kurloo

Low-cost GNSS solution to densify the national terrestrial reference frame stations

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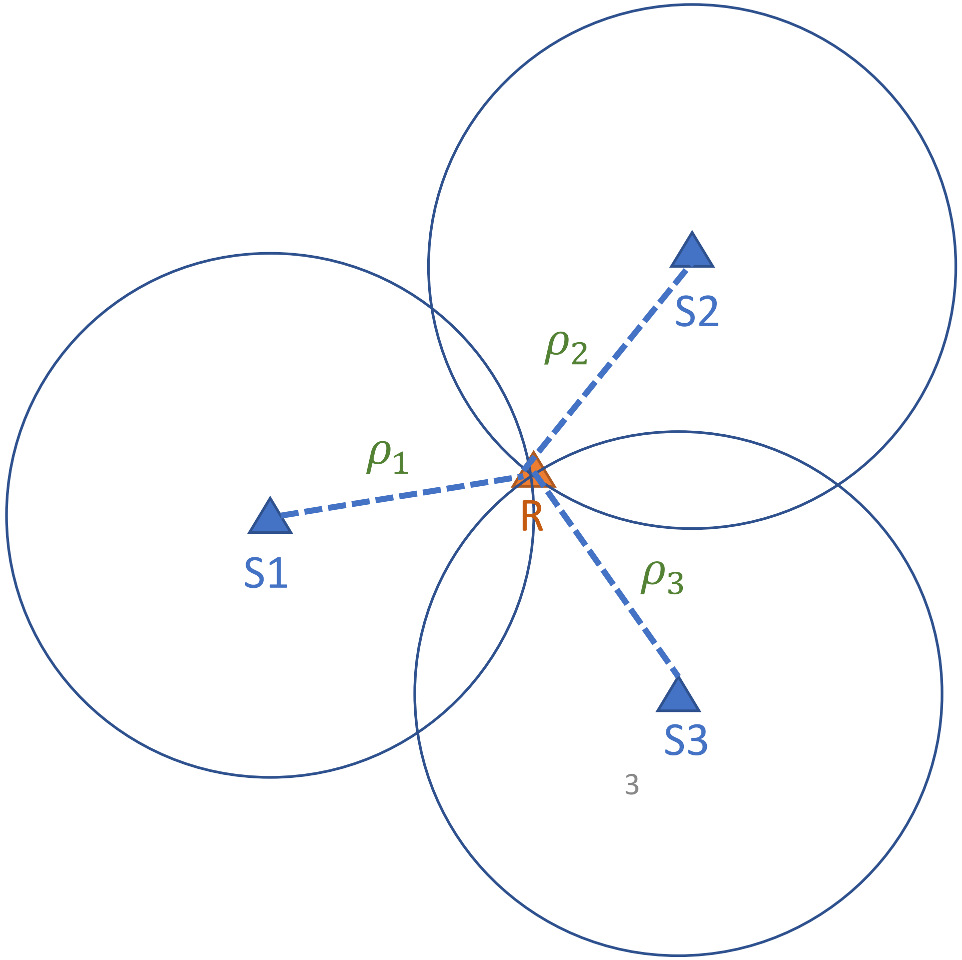
Basic Principle of ***GNSS Positioning***

Basic principle of GNSS positioning

"Positioning" in a 2D space

Positions of points S1, S2, and S3 are known

If the distances from points S1, S2, and S3 to point R are measured, the position of R can be determined.



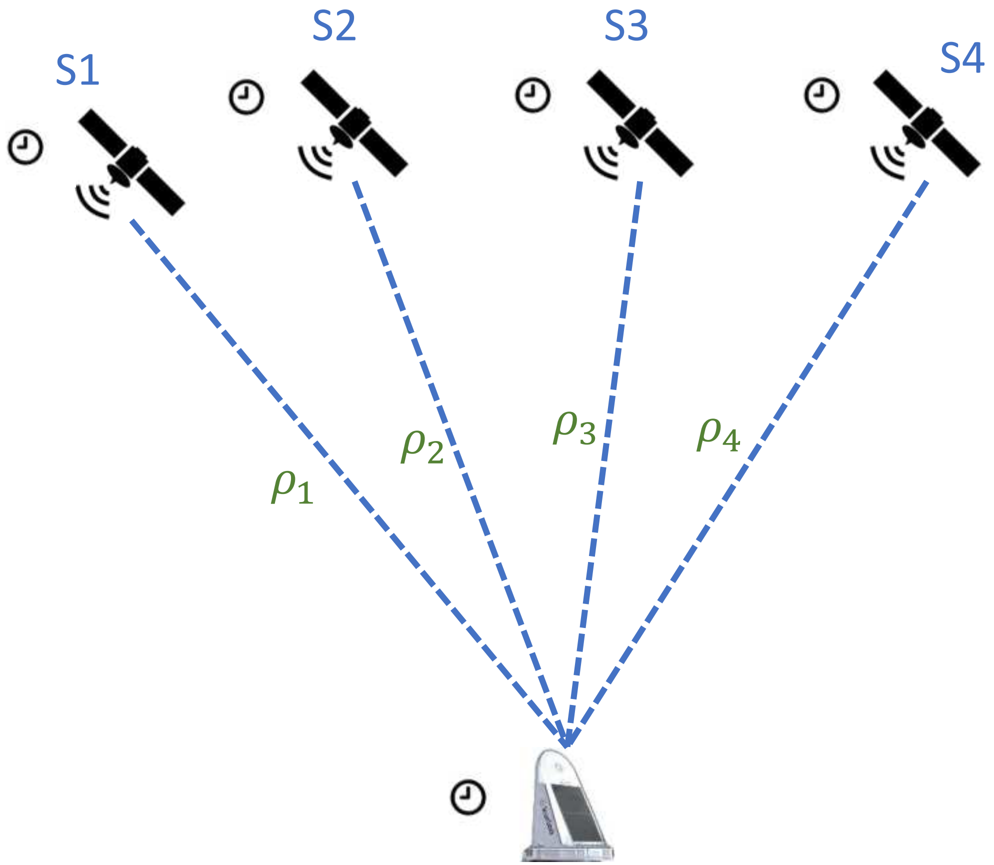
ρ_n: *Range between point* S_n *and point R*

Basic principle of GNSS positioning

Positioning in the ideal 3D space

Assume:

1. **Positions of satellites are accurately known**
2. **Clocks on satellites and receiver have no bias**
3. **Signal is transmitted in the vacuum**



$$\rho = c * \Delta t$$

ρ: *Range between satellite and receiver*

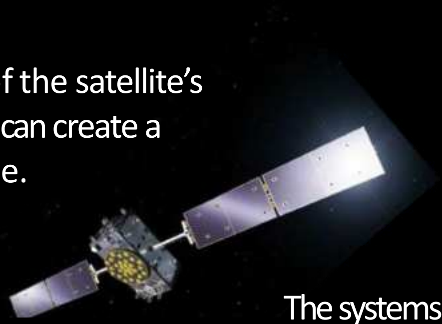
c: *Speed of signal transmatting in vacuum*

Δt: *Time difference between satellite and receiver*

Orbit and clock variations

Because the system takes measurements based on the speed of light – big number – tiny variations in orbit position and satellite clock time has a big effect on a calculated position on Earth.

The power of the satellite's transmitter can create a pushing force.

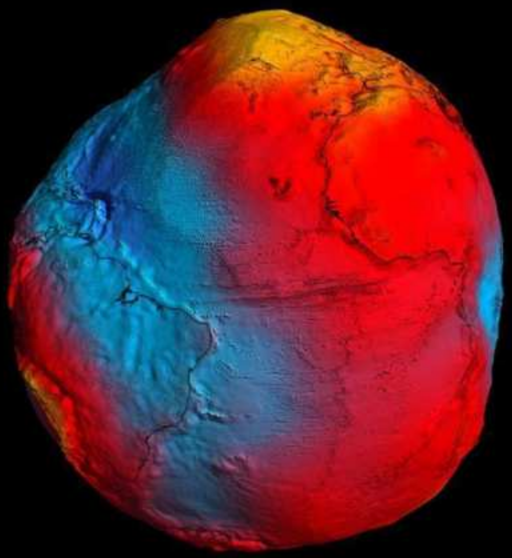


The movement of the moon and other bodies have gravitational effects on the satellites.

The systems within the satellite itself have "biases" – delays in time on signals due to the physical creation of the signal within the electronics.

Satellites carry very accurate clocks, but even they will drift a little over time and need to be corrected.

The "pressure" of sunlight on the satellite can push it away from the Sun



The Earth changes shape – Solid Earth Tides – in response to the gravitational pull of the Sun and Moon.

The Earth is not a perfect sphere – it's fatter round the middle and has "lumpy" gravity.

Rupert W Brown July 2021

Atmospheric effects

The Troposphere and Ionosphere

End of the Ionosphere at ~2,000km

The Ionosphere is a shell of electrons and electrically charged atoms and molecules that surrounds the Earth. It exists primarily due to ultraviolet radiation from the Sun.

The irregular electron density in the Ionosphere can cause phase and amplitude fluctuations in the GNSS signal so degrading its accuracy.
The Ionosphere is dispersive – it delays radio of different frequencies by different amounts.

