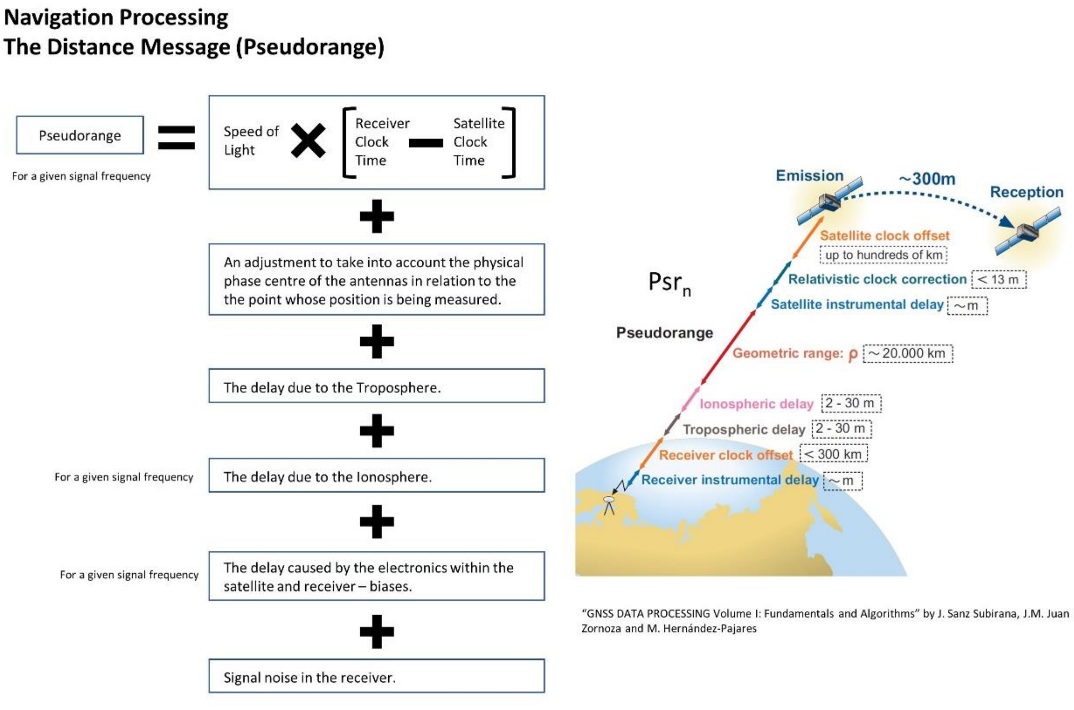
Ginan
User Stories

Ginan and the ionosphere

Rupert Brown v0.5 December 2022 - incorporating comments from Professor Han and Dr Dao

Ginan employs a technique called *trilateration* to calculate precise positions. Trilateration is similar to using Pythagoras to work out the lengths of the sides of a triangle, but trilateration works in three dimensions.

If we know the distance between a Global Navigation Satellite System (GNSS) receiver and at least three GNSS satellites, trilateration can be used to calculate the position of the receiver. This is the basis of all GNSS positioning. It follows that understanding the distance between a receiver and a satellite is very important. We must ***understand*** that distance, rather than just ***know it***, because that distance is made up of several parts. By understanding what those parts are and what they mean, we can exploit trilateration for other purposes.

