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Geo4Nonpro 2.0

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Middlebury Institute *of* International Studies at Monterey
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James Martin Center for Nonproliferation Studies
nonproliferation.org

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Contents

Commonly Used Acronyms vi
Executive Summary 1
Evolution of Project Concept 2
Geo4Nonpro 1.0 2
Geo4Nonpro 2.0 3
Training 4
Synthetic Aperture Radar 4
Hyperspectral 5
Rebuilding the Site 7
User Interface 8
Campaign Pages 8
Navigation 9
Pins 10
Geo4Nonpro in the Media 10
Case Studies 12
Syria Chemical-Weapons Facilities 12
Hamhung Solid Fuel Motor Development 13
Shahrud Missile-Test Facility 14
Kaliningrad Munitions Storage Facility 17
Kangson Suspected Enrichment Facility 19
Korla Missile-Test Complex 20
Punggye-ri Nuclear-Test Site 21
Next Steps 24
About the Authors 26
Acknowledgements 28

Commonly Used Acronyms

Geo4Nonpro (G4N)

James Martin Center for Nonproliferation Studies (CNS)

area of interest (AOI)

synthetic aperture radar (SAR)

near-infrared (NIR)

weapons of mass destruction (WMD)

distributed denial of service (DDOS)

hypertext transfer protocol (HTTP)

HTTP secure (HTTPS)

Executive Summary

On June 16, 2018, the James Martin Center for Nonproliferation Studies (CNS) launched Geo4Nonpro 2.0. With a mission to engage a "curated" crowd of satellite imagery analysis experts, Geo4Nonpro (G4N) is a tool for sharing open-source geographic information of known or suspected weapons of mass destruction (WMD) sites.

The new version aimed to improve the user experience by renovating the layout of the website, making it easier to log-in and navigate, and streamlining the process by which users can explore and tag the satellite images. The new version of the website was developed by CNS with engineering support from Harris Geospatial and is hosted on Amazon Web Services with cybersecurity support from Google's Project Shield.

CNS broke several international news stories in major outlets—including, *inter alia*, the *New York Times*, National Public Radio, and the *Wall Street Journal*—using imagery on G4N. It has served as the ideal platform for people located around the world to collaborate on satellite-imagery analysis.

The most impressive discovery was North Korea's Kangson uranium-enrichment facility. CNS believes it to be the first time this facility has been identified or analyzed in the open-source literature. It represents the possibility that North Korea has been producing—and can continue to produce—as much, if not more, fissile material for nuclear weapons than it could have using the only previously known enrichment site at Yongbyon.

The first section of this report discusses the evolution of the platform: from the conception of Geo4Nonpro 1.0 and the initial training of G4N team members, to the lessons learned during the first phase of the project and how these lessons fed into the platform's continued development. The second section describes the launch of Geo4Nonpro 2.0, its new features, and highlights news stories that featured Geo4Nonpro and the central role that it played in many of these discoveries. This is followed by an analysis of each campaign. Lastly, the team proposes the next steps and future applications for this innovative platform.

Evolution of Project Concept

Geo4Nonpro continues to serve its original mission of providing high-quality remote-sensing data to a curated crowd of experts, namely those with a background in the region, WMD, or satellite imagery. The pivot in the project's second year was to focus on tool building to enable ease of use, while continuing to offer excellent, timely analysis.

Version One: Geo4Nonpro 1.0

Geo4Nonpro 1.0 was a web-based platform for public viewing and annotating satellite images.[1] Researchers at CNS first launched Geo4Nonpro in April 2016 at the State Department's "Innovation Forum" held at Stanford University. By May 2016, the CNS team invited 526 experts from across regional and technical specialties to join the site and rolled out the first campaigns over the course of the project until December 2017:

- Punggye-ri Nuclear Test Site in North Korea
- Directorate of Defense Industries (DDI) facilities in Myanmar
- Sinpo Submarine Naval Shipyard in North Korea
- Novaya Zemlya Nuclear Test Site
- Shahrud Missile Test Facility
- Korla Missile Test Complex
- Kaliningrad Munitions Storage Sites

The first version of the platform was a PostGIS server hosted in an EC2 instance at Amazon Web Services using open-source software GeoServer on a Linux CentOS operating system. The homepage was created through Wix. This was an extremely cost-affordable approach that was reasonably simple for CNS and a short-term consultant to implement. However, the tradeoffs included a cumbersome user log-in and navigation system, unpredictable outages, and some minor security risks.

In the first year, staff time was devoted to pushing Geo4Nonpro as a "brand" through social media, traditional media, and email engagement. Two hundred and thirty-seven users or 45 percent of the initial target number joined the site. The sample size is currently too small to apply to machine-learning programs that can automate this analysis process.

Nonetheless, the site was lauded inside the WMD research community. Geo4Nonpro was featured at the 2017 Institute of Nuclear Materials Management (INMM) Symposium and the Ploughshares Fund awarded Melissa Hanham the Paul Olum Grant for being one of the most inventive scientific and technical minds working to reduce the threat of nuclear weapons in 2018, in part due to her leadership on the Geo4Nonpro project.

[1] For a public report on Geo4Nonpro's first year, see: Melissa Hanham et al., "Geo4Nonpro.org: A Geospatial Crowd-Sourcing Platform for WMD Verification," CNS Occasional Paper #28, June 2017, https://www.nonproliferation.org/wp-content/uploads/2017/06/op28-geo4nonpro-org-a-geospatial-crowd-sourcing-platform-for-wmd-verification.pdf.

