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Biennial report for Permanent Supersite/Natural Laboratory

Hawai'i Supersite

History	*https://geo-gsnl.org/supersites/permanent-supersites/hawaiian-volcanoes-supersite/*
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1. Abstract

In 2008, the Hawai`i Supersite was established to encourage collaborative research into volcanic processes on the Island of Hawai`i, and to aid with the assessment and mitigation of volcanic hazards to the local population. Made permanent in 2012, the Supersite now hosts a diverse array of data from a variety of sources. Comprehensive ground-based monitoring, conducted by the Hawaiian Volcano Observatory and collaborators, consists of deformation, seismic, gravity, gas emissions, camera observations, and geochemical analyses. Space-based data include thousands of Synthetic Aperture Radar (SAR) images provided by numerous national space agencies, as well as optical and thermal datasets that can be used to detect changes in topography and variations in thermal and gas emissions. Using these datasets, a variety of insights have been gained into how Hawaiian volcanoes work. For example, magma supply to Kīlauea appears to fluctuate on timescales of just a few years and has a direct impact on eruptive activity. Magma accumulation at Kīlauea can promote slip on nearby faults, triggering M4+ earthquakes. Magma storage and transport pathways were mapped at both Kīlauea and Mauna Loa volcanoes, providing a basis upon which to interpret past, present, and future monitoring data. In addition, Supersite data, particularly SAR, have been invaluable for operational monitoring of deformation and eruptive activity—critical information for understanding the evolving nature of volcanic hazards in Hawai`i. These datasets were particularly important before, during, and following the 2018 flank eruption and summit collapse at Kīlauea—an event that destroyed hundreds of homes and caused major disruption to the local population due to earthquake shaking and toxic gas emissions. The wealth of available data has not only fueled hazards responses and scientific investigations but has also facilitated the development of new methodologies for processing and analyzing SAR data, given the large number of images, availability of ground-based data for calibration/validation, and continuous volcanic activity against which to test new methods. This combination of data availability and volcanic activity have led to an extensive publication record, which demonstrates the success of the Supersites initiative. Recent research has focused on the 2018 flank eruption and summit collapse—the most significant activity to have occurred at Kīlauea in over 200 years and the best-observed caldera collapse sequence ever—as well as the post-collapse recovery of the volcano as it entered a new period of eruptive activity. Supersite datasets have facilitated exploration of, for example, the process of caldera collapse and the nature of magma-tectonic interactions. In addition, neighboring Mauna Loa is experiencing heightened levels of unrest that may ultimately lead to the first eruption of the volcano since 1984. Inflation of the volcano and motion along caldera-bounding faults has been well documented by InSAR and might not have been so clearly interpreted without the aid of the Supersite. Insights from Supersite data have become invaluable to stakeholders on the Island of Hawai`i, and results provide exceptional fodder for scientific exploration into how volcanoes work.

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Scientists/science teams issues

A few new science team members were added during this reporting period; these scientists mostly hoped to take advantage of the vast dataset spanning Kīlauea's 2018 collapse and 2020-2022 eruptive activity to model volcanic processes and test data processing and analysis methods. Communication between the science teams and PoCs remains limited, but the impact of the Supersite is clear through the numerous research products that have made use of the datasets spanning Kīlauea's 2018 flank eruption and summit collapse. The COVID-19 pandemic made in-person meetings mostly impossible until late 2022, so interactions between *independent Supersite scientists and science teams remained limited. There is high hope that such interactions will grow in 2023 and 2024, especially if a tentatively planned AGU Chapman Conference on Kīlauea's activity takes place in 2024.*

Note that the list of Supersite users provided above is comprised of individuals who have requested access to CSK data, which are the only Supersite data that truly require PoC involvement. Other users who may access data via other means (for example, via their own PI agreements with space agencies) are not listed. It is difficult to define the scientists and science teams for the Hawaiʻi Supersite since there are so many people utilizing these data. This represents an ambiguity that GSNL may need to address at some point.

3. In situ data

Type of data	Data provider	How to access	Type of access
GPS	*USGS – HVO*	*UNAVCO*	*Unregistered public*
Seismic	*USGS – HVO*	*IRIS*	*Unregistered public*
Gas emissions	*USGS – HVO*	*Publications and DRs**	*Unregistered public*
Gravity	*USGS – HVO*	*Publications and DRs**	*Unregistered public*
Tilt	*USGS – HVO*	*Contact USGS – HVO***	*GSNL Scientists*
Camera	*USGS – HVO*	*Contact USGS – HVO***	*GSNL Scientists*
Strain	*USGS – HVO*	*Contact USGS – HVO***	*GSNL Scientists*

** Denotes data that are only released when published because significant data processing is necessary to achieve useable results. Peer review is required to assure the quality of the processed data. Since 2018, these data are made available via the USGS ScienceBase system.*

*** Denotes data that are not made publicly available due to lack of a suitable archive but that can be obtained through collaboration with scientists at the USGS Hawaiian Volcano Observatory or, in some cases, via the USGS ScienceBase system.*

In situ data issues

A few datasets, like gas emissions and gravity, require significant post-processing. Because of the need for stringent quality control, such data are not made publicly available until they have been through the peer review process. When approved, these data are released via the USGS ScienceBase archive, where metadata are also available (https://www.sciencebase.gov/catalog/). Other datasets, including tilt, visual/thermal camera, and strain, are only available by contacting the data provider, since there are no established archives or agreed-upon formats for storing such data. The data may also be difficult to understand, requiring the provider to offer guidance on processing and interpretation. There are plans to have these data eventually posted in the ScienceBase system and updated regularly as new data are collected—this will be especially valuable for continuous datasets like ground tilt and continuous gas emission and chemistry measurements. For GPS and seismic data, *UNAVCO and IRIS, respectively, continue to serve as the primary archives. In late 2022, UNAVCO and IRIS will merge to form the Earthscope Consortium, but this will not impact data archives and availability.*

4. Satellite data

Type of data	Data provider	How to access	Type of access
ENVISAT	*ESA*	*https://earth.esa.int/eogateway/missions/envisat/data*	*Registered public*
RADARSAT-1	*CSA*	*Uncertain**	*Registered public*
ALOS-1	*JAXA*	*https://search.asf.alaska.edu/*	*Registered public*
TerraSAR-X	*DLR*	*Available after acceptance of PI proposal by DLR*	*GSNL scientists*
Cosmo-SkyMed	*ASI*	*POC requests access from ASI for individual users, data then accessible via Geohazards TEP and UNAVCO*	*GSNL scientists*
RADARSAT-2	*CSA*	*POC requests access from CSA for individual users, data then accessible via UNAVCO***	*GSNL scientists*
ALOS-2	*JAXA*	*POC requests access from JAXA for individual users, data then accessible via UNAVCO****	*GSNL scientists*
Sentinel-1 a/b	*ESA*	*https://scihub.copernicus.eu/*	*Registered public*
PAZ	*INTA*	*POC requests access from INTA for individual users*	*GSNL scientists*
Pleiades	*CNES*	*POC requests access from CNES for individual users*	*GSNL scientists*

NOTE: This list only includes SAR and Pleiades optical data, which often require payment or approval of a research proposal. Freely available data (e.g., MODIS, Landsat) are not listed.

