RONGOWAI: A PATHFINDER NASA/NZ GNSS-R INITIATIVE SUPPORTING SDG-15 - LIFE ON LAND

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ABSTRACT

Earth observations are pivotal for developing informed, evidence-based sustainable practices and are of direct consequence to four of the seventeen UN Sustainable Development Goals (12-15). Among these, Earth observations using signals of opportunity such as GNSS-R have significantly evolved in recent years including expanding efforts to consider geophysical retrievals over complex and heterogeneous surfaces, primarily from space-borne missions. Airborne GNSS-R however has the advantages of higher resolution and signal strength and as such can provide critical data to inform algorithm development for complex environments. This paper presents the upcoming airborne Rongowai mission whereby Air New Zealand will fly a NASA-developed next-generation GNSS-R receiver as a unique international collaboration. Rongowai promises to deliver rich environmental records for sustainable land-use and water management including coastal and open ocean over many years at unprecedented spatial and temporal resolutions. We present representative coverage, and methodology for product development with specific focus on soil-moisture as it relates to land-use and water management gather

Index Terms— Bistatic radar, remote-sensing, terrestrial hydrology, GNSS-R, soil-moisture

1. INTRODUCTION

A pathfinder airborne GNSS-R mission, Rongowai opens a new carbon-neutral paradigm for Earth observations addressing globally relevant problems. The Rongowai mission is a collaborative program between NASA, the New Zealand government's Ministry of Business Innovation and Employment and Air New Zealand (AirNZ) in conjunction with NASA's CYGNSS mission (Cyclone GNSS - see https://www.nasa.gov/cygnss/). For this mission, AirNZ will fly the next-generation GNSS-R receiver (NGRx), developed under a NASA Earth Science Technology Office grant, and commercial aviation GPS omnidirectional antennas on a domestic Q300 aircraft. This effort will not only further mature the NGRx technology for future mission readiness, it will provide unprecedented high-resolution, wide coverage long-term records of soil moisture and inundation dynamics over New Zealand's diverse landscape and ecosystems. Figure 1 summarizes the representative coverage expected from a year of operations of a single AirNZ Q300 aircraft based on historical flight data [1].

In anticipation of the mission's potential impact the name Rongowai has been given, combining the Māori words Rongo (to sense: hear, feel, smell etc.) and Wai (water). As such it signifies an embodied approach acknowledging Rongowai's contribution to mauri (life force) restoration. Figure 2 shows the Rongowai logo which takes the form of a manaia which in this case is a lens or whatu. The space within the whatu of the manaia is in a state of mauri ora (thriving life force). The whenua within the whatu is living and thriving due to the differing bodies of water (ua (rain), awa (rivers, stream), wairere (falls) that feed into it replenishing its mauri. The feeding of the water into the whenua within the whatu is represented by the curved head of the manaia that turns inward as an awa.

The United Nations Sustainable Development Goal 15 (UN SDG 15)is summarised on the official website as: "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" (https://sdgs.un.org/goals/goal15). It is readily argued that soil-moisture is a critical observable in identifying sustainable (and unsustainable) trends in management practices. With Rongowai we will utilize signals of opportunity whilst operating from a platform of opportunity (via AirNz) to provide underpinning data for science in support of SDG 15.

Section 2 provides an overview of in-situ sites which will support cross calibration between CYGNSS and Rongowai. Section 3 discusses the significance of the GNSS-R soil-

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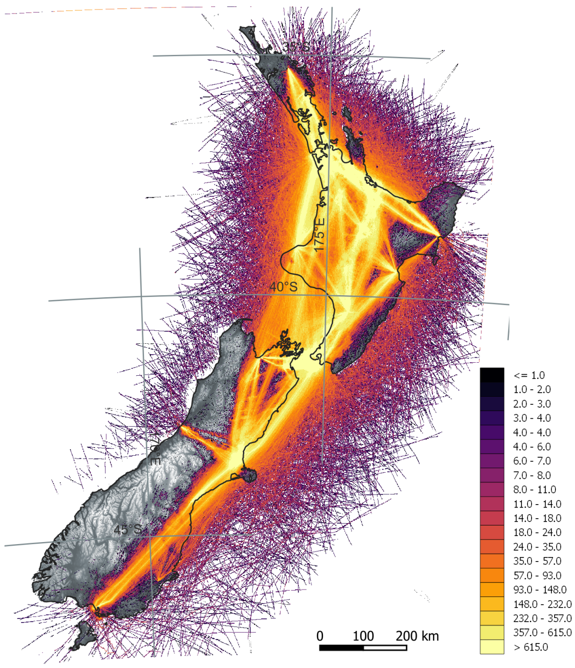

