Retrieving Temporally Dense GNSS-RO Profiles from Long Duration Balloon Platforms

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Abstract

Night Crew Labs (NCL) developed a balloon-borne instrument named GNSS-RO and Observable Truth (GROOT), using commercial-off-the-shelf technology. It was flown on a long-duration high-altitude balloon flight, collecting GNSS-RO data in the stratosphere. ROs with **unprecedented temporal and spatial resolution** were retrieved with novel balloon-RO algorithms. This flight test demonstrates that aerial platforms (e.g. balloons, aviation) are an attractive method for retrieving ROs over on-demand, regional areas of interest for operational weather data collection.

Introduction

There is an opportunity to augment space-based GNSS-RO by using high-altitude, balloon-based platforms. Long duration high-altitude balloons can maintain altitudes of up to 30 km (100,000 ft) up to several months at a time, while station-keeping over desired regions using altitude-control technology. **These balloon platforms are tools to 1) provide persistent, on-demand RO data for specific regions of interest, and 2) reduce high costs, and 3) expedite long mission timeframes** that are typically associated with LEO satellite constellations.

Acknowledgements

Special thanks to Dr. Feiqin Xie and Kevin Nelson (TAMU-CC) for providing post-processing support.

Thanks to NASA Flight Opportunities program, NOAA SBIR program, and ACubed for funding support.

Thanks to World View Enterprises for hosting our hosted payload on their balloon platform.