The start of the Ionosphere at ~85km

The Mesosphere and Stratosphere The

Troposphere up to 18km

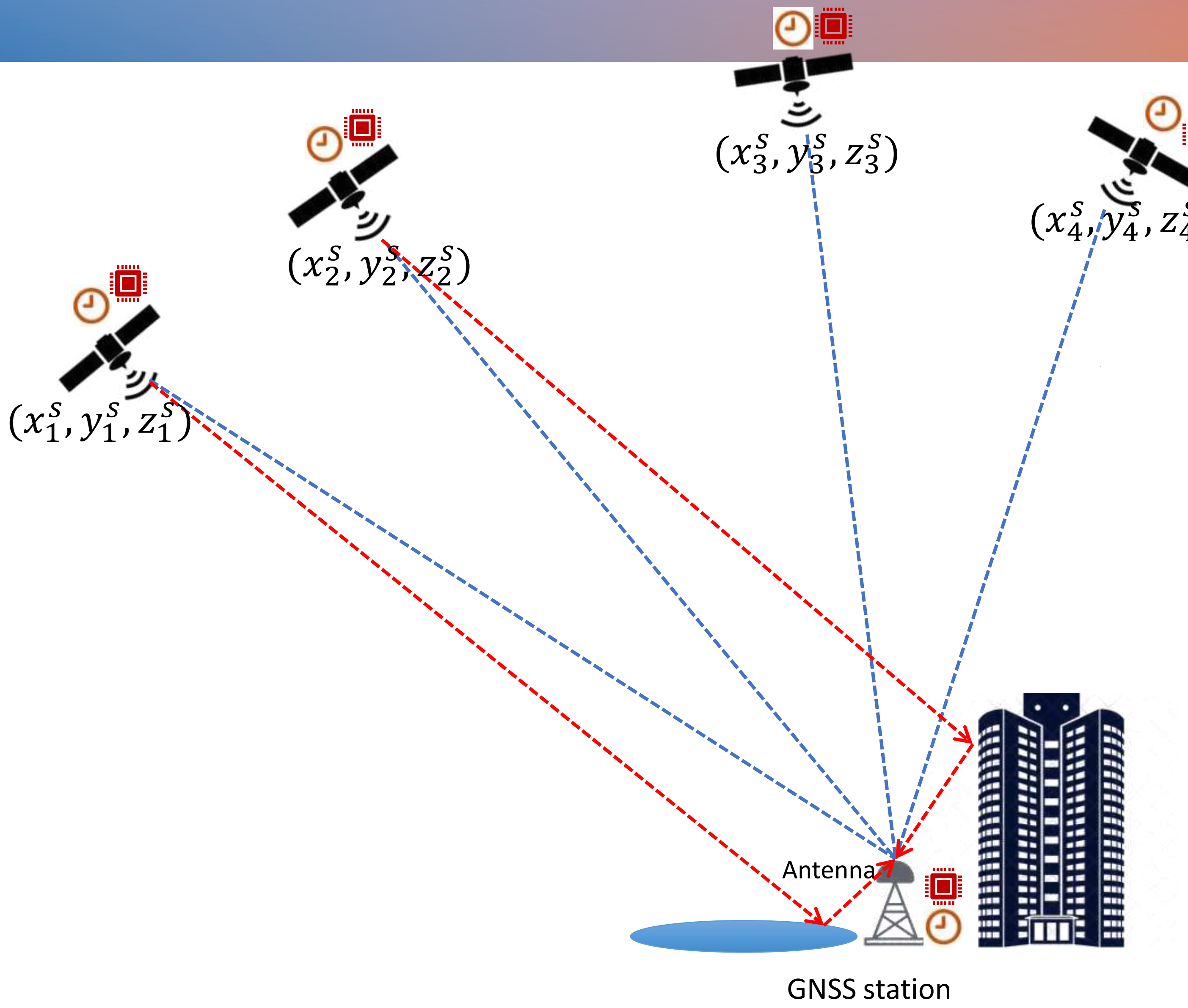
The surface of the Earth

The Troposphere gives the Earth its weather.
It's a layer up to 18km thick that contains 75% of the Earth's atmosphere and 99% of the water vapour. It both delays and refracts GNSS signals.

The Troposphere is not ionised – it does not contain free electrons.
The Troposphere is not dispersive – it delays radio of all frequencies by an equal amount.

The Troposphere hydrostatic (dry) delay is caused by dry gases and particles in the troposphere, and it is about 80–90% of the total tropospheric delay. Hydrostatic delay can be precisely determined from surface pressure measurements using empirical models. The tropospheric wet delay is due to water vapor content in the troposphere, and is difficult to precisely model.

KEY GNSS POSITIONING ERROR SOURCES



Satellite-dependent

- Hardware delays
- Satellite clock biases
- Satellite ephemeris biases

Propagation-dependent

- Ionospheric delay
- Tropospheric delay

Receiver-dependent

- Hardware delays
- Receiver clock biases
- Multipath errors

Difference between RTK and PPP

PPP

$$P_r^s = \rho_r^s + c(\delta\tau_r - \delta\tau^s) + T_r^s + I_r^s + d_r + d^s + O^s + \varepsilon_r^s$$

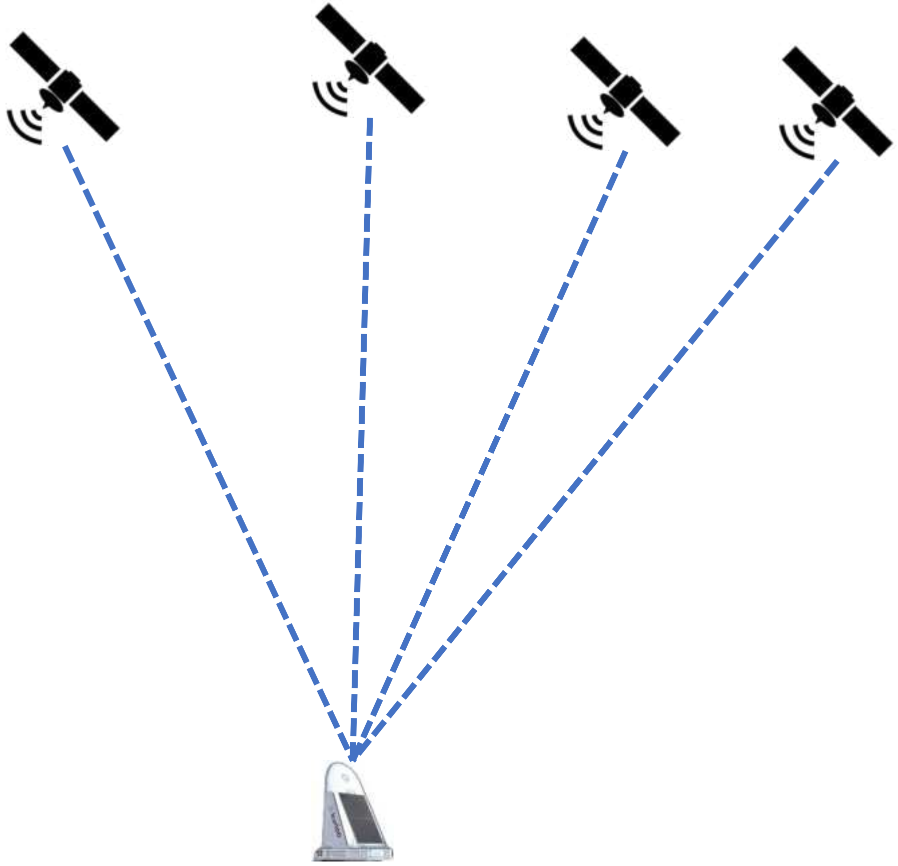
All the errors should be carefully corrected or estimated through models or available products （FIN, RAP）

Main differences between RTK and PPP:

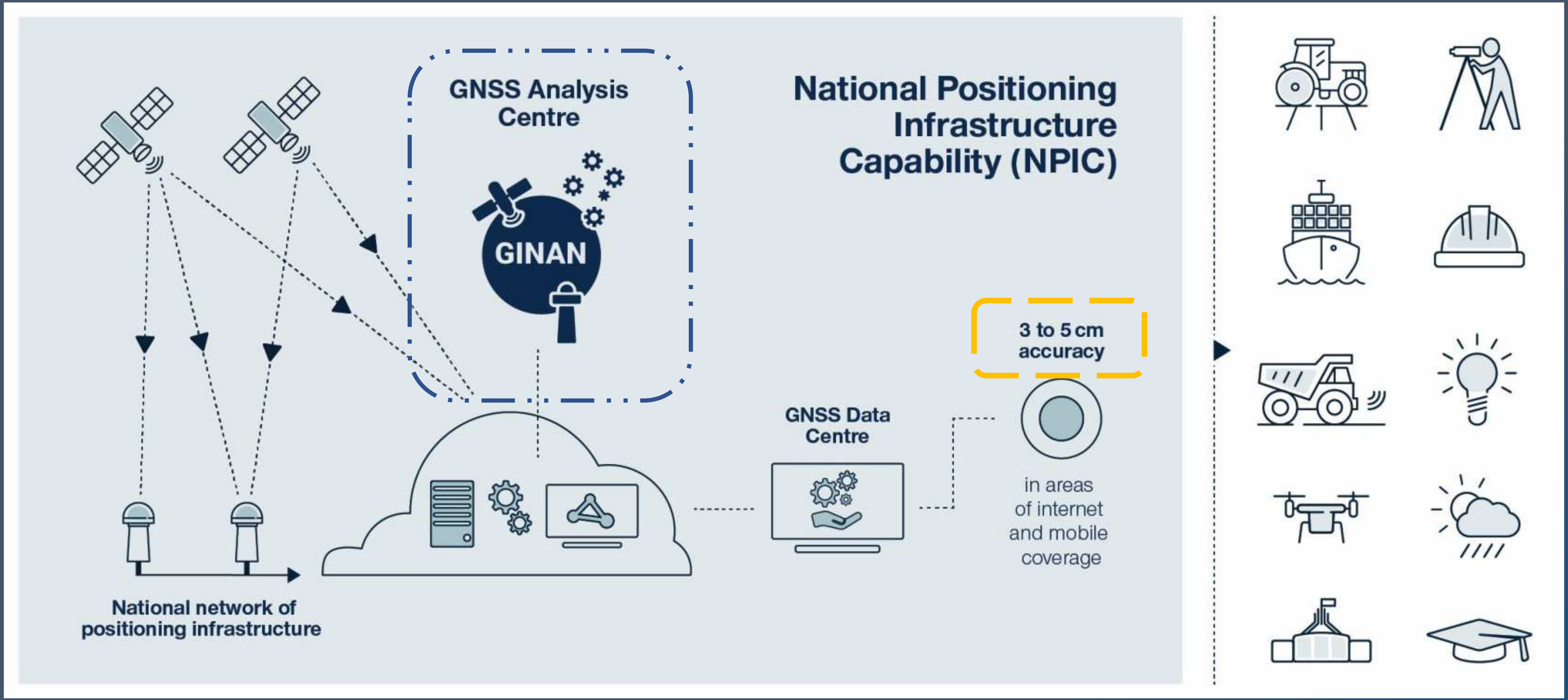
1. In terms of error and bias correction method
   - RTK: use differenced observations
   - PPP: through models and products