Fig. 1. Predicted Rongowai coverage across New Zealand, shown as the number of observations per pixel on a 700 m grid. The background image shows topography which can block signals, as is particularly apparent for the west coast of the South Island, due to the presence of the Southern Alps.

RONGOWAI

Fig. 2. Rongowai logo designed by student artist Waimihia Maniapoto-Love

moisture monitoring capability which is relevant not only for New Zealand, but a paradigm that is scaleable via its support for future GNSS-R satellite terrestrial-algorithm advances and possible adoption by other airlines. Section 4 shows contextual examples of the sampling and spatio-temporal resolution expected from Rongowai for the soil moisture retrievals. We conclude with the mission status and timeline in Section 5.

2. CYGNSS CROSS-CALIBRATION AND SOIL MOISTURE VALIDATION SITES

The initial focus of the terrestrial science data will be on soil-moisture retrievals and including cross-comparison with NASA's foundational CYGNSS. Mission. To this end, several NASA SoilScape [2] monitoring sites are being established in New Zealand as shown in Fig 3. The SoilScape sites (yellow stars) include forest and open pasture, complement existing local council monitored sites (blue dots), and overlap CYGNSS coverage which falls off rapidly below 38 degrees south. There is also considerable and extensive overlap with Rongowai to support cross-calibration with the exception of the farthest north SoilScape installation on the Aupouri peninsula. The Aupouri is a narrow peninsula (approximately 10km across) with a unique geometry well suited for assessing impact of water proximity on terrestrial retrievals under varying wind/wave conditions. For ths reason a dedicated SoilScape installation is planned focused analysis of CYGNSS data. The SoilScape installations are projected for Q1 2022.

In addition to the Northern New Zealand in situ sites noted (with CYGNSS overlap), a second area of focus is greater-Canterbury in the South Island (indicated by the lower pink rectangle). This region, particularly around Christchurch airport will have dense Rongowai coverage that is complemented by existing council in-situ monitoring.

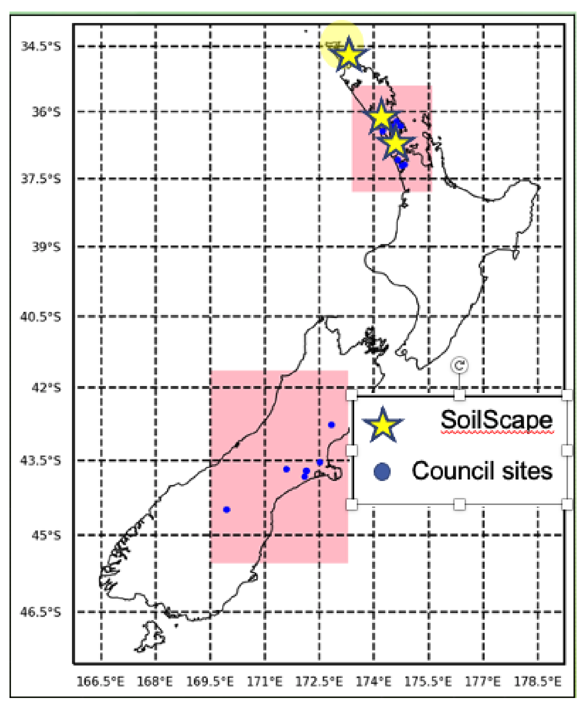

Fig. 3. Locations of existing (blue dots) and planned (stars) in situ soil moisture sites to support Rongowai, in addition to CYGNSS cross-calibration (North island only)

