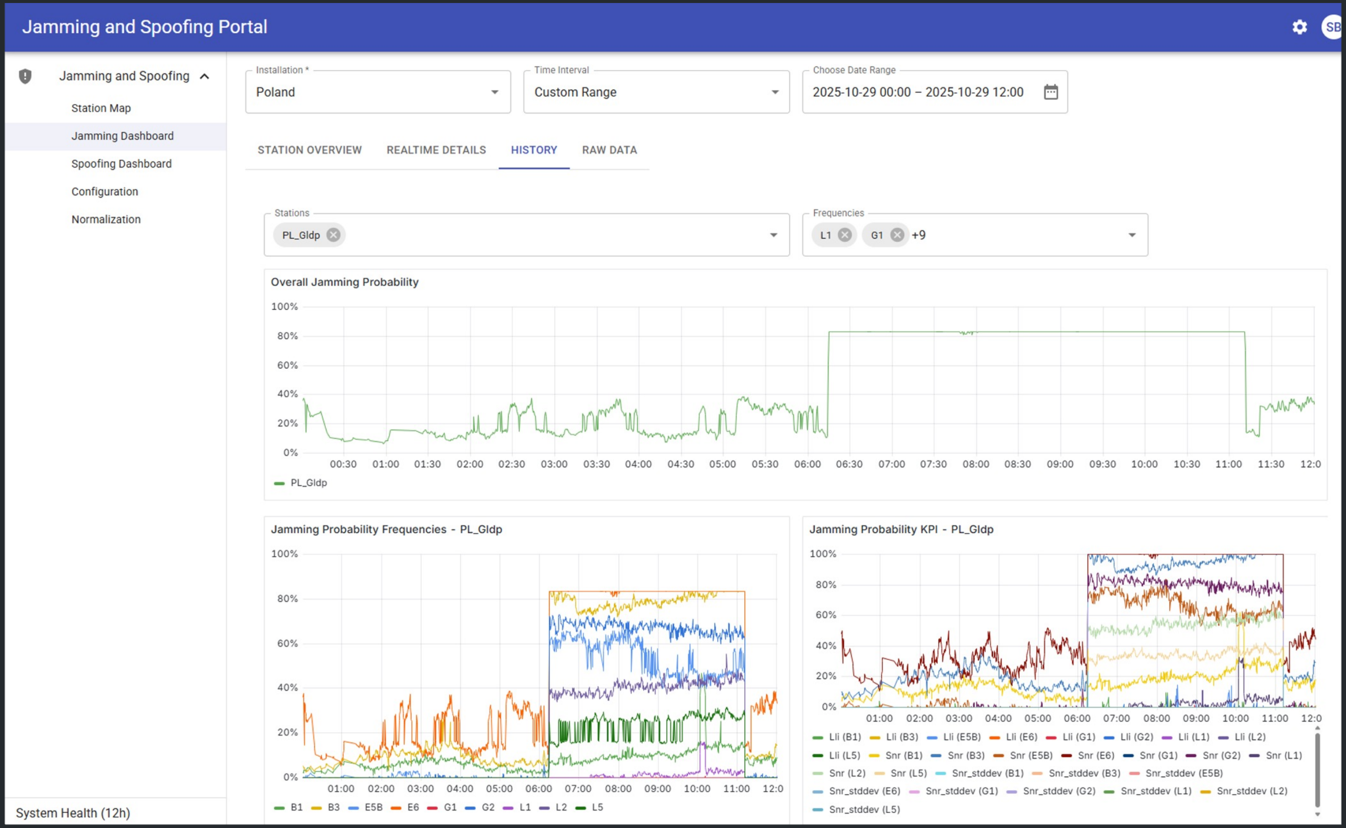
Pivot 5.3 - Jamming and Spoofing Portal





Pivot 5.3 - Jamming and Spoofing Portal

- In this case there’s jamming on most bands



Coordinate Transformations Overview

01 Trimble RTX

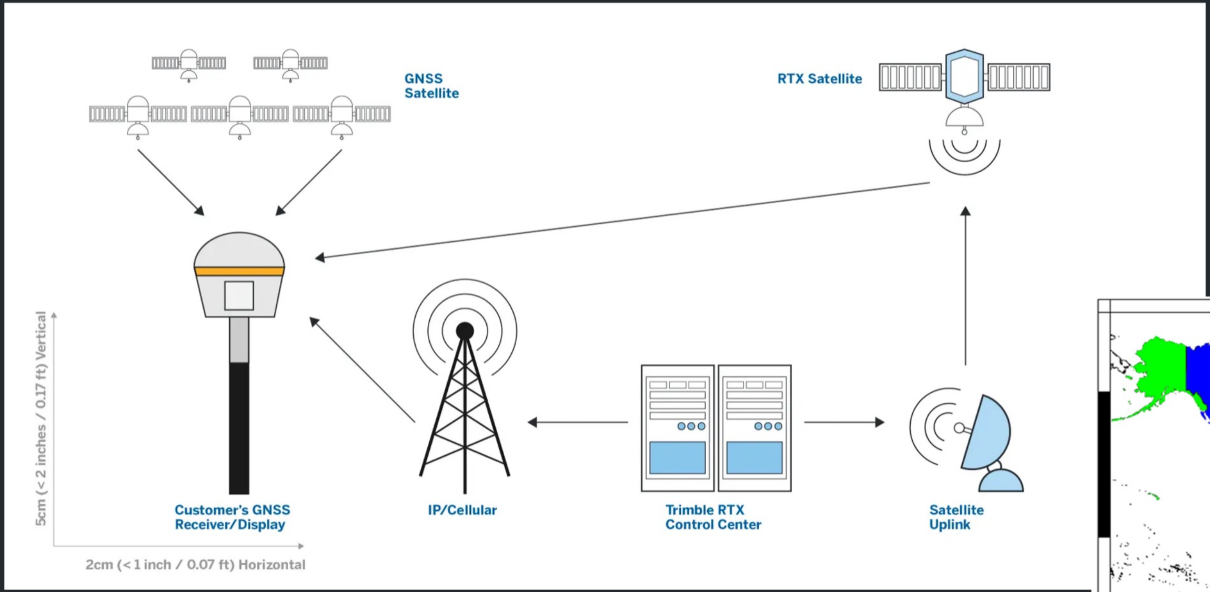
02 Trimble Geodetic Library (TGL)