** Radarsat-1 data were available via the legacy Supersite pages, but those links have not worked for over 6 years, and the new Supersite pages do not contain any links to archive data.*

*** Radarsat-2 data have not been available since 2016 owing to expiration of the SOAR proposal for Hawai'i Supersite data. The Supersite would benefit from a renewal of this proposal, but it is unclear if the project would be supported by CSA.*

**** All ALOS-2 data for Hawai'i were supplied via RA-4 and RA-6 data grants to the PoC, but these grants expired in early 2021, and no new data have been acquired/processed by the Supersite since that time.*

Satellite data issues

Issues regarding data availability and accessibility have not changed over the life of the Hawai'i Supersite. These issues include:

- Links to RADARSAT-1 data used to be available on the legacy Supersite web pages, but these never worked, and the legacy pages have now been removed. It is therefore unclear how

anyone could gain access to these data. Fortunately, ALOS-1 data are now available via the Alaska Satellite Facility.

- There is no streamlined method for requesting user access to SAR data; each space agency has a different access policy, some of which require PoC approval (e.g., ASI), others of which do not (e.g., DLR). A single method for "joining" a Supersite and accessing restricted data (mostly SAR imagery) would be preferable, but would obviously be difficult to implement.

- There is no Supersite-specific archive for non-SAR satellite data, like EO-1, Landsat, MODIS, ASTER, and other usually free datasets (although the USGS Hazards Data Distribution System has been stockpiling some imagery of Kīlauea since 2014, and this archive was expanded in 2018 due to the eruption crisis at Kīlauea). This imagery constitutes an important source of information for synergistic studies using SAR and ground-based data. Developing an archive for visual and thermal remote sensing data, as well as other relevant resources (e.g., DEMs, many of which were acquired during Kīlauea's 2018 summit collapse and are available via the USGS ScienceBase system), would be an important next step in growing the Hawaiʻi Supersite to a new level of capability and utility. This step will probably require some level of additional funding and personnel, which have been difficult to procure even with the additional attention due to the 2018 eruption crisis.

For information regarding specific requests for satellite datasets for the 2023-2024 period, please see the end of section 9, below.

5. Research results

During the 2021–2022 reporting period, research results that utilized Supersite data continued to focus on Kīlauea's 2018 flank eruption and summit collapse. In addition to the large literature that addressed the 2018 activity, including its onset (e.g., Poland et al., 2022), several studies focused on pre-2018 volcanism at Kīlauea—including investigations of deformation and gravity change over the course of the 2008–2018 summit eruption (Koymans et al., 2021; Poland et al., 2021), as well as a magmatic intrusion that occurred in 2015 but had not been comprehensively investigated until recently (Bemelmans et al., 2021). Studies also focused on Mauna Loa volcano (e.g., Varugu and Amelung, 2021)—the largest volcano on Earth, and one that has been experiencing inflation and elevated seismicity over the past several years as potential prelude to eruption.

Volcanic unrest and eruptive activity from late 2020 to late 2022 provided exceptional opportunities to exercise the capabilities of the Hawaiʻi Supersite. The period saw the end of 2+ years of no eruptive activity at Kīlauea. Over the course of 2019 to 2020, a water lake accumulated in the 2018 collapse crater as groundwater returned to the summit region. On December 2, 2020, a magmatic intrusion caused the caldera to inflate and nearly reached the surface, indicating that pressure in the magmatic system had reached a point where a return to eruptive activity was possible (Figure 1a). Then, on December 20, the first eruption since 2018 occurred. The summit deflated (Figure 1b) as lava began filling the 2018 collapse pit, rapidly *vaporizing the water lake. The eruption continued until May 2021, but the volcano inflated throughout the lava extrusion, indicating that pressure was still accumulating in the magmatic system. After a few months of quiescence, another intrusion occurred in the south part of Kīlauea caldera during August 23–30, 2021 (Figure 1c), although unlike in early December 2020, this one remained more than a kilometer beneath the surface based on modeling of deformation data. The persistent inflation culminated on September 29, 2021, when another eruption began, and lava began filling more of the 2018 collapse pit, accumulating atop the lava of the previous eruption. The summit deflated rapidly in response to the onset of the eruption (Figure 1d). Eruptive activity persisted through at least late November 2022 (the time of this report), and the volcano has returned to a state of persistent inflation. The eruption that began in September 2021 has been intermittently interrupted by lulls and surges; one of these transients was associated with intrusion of a sill at shallow depths (hundreds of meters) beneath the summit lava pond (Figure 2). This sill intrusion would not have been recognized without the high-resolution SAR data made available via the Supersite.*