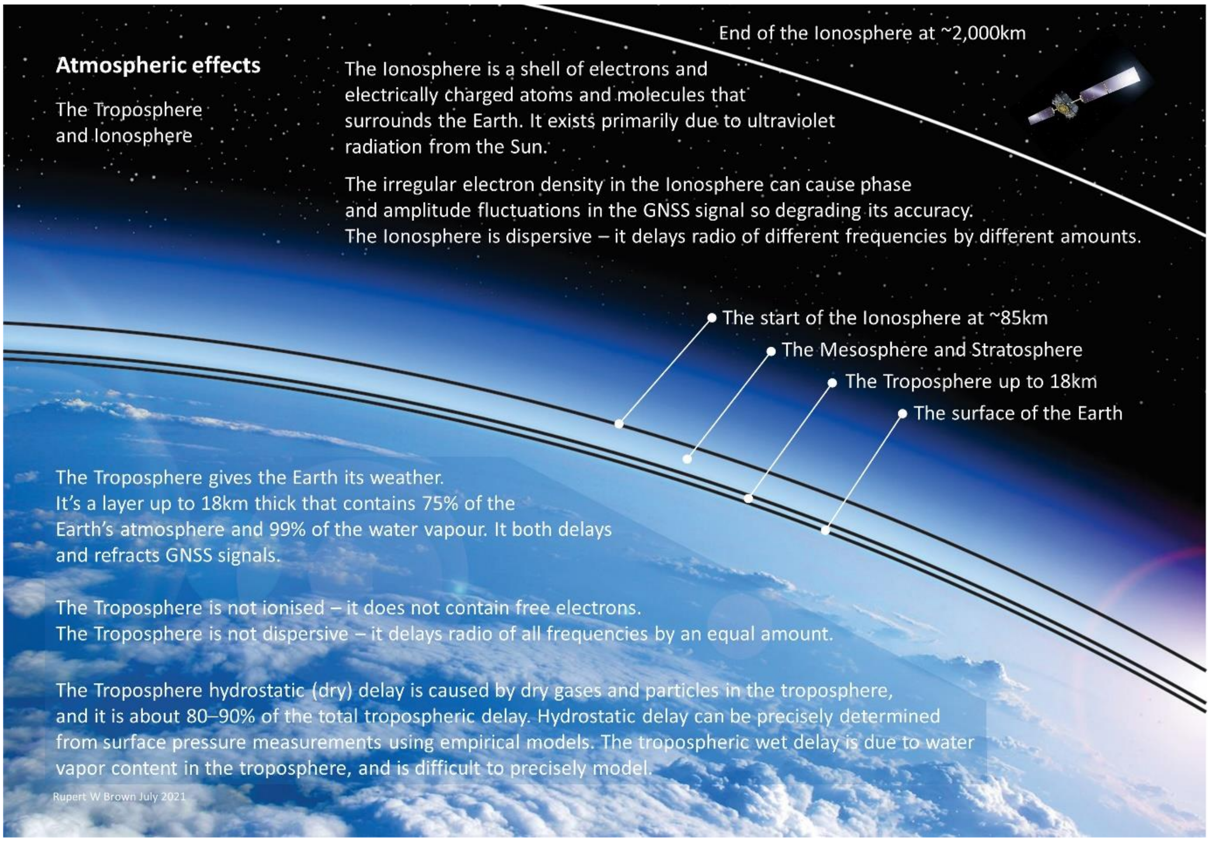


"GNSS DATA PROCESSING Volume I: Fundamentals and Algorithms" by J. Sanz Subirana, J.M. Juan Zornoza and M. Hernández-Pajares

Figure 1 – Understanding the distance between a GNSS receiver and satellites.

A radio signal takes a very small amount of time to travel from a GNSS satellite to a receiver. This is because it is travelling at the speed of light. A clock on the satellite puts a time stamp into the signal so that when the receiver picks it up and compares it to the time the message was received, it can work out the distance travelled – because we know how fast light travels. But some things slow down the speed of light, like ions in the Ionosphere and water vapour in the Troposphere.

This understanding allows us to write an equation where the actual range between a receiver and a satellite is the observed distance plus other things like the delays caused by the Ionosphere and Troposphere. In GNSS positioning, this is a fundamental and very useful equation.



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 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.

Figure 2 – the ionosphere and troposphere

The different parts of the equation are called terms. If you have values for all the terms you can work out an answer. Also the terms in an equation may be rearranged. You may already know the answer and all the other terms bar one – you want to find the value of that term. You can re-write the equation to find the solution to the one term you are interested in.

Equation: Answer = A term + B term + C term

Situation: Answer = A term + B term + C term

Solved for B: B term = Answer - A term - C term

Professor Shin-Chan Han from Newcastle University, and Dr Tam Dao from RMIT have been exploring aspects of the ionosphere. They have re-written the equation to help them create a plan to calculate a value for the ionospheric delay, and then used parts of the Ginan software to crunch the numbers.

Dr Dao, supervised by Professor Suelynn Choy, has been using Ginan to study the signals travelling between GNSS satellites and the network of Continuously Operating Reference Stations (CORS) that are located across Australia. This CORS network has recently been upgraded and expanded as part of the Positioning Australia program run by Geoscience Australia.

