OPERATIONAL AIRBORNE GNSS-R ABOARD AIR NEW ZEALAND DOMESTIC AIRCRAFT

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ABSTRACT

NASA's Cyclone Global Navigation Satellite System (CYGNSS) mission has been a pathfinder in the field of GNSS reflectometry (GNSS-R), with a constellation of 8 microsatellites measuring windspeeds over the entire tropics every few hours. More recently, terrestrial GNSS-R is being exploited to reveal records of soil moisture and surface water inundation dynamics. In an exciting partnership between NASA and New Zealand, Air New Zealand will accommodate and host a recently developed next-generation GNSS-R receiver (NGRx) and commercial aviation GPS omnidirectional antennas on a domestic Q300 aircraft. The result will be unprecedented high-resolution, wide coverage long-term records of soil moisture and inundation dynamics over New Zealand's diverse landscape and ecosystems, independent of cloud cover. Such data will support terrestrial calibration and validation of CYGNSS while simultaneously advancing the technology readiness level of the NgRx and enabling new remote sensing science investigations in New Zealand.

Index Terms— *GNSS Reflectometry, Bistatic radar*

1. INTRODUCTION

Over the last 6 years, there has been a surge of activity using GNSS signals reflected off of the surface of the Earth for remote sensing. The GNSS receiver and GNSS satellites form a unique passive bistatic L-band radar system. Since the receive-only GNSS instrument can be made at much lower cost, mass, volume and power than traditional radars, large constellations of small satellites are readily possible, enabling completely new Earth observing strategies.

A prime example is NASA's CYGNSS (Cyclone GNSS) mission, which is a constellation of 8 microsatellites forming the first dedicated spaceborne GNSS reflectometry mission [Ruf et al., 2018]. CYGNSS has already operated successfully for 4 years, and its mission has been extended for several more. The next focus will be on exploring novel land applications that have been discovered. Furthermore, GNSS satellites have continued to proliferate and advance and as such the GNSS-R capability will similarly improve in capability (coverage, resolution, accuracy). In response, NASA's Earth Science Technology Office (ESTO) funded a 3-year effort to develop a more capable next-generation receiver (NGRx) [Ruf et al., 2020]. It is this NGRx, that Air New Zealand will integrate and fly on a domestic Q300 aircraft (see Figure 1). Our effort will not only mature the NGRx technology for future mission readiness, it will also provide unique high spatio-temporal resolution data over diverse climatologies, with varying land-cover, land-use.

GNSS satellites make an ideal signal-of-opportunity for passive bistatic radar since the signals are precisely timed (picosecond) and the positions of the transmitters are known to within several centimeters. However, while it is well understood how to measure the reflected GNSS signals over the ocean, measurements over land tend to be much more complex due to a number of factors (inhomogeneous scenes, mixed coherent/non-coherent scattering, spatial mapping into delay-Doppler space, etc). The enhanced resolution and accuracy of the NGRx combined with substantial airborne acquisitions over New Zealand's diverse yet characterized locations will advance our ability to utilize this powerful capability for new applications including optimizing the science capabilities of the next space constellation mission(s). Coherent GNSS-R terrestrial reflections can open up many interesting applications including wetland monitoring and dynamics, flood inundation, potential for cm level altimetry, near-surface soil-moisture and freeze/thaw monitoring.



Figure 1: An Air New Zealand Q300

2. AIRBORNE NGRX

This program expands on NASA ESTO's investment to advance the state of the art of GNSS-R. A comparison of the NGRx with that of the CYGNSS instrumentation is given in Table 1. A mission hosting the NGRx would result in higher resolution, better sampled measurements and additional information for enhanced science product retrievals.

To support this program, the NGRx hardware has been adapted for compatibility with routine airborne operations including certification compliance testing and automated data-handling and transmission. For the Q300 configuration we will use commercial aviation GPS omnidirectional antennas. For the airborne geometry we will be sensitive to specular reflections beyond those typically observed by satellite GNSS-R to include extreme grazing angles (>80 degrees). At these angles we expect to observe different behaviors in the GNSS reflection in terms of different polarizations and an increase in coherence [Linnabary et.al., 2020].

Table 1: Summary of GNSS-R receiver upgrades.

	CYGNSS	NGRx
GNSS	GPS L1	GPS L1 & L5 Gallileo E1 & E5
Simultaneous Channels	4	20
Polarization	Co-Pol	Co & Cross-pol

3. OPERATIONAL CHARACTERISTICS OF FLYING ON A DOMESTIC PASSENGER AIRCRAFT

While NASA and other national space agencies commonly use airborne assets for pre-mission and mission support, this effort is unique in that a major commercial airline, Air New Zealand, has committed to integrate, certify and host the payload. This opens the potential for a multiyear high density, high resolution coverage that would never be achieved with the usual handful of dedicated chartered flights. Not only will these acquisitions help design future GNSS-R missions and mature retrieval algorithms, but the observations will also be scientifically compelling. Over New Zealand, the science records will be useful for monitoring regional susceptibility to drought, flooding, changing regional patterns due to climate change and/or local land use and management.