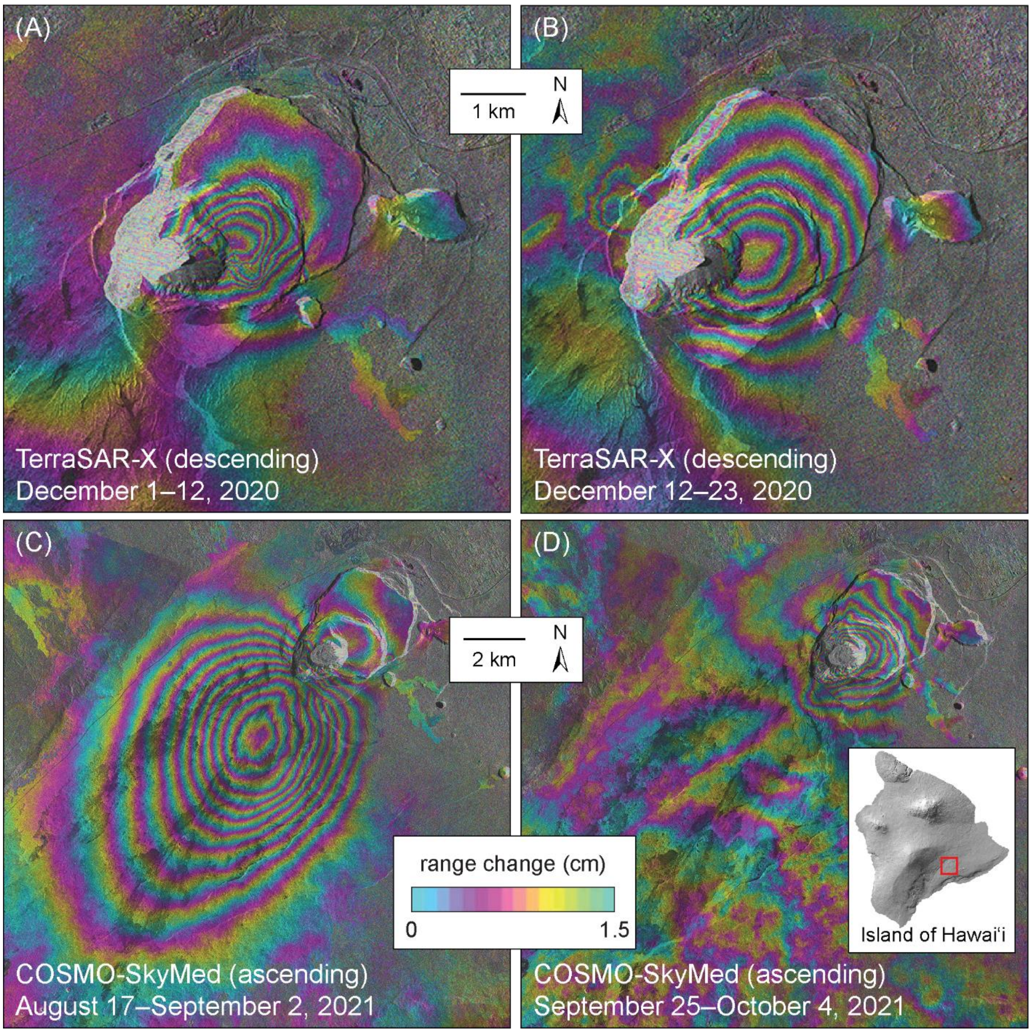

Figure 1. Interferograms from TerraSAR-X and COSMO-SkyMed spanning the December 2, 2020, intrusion beneath the summit caldera (A), onset of eruptive activity on December 20, 2020 (B), an intrusion beneath the south part of the caldera during August 23–30, 2021 (C), and the onset of a second eruption on September 29, 2021 (D).

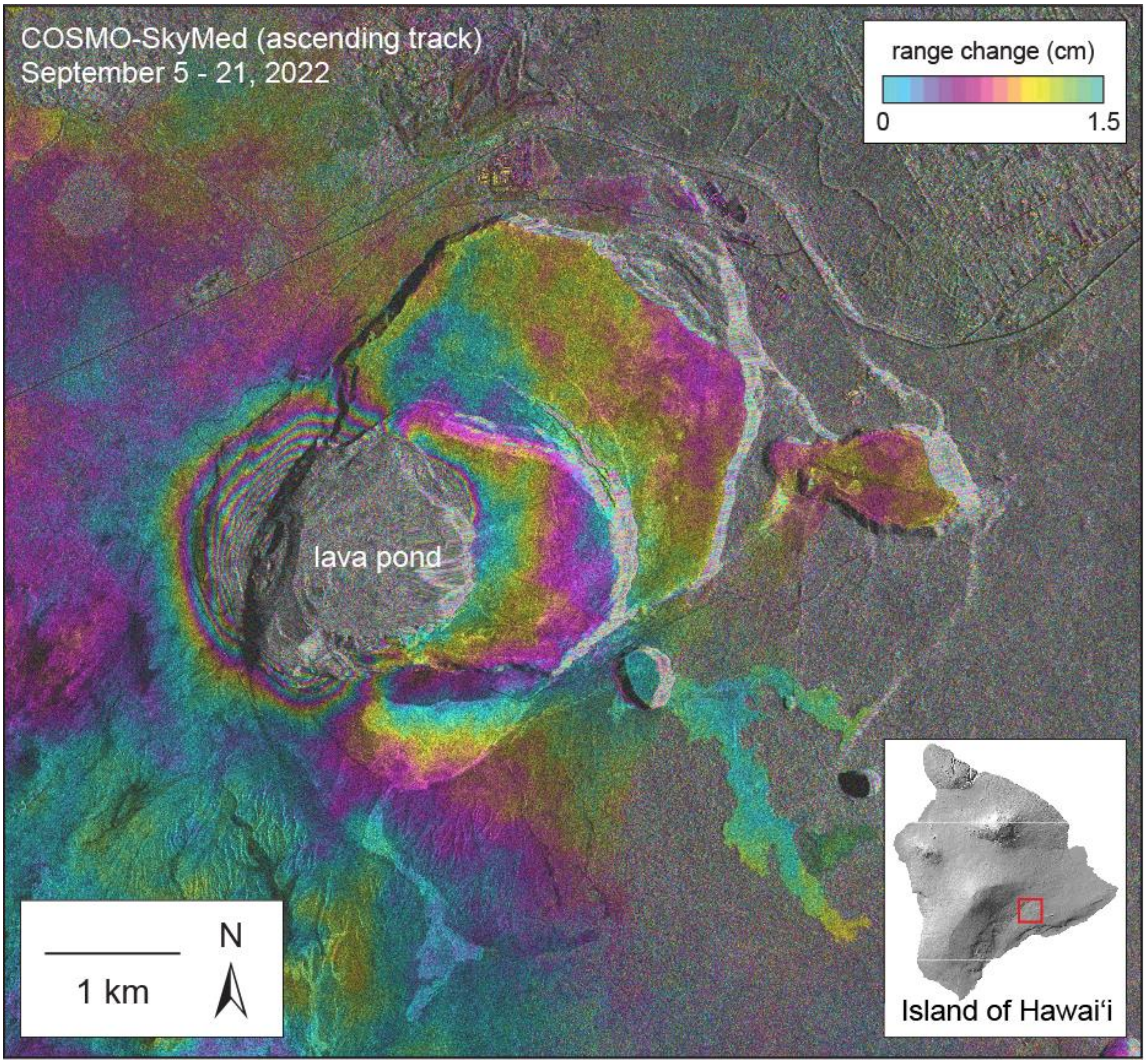

Figure 2. COSMO-SkyMed interferogram spanning September 5 – 21, 2022, and showing deformation on the margins of the active lava pond that is associated with intrusion of a shallow sill.

Meanwhile, Mauna Loa volcano continued to inflate at a variable rate. Of special note was a M3.2 earthquake on March 6, 2021. The event was extremely shallow and occurred at the culmination of a period of inflation that had reached rates of several centimeters per year. Shortly after the earthquake, the volcano deflated slightly, and deformation rates remained low for the rest of 2021. Interferograms spanning the shallow earthquake show highly localized deformation along the caldera wall (Figure 3), indicating that the earthquake and deformation are related to motion along the caldera-bounding fault, perhaps as a result of stress changes induced by magma chamber inflation. This insight would not have been possible without data provided through the Hawai'i Supersite.