2. In terms of timeliness
   - RTK: real-time
   - PPP: post-processing
   - (PPP-RTK can obtain real-time results, but it is not supported in GINAN Version 2)

3. In terms of results
   - RTK: the derived position is relative to reference station
   - PPP: independent absolute position



Precise Point Positioning



Introduction of GINAN and CSRS-PPP

Ginan is an open source toolkit for creating precise point positioning (PPP) analysis products, correction streams and positions. It is being actively developed in a Geoscience Australia Positioning Australia program.

CSRS-PPP is an online application for GNSS data post-processing. It uses precise satellite orbit, clock and bias corrections derived from a global network of receivers to determine accurate user positions anywhere on the globe, regardless of proximity to reference stations.

According to Vázquez-Ontiveros, J.R., et al (2023), the CSRS is one of three best PPP processing software in the world. Therefore, we set the CSRS-derived results as benchmark.

Auto-run of GINAN

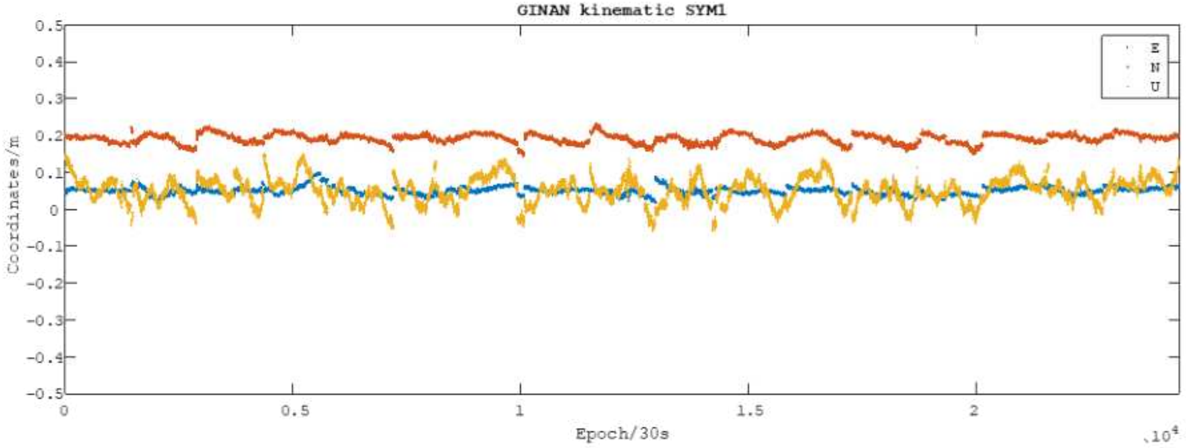
Developed a Python script for automatic PPP processing using GINAN

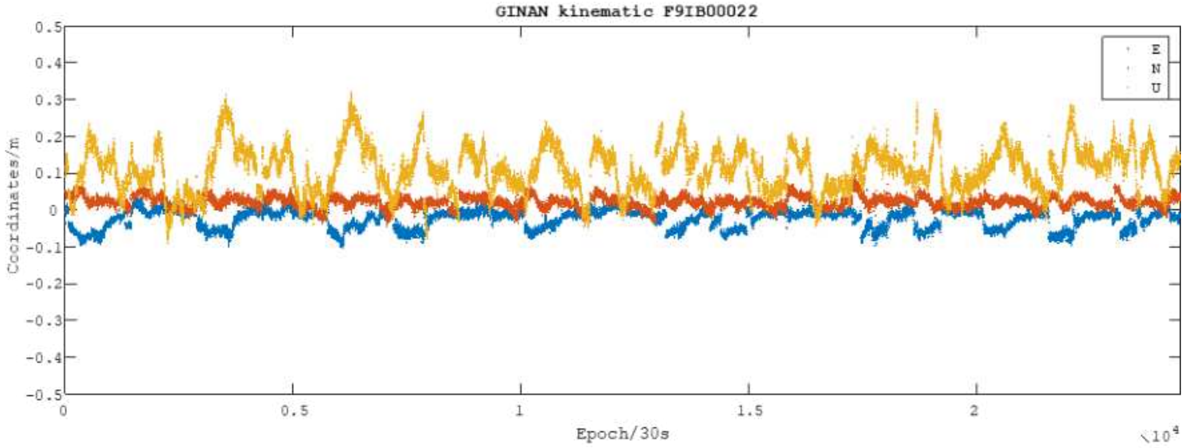
```
root@1dac772d269b:/data/scripts# python3 auto_run.py --help
Usage: auto_run.py [OPTIONS]

Options:
  -s, --sta TEXT                Station name  [required]
  -sd, --start_date TEXT        Start date of the obs to be processed
                                [required]
  -ed, --end_date TEXT          End date  [required]
  -cf, --configure_folder TEXT  Path of folder containing configuration files
                                [default: ../configs]
  -of, --obs_folder TEXT        Path of folder containing observation files
                                [default: ../obs]
  -od, --obs_dateformat TEXT    Date formate for the obs files  [default:
                                %Y-%m-%d]
  -pf, --pro_folder TEXT        Path of folder containing products (SP3, CLK,
                                ERP, BIA) files  [default: products/]
  -pp, --pro_provider TEXT      Institution name  [default: COD]
  -pt, --pro_type TEXT          Products type (FIN, RAP, ULT)  [default: FIN]
  -t, --template TEXT           The yaml template for GINAN processing
                                [default: PPP_template.yaml]
  -m, --ppp_mode TEXT           PPP processing mode  [default: kinematic]
  -i, --interval INTEGER        Time interval for obs  [default: 15]
  -e, --epochs INTEGER          Number of epochs to be processed  [default:
                                1440]
  -c, --consellation TEXT       Consellations applied in processing  [default:
                                GE]
  -y, --yamlfile TEXT           Path(name) of derived yaml file  [default:
                                out.yaml]
  -on, --out_folder_name TEXT   Name of the folder containing derived results
  --help                        Show this message and exit.
```

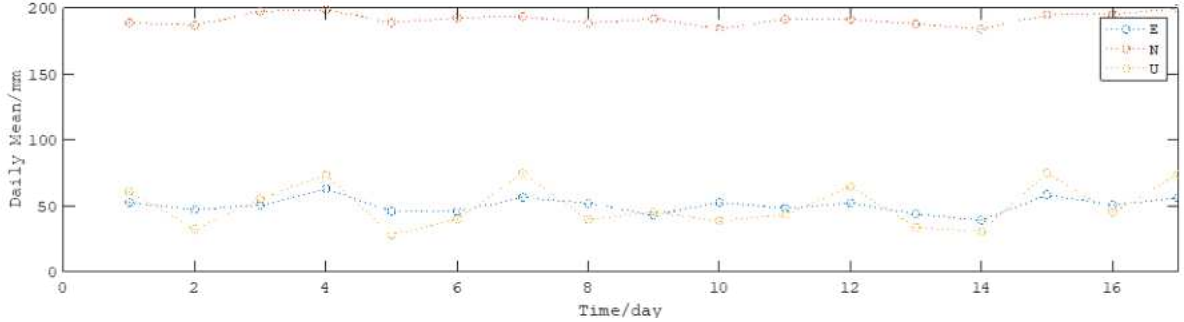
Comparison of ***Kurloo and GA receiver***