Dr Dao reorganised the “distanced travelled” equation so that she can calculate the delays to GNSS signals caused by the ionosphere. These delays correspond to the Total Electron Content (TEC) along the signal path which is a way of describing the composition of the ionosphere. Using the delays calculated by the ionospheric module in the Ginan toolkit, Dr Dao has been able to compile a unique map of the ionospheric corrections across Australia.

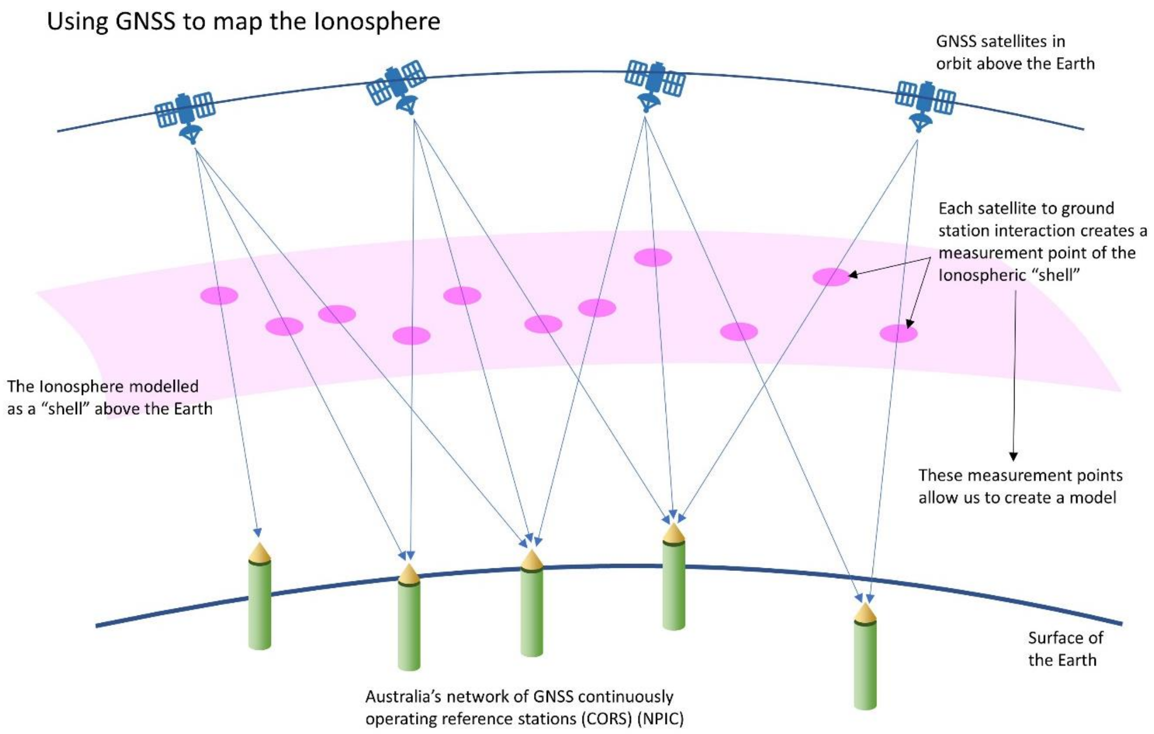


Figure 3 – Using GNSS signals to create a map of the ionosphere.