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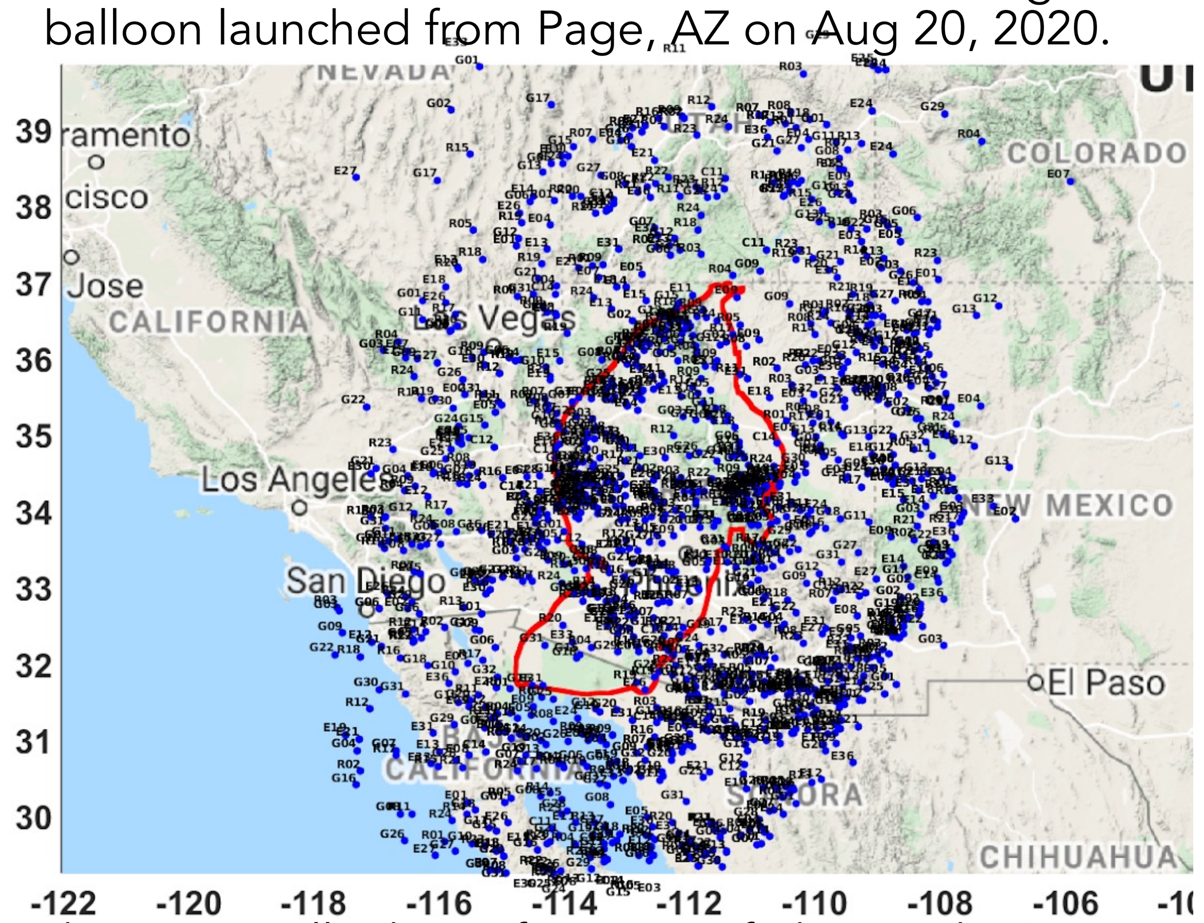
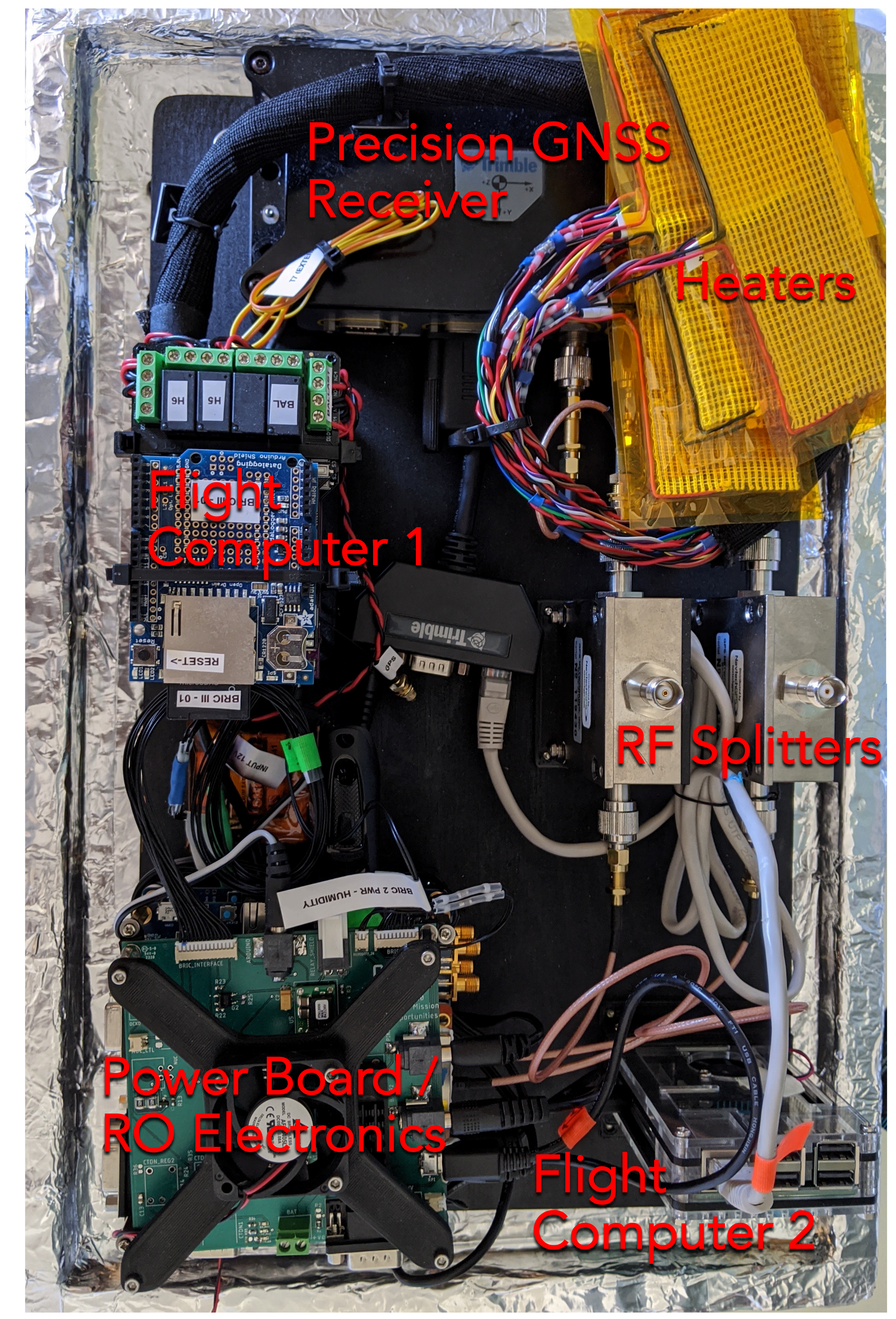
NCL's GROOT instrument was hosted on a long duration balloon launched from Page, AZ on Aug 20, 2020.