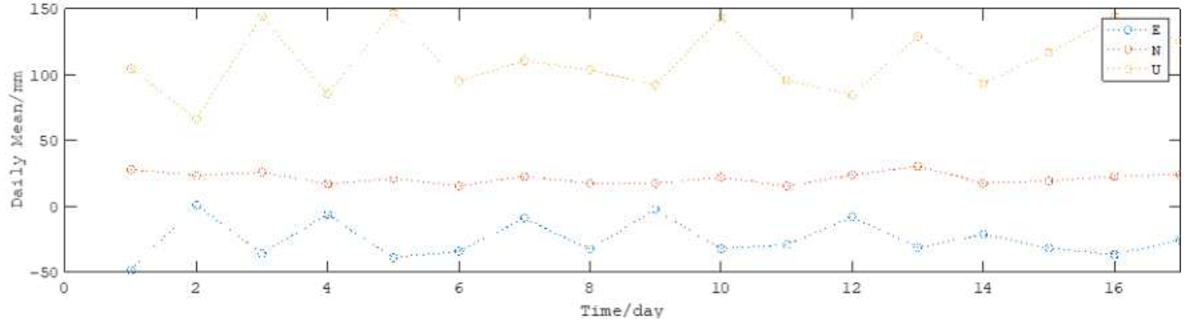
kurloo

GINAN Kinematic results







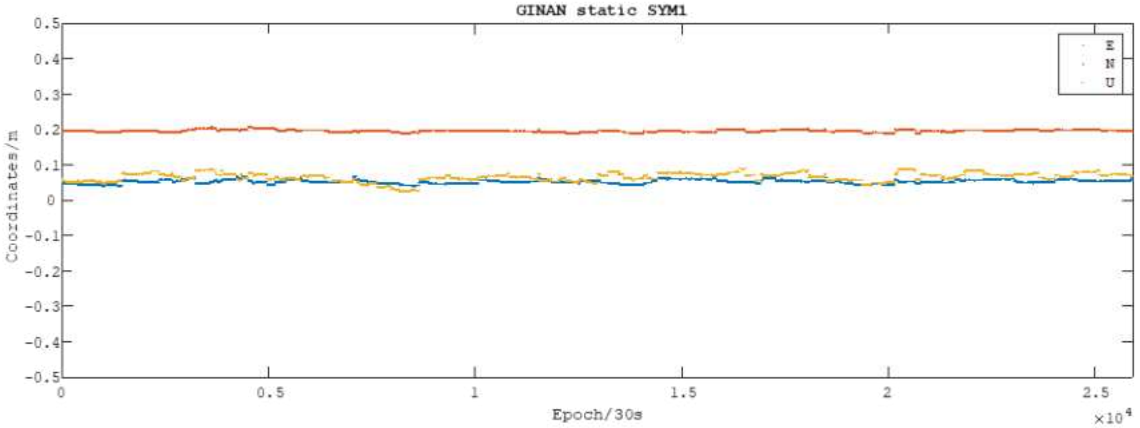


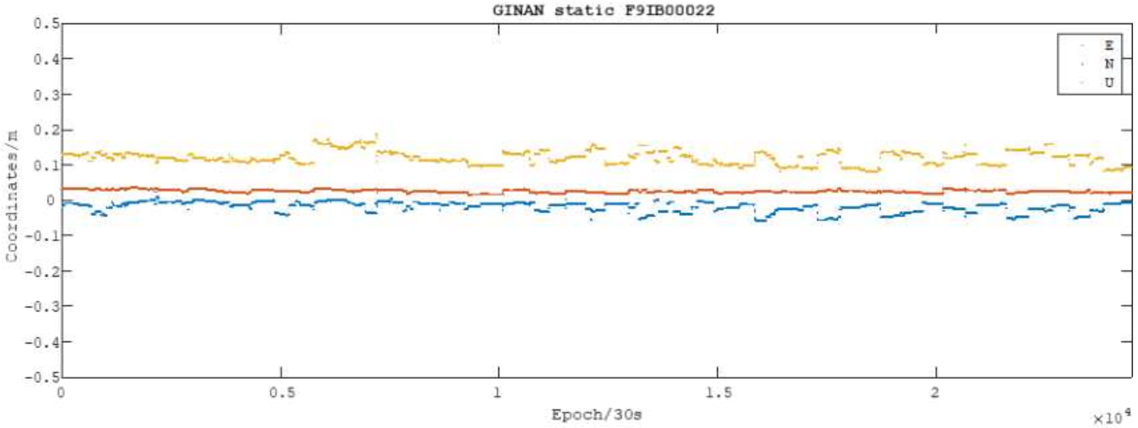
Location: GA
Mode: **Kinematic**
Date: 06/07/2023 – 22/07/2023
Number of days: 17
Interval: 15s
Obs hours per day: 6h

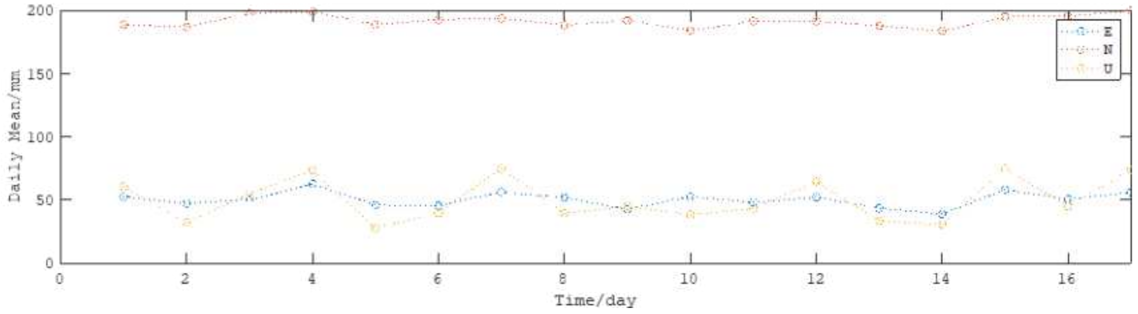
Antenna type on SYM1:
TRM59800.00

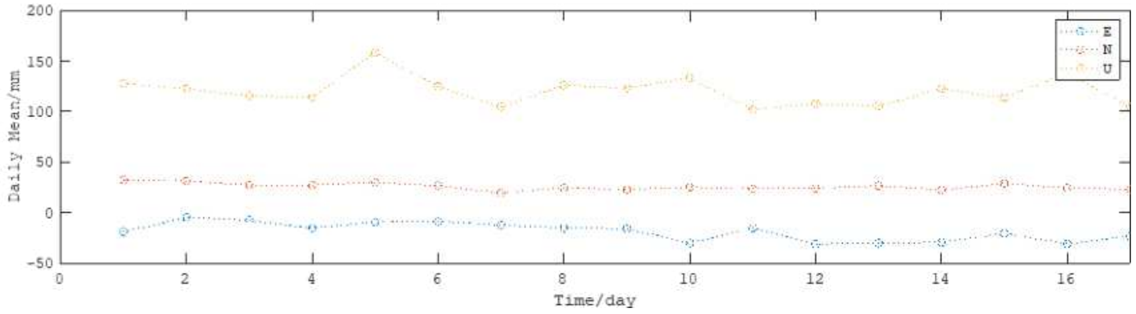
	Max – Min (mm)			STD of daily means (mm)			STD of raw time series (mm)		
	E	N	U	E	N	U	E	N	U
SYM1	24.0	15.9	46.8	6.1	4.8	16.9	10.7	12.8	35.3
F9IB00022	49.3	15.2	80.5	14.1	4.4	24.3	25.0	15.9	61.5

GINAN Static results







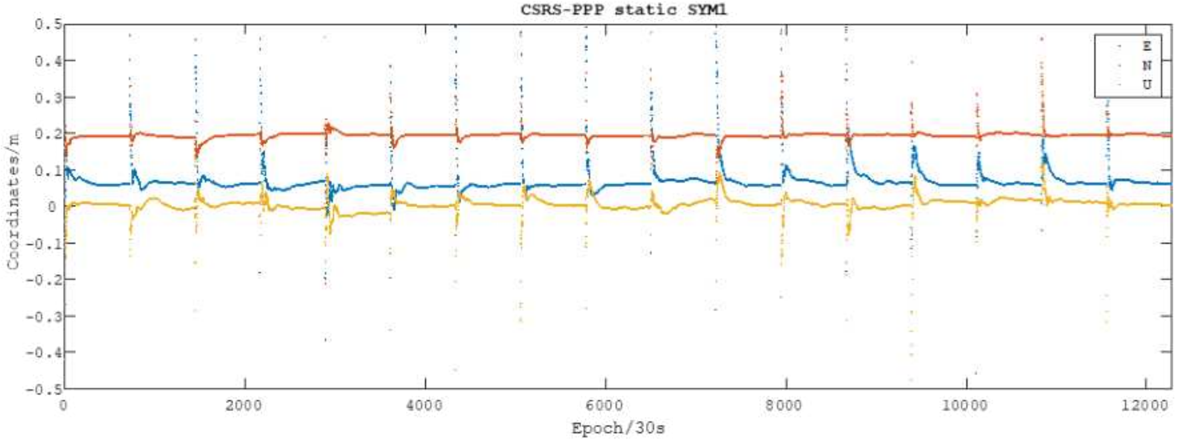


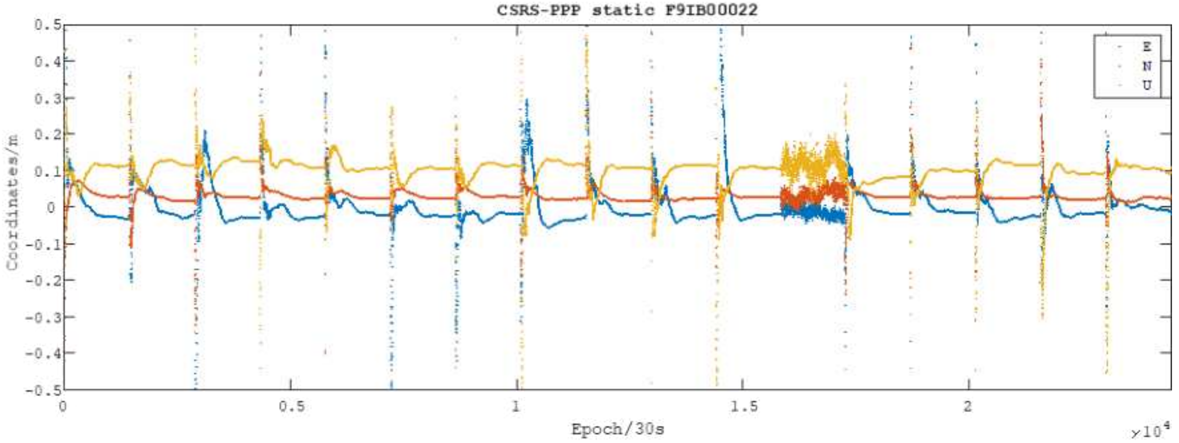
Location: GA
Mode: **Static**
Date: 06/07/2023 – 22/07/2023
Number of days: 17
Interval: 15s
Obs hours per day: 6h