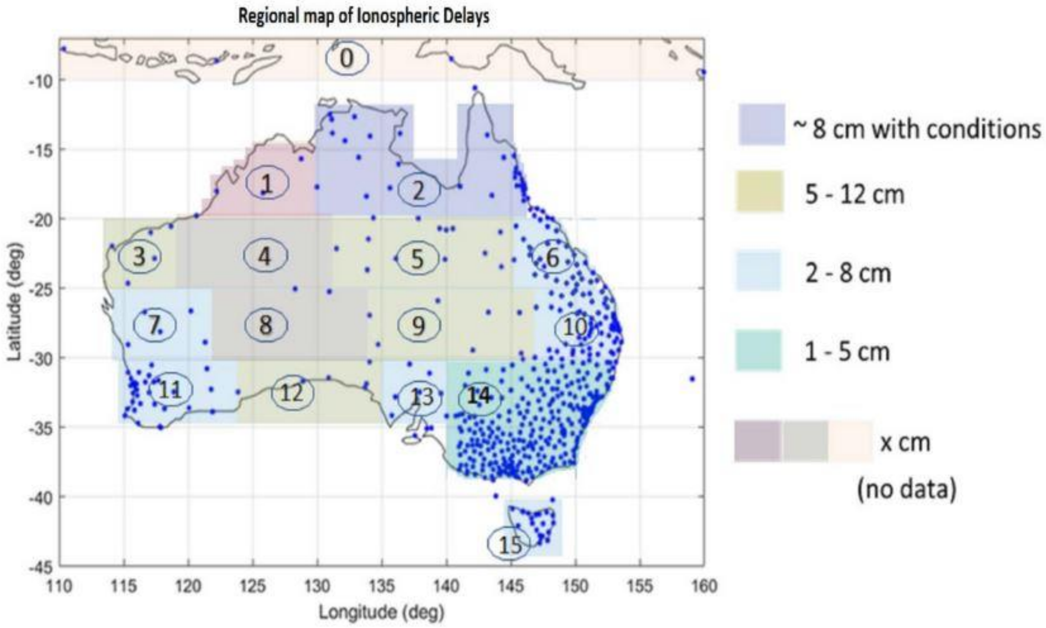


Figure 4 – Dr Dao's map shows the recommended regions for mapping of the single difference ionospheric corrections as well as the achievable accuracy using a simple linear interpolation method. The blue dots represent CORS stations used in testing. The labels 1 to 15 describe 15 regional maps that are divided based on the available testing stations. [Ref. 1]

Professor Shin-Chan Han's work focusses on analysing GNSS signals in space.

GNSS satellites orbit the Earth at an altitude of approximately 20,000 km, a middle Earth orbit (MEO). In the last twenty years there has been a huge amount of development in satellites for low Earth orbit

(LEO). One LEO constellation in operation today is called Spire. Their constellation of 140 small satellites carries an array of telecommunications and Earth observation sensors, including GNSS receivers. The satellites orbit the Earth at an altitude of 500 km.

The GNSS satellites in effect “look down” on the Spire satellites as they orbit the Earth. Signals from the GNSS satellites must pass through the ionosphere to reach the Spire satellites. Sometimes the signals pass sideways through the Ionosphere when the satellites are on opposite sides of the Earth and just above the horizon, giving us a new perspective on the composition of the ionosphere.

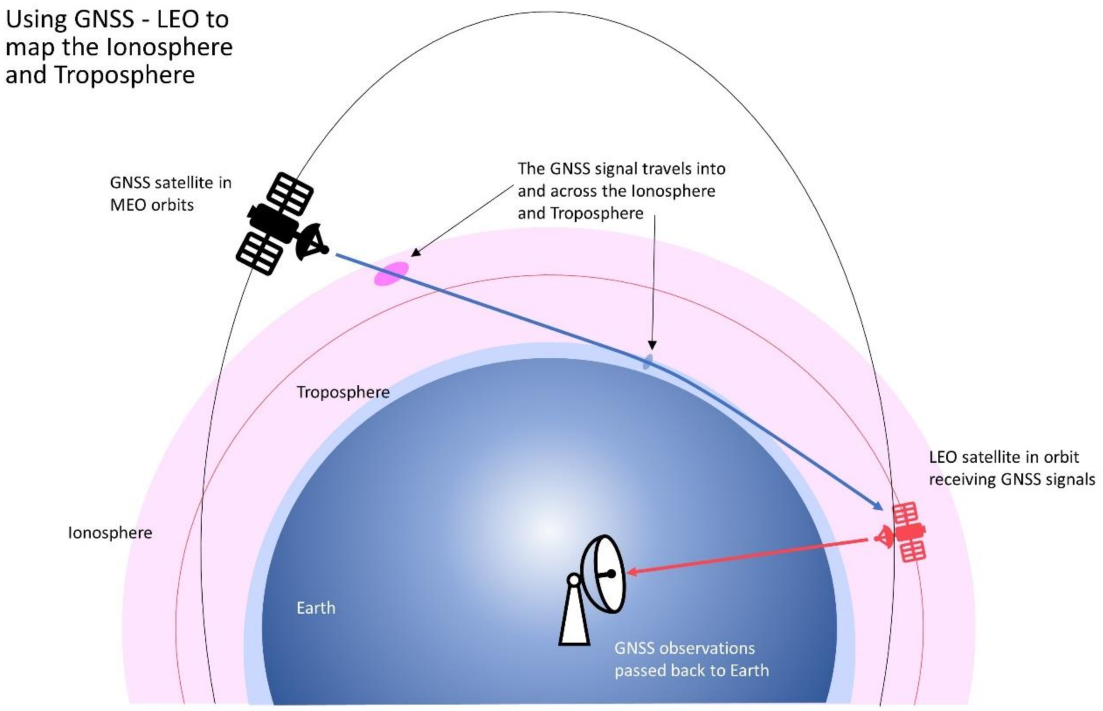
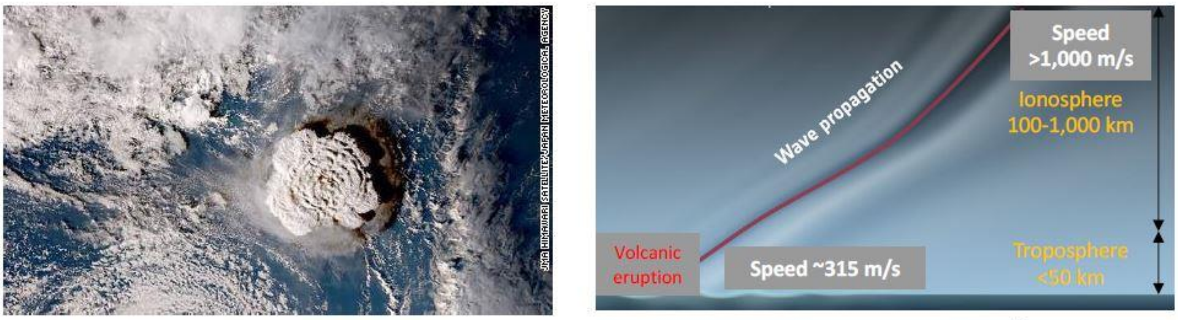


