THE ARIA-S1-GUNW: THE ARIA SENTINEL-1 GEOCODED UNWRAPPED PHASE PRODUCT FOR OPEN INSAR SCIENCE AND DISASTER RESPONSE

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ABSTRACT

NASA has committed to open-source science that enables Earth observation data transparency, inclusivity, accessibility, and reproducibility – all fundamental to the pace and quality of scientific progress. We have embraced this vision by producing standard InSAR science products that are freely available to the public through NASA Data Active Archive Centers (DAACs) and are generated using state-of-the-art open-source and openly-developed methods. The Advanced Rapid Image Analysis (ARIA) project's Sentinel-1 Geocoded Unwrapped Phase product (ARIA-S1-GUNW) is a 90 meter InSAR product that spans major, land-based fault systems, the US Coasts, and active volcanic regions through the complete Sentinel-1 record. The products enable the measurement of centimeter-scale surface displacement with applications across the solid earth, hydrology, and sea-level disciplines. The ARIA-S1-GUNW also enables rapid response mapping of surface motion after earthquakes, landslides, and subsidence. The ARIA-S1-GUNW products are freely available through the Alaska Satellite Facility (ASF) DAAC. In the last year, we have successfully grown the archive to over 1.1 million products, a 6 fold increase, through NASA ACCESS by improving our processing workflow and leveraging HyP3, an AWS-based cloud processing environment. We are continuing to partner with researchers to generate more products over relevant areas of scientific interest. All the processing software and cloud infrastructure are open-source to ensure reproducibility and enable other scientists to modify, improve upon, and scale their own cloud workflows for related InSAR analyses. We have, in parallel, developed and supported open-source, well-documented tools to further streamline time-series analysis from the ARIA-S1-GUNW into deformation analysis workflows.

Index Terms— InSAR, Open Science, Surface Deformation, Disaster Response

1. INTRODUCTION

Interferometric SAR (InSAR) has revolutionized how we understand and observe our dynamic planet, providing global, repeat imagery of the Earth's surface, identifying centimeter scale surface motion. InSAR surface displacement is used *to map* plate tectonics [1], glacial motion [2], and hydrological dynamics (including, sea-level rise) [3]; *to support* disaster response after earthquakes [4], landslides [5] and volcanic eruptions [6]; and *to monitor* ground subsidence and uplift from groundwater extraction and other anthropogenic activities [7]. The 2017 Decadal Survey for Earth Science and Applications from Space identifies InSAR to be the primary mode of measurement for surface deformation and change [8] and yet InSAR analysis remains massively underutilized due to the low-level, computationally heavy radar processing required to to measure surface displacement between two SAR acquisitions. The ARIA-S1-GUNW product removes this prerequisite, providing a disk-efficient product that can be quickly accessed, aggregated, and analyzed to understand surface motion at scale.

The ARIA project was designed to provide InSAR products rapidly to support disaster response after earthquakes, landslides, and flooding events. As the project's cloud capabilities increased, InSAR products were generated to study seismically active regions at larger spatial scales and longer temporal range. Through a NASA ACCESS grant, we have significantly expanded the archive, surpassing 1.1 million

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*dbekaert@jpl.nasa.gov. This work was done with support from ACCESS 19-0023. The InSAR processor was first developed under JPL-Caltech's ARIA project. United States Government Sponsorship acknowledged. All rights reserved ©2023. Some of the research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004).

products. We also partner with researchers to fund the generation of the ARIA-S1-GUNW products over relevant areas of interest. Our cloud pipeline automatically publishes the generated ARIA-S1-GUNWs to the ASF DAAC so the entire science community can explore and reuse this data for their own analyses. While there is a comparable Sentinel-1 data archive and associated open-source time-series tools provided via Comet [9], the ARIA-S1-GUNWs wealth of online and video tutorials for InSAR displacement analysis using ARIA-Tools [10] and MintPy [11] attempt to provide a lower barrier to entry.