The temporally dense footprint of observed ROs in a 120 hour period over the southwestern United States.

Methodology

Based on a 2018 Phase I SBIR effort on commercial GNSS receivers and weather balloons, a high-level concept of the GROOT was formulated. Trimble and Swiftnav GNSS receivers were incorporated as the primary equipment for radio occultation applications. These receivers were integrated with support equipment to provide adequate power, thermal control, data processing, and a communications relay during the balloon flight. In August 2020, GROOT was integrated to a long duration balloon platform managed by World View Enterprises as a secondary hosted payload. The balloon was launched from Page, AZ and lifted GROOT to 15 km to 19 km altitude where it remained aloft for 120 hours. During this time, GROOT continuously operated and collecting RO data from GPS, Galileo, and Beidou GNSS constellations. After mission termination, the data was recovered and processed by the team.

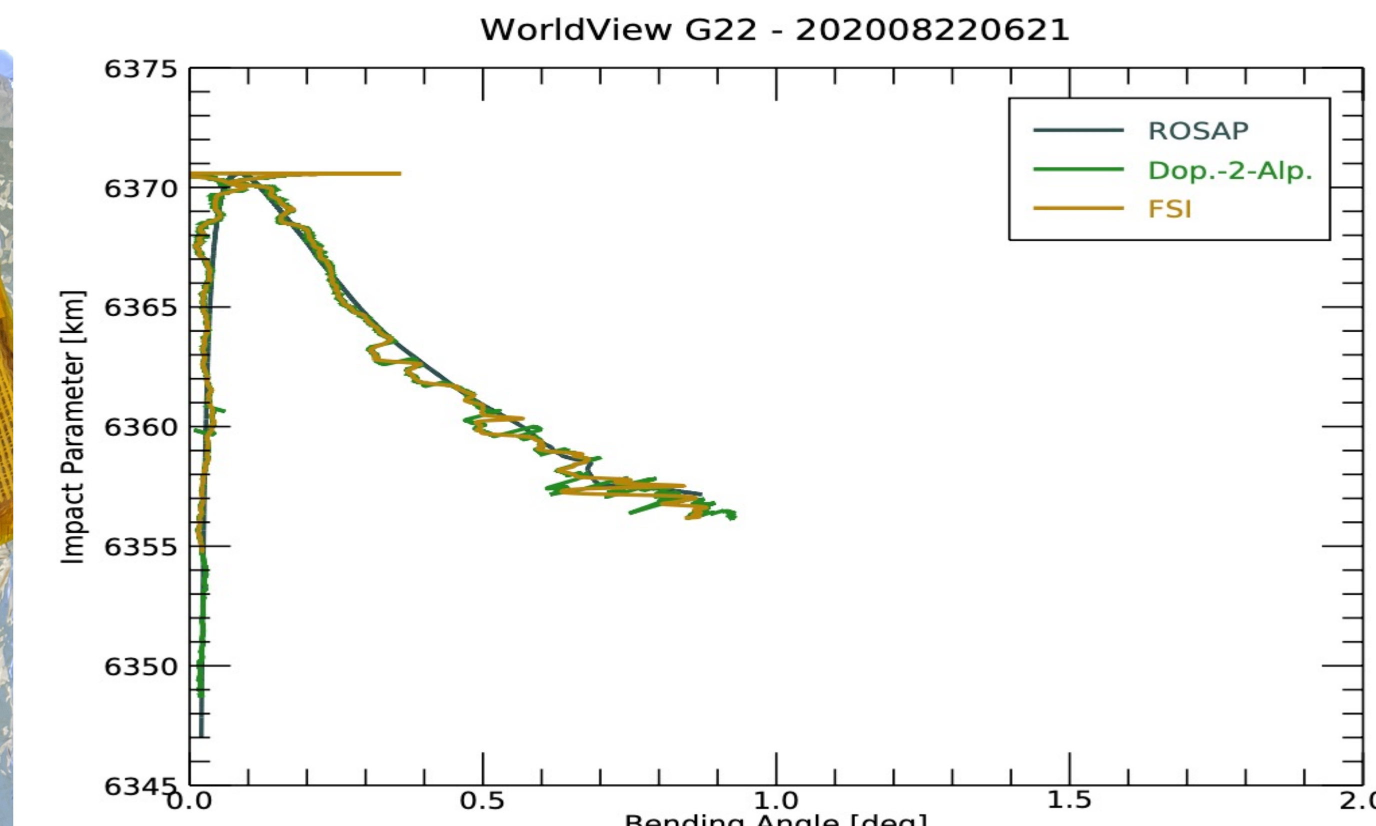


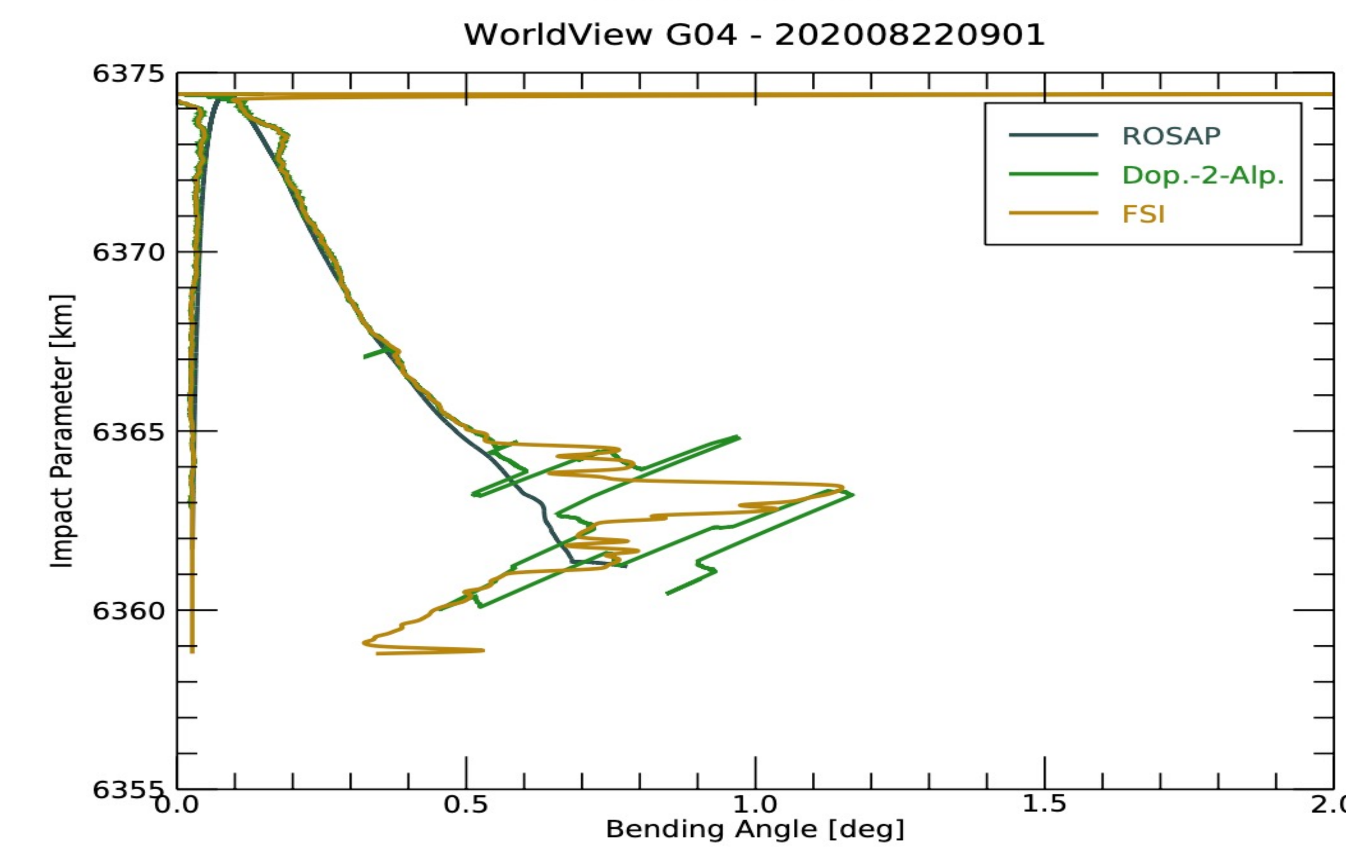
The GROOT balloon instrument.