Figure 5 – Using a LEO satellite to look “sideways” through the ionosphere.

Professor Shin-Chan Han uses elements of Ginan to calculate the very precise orbital positions needed to correctly interpret the data received from the Spire satellites. In a recent talk at Geoscience Australia, the Professor described how he was able to use this technique to observe and analyse the shock wave that passed through the ionosphere as a result of the Hunga Tonga-Hunga Ha’apai volcanic eruption of 15th January 2022. His team studies GNSS ionosphere signals to better understand geohazards such as volcanoes and develop methods to locate and predict tsunamis. Geoscience Australia’s Ginan provides critical tools for analyzing GNSS tracking data not only for positioning but also for GNSS-based Earth observation.



Adapted from ESA, https://www.esa.int

Figure 6 – The Hunga Tonga-Hunga Ha’apai volcanic eruption in January 2022. [Ref. 2]

The ionosphere is not a static and homogeneous part of the atmosphere. It is in a constant state of flux as the Sun heats it during the day, and as it cools off at night. It is lashed by solar storms and changes as the Sun passes through its eleven year solar cycle. The area of Australia North of the 20 degree South latitude, and a large part of the South Pacific, are within the Equatorial Ionospheric Anomaly, a region of the Ionosphere that is particularly dynamic complete with electron plasma bubbles and density gradient cliffs.

Stars twinkle at night because the light is being affected by variations in the Ionosphere. This is great for the casual observer, but when the same thing happens to GNSS signals the outcomes are generally not good. Thinking back to that “distanced travelled” equation, if the Ionospheric delay is fluctuating wildly, a GNSS position will be changing in a dynamic and dangerous way, especially if you are using GNSS to land a plane.