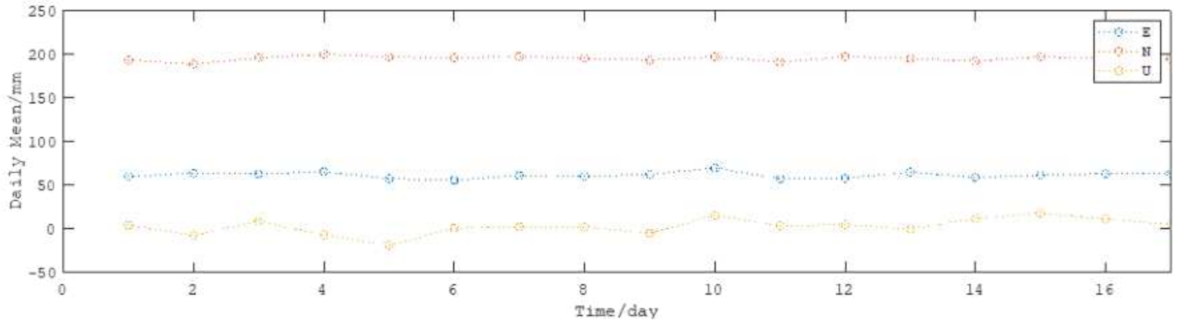
	Max – Min (mm)			STD of daily means (mm)			STD of raw time series (mm)		
	E	N	U	E	N	U	E	N	U
SYM1	14.2	11.5	36.5	3.6	2.9	9.0	3.8	2.9	8.9
F9IB00022	26.7	12.8	56.3	9.0	3.4	14.6	15.0	4.3	19.2

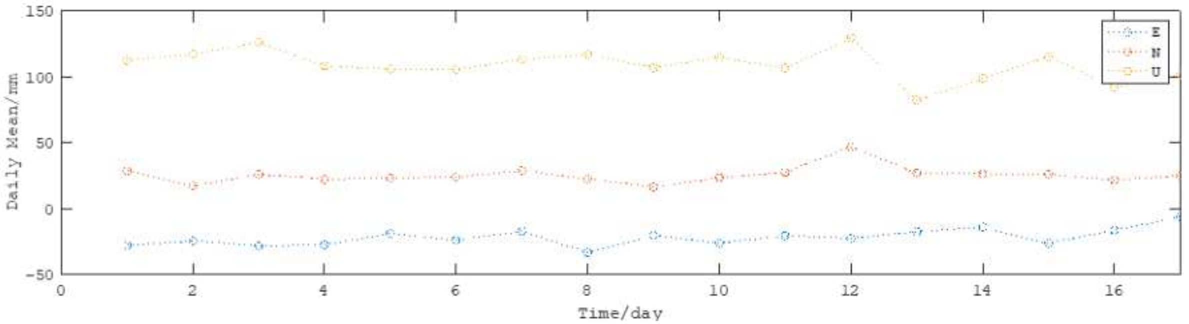
No phase centre offset and variation corrections for **F9IB00022**

CSRS Static results









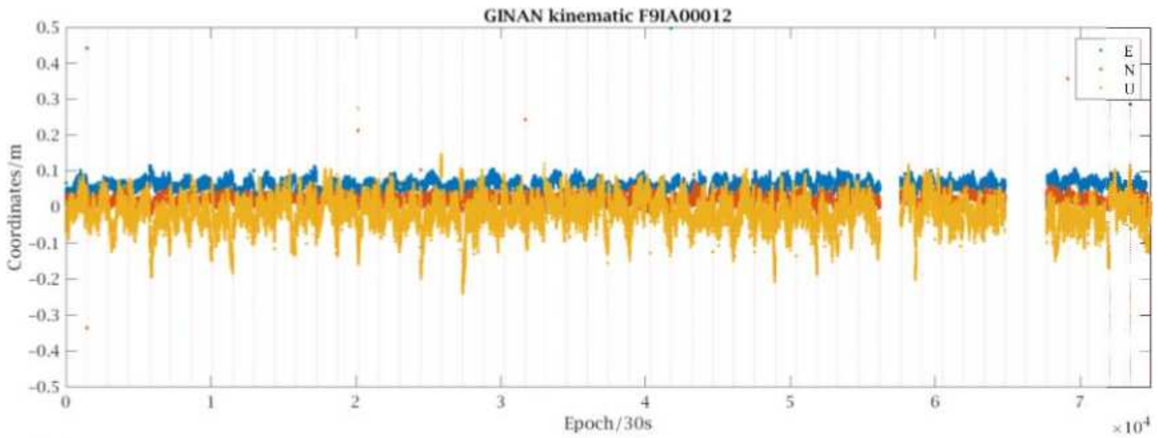
Location: GA
Mode: **Static**
Date: 06/07/2023 – 22/07/2023
Number of days: 17
Interval: 15s
Obs hours per day: 6h

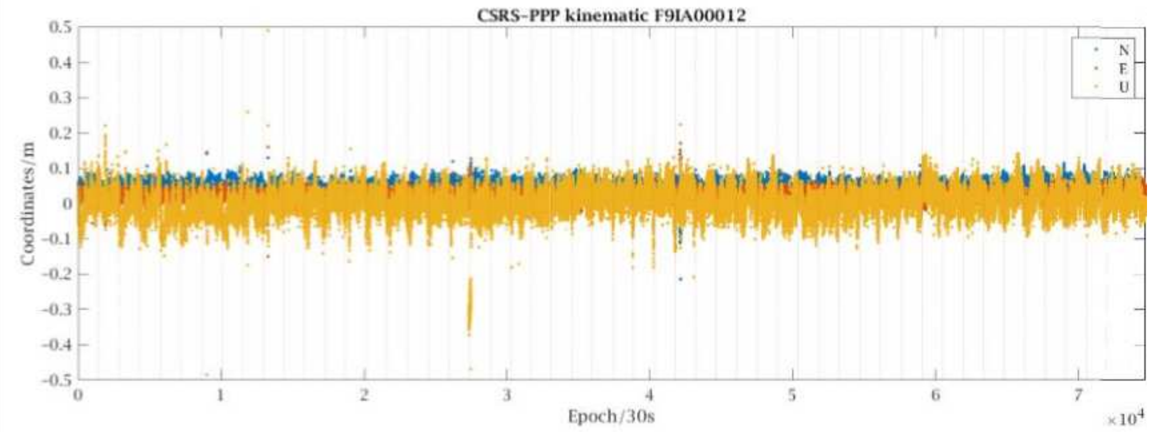
	Max – Min (mm)			STD of daily means (mm)			STD of raw time series (mm)		
	E	N	U	E	N	U	E	N	U
SYM1	14.2	11.5	36.5	3.6	2.8	9.1	3.9	2.9	9.0
F9IB00022	27.0	30.6	47.5	6.5	6.6	11.6	7.0	7.1	13.4

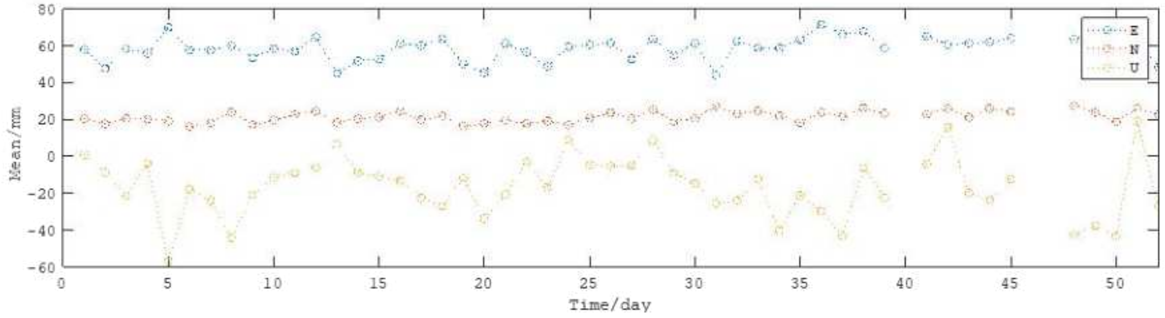
No phase centre offset and variation corrections for **F9IB00022**