2. THE ARIA-S1-GUNW PRODUCT

The ARIA-S1-GUNW is currently the largest InSAR archive spanning major, land-based fault systems and active volcanic regions with over 1.1 million products freely searchable and accessible through the ASF DAAC. As shown in figure 1, we have generated over 1 million products in the previous calendar year to massively expand the archive and continue to add new products. Figure 2 captures the archive's coverage. The ARIA-S1-GUNW archive embodies NASA's commitment to open science. ARIA-S1-GUNWs are generated using open source tools so that each product can be reproduced anywhere using the metadata embedded within the product itself. InSAR analysis of the ARIA-S1-GUNW is further streamlined with a robust ecosystem of open-source tools for accessing and aggregating the data (ARIA-Tools [10]) and understanding surface motion through time (MintPy [11]). There are numerous online resources including video tutorials on how to perform deformation analysis with these products [12].

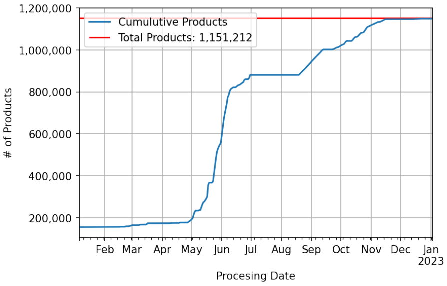

Fig. 1: Cumuluative growth of ARIA-S1-GUNW archive

2.1. Format

The ARIA-S1-GUNW products contain (a) input sensor data, (b) sensor/interferometric imaging geometry, and (c) interferometric rasters such as the unwrapped phase and perpendicular baseline, which have a 90-meter pixel-spacing. The products are distributed as ≈50 MB geocoded, CF-compliant netCDF files. Importantly, the ARIA-S1-GUNW products are organized into a *sensor-neutral* InSAR data product and can be extended to other missions such as NISAR [13]. This allows InSAR analysis workflows developed for any ARIA GUNW product to be shared across sensors greatly enhancing the reuseability of InSAR analyses.

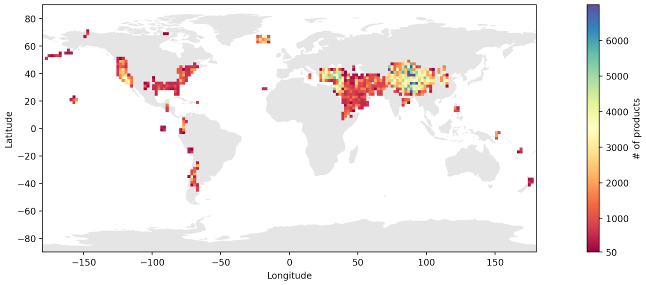

Fig. 2: Coverage of the ARIA-S1-GUNW archive

2.2. Methodology

ARIA-S1-GUNWs are generated by (1) enumerating SLCs to find Interferogram pairs, (2) submitting SLC pairs to HyP3-ARIA for processing in the cloud which (3) generates GUNWs using the ISCE2-based ARIA processor, and (4) publishing the resulting products to ASF DAAC. The evolution of this workflow has been considerably matured and simplified thanks to new open-source tools and lessons learned in the ARIA project. All the software for the above can be found in the ACCESS Cloud-based InSAR GitHub organization. For (1), we developed an enumeration tool [14] to extract metadata from NASA CMR and enumerate inteferogram pairs. For (2) and (3), we submit processing using a collection of Jupyter Notebooks [15] to custom HyP3 [16] deployment for the ARIA project. Users are authenticated through Earthdata accounts and there is a single operational user whose product submissions, once completed, will be published to the ASF. The ARIA processor [17] is used to generate the ARIA-S1-GUNWs in the cloud and is based on the ISCE2 TopsApp InSAR processor [18] which has been developed at JPL over the last decade. A key feature of ARIA processor is that all input datasets are localized from publicly available datasets upon start so that ARIA-S1-GUNWs can be generated locally exactly as it would be in the cloud.

3. OPEN SCIENCE APPLICATIONS

In this section we highlight current and forthcoming research by collaborators that utilize the ARIA-S1-GUNW to showcase the robust, open-source ecosystem built around these products. We, however, will not discuss the analysis conducted using these products in depth as they will be published separately.