Separately, balloon retrieval algorithms were developed by the TAMU-CC team. Unlike space-borne ROs, the bending and diffraction effect near the RO receiver inside the atmosphere become non-negligible and need to be accounted for. Similar to the aircraft-based RO measurements, the balloon-borne RO receiver is also inside the atmosphere, but generally moving in a much slower speed. In addition to the tracking the RO signal below the local horizon, RO signals from above the local horizon also need to be recorded. Initially, geometric optic retrieval code was developed to produce bending angles and refractivity. The code was improved by adding a radio holographic retrieval capability through the Full Spectrum Inversion (FSI) technique. FSI 1) mitigates multi-path effects arising from diffraction due to the moist lower troposphere, and 2) improves vertical resolution. Retrieval results were compared to ROSAP and ERA5 re-analysis models.

Results

During the flight, the balloon platform showcased station-keeping ability and generally remained in Arizona airspace. 1,354 ROs were observed within a relatively tight 900 km x 1000 km area (see RO footprint figure). **The temporal RO sounding density, defined as [daily ROs per million square miles], exceeded 340 for this single balloon flight, compared to approximately 50 from all operational space-based RO sources in 2020 – a 6.5x increase.**





Geometric Optic (listed as "Dop-2-Alp") and FSI-based bending angle retrievals matched well with ROSAP simulations, see plot figures. **In the G04 case, the signal is tracked to -4.2° elevation angle, and to 1.5 km from local terrain surface.** Here, there is multipath error introduced by tropospheric moisture that the Geometric Optic retrieval has trouble resolving. In contrast, the FSI retrieval has a 1:1 matching of impact parameter to bending angle data, which demonstrates that multipath errors are being corrected.

Conclusions

NCL's balloon-borne GNSS-RO prototype instrument captured quality data with extreme temporal and spatial resolution, compared to space-borne assets. Using phase-lock loop receivers as a demonstrator, RO soundings often penetrated the planetary boundary layer (2-3 km) and FSI-based retrievals showcased multipath error removal. Several research data collection flights on balloon and fixed wing platforms are being conducted to contribute to this body of work. Developing near real-time processing capability is the main hurdle to transition the technology from research to operations.