The left panel of Figure 2 shows the CYGNSS coverage over New Zealand. The inclination of CYGNSS' orbit is 35 degrees and thus has a sharp fall-off in measurement coverage South of ~-37.5 degrees latitude. In comparison, the right graphic of Figure 2 shows a heat map of the expected coverage from a single Q300 for a year. To simulate the coverage, historical flight data for an Air NZ Q300 was pulled from FlightAware and reflections based on GNSS satellite orbits mapped. The density of returns gridded into 370m cells indicates very good coverage except for mountainous regions in the South West South Island.

It is evident from Figure 2 that, in addition to coincident observations in the overlap region, the Q300 flights will extend the CYGNSS mission coverage to incorporate more extreme latitudes and thereby advance terrestrial and coastal retrievals. The environmental and climate science enabled by Air New Zealand hosting the NASA NGRx could be transformational in terms of environmental monitoring.

4. CALIBRATION/VALIDATION

The initial focus of the terrestrial science data will be on soil-moisture retrievals and including cross-comparison with CYGNSS. To this end, several NASA SoilScape [Moghaddam et. al., 2010] monitoring sites are being established in New Zealand: Ararimu; Riverhead Forest; and the Aupouri Peninsula. Ararimu is an agricultural open pasture site already monitored by Auckland City Council that will be augmented by a SoilScape installation. In addition to Ararimu there are 8 additional sites that Auckland Council monitors for which the data will be available. The location of these sites (yellow circles) are shown overlaid on the CYGNSS coverage (and the Q300 prediction coverage (Figure 3 left and right graphics respectively). Also shown is Riverhead Forest which is a managed pine forest and will be instrumented with SoilScape.

In addition to the sites in the Auckland region, another SoilScape calibration/validation is planned for the Aupouri peninsula at the extreme North of New Zealand. Shown in Figure 4, Aupouri is a narrow peninsula (approximately 10km across) and was chosen due its unique well defined geometry. It is well suited for assessing impact of water proximity on terrestrial retrievals under varying wind/wave conditions. Although the Aupouri is too far North for Air New Zealand domestic coverage it is frequently covered by CYGNSS. In addition to locating a SoilScape site in an open agriculture region near Ngataki, there will be a similar soil-moisture monitoring installation in nearby Te Hiku forest (indicated by the red outline region in Figure 4).

Finally, in addition to the *in situ* monitoring, there will be airborne P- and L- band polarimetric synthetic aperture radar (SAR) and multispectral (color-IR) data acquired during dedicated campaigns. These data will be analyzed to support soil-moisture retrievals as a complement to the GNSS-R for a uniquely rich data set.

5. STATUS

Unsurprisingly, the Covid-19 pandemic has caused programmatic delays but despite this the development is maturing with integration and test Q1 2021. Installation is

anticipated for Q2/3 2021 and an intensive calibration phase in the latter months of 2021. The SoilScape installations will be established and operational prior to flights in Q1 2021.

To support operations a dedicated science payload operations centre (SPOC) is being developed to provide sensor communications, calibration, generation and dissemination of derived geophysical products. Ancillary data from other sensors including the in-situ installations and SAR overflights will be incorporated as relevant for analyses.

11. REFERENCES

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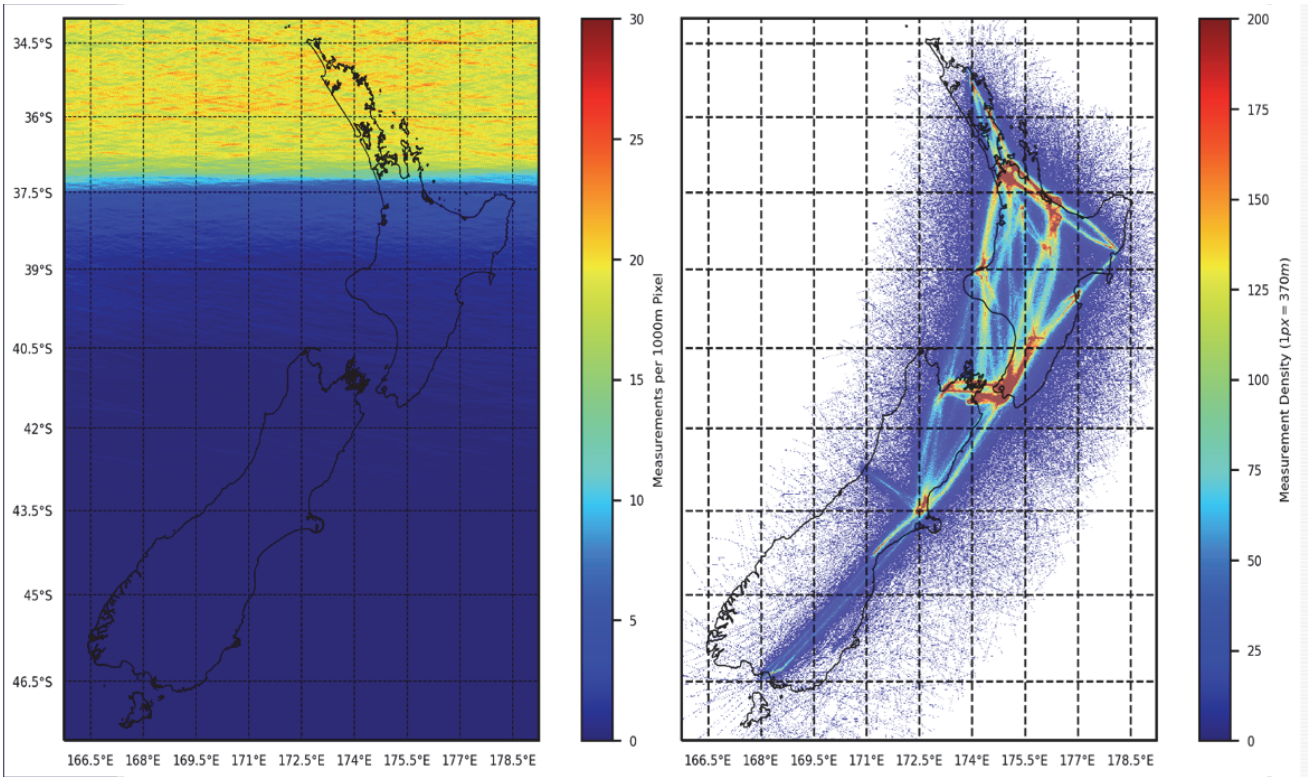