3. SIGNIFICANCE OF RONGOWAI FOR SOIL-MOISTURE MONITORING

Rongowai will provide a step-change in the availability of soil moisture data in New Zealand. For regions with significant agriculture such as Canterbury in the South Island, this additional information will enable improved, more sustainable agricultural practices. The eastern (low lying) Canterbury region is a good example of where Rongowai will have significant impact: annual rainfall is low (around 400 mm precipitation annually) and soils are thin, stony, and freely draining, with low moisture holding capacity and low fertility. This means that to enable agriculture, land is extensively irrigated and a large amount of fertiliser used. However, climate change projections from the National Institute for Water and Atmosphere indicate that the region will see similar or slightly increased levels of precipitation (0 - 10% increase), but an increase of 2 - 2.5°C in the annual mean air temperature, likely leading to increased evapotranspiration or loss of moisture from the ground and soil. There is a need to understand and improve what the environment will look like in the future and, as part of this, understand what information is available to make decisions towards building resilience in the long-term. Within this context, the additional information on soil moisture provided by Rongowai will be invaluable.

The existing available data for soil moisture are often insufficient for field-scale decision making. In-situ soil moisture sensors provide data at a high temporal resolution, often for multiple soil layers. However, without a dense network of gauges, they lack the ability provide spatial information across a field. Remote sensing platforms such as SMAP (Soil Moisture Active Passive) provide global coverage daily at 3 km spatial resolution, or every 3 hours at 9 km spatial resolution [3]; Sentinel-1 SAR data have been used to obtain soil moisture at around 1 km spatial resolution, with a temporal resolution of 6 or 12 days [4]. Rongowai finds a balance between these spatial and temporal trades-offs and provides data multiple times a day at a finer spatial resolution (around 400 m).

4. RONGOWAI TERRESTRIAL DATA PRODUCT PLANS

We estimate that Rongowai observations will be available for a majority of the country, as illustrated in the flight coverage analysis shown in Figure 1. The routes that the Q300 aircraft will fly during the mission, and therefore the actual coverage, will be determined by AirNZ operational requirements. Unusual for a remote sensing mission, we will not control where the aircraft goes, meaning that coverage for each region will vary depending the flight schedules, as well as being affected by topography. However, previous Q300 operations by AirNZ suggest that a large volume of data will be collected. Based on recorded flight operations for one Q300 aircraft over the course of a year, we expect good coverage for most of the North Island and the east coast of the South Island, as can be seen in the bright orange and yellow colours in Fig 1. Observations of the west coast region are limited due to the effects of the Southern Alps mountains blocking the signals. For North Island, most of the region is monitored except for a few gaps. Flights go as far north as Kerikeri.

For areas with frequent flights, we expect to obtain observations multiple times a day, although there will be periods with no data available, such as when the aircraft is operating in a different region, or is being serviced. Some locations near the flight path into Christchurch airport, have a much higher density of data collected with multiple observations per day (Fig 4). Each transect, which are shown as pink lines on the map in Fig 4, are formed of multiple points of reflectance of GNSS signals, which we will use to estimate soil moisture and surface water. Each transect represents a different GNSS satellite, and the shape and location of the transect results from the orientation and movement of both the satellite and the aircraft. Figure 4 shows one example flight from Christchurch to Nelson (south to north).

To provide an illustrative example of the data expected from Rongowai, we have “upsampled” a SMAP soil moisture observation from a spatial resolution of around 9 km to 90 m, data based on a weighted interpolation using topographic wetland index generated from SRTM (Fig 5). Although only illustrative and approximate, this gives an indication of the likely spatial variability in soil moisture that exists in reality, and how it may be sampled. Once processed, we expect Rongowai data from one flight to look like the illustration shown in Fig 5. The signal from each transect will change depending on ground conditions including soil moisture, our initial variable of interest. The inset map in Fig 5, illustrates how each point will cover approximately a 400 m diameter area on the surface (due to the signal Fresnel zone), each of which will overlap providing added information in the direction of each track.

5. CONCLUSION

Aligned with SDG 15, the upcoming Rongowai airborne GNSS-R mission promises to establish an operational capability to monitor critical observables relevant to sustainability of life on land. In particular Rongowai will demonstrate using platforms of opportunity to gather rich environmental records and support technological advances. While we have focused on soil-moisture as a key observable and initial priority, Rongowai will additionally help mature GNSS-R retrieval algorithms for wetland dynamics and coastal dynamics to include space-borne GNSS-R algorithm refinement and down-sampling assessments. All Rongowai Level 1 data and subsequent derived geophysical products will be made publicly available. The installation is planned for mid 2022 based on aircraft maintenance scheduling.