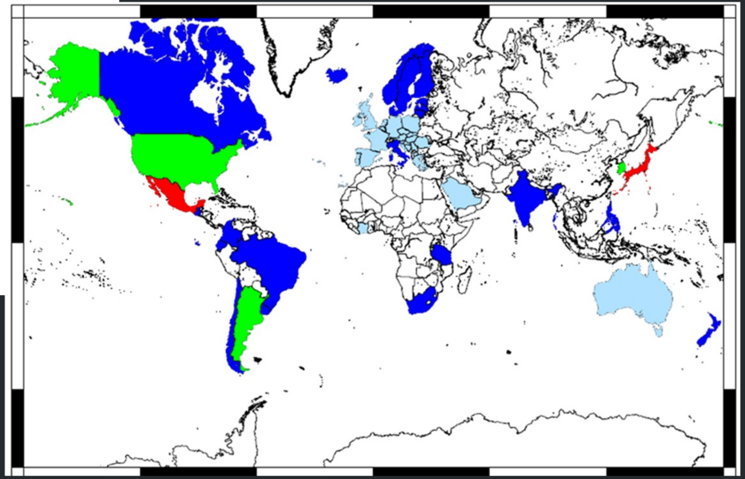
03 Other Applications

04 Deformations and velocity models

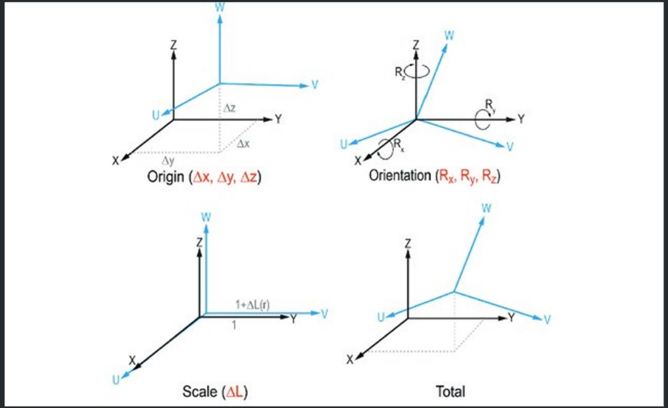
05 Case-Study for Chile

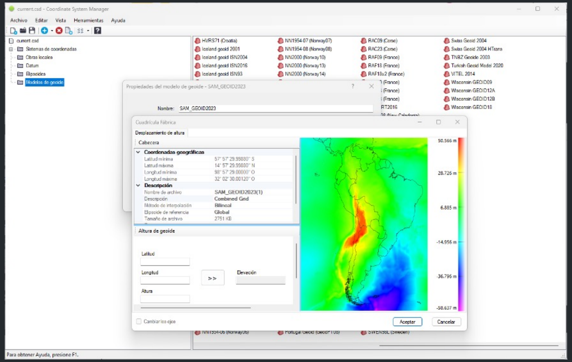
Trimble RTX

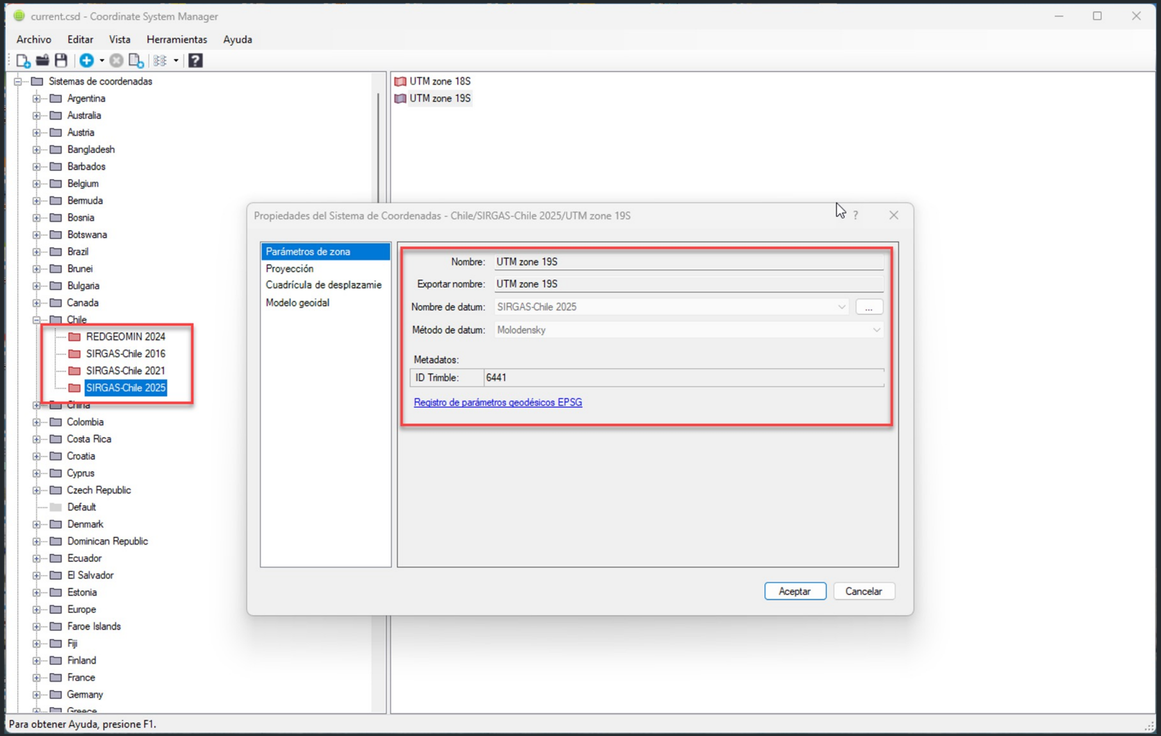

GNSS
Satellite
RTX Satellite
5cm (< 2 inches / 0.17 ft) Vertical
Customer's GNSS
Receiver/Display
IP/Cellular
Trimble RTX
Control Center
Satellite
Uplink
2cm (< 1 inch / 0.07 ft) Horizontal