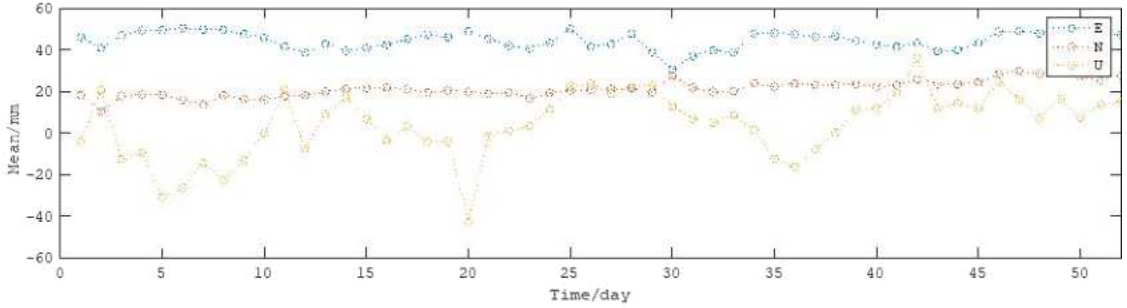
Results analysis for ***F9IA00012***

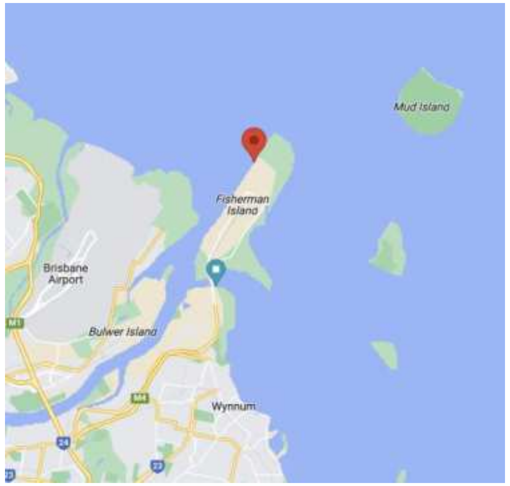
Kinematic results for F9IA00012







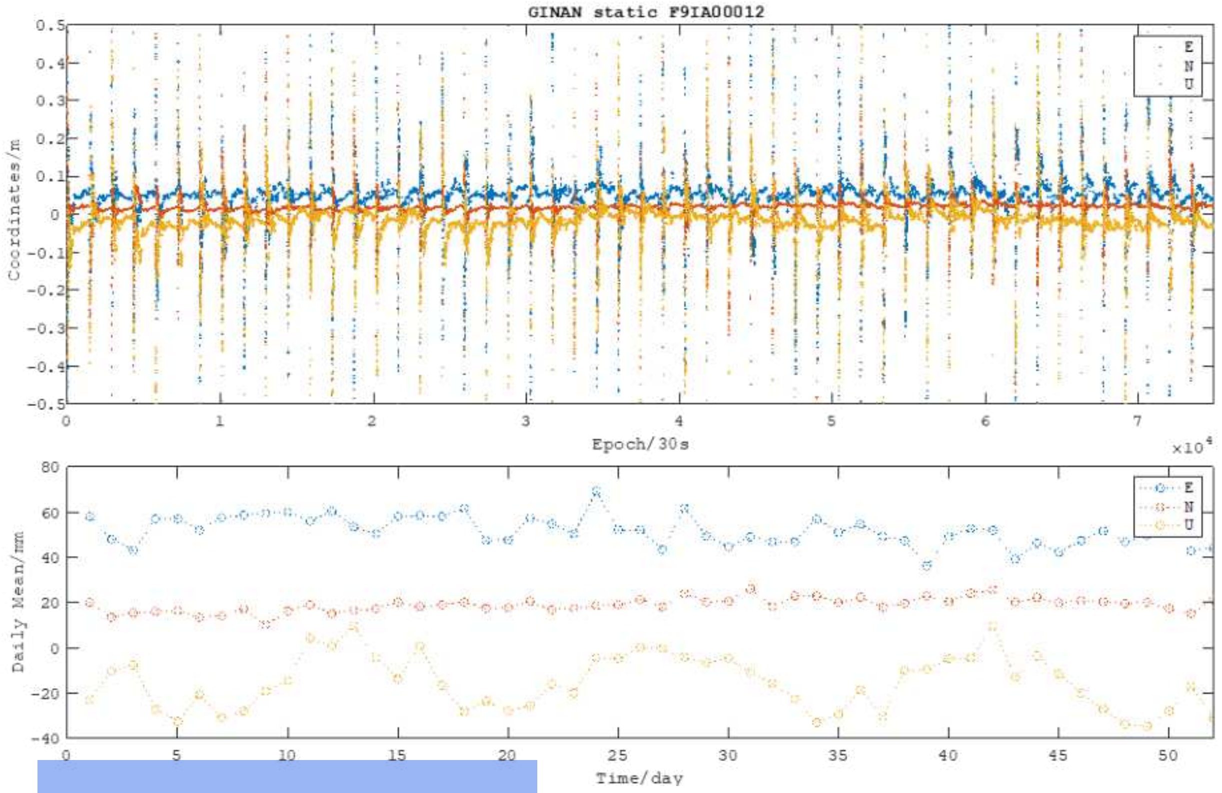


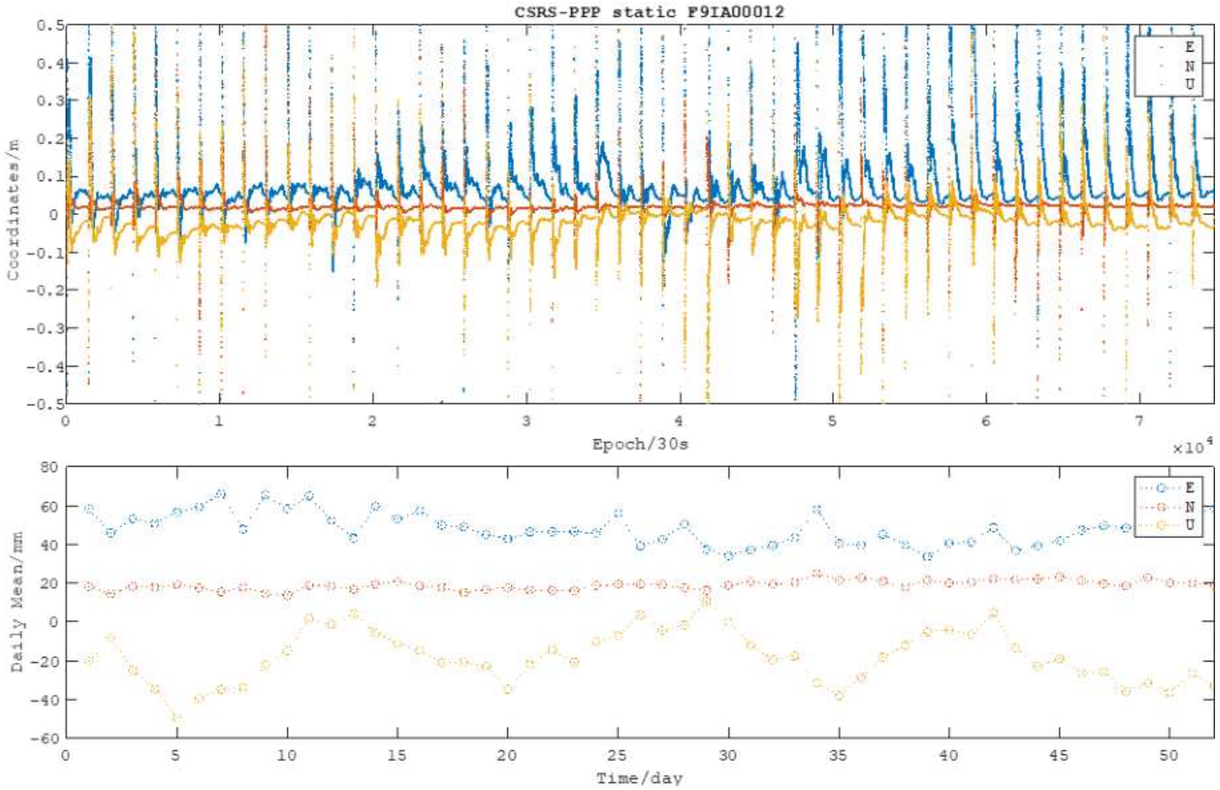


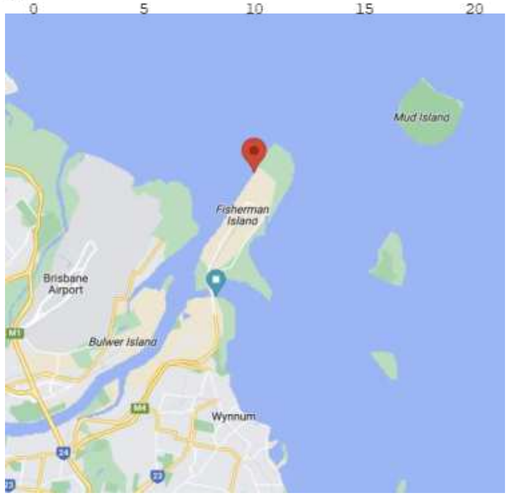
Location: FPE Seawall
Mode: Kinematic
Date: 01/06/2023 – 22/07/2023
Number of days: 52
Interval: 15s
Obs hours per day: 6h

	Max – Min (mm)			STD of daily means (mm)			STD of raw time series (mm)		
	E	N	U	E	N	U	E	N	U
GINAN	27.3	11.2	75.8	6.5	3.0	16.1	16.1	11.2	41.8
CSRS	19.6	19.6	79.0	4.3	4.0	15.6	14.7	13.4	39.6