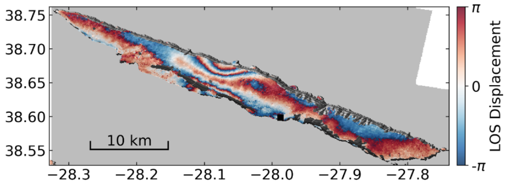

Fig. 3: LOS displacement in Sao Jorge. (*Courtesy: Grace Bato*)

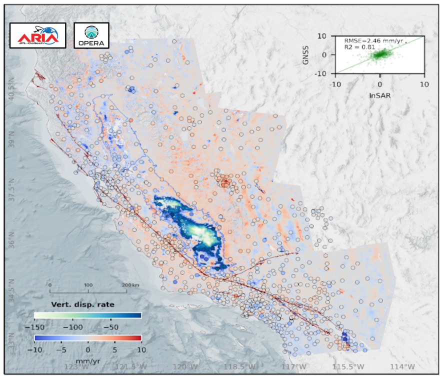

Fig. 4: Vertical land motion over CA. (*Courtesy: Marin Govorcin*)

3.1. NASA Disasters

Grace Bato and The JPL disasters team has used the on-demand capabilities of the HyP3-ARIA cloud system to create ARIA-S1-GUNWs after volcanic unrest or earthquakes: Sao Jorge volcano in Portugal (2021) shown in Figure 3, Cumbre Vieja volcano ridge in La Palma (2022), Turkey/Syria earthquake (2023), and eruption of Mauna Loa in Hawaii (2022). These products were be provided to first responders and local governments.

3.2. Vertical Land Motion

Marin Govorcin (OPERA) has used the ARIA-GUNWs to estimate vertical land motion across CA using a dense time series of GUNWs calibrated by GNSS as in Figure 4.

3.3. Aleutian Volcano Chain

ACCESS science CO-I Zhong Lu and Jaihui Wang used newly generated ARIA-S1-GUNWs to analyze the Aleutian volcano chain across the Sentinel-1 catalog. Figure 5 shows the displacement velocity.

3.4. Tibetan Tectonic Motion

Using approximately 500k ARIA-S1-GUNWs, Rob Zinke analyzed the tectonic motion of the Tibetan plateau. Motion along two fault lines can be seen in Figure 6.

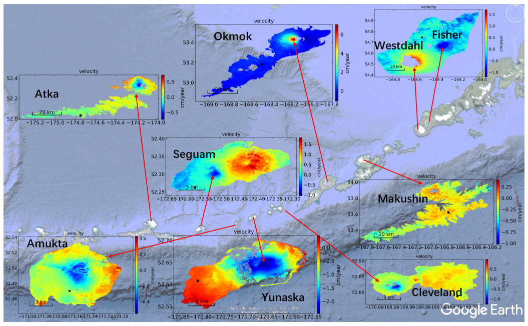

Fig. 5: The displacement velocities for Aleutian volcanoes. (*courtesy: Jaihui Wang, Zhong Lu*)

4. CONCLUSIONS AND FUTURE WORK

The ARIA-S1-GUNW is a sensor-neutral InSAR product that greatly streamlines InSAR analysis. Using our improved cloud pipeline developed under ACCESS, we have significantly expanded the archive and reduced latency for acquiring analysis ready interferograms, supporting distaster response and continental-scale analyses. In the coming months, we will continue to improve upon the products (ensuring backward compatibility) including additional layers such as tropospheric and ionospheric phase corrections for improved displacement retrievals. All improvements will be openly developed and the improved products will continue to be freely available via the ASF DAAC.

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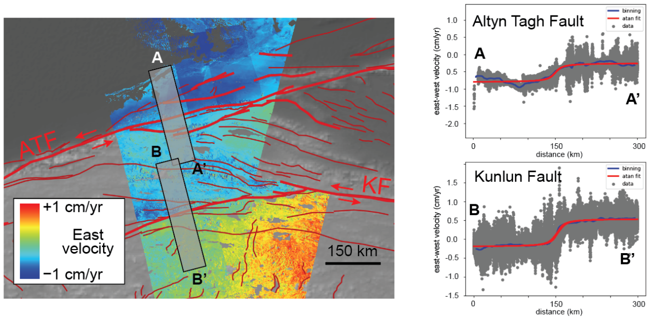

Fig. 6: East-west ground surface velocity across Tibetan faults. (*courtesy: Rob Zinke*)

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