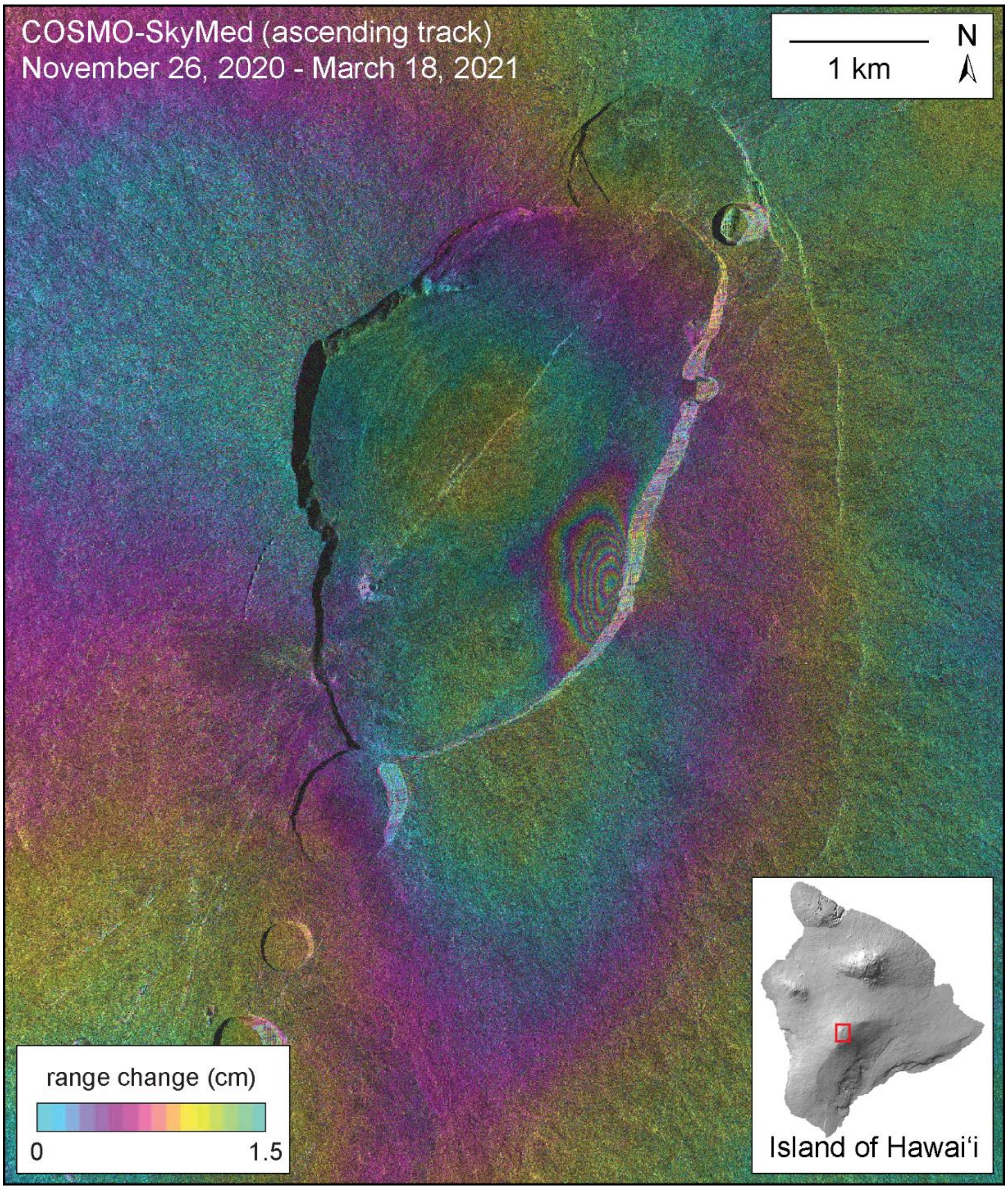

Figure 3. COSMO-SkyMed interferogram spanning November 26, 2020–March 18, 2021, and showing motion along the caldera-bounding fault at the summit of Mauna Loa volcano. The broad butterfly pattern of fringes in the interferogram reflects overall inflation of the volcano during the time spanned.

COSMO-SkyMed and TerraSAR-X remain some of the most consistent datasets available for monitoring deformation and surface change of Hawaiian volcanoes. In addition, Sentinel-1 provides a reliable source of island-wide SAR data, allowing for easy tracking of deformation at both Kīlauea and Mauna Loa (Figure 4).