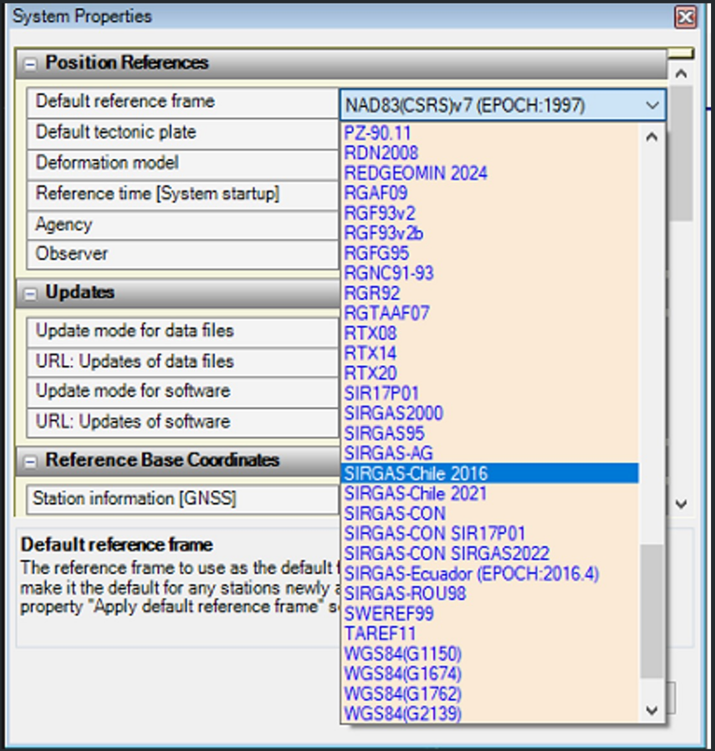
Trimble Geodetic Library (TGL)