Static results for F9IA00012







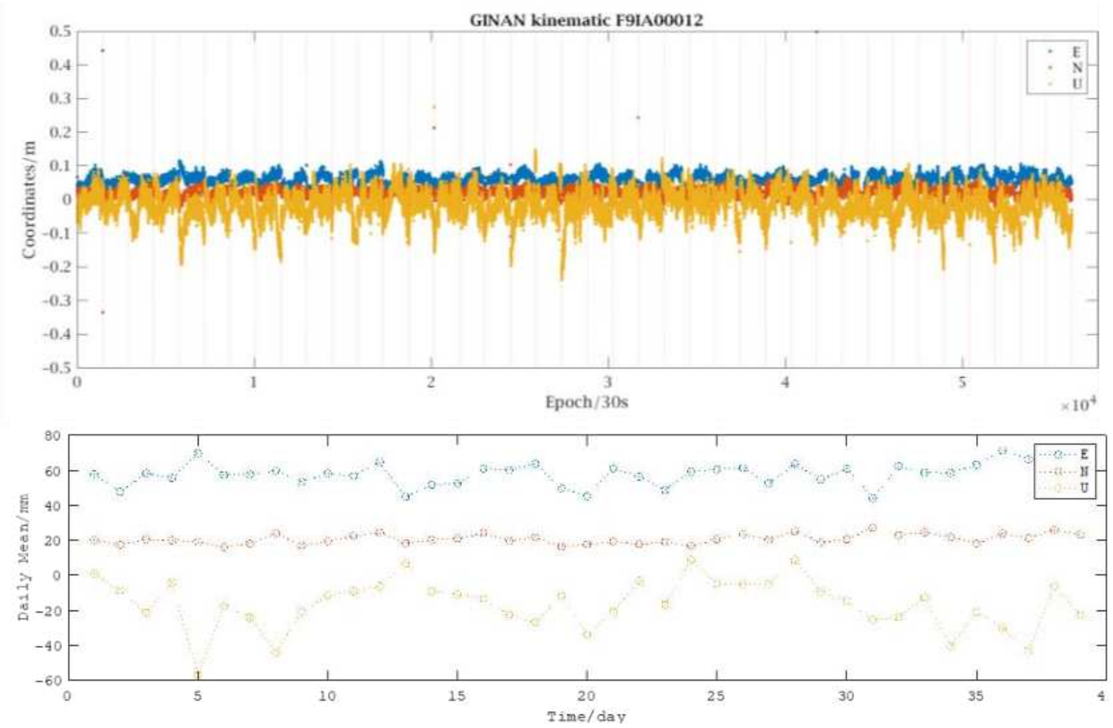
Location: FPE Seawall
Mode: Static
Date: 01/06/2023 – 22/07/2023
Number of days: 52
Interval: 15s
Obs hours per day: 6h

	Max – Min (mm)			STD of daily means (mm)			STD of raw time series (mm) (After convergence)		
	E	N	U	E	N	U	E	N	U
GINAN	33.0	15.9	44.4	6.5	3.1	12.1	11.2	3.7	12.9
CSRS	32.4	11.2	60.4	8.2	2.4	13.7	10.5	2.5	13.8

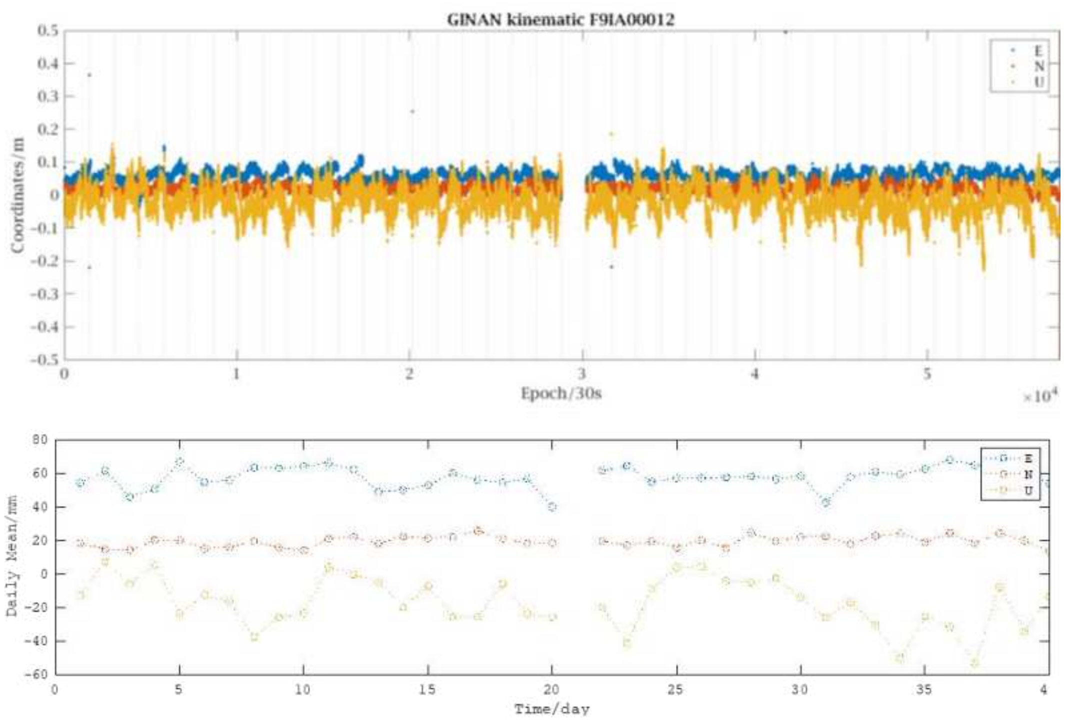
Products comparison: ***FIN or RAP?***

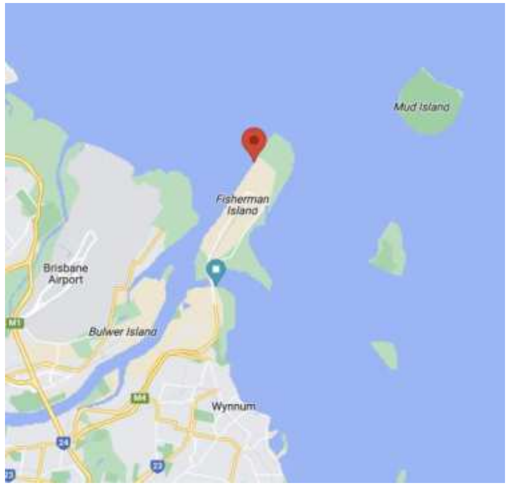
kurloo

FINAL



RAPID





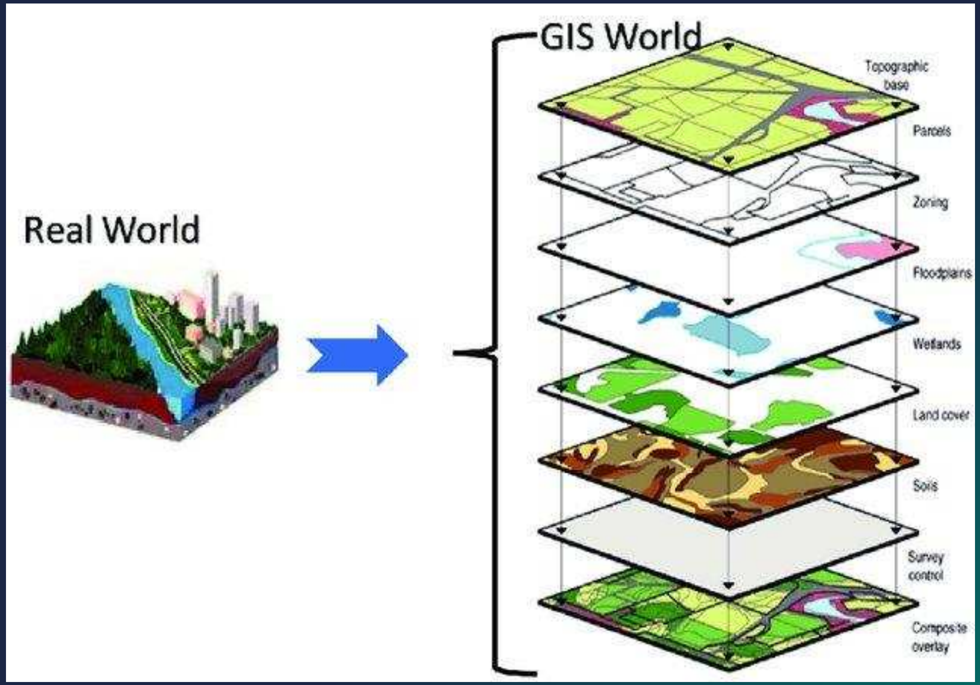
Location: FPE Seawall
Mode: Kinematic
Date: 01/06/2023 – 11/07/2023
Number of days: 40
Interval: 15s
Obs hours per day: 6h

	Max – Min (mm)			STD of daily means			STD of raw time series		
	E	N	U	E	N	U	E	N	U
GINAN (FIN)	27.3	11.2	65.6	6.5	2.8	14.5	16.1	11.0	41.5
GINAN (RAP)	28.2	12.1	60.4	6.5	3.2	15.1	16.8	11.8	43.0