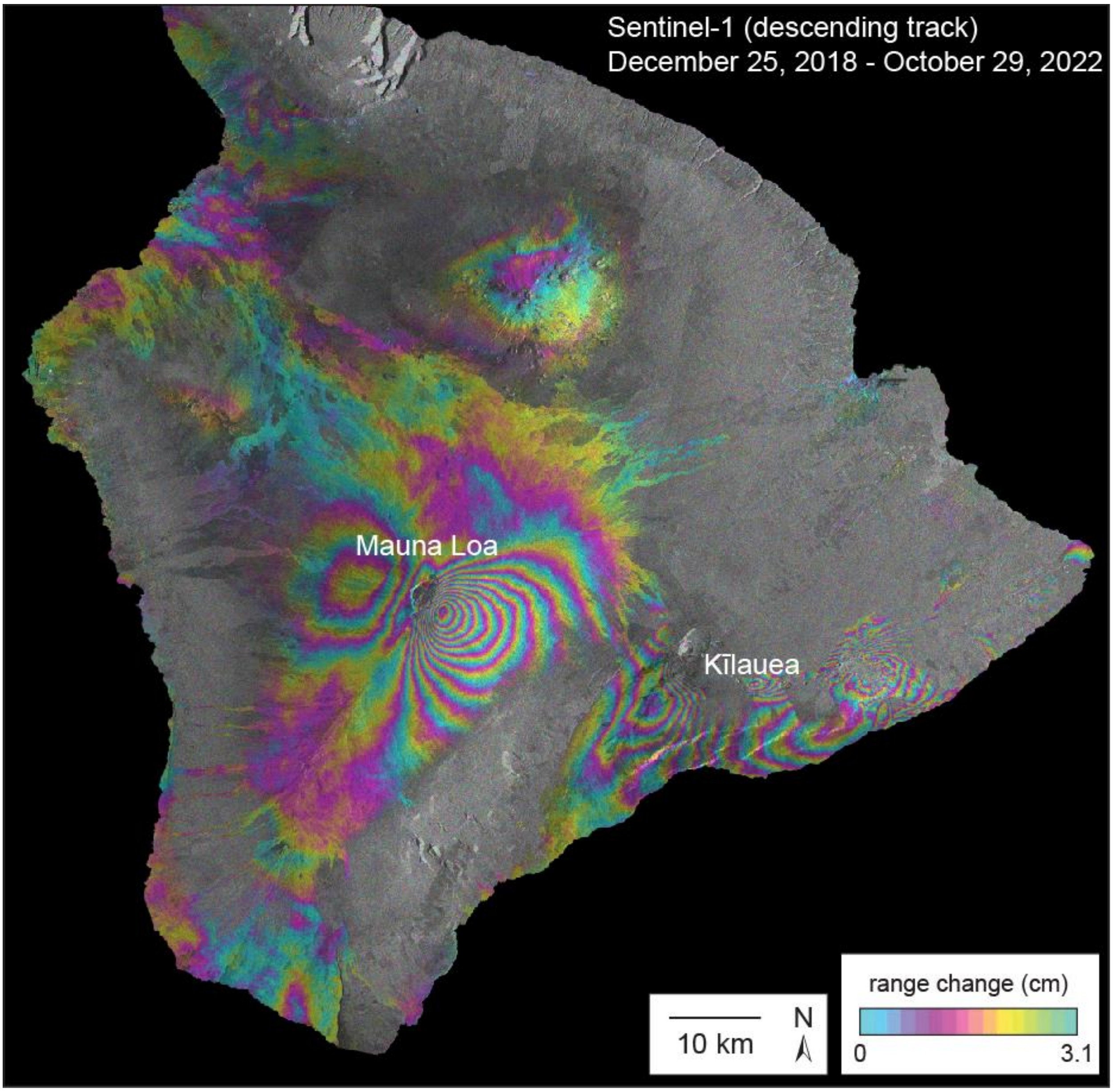

Figure 4. Sentinel-1 interferogram of the Island of Hawaiʻi and spanning December 25, 2018 – October 29, 2022. The nearly 4-year period includes significant inflation of Mauna Loa and Kīlauea volcanoes, as well as deformation of Kīlauea's rift zones.

The Supersite has also provided exploratory data to investigate the utility of PAZ (Instituto Nacional de Técnica Aeroespacial of Spain) and SAOCOM (Comisión Nacional de Actividades Espaciales). Both satellites provide useful perspectives of Hawaiian volcanism. PAZ has been collecting high-resolution views of Kīlauea's summit that span such events as the August 2021 intrusion (Figure 5a) and September 2021 eruption (Figure 5b). SAOCOM's L-band wavelength can "see" through much of the dense vegetation present on Hawaiian volcanoes, which is especially valuable for tracking ground deformation on Kīlauea's East Rift Zone (Figure 6).

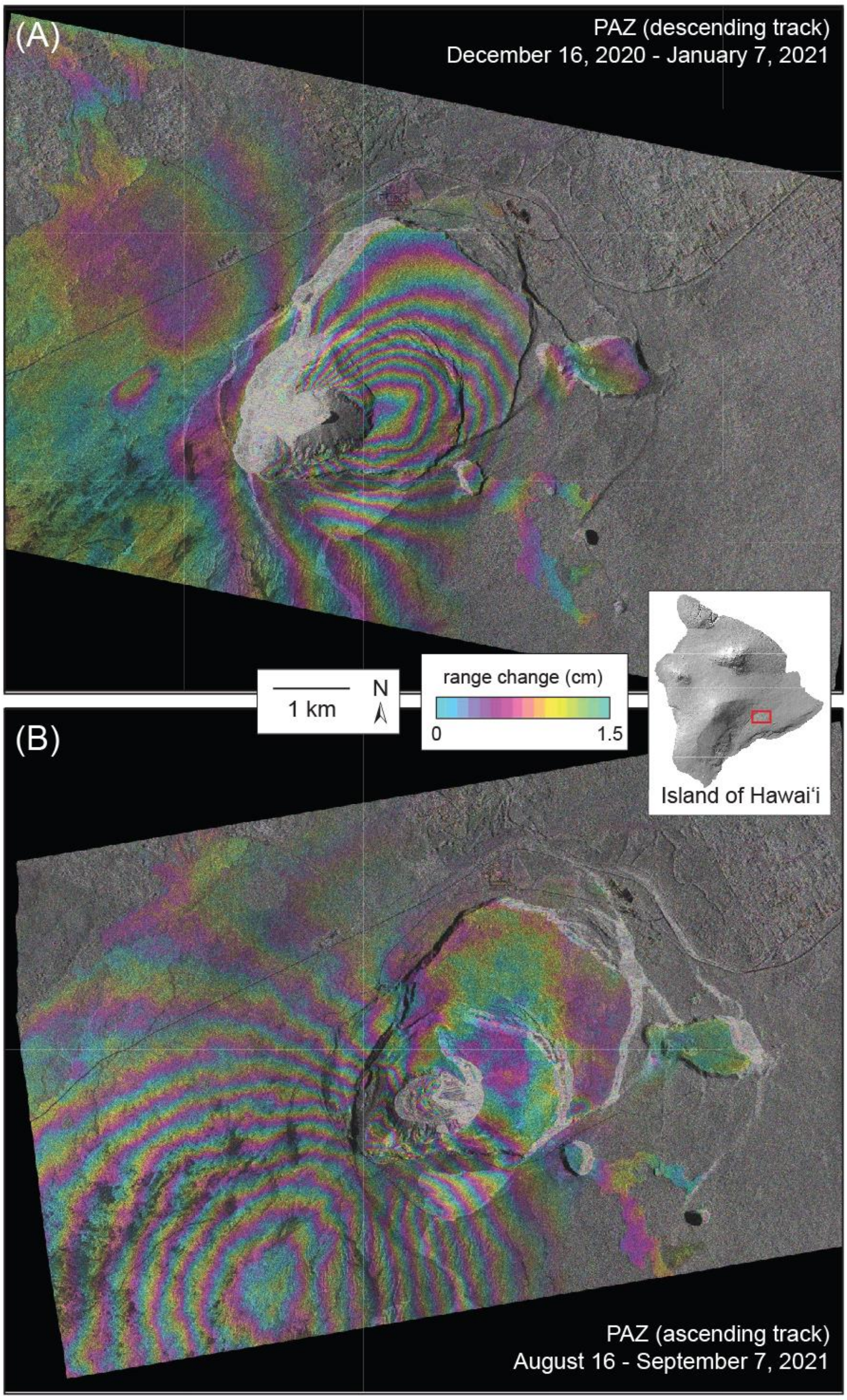

Figure 5. PAZ interferograms spanning the onset of eruptive activity at Kīlauea on December 20, 2020 (A) and an intrusion in the south part of Kīlauea caldera during August 23–30, 2021 (B).