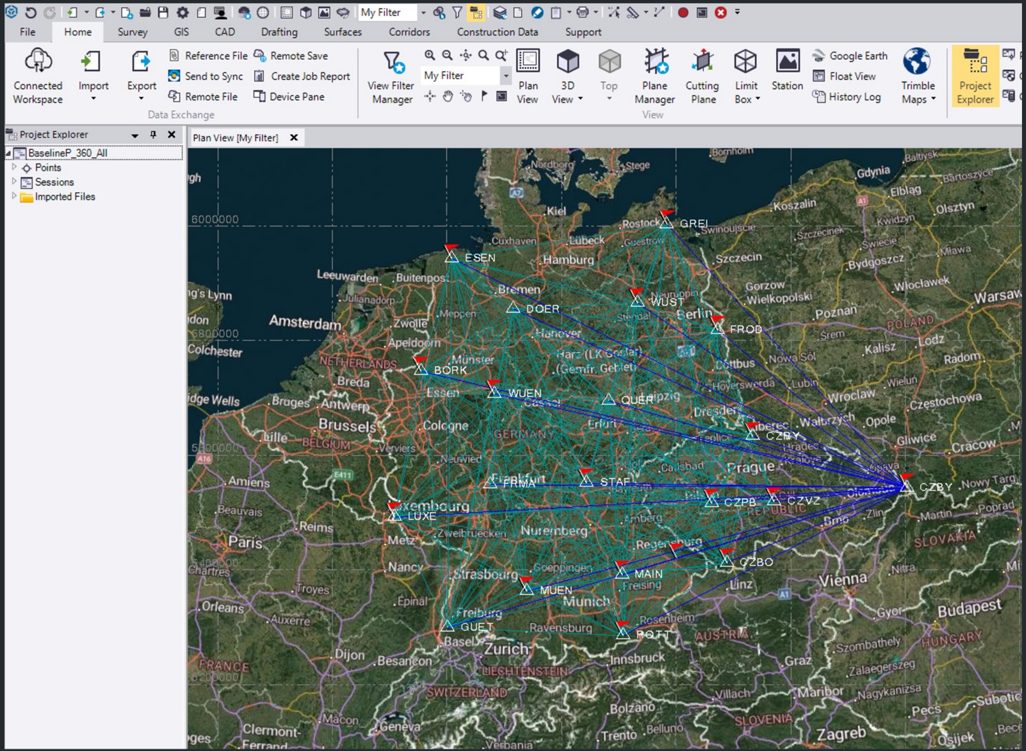




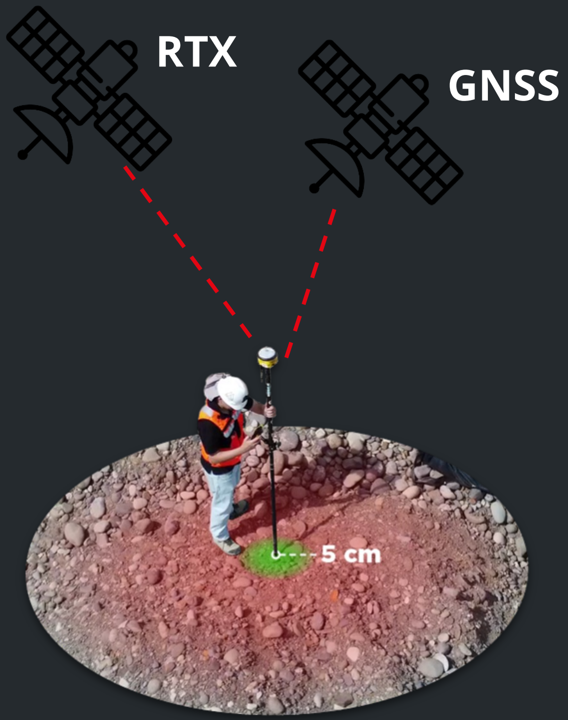


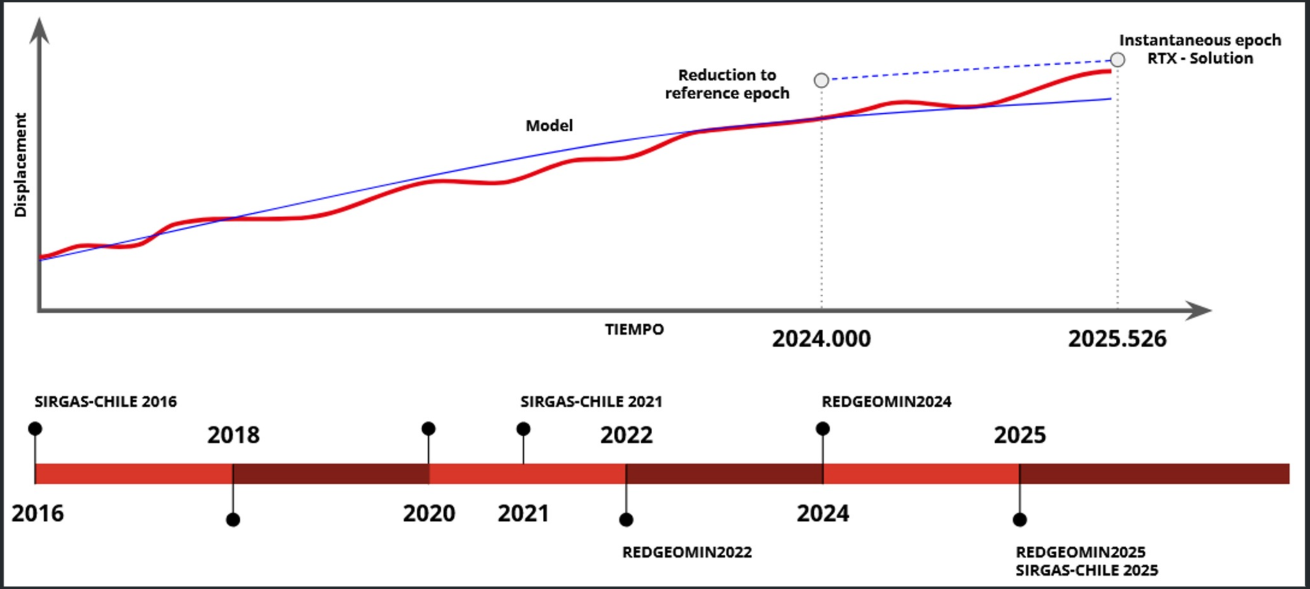
Other Applications





Deformations models on Trimble Geodetic Library - velocity models





Deformations and velocity models on Trimble Geodetic Library

Sistema

Chile/SIRGAS-Chile 2025

Datum local

SIRGAS-Chile 2025 (Mol)