Figure 2: Left - coverage of CYGNSS mission over New Zealand. A sharp drop-off occurs South of -37.5 degrees latitude. Right - predicted yearly coverage of a single Q300 aircraft.

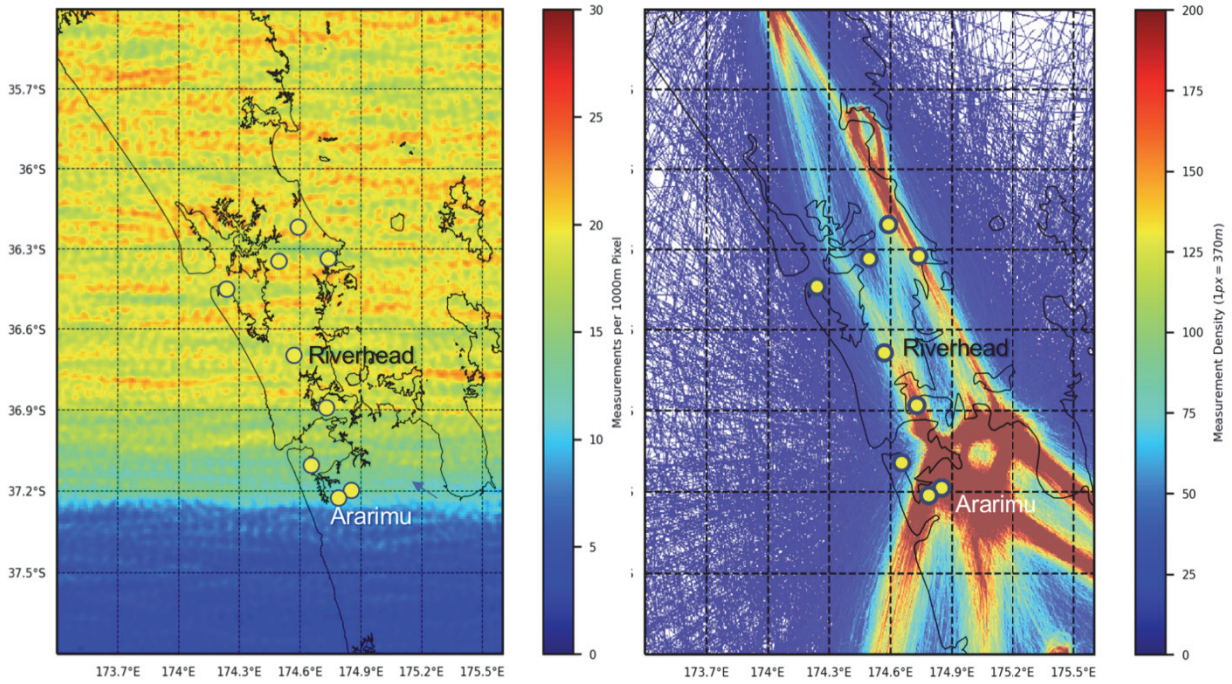


Figure 3: Auckland Council soil-moisture sites and Riverhead forest calibration site locations. Left - CYGNSS coverage. Right - predicted Q300 NGRx coverage

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Figure 4: Aupouri peninsula in the far North of New Zealand. Soil moisture calibration sites for forested and open areas to be established in Te Hiku forest (red outline) and near Ngataki respectively.