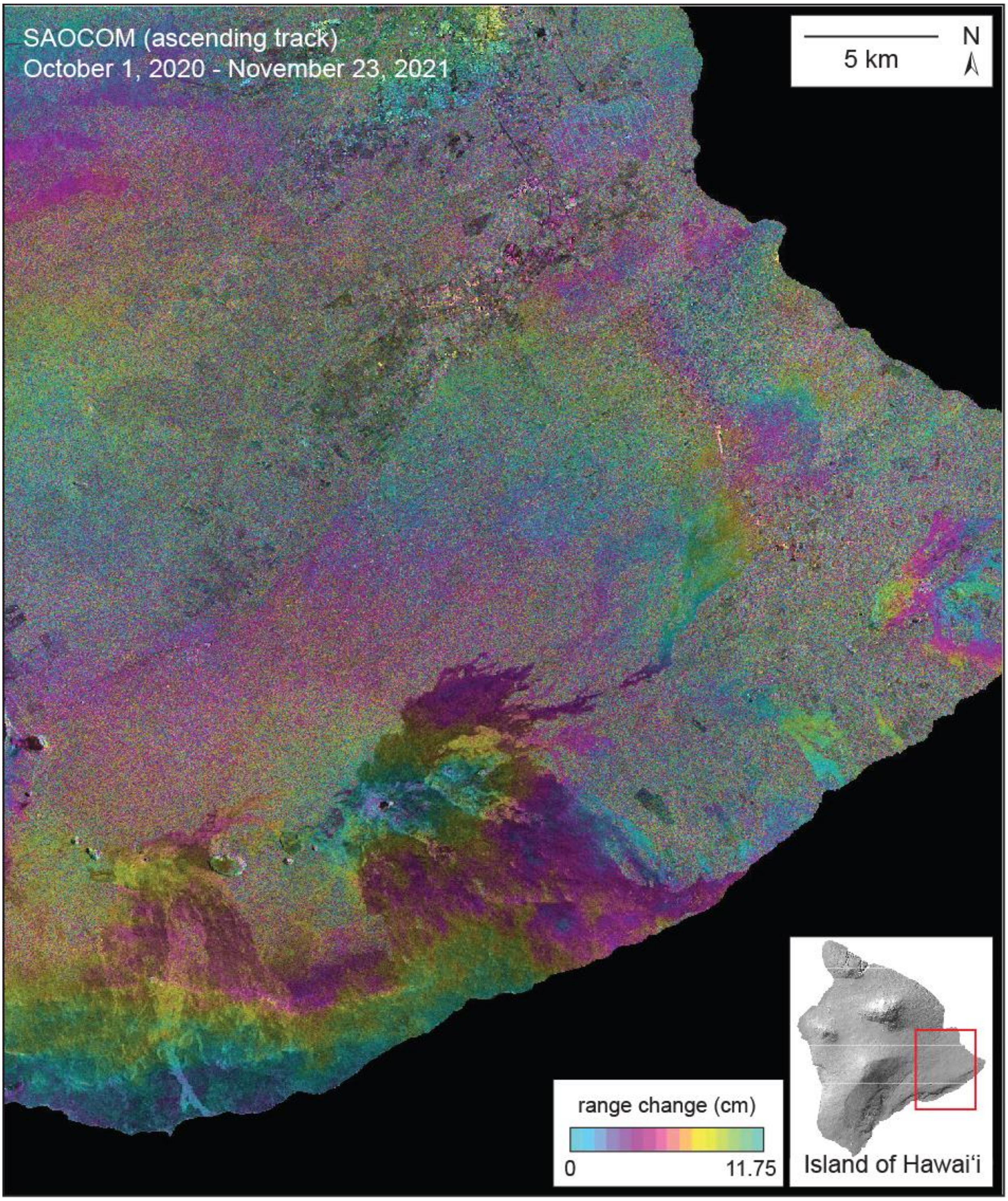

Figure 6. SAOCOM interferogram of the East Rift Zone of Kīlauea volcano spanning October 1, 2020 – November 23, 2021. Coherence is remarkable in this heavily vegetated region thanks to the L-band wavelength.

Publications

Selected peer-reviewed journal articles
Bemelmans, M. J. W., E. de Zeeuw- van Dalfsen, M. P. Poland, and I. A. Johanson (2021), Insight into the May 2015 summit inflation event at Kīlauea Volcano, Hawai'i, J. Volcanol. Geotherm. Res., 415, 107250, https://doi.org/10.1016/j.jvolgeores.2021.107250.
Cao, Y., S. Jónsson, and Z. Li (2021), Advanced InSAR Tropospheric Corrections from Global Atmospheric Models that Incorporate Spatial Stochastic Properties of the Troposphere, Journal of Geophysical Research: Solid Earth, 125(5), e2020JB020952, https://doi.org/10.1029/2020JB020952.
Corsa, B., M. Barba-Sevilla, K. Tiampo, and C. Meertens (2022), Integration of DInSAR Time Series and GNSS Data for Continuous Volcanic Deformation Monitoring and Eruption Early Warning Applications, Remote Sensing, 14(3), 784, https://doi.org/10.3390/rs14030784.
Koymans, M. R., E. de Zeeuw-van Dalfsen, L. G. Evers, and M. P. Poland (2022), Microgravity Change During the 2008 – 2018 Kīlauea Summit Eruption: Nearly a Decade of Subsurface Mass Accumulation, Journal of Geophysical Research: Solid Earth, 127(9), e2022JB024739, https://doi.org/10.1029/2022JB024739.
Leeburn, J., C. Wauthier, E. Montgomery-Brown, and J. Gonzalez-Santana (2022), New insights on faulting and intrusion processes during the June 2007, East Rift Zone eruption of Kīlauea volcano, Hawai'i, J. Volcanol. Geotherm. Res., 421, 107425, https://doi.org/10.1016/j.jvolgeores.2021.107425.
Poland, M. P., S. Hurwitz, J. P. Kauahikaua, E. K. Montgomery-Brown, K. R. Anderson, I. A. Johanson, M. R. Patrick, and C. A. Neal (2022), Rainfall an unlikely factor in Kīlauea's 2018 rift eruption, Nature, 602(7895), E7-E10, https://doi.org/10.1038/s41586-021-04163-1.
Poland, M. P., A. Miklius, I. A. Johanson, and K. R. Anderson (2021), A decade of geodetic change at Kīlauea's summit—Observations, interpretations, and unanswered questions from studies of the 2008–2018 Halema'uma'u eruption, in The 2008–2018 summit lava lake at Kīlauea Volcano, Hawai'i, edited by M. R. Patrick, T. R. Orr, D. A. Swanson and B. F. Houghton, U.S. Geological Survey Professional Paper 1876-G, 29 pp., https://doi.org/10.3133/pp1867G.
Roman, A., and P. Lundgren (2021), Dynamics of large effusive eruptions driven by caldera collapse, Nature, 592(7854), 392-396, https://doi.org/10.1038/s41586-021-03414-5.
Varugu, B., and F. Amelung (2021), Southward growth of Mauna Loa's dike-like magma body driven by topographic stress, Sci Rep, 11(1), 9816, https://doi.org/10.1038/s41598-021-89203-6.
Wang, T., Y. Zheng, F. Pulvirenti, and P. Segall (2021), Post-2018 caldera collapse re-inflation uniquely constrains Klauea's magmatic system, Journal of Geophysical Research: Solid Earth, 126(6), e2021JB021803, https://doi.org/10.1029/2021JB021803.
Conference presentations/proceedings
…
…
…

NOTE: It would be impossible to list all presentations that make use of Hawai'i Supersite data (there would be several dozen), especially without direct input from science team members; therefore, the table has been left blank. The most relevant research results are contained within the publication list.