Datum de referencia global

SIRGAS-Chile 2025

Modelo de desplazamiento

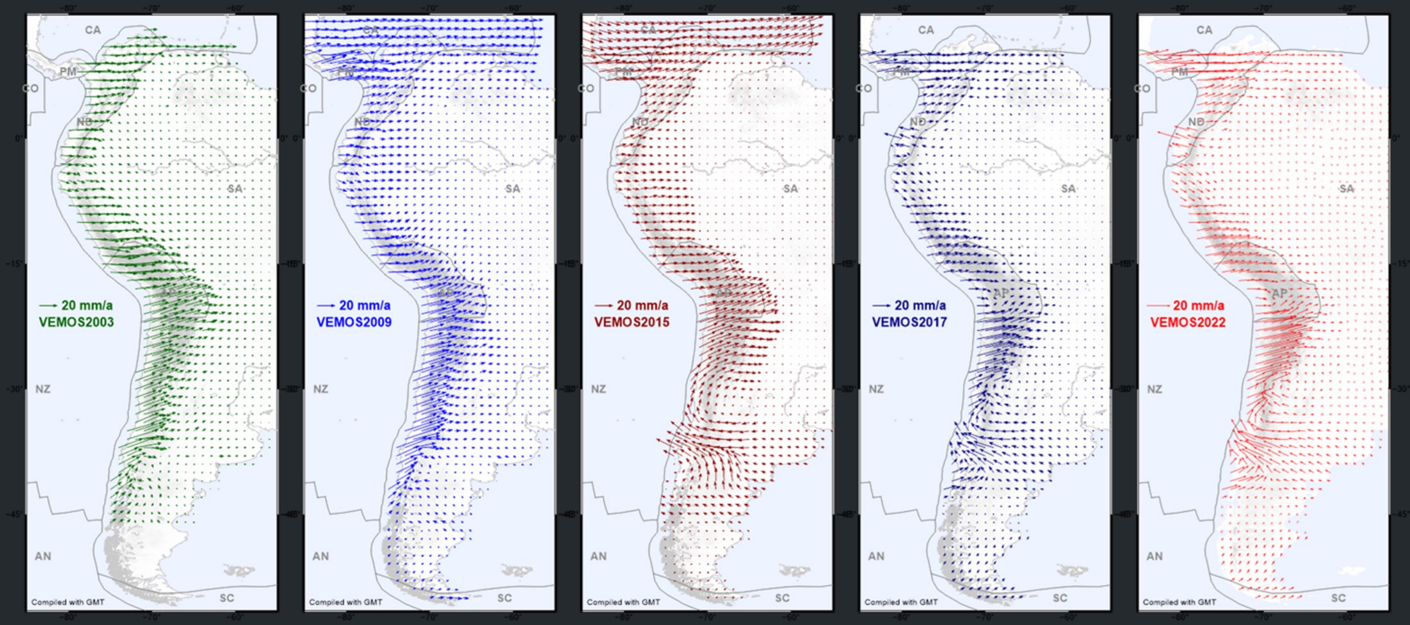
VEMOS2022 2024-02-01

Usar modelo geoidal

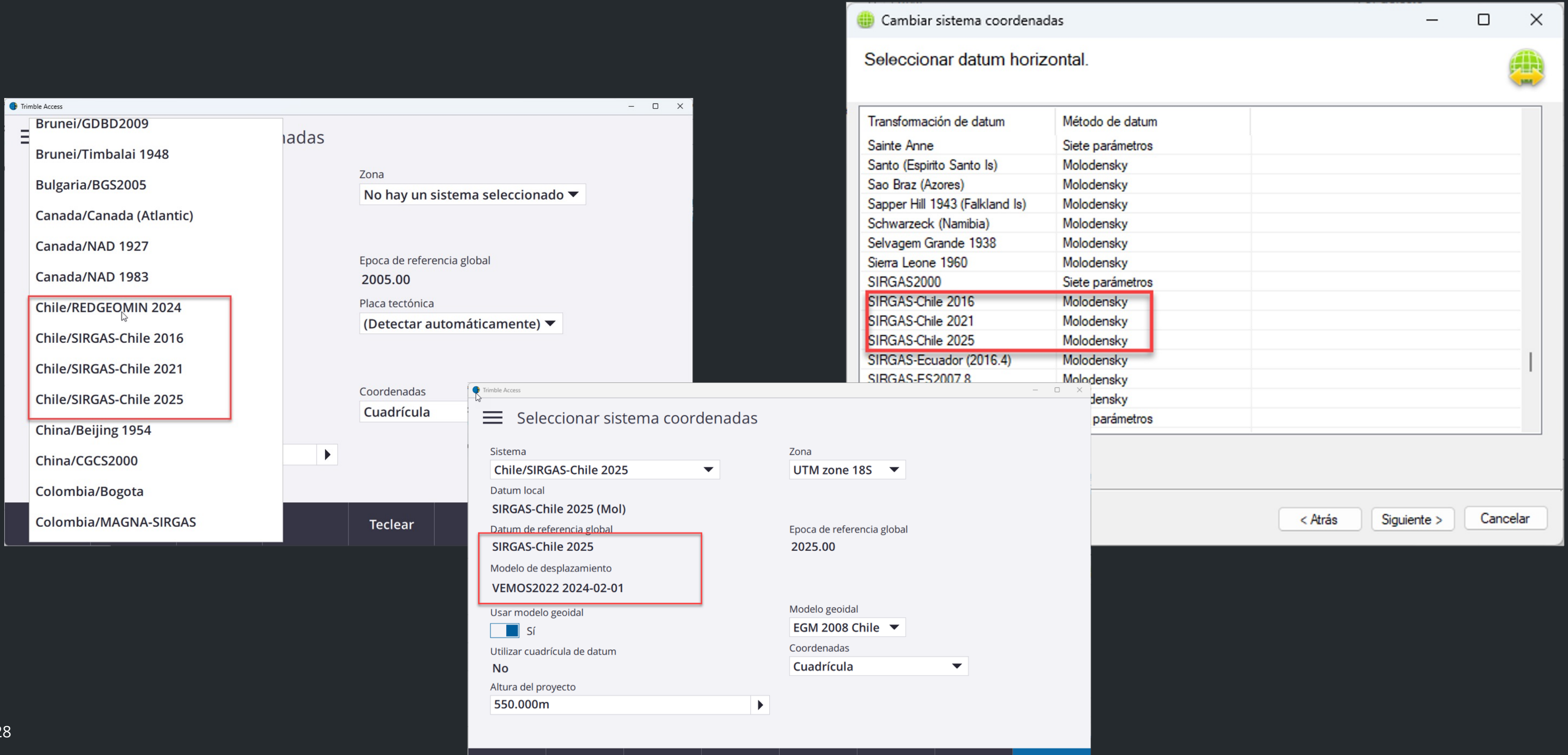
Sí

Utilizar cuadrícula de datum

No



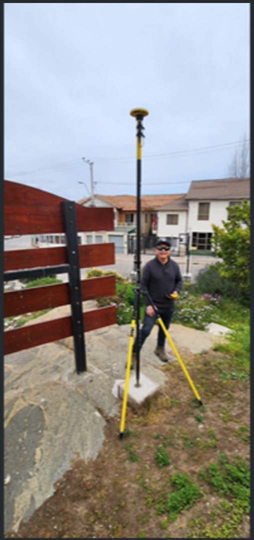
Case-study for Chile