Station	Location	Date	Processed by	Mode	Products	Max daily mean - Min daily mean			STD of daily means			STD of raw results		
						E	N	U	E	N	U	E	N	U
SYM1	GA CORS	06/07/2023 – 22/07/2023	GINAN	Kinematic	COD_FIN	24.0	15.9	46.8	6.1	4.8	30.6	10.7	12.8	35.3
		06/07/2023 – 22/07/2024	GINAN	Static	COD_FIN	14.2	11.5	36.5	3.6	2.9	1.7	3.8	2.9	8.9
		06/07/2023 – 22/07/2025	CSRS	Kinematic	COD_FIN	11.3	12.9	26.7	3.3	3.0	11.5	6.8	6.2	13.3
		06/07/2023 – 22/07/2023	CSRS	Static	EMR_ULT	14.2	11.5	36.5	3.6	2.8	1.7	3.9	2.9	9.0
F9I200006	Benchmarking	01/06/2023 – 22/07/2023	GINAN	Kinematic	COD_FIN	72.2	25.6	131.1	14.5	6.1	61.4	30.6	17.6	68.5
		01/06/2023 – 11/07/2023	GINAN	Kinematic	COD_RAP	91.1	28.6	97.9	19.5	6.5	59.9	33.0	18.3	66.3
		01/06/2023 – 22/07/2023	CSRS	Kinematic	EMR_ULT	34.4	20.4	100.6	6.4	4.4	57.1	20.5	18.5	63.7
		01/06/2023 – 22/07/2023	CSRS	Static	EMR_ULT	31.9	22.9	38.5	6.5	5.7	3.3	7.3	5.9	10.5
F9IA00012	FPE Seawall	01/06/2023 – 22/07/2023	GINAN	Kinematic	COD_FIN	27.3	11.2	75.8	6.5	3.0	37.8	16.1	11.2	41.8
		01/06/2023 – 11/07/2023	GINAN	Kinematic	COD_RAP	28.2	12.1	60.4	6.5	3.2	39.6	16.8	11.8	43.0
		01/06/2023 – 22/07/2023	GINAN	Static	COD_FIN	34.0	13.5	45.4	6.7	3.3	5.7	11.7	4.1	14.1
		01/06/2023 – 11/07/2023	GINAN	Static	COD_RAP	27.7	10.9	39.2	5.3	2.7	5.5	10.7	3.4	12.8
		01/06/2023 – 22/07/2023	CSRS	Kinematic	EMR_ULT	19.6	19.6	79.0	4.3	4.0	35.0	14.7	13.4	39.6
		01/06/2023 – 22/07/2023	CSRS	Static	EMR_ULT	32.4	11.2	60.4	8.2	2.4	2.3	10.5	2.5	13.8
F9IA00011	Poatina Power Station	01/06/2023 – 22/07/2023	GINAN	Kinematic	COD_FIN	90.4	64.7	222.7	23.9	13.2	66.9	32.9	26.8	83.4
		01/06/2023 – 11/07/2023	GINAN	Kinematic	COD_RAP	115.0	43.0	215.3	23.5	10.6	70.3	30.6	24.1	84.8
		25/06/2023 – 22/07/2023	GINAN	Static	COD_FIN	62.4	32.8	164.9	17.0	7.9	24.2	23.1	10.8	38.7
		01/06/2023 – 11/07/2023	GINAN	Static	COD_RAP	72.6	34.1	118.2	13.5	7.1	19.6	18.7	8.6	33.1
		01/06/2023 – 22/07/2023	CSRS	Kinematic	EMR_ULT	176.1	338.2	437.4	25.5	47.9	123.4	42.9	148.3	162.0
F9IA00013	Dunstan Drive,Robina	01/06/2023 – 22/07/2023	GINAN	Kinematic	COD_FIN	113.1	94.9	328.3	21.6	20.8	110.5	39.2	39.4	139.5
		01/06/2023 – 11/07/2023	GINAN	Kinematic	COD_RAP	140.8	113.7	334.1	27.4	23.8	108.3	45.8	43.5	136.9
		01/06/2023 – 22/07/2023	GINAN	Static	COD_FIN	107.9	93.6	315.2	25.0	20.9	25.2	29.9	21.6	86.9
		01/06/2023 – 11/07/2023	GINAN	Static	COD_RAP	128.9	74.1	399.8	24.9	20.7	23.8	29.5	21.4	90.7
		01/06/2023 – 22/07/2023	CSRS	Kinematic	EMR_ULT	150.2	75.4	435.2	39.9	18.9	137.1	102.2	55.8	162.7
		01/06/2023 – 22/07/2024	CSRS	Static	EMR_ULT	66.0	38.9	123.4	15.4	7.9	14.3	16.4	8.7	31.6
F9IA00016	Toowoomba Bypass	15/06/2023 - 22/07/2023	GINAN	Kinematic	COD_FIN	47.4	21.1	70.1	11.7	5.8	54.6	35.6	17.9	59.7
		17/06/2023 - 10/07/2023	GINAN	Kinematic	COD_RAP	40.0	20.5	84.1	9.8	6.1	62.8	34.4	17.1	77.4
		15/06/2023 - 22/07/2023	GINAN	Static	COD_FIN	28.2	19.2	55.4	6.9	5.2	6.5	14.3	5.7	13.4
		15/06/2023 - 21/07/2023	GINAN	Static	COD_RAP	28.2	19.2	55.4	7.0	5.2	6.4	14.3	5.7	13.5
		15/06/2023 - 22/07/2023	CSRS	Kinematic	EMR_ULT	140.3	51.2	80.1	29.3	10.7	46.6	69.7	28.2	54.6
		15/06/2023 - 22/07/2023	CSRS	Static	EMR_ULT	44.5	12.5	46.9	11.6	3.6	4.2	14.6	3.7	13.3
F9IB00022	GA Benchmark	05/07/2023 – 22/07/2023	GINAN	Kinematic	COD_FIN	49.3	15.2	80.5	14.1	4.4	55.9	25.0	15.9	61.5
		05/07/2023 – 09/07/2023	GINAN	Kinematic	COD_RAP	41.2	12.9	67.4	18.2	5.4	70.5	27.1	15.0	75.4
		05/07/2023 – 22/07/2023	GINAN	Static	COD_FIN	26.7	12.8	56.3	9.0	3.4	11.8	15.0	4.3	19.2
		05/07/2023 – 09/07/2023	GINAN	Static	COD_RAP	20.2	10.6	31.6	9.7	4.4	10.3	4.0	4.7	15.9
		05/07/2023 – 22/07/2023	CSRS	Kinematic	EMR_ULT	17.3	14.4	33.6	3.9	4.0	26.6	12.6	13.4	28.1
		05/07/2023 – 22/07/2023	CSRS	Static	EMR_ULT	27	30.6	47.5	6.5	6.6	3.5	7.0	7.1	13.4
F9IB00023	Toowoomba Bypass	01/06/2023 – 22/07/2023	GINAN	Kinematic	COD_FIN	89.6	27.0	45.2	15.1	6.3	51.5	29.1	14.4	53.8
		01/06/2023 – 11/07/2023	GINAN	Kinematic	COD_RAP	78.3	25.8	63.2	14.1	6.4	53.2	27.2	14.9	56.8
		01/06/2023 – 22/07/2023	GINAN	Static	COD_FIN	44.2	19.6	36.7	8.9	4.9	6.8	14.4	5.4	11.2
		01/06/2023 – 11/07/2023	GINAN	Static	COD_RAP	46.2	15.0	37.9	9.8	4.1	7.6	15.2	4.5	12.2
		01/06/2023 – 22/07/2023	CSRS	Kinematic	EMR_ULT	77.8	55.7	72.1	15.5	9.0	45.7	33.9	24.3	59.3
		01/06/2023 – 22/07/2023	CSRS	Static	EMR_ULT	50.7	12.7	45.8	11.6	3.2	4.6	13.2	3.5	13.6
F9IB00027	Mt Bogong	01/06/2023 – 22/07/2023	GINAN	Kinematic	COD_FIN	152.7	128.9	351.7	32.4	25.9	93.4	44.4	38.9	118.2
		01/06/2023 – 11/07/2023	GINAN	Kinematic	COD_RAP	139.8	111.5	272.3	30.0	23.8	95.7	41.5	37.1	122.4
		01/06/2023 – 22/07/2023	GINAN	Static	COD_FIN	220.5	130.7	229.3	34.2	21.4	30.3	41.6	24.3	67.5
		01/06/2023 – 11/07/2023	GINAN	Static	COD_RAP	117.3	71.1	208.7	29.0	16.2	32.4	35.5	20.7	66.4
		01/06/2023 – 22/07/2023	CSRS	Kinematic	EMR_ULT	103.7	193.5	602.8	21.0	27.2	143.5	87.4	130.7	261.7
		01/06/2023 – 22/07/2023	CSRS	Static	EMR_ULT	64.1	46.1	142.2	18.7	9.7	19.1	19.6	11.2	41.3

Fundamental Role of Reference Station

- Enable the accurate positioning of points on the earths surface
- Direct connect to specifical Reference Frames, Nationally and Globally
- The importance of Geospatial Reference Systems was recognised by the United Nations in 2015 adoption of a General Assembly Resolution promoting the importance of an accurate, sustainable and accessible Global Reference Frame to support science and society (Nicholas Brown, 2019)
- Well defined and realised station coordinates (and velocities) underpin science of the Earth's interior, solid Earth, atmosphere, oceans, space environment (John Dawson, 2019)
- **The stability of its reference station is crucial to obtain accurate and reliable monitoring results (Guanwen Huang, 2023)**



kurloo

What if the reference station is not stable ?



What if you don’t have a reference station?



Conclusions

1. Kurloo receiver demonstrates a remarkable PPP precision, achieving 1.5, 1.5, and 4.0 cm in kinematic mode, and 1.0, 1.0, and 1.5 cm in static mode on E, N, and U directions. (Based on the results of F9IA00012)

2. GINAN is capable of achieving comparable PPP precision to CSRS, although in certain stations, the results derived from CSRS show better precision.

3. The results obtained from rapid-products and final-products exhibit comparable positioning precision.

4. Despite utilizing the same receivers across different stations, their positioning performance varies. The reason need to be investigated.

5. Using the combination of GPS and Galileo constellations for GINAN PPP processing can achieve better PPP performance.

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