Research products

In a strict sense, the Hawai'i Supersite has yet to directly produce any formal community research products. The data have been used by individual investigators to develop products, however, which are having an impact on the overall field. Chief among these are:

- new methods for extracting three-dimensional displacement data from SAR imagery

- deformation maps and time series generated by numerous investigators

- schemes for mapping change due to active volcanism, particularly associated with the emplacement of lava flows (via coherence, amplitude, and topographic data)

- strategies for modeling atmospheric delay

Because these products are either in development for release as part of InSAR processing software (for example, Multiple Aperture Interferometry methods) or are primary research results or operational tools with specific applications (for example, interferometry time series, topographic change due to lava flow emplacement, and atmospheric modeling strategies), they should not yet be considered research products, and the table below has been left blank.

Type of product	Product provider	How to access	Type of access
Range change time series	*Falk Amelung, University of Miami*	*http://insarmaps.miami.edu*	*public*
Interferograms	*Various*	*https://winsar.unavco.org/insar/*	*registered*

Research product issues

There are currently few publicly available research products for the Hawai'i Supersite. Time series products from the University of Miami are available to the public, but require interacting with a GUI in a manner that may be cumbersome for large-scale analysis. The WInSAR consortium of UNAVCO (soon to be merged with IRIS into the Earthscope Consortium) provides a portal for users to upload and assign DOI numbers to products, like interferograms and time series (https://winsar.unavco.org/insar/). Some interferogram products are available, but users have yet to take widespread advantage of this resource. Several investigators have provided links to time series and deformation maps on their personal websites. Most Supersite researchers, however, have yet to make products available beyond their own publications (although published data are, in most respects, considered open source, and so should be available in manuscript supplements or by contacting the authors). Funding, staff, and other assistance are needed to aid with the dissemination of research products. Few organizations have the funding to develop a resource to its full potential, especially once the research has been published (the "end game" for many scientists). The only exceptions include projects that have been created to specifically develop a resource—for example, the GMTSAR software from the Scripps Oceanographic Institution and the JPL ARIA project—but these are few in number.

6. Dissemination and outreach

The primary means of informing the public of the existence and benefits of the Hawai'i Supersite are outreach efforts, including newspaper articles, social media, and lectures. For example, *public presentations on the Island of Hawaiʻi as part of "Volcano Awareness Month" (every January) and weekly "Volcano Watch" newspaper articles have highlighted the benefit of the Supersite for the assessment and mitigation of volcanic hazards in Hawaiʻi, and also the greater understanding of Hawaiian volcanoes that the Supersite makes possible (through better access to data and by attracting scientific innovators to work on those data). Several Volcano Watch articles have specifically highlighted InSAR data, made available via the Supersite, including https://www.usgs.gov/news/volcano-watch-reading-rainbow-how-interpret-interferogram and https://www.usgs.gov/observatories/hvo/news/volcano-watch-inflating-volcanoes-or-cloudy-data-discerning-deformation. Outreach to the scientific community is done via conference presentations (highlighting the available datasets and encouraging their exploitation), especially at the American Geophysical Union and the European Geosciences Union annual conferences, although these conferences were heavily disrupted by the COVI-19 pandemic, with many moved to online-only or hybrid modes. Personal and virtual (the latter especially so since the COVID-19 pandemic) visits to research institutions and universities around the world allow Supersite researchers to share their results and encourage new users to participate in the work. As a result of these sorts of visits, new attention is being paid to underutilized Supersite resources. For example, a University of Leeds (U.K.) Ph.D. student examined how amplitude data could be used to better understand activity at Kīlauea, and a Ph.D. student at the University of Bristol is using high-resolution X-band data to investigate localized deformation on volcanoes in Hawaiʻi and elsewhere around the world.*

7. Funding

There is no dedicated nor specific funding for the Hawaiʻi Supersite. The Volcano Hazards Program of the U.S. Geological Survey, however, supports the Supersite by directing the PoCs (who are USGS employees) to manage the effort and cultivate a user community. This includes the use of funds from the Volcano Hazards Program's InSAR project to archive and manage SAR data from Hawaiʻi and to build computing resources for SAR data processing and analysis. In 2023, a new postdoctoral researcher will join the USGS to explore the potential for machine learning approaches to recognizing changes in interferograms and other SAR products, with a particular focus on data acquired over Hawaiʻi. In addition, the USGS Volcano Science Center will hire a data scientist that will focus on SAR data for 50% of their time. Individual project scientists from outside the USGS have obtained research funding from various organizations—like the U.S. National Science Foundation and NASA—and have leveraged the availability of Supersite data in their proposals.

8. Stakeholders interaction and societal benefits

The most direct beneficiary of the Hawaiʻi Supersite is the U.S. Geological Survey's Hawaiian Volcano Observatory (HVO). Founded in 1912, HVO maintains a dense network of geophysical stations around the island (which have been made available to the Supersite) and also collects geochemical and geological data on volcanic and seismic activity. These measurements fulfill a US Congressional mandate (the John D. Dingell, Jr. Conservation, Management, and Recreation

Act) to provide volcano and earthquake hazard warnings, supported by research, to local populations, emergency managers, and land-use planners. SAR data constitute a critical resource for this monitoring and research but would be cost-prohibitive if not for the Supersite.

HVO communicates hazards information, much of which is aided by Supersite data, to a number of other organizations—primarily the National Park Service and Hawai'i County Civil Defense. These agencies are tasked with managing responses to volcanic and earthquake crises in the lands they oversee, while HVO is responsible for providing the information needed by responders to make decisions. This level of cooperative interaction has been demonstrated repeatedly, for example, during the return to eruptive activity at Kīlauea in 2020–2022, and as Mauna Loa experiences heightened levels of unrest. Supersite and in situ data are used to support multiple public documents about the potential hazards of current and future eruptive activity. These documents are released to the public and form the basis for responses by both Hawai'i Volcanoes National Park and the County of Hawai'i.

Both during and before/after volcanic and seismic crises, Supersite data contribute to the development of interpretations that are communicated to the public as part of daily volcanic activity updates, weekly newspaper articles, online content, and community outreach events (presentations, open houses, exhibits, etc.).