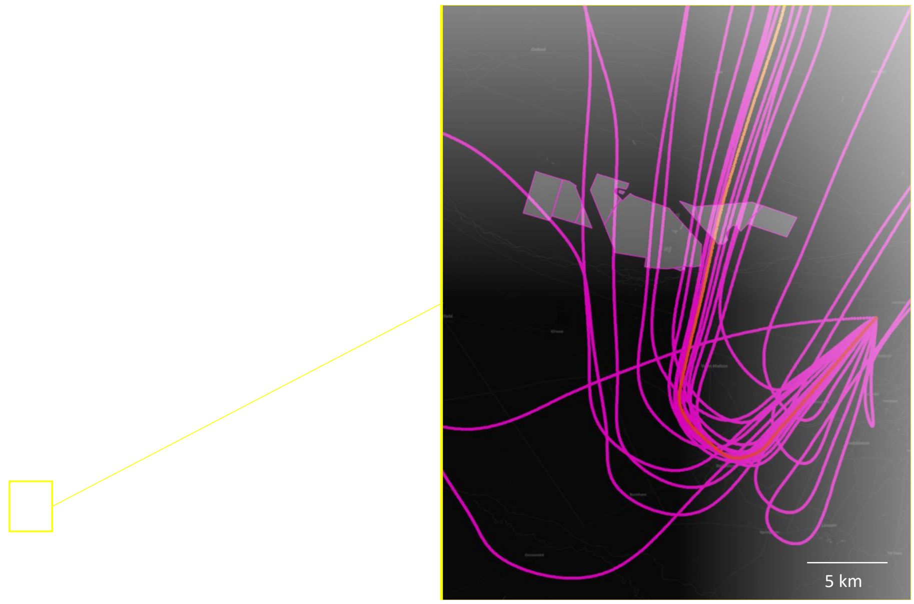

Fig. 4. Example flight from Christchurch to Nelson. Left: pink lines represent the location of reflected GNSS signals during the flight (flight direction: south to north). Right: inset map illustrating representative data for a farm near Christchurch airport.

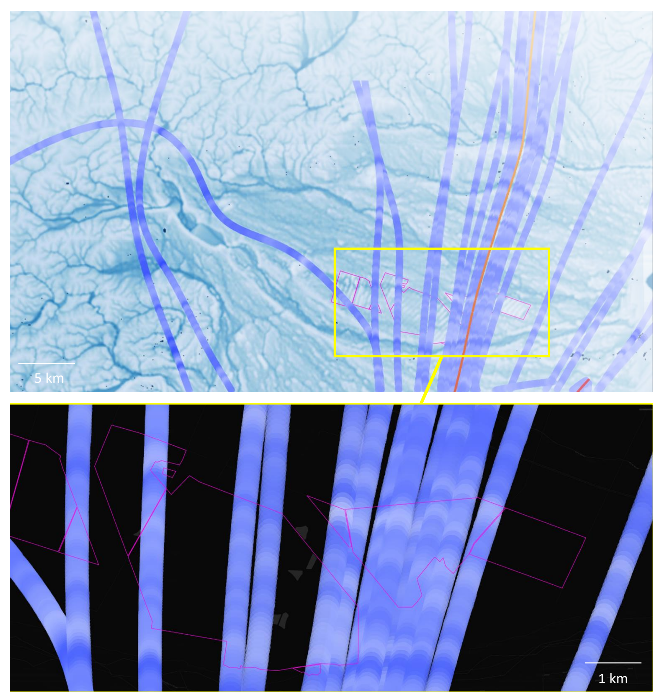

Fig. 5. Illustrative example of expected data from the Rongowai GNSS-R sensor. Top: flight line (in orange) and sampled soil moisture from GNSS-R (blue lines); the background illustrates the likely spatial variability in soil moisture present, derived from SMAP data and a topographic wetness index. Bottom: enlarged area showing a local densely sampled farm. Each transect consists of a series of reflections around 400 m in diameter, but substantially overlapping along-track.

6. REFERENCES

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