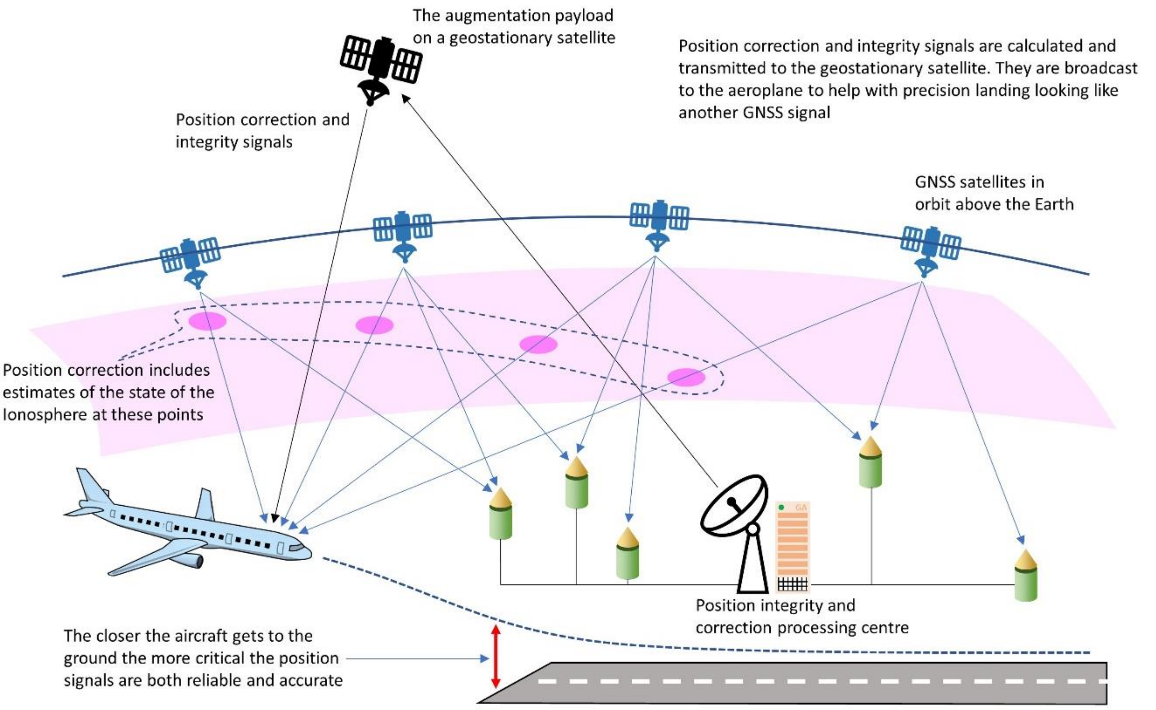


Figure 7 – A model of the ionosphere forms an integral part of a satellite-based augmentation system guiding an aircraft to complete precision landings at airfields without landing aid infrastructure.

Across the world, GNSS, with significant augmentations, are being pressed into service to help aircraft land with great precision. The big advantage of this kind of system is that infrastructure is not required at the airport if the plane is carrying a receiver capable of getting the signals from space. For Australia this is a great benefit as Australia has hundreds of small airports and landing strips scattered across the country, all of which could be served by a satellite system.

For precision satellite guided approaches to be safe, we must understand what the ionosphere is doing and be able to model it accurately so we can compensate for its fluctuations. Ginan is helping researchers like Professor Han and Dr Dao better understand the ionosphere. The more we understand about this very important piece of the sky, the better will be the ionosphere model we can build. A better model will enhance the safety of Australia and New Zealand’s own satellite augmentation system SouthPAN.

References

Ref. 1

Regional Ionospheric Corrections for High Accuracy GNSS Positioning

Tam Dao 1,* , Ken Harima 2,3, Brett Carter 1 , Julie Currie 1 , Simon McClusky 2, Rupert Brown 3, Eldar Rubinov 3 and Suelynn Choy 1

1 SPACE Research Centre, School of Science, Royal Melbourne Institute of Technology (RMIT) University, Melbourne 3000, Australia; brett.carter@rmit.edu.au (B.C.); julie.currie@rmit.edu.au (J.C.); suelynn.choy@rmit.edu.au (S.C.)

2 Geoscience Australia, Canberra 2609, Australia; ken.harima@ga.gov.au (K.H.); simon.mcclusky@ga.gov.au (S.M.)

3 FrontierSI, Melbourne 3000, Australia; rbrown@frontiersi.com.au (R.B.); erubinov@frontiersi.com.au (E.R.)

* Correspondence: tam.dao@rmit.edu.au

Ref. 2

Geodesy and geohazard experiment with CubeSat GNSS tracking data

Presented at Australian Geodesy and Skykraft LEO Workshop, 28th-30th June 2022

Shin-Chan Han (University of Newcastle), shin-chan.han@newcastle.edu.au

Acknowledgement

Simon McClusky (GA & ANU), Thomas Papanikolaou (GA & Aalborg University), Colin Waters (University of Newcastle), John LeMarshall (BoM), Dylan Mikesell (NGI) Dallas Masters and Vu Nguyen (Spire Global, Inc.)

GA’s Ginan open source software

NASA Commercial Smallsat Data Acquisition (CSDA) Program