9. Conclusive remarks and suggestions for improvement

The Hawai'i Supersite has been invaluable for tracking and understanding the reawakening of Kīlauea from 2+ years of eruptive slumber. SAR data from a variety of satellites tracked deformation associated with 2 intrusions and 2 eruptions, as well as co-eruptive deformation that included the emplacement of a very shallow sill—a process that clearly has occurred in the past based on geological exposures but has never been witnessed geodetically. In addition, Supersite data were critical for assessing unrest at Mauna Loa, including the mechanism for shallow earthquakes and long-term inflation. The Supersite also continues to pay dividends for investigations of Kīlauea's 2008–2018 summit eruption, as well as the 2018 lower East Rift Zone eruption and summit collapse. These data and resulting studies are not only important for hazards response and mitigation, but also for better understanding how Hawaiian volcanoes work—information that feeds into hazards assessments and models.

Additional insights into Hawaiian volcanism since the founding of the Hawai'i Supersite in 2008 include:

- understanding of magma supply variations to Kīlauea Volcano and the impact of these variations on eruptive activity,

- elucidation of the magma plumbing systems at Kīlauea and Mauna Loa volcanoes, which provide an essential framework for interpreting past, present, and future unrest,

- investigations into interactions between magmatism and tectonism at Hawaiian volcanoes,

- tracking of geophysical changes—especially deformation and seismicity—at Kīlauea and Mauna Loa, which provides situational awareness of potential future eruptions or changes to ongoing eruptions,

- development of new tools for tracking lava flow emplacement, including both areal coverage and effusion rate, and implementation of these tools in an operational framework to aid volcano monitoring efforts,

- testing of new algorithms for determining 3D displacements from InSAR data,

- exploration of means for mitigating the impacts of atmospheric conditions on interferograms,

- providing high-resolution views of small-scale processes, including the formation and evolution of pit craters (at both Kīlauea and Mauna Kea),

- documenting the processes of magma transport, flank motion, and caldera collapse associated with Kīlauea's 2018 activity,

- tracking eruptive and intrusive activity associated with lava pond formation and evolution at Kīlauea volcano.

As has been the case since the Supersite was established, a few issues continue to prevent even more comprehensive work by Hawai'i Supersite researchers:

- The scientific teams operate independently, and so there is no organized effort to promote any specific scientific goals. The 2018 activity helped to mitigate this issue by focusing attention on Kīlauea during a number of special sessions at scientific conferences, which resulted in improved coordination between investigators and better exploitation of research opportunities. In addition, the 2020–2022 eruptive activity at Kīlauea's summit has spurred interest, and the formation of a Scientific Advisory Committee provides a mechanism to facilitate scientific collaborations.

- It is not clear how the formal science team and participating scientists should be defined for the purposes of this report. Is the science team made up of people and groups that work with Supersite data? Only people/groups that have applied for access to the data? It would be helpful if GSNL could address this ambiguity.

- There is no specific funding for the Hawai'i Supersite, outside of in-kind support by the U.S. Geological Survey. If funding were available, it could be used to better organize the user community and support collaborations and better dissemination of results. The pending hire of a new data scientist and InSAR specialist by the USGS Volcano Science Center should help to partially alleviate this issue.

- The website for the Hawaiʻi Supersite does not contain any links to data (including freely available SAR datasets), only links to TerraSAR-X and COSMO-SkyMed archives for the Supersite. A more dynamic web presence would allow for posting of research results and products, and it could also be used for dissemination and outreach efforts aimed at not only scientific users and agencies, but also stakeholders and the general public.

A few operational challenges also exist:

- RADARSAT-2 data have not been part of the Hawaiʻi Supersite for several years. Any RADARSAT-2 data from Hawaiʻi since 2016 have been acquired via contracts between CSA/MDA and the US Government, and the raw data cannot be made available via the Supersite. This is a vastly underutilized resource given the volume of data collected by RADARSAT-2 over Hawaiʻi.

- Non-SAR satellite data from Hawaiʻi are only archived via the USGS Hazards Data Distribution System. A more comprehensive archive that is linked to the Supersite would facilitate data fusion efforts that would merge SAR, visual, and thermal remote sensing imagery to gain new insights into Hawaiian volcanism.

- There is no archive for user-generated supporting data, like DEMs, which could be useful to Hawaiʻi Supersite investigators, as well as the general public and stakeholders. These items could be stored in the InSAR product archive hosted by WInSAR, but that resource has not yet been used for this purpose.

These challenges should not dissuade support for the continued operation of the Hawaiʻi Supersite, however, especially given the importance of Supersite datasets in the interpretation and investigation of Kīlauea's 2018 lower East Rift Zone eruption and collapse, post-2018 recovery of the volcano and renewed eruptive activity, and unrest of Mauna Loa volcano. The full value of the Hawaiʻi Supersite has been realized as a result of the frequent volcanic activity, with numerous researchers taking advantage of the abundance of data to pursue numerous innovative studies.

As a final note, the Hawaiʻi Supersite would like to specifically acknowledge the support of ASI and DLR. All space agencies have graciously agreed to support Supersite operations, but these organizations are deserving of special thanks for their work in ensuring that these otherwise costly satellite data are not just made available, but also tasked and delivered to Supersite users in a timely manner, which supports both research efforts and operational monitoring for hazards assessment/mitigation.

DATA REQUESTS FOR FUTURE OPERATIONS

SAR data acquisitions have continued to be exceptional during 2021–2022; we have not requested additional Pleiades data because no significant topographic changes have occurred at Kīlauea since 2018 (aside from filling of the summit collapse pit with lava). With respect to CEOS datasets, we request the following allocations:

- ***TerraSAR-X**: Continue existing availability (approximately 70 acquisitions per year)*

- ***COSMO-SKyMed***: *Continue existing relationship (currently providing approximately 100 images per year over both Kīlauea and Mauna Loa). We would also like to request that second-generation CSK data be made available as part of the Supersite, since those data are not currently provided by the auto-FTP delivery system.*
- ***SAOCOM***: *We would like to request a new quota of ~200 scenes per year for the Hawai'i Supersite, distributed between Kīlauea and Mauna Loa volcanoes (if scenes do not cover both in one acquisition). L-band SAR clearly is an important tool for tracking deformation in heavily forested regions on the Island of Hawai'i, and SAOCOM data are at present the only readily accessible L-band SAR data. This quota may exceed what can be acquired by the satellite in a given year, but that is something we can evaluate once we have more of an understanding of the utility of specific acquisition modes and imaging geometries.*
- ***RADARSAT-2***: *These data provided exceptional insights into deformation of Hawaiian volcanoes for many years, until the expiration of a SOAR agreement in 2016. We would welcome any new quota that CSA would be willing to provide of RADARSAT-2 data or Radarsat Constellation data. The RADARSAT-2 data, especially, have a unique combination of resolution, polarization, and long history of acquisitions that constitute critical value added to the Supersite and that are not available from any other source.*

10. Dissemination material for CEOS (discretionary)

Please see section 5.