Case-study for Chile - RTX RT vs SIRGAS-CHILE 2021

MOLL1

MOLL2



GOBQ

DR1

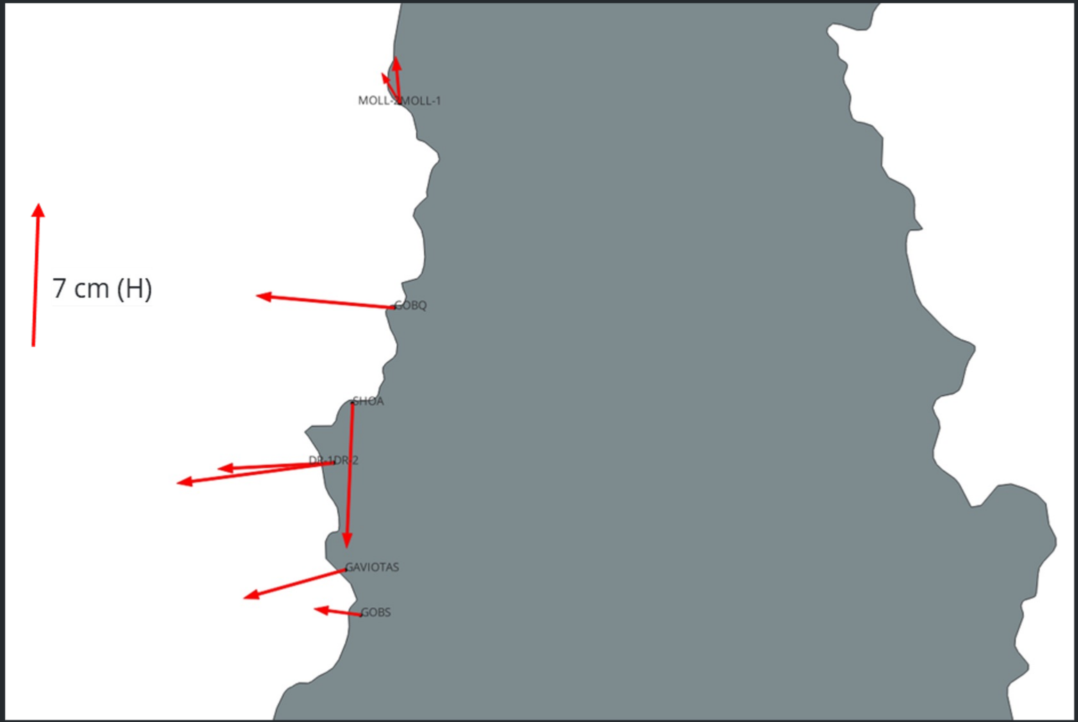
DR2

GAVIOTAS

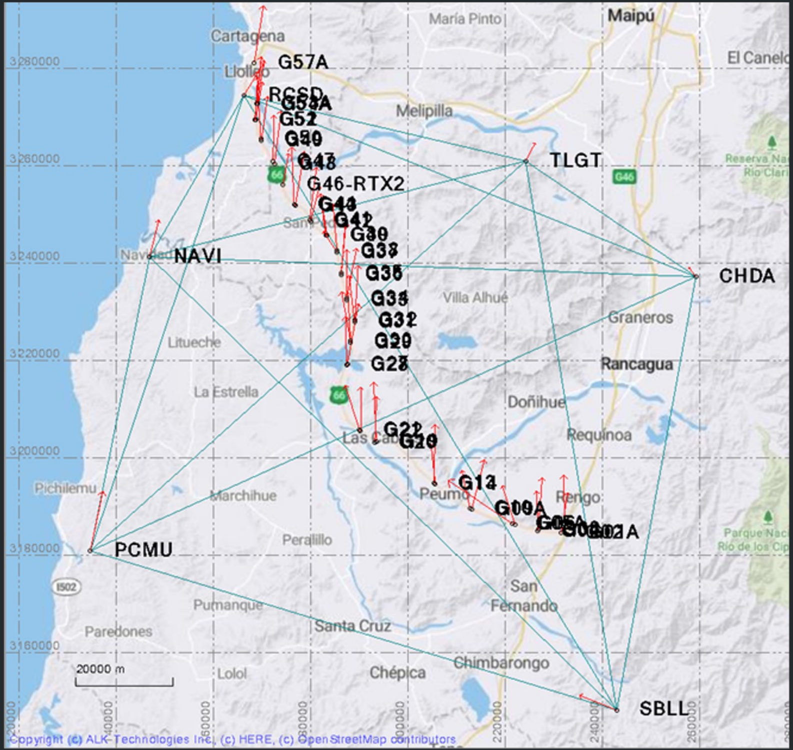
GOBS

Case-study for Chile - RTX RT vs SIRGAS-CHILE 2021

∆=~ 4.8 cm



Case-study for Chile - RTX RT vs SIRGAS-CHILE 2016



Dif. horizontal = 0.032 m
Dif. vertical = 0.042 m

Trimble

Danke شكرا Tack

ありがとうございます

Teşekkürler Спасибо

Grazie 감사합니다 Obrigado

Thank you

Gracias Tak Merci 谢谢

Takk Dziękujemy Terima kasih

Dankjewel धन्यवाद

Cảm ơn Kiitos

Dr. Chris Pearson

Memory Tree

Facebook

1952 - 2025