Version Two: Geo4Nonpro 2.0

Based on the lessons learned from Geo4Nonpro 1.0, CNS focused on completely overhauling the Geo4Nonpro site with a professional engineering team. After an exhaustive search through individual developers, as well as in-house teams at Digital Globe and Terrestris, CNS decided to contract with Harris Geospatial Solutions to design and build the site, as well as to aid with the migration of existing data to the new site and to provide customer support.

Geo4Nonpro 2.0 updated the following campaigns:

- Punggye-ri Nuclear Test Site in North Korea
- Shahrud Missile Test Facility in Iran
- Korla Missile Test Complex in China
- Kaliningrad Munitions Storage Sites

Geo4Nonpro 2.0 added the following campaigns:

- Barzah[2] and Homs chemical-weapons facilities in Syria
- Hamhung, solid-fuel production and testing in North Korea
- Suspected uranium-enrichment site in Kangson, North Korea

Anticipated by October 2018, with term-limited funding from Skoll Foundation, the following sites will be added:

- Sverney nuclear cruise-missile test site in Russia
- Pyongyang Biotechnical Institute, suspected to be able to produce anthrax in North Korea
- Uranium mines and mills in North Korea, Pakistan, India, and China.

Geo4Nonpro 2.0 now includes imagery from Planet, a San Francisco-based private firm that operates the world's largest constellation of Earth-imaging satellites. Planet imagery is high-frequency, enabling the team to collect and disseminate images as events unfold. It also means that Planet is often the only commercial company with an image on any specific day. Their images were particularly useful in the Hamhung, Shahrud, and Kaliningrad campaigns.

CNS also added Airbus TerraSAR-X synthetic aperture radar (SAR) data to Geo4Nonpro 2.0.[3] CNS entered into an agreement with Airbus in 2017 to share data and insight. Airbus's TerraSAR-X sensor is the highest resolution SAR sensor in commercial operation. Since September 2017, Airbus provided training and low-resolution JPG (standard digital picture files) images of Shahrud, Hamhung, Punggye-ri, and Kaliningrad. Airbus also accepted sensor-tasking requests on a case-by-case basis.

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[2] Also sometimes spelled Barzeh.

[3] SAR data is created by using radar to sense the surface of the earth. See https://geo4nonpro.org/help/5b71e7bcbfca9d0c174bb8ae.
Comparing two or more SAR images can detect changes in the surface over time, e.g. dirt that has been removed, vehicle tracks in sand, a mountain that collapsed, etc.
Jeffrey Lewis, "SAR Image of Punggye-ri", September 13, 2017,
https://www.armscontrolwonk.com/archive/1203852/sar-image-of-punggye-ri/

Airbus has now provided full-resolution Tagged Image File Format (TIFF) files of SAR data at Punggye-ri, North Korea, and Shahrud, Iran. In September 2018, data scientists will also provide webinar training for the G4N team on what SAR is and how it can be interpreted. CNS continues to negotiate future data collaboration and training.

CNS received Airbus digital elevation models for the Punggye-ri campaign. Airbus's WorldDEM products are the highest resolution available in the commercial world. The current site runs primarily on Mapbox tools, which does not yet provide 3D visualizations of terrain, so CNS will display the layers as a two-dimensional hill shade until Mapbox makes 3D visualizations available, possibly as early as next year.

Training

Synthetic Aperture Radar

In anticipation of receiving synthetic aperture (SAR) data, CNS received three days of training on SAR imagery from TerraSAR-X division of Airbus satellite that collects SAR data. Radar does not rely on sunlight and thus can give valuable insights at night, through clouds, and even some types of roofing material. It has also proved valuable when monitoring road traffic in arid climates. SAR processing and interpretation is more complex than optical interpretation and therefore necessitated additional training from geospatial experts.

In September 2017, Catherine Hartley and Lars Petersen from Airbus flew to Monterey and taught the G4N team the basics of how radar bounces off objects. CNS and Airbus reviewed requested imagery from Shahrud, Iran; Punggye-ri, North Korea; and Kaliningrad, Russia. Because the scientists arrived just after the September 2017 Punggye-ri nuclear test, they were able to share low-resolution JPG files of SAR data with CNS for the purpose of demonstrating earth subsidence (a downward shift in the ground, relative to the horizontal plane) in the aftermath of a nuclear test.[4]

Airbus provided images annotated with amplitude and coherence change detection, comparing two images of the test site before and after its purported demolition in May 2018. They also provided similar analysis comparing two images at Iran's missile motor-testing facility at Shahrud.

[4] See more at: Catherine Dill, et al. "SAR Image of Punggye-ri," Arms Control Wonk, September 13, 2017, https://www.armscontrolwonk.com/archive/1203852/sar-image-of-punggye-ri/.

Figure 2: Dave Schmerler, Lars Petersen, Brendan Knapp, Catherine Hartley, Catherine Dill, and Allison Puccioni at CNS in Monterey, CA, September 6, 2017. Photo: Melissa Hanham

As of August 15, 2018, there are two SAR images on Geo4Nonpro. One image is of Shahrud, Iran, and shows several solid-fuel motor horizontal testing stands and a large vertical launch pad. The second SAR image is of Punggye-ri, North Korea. This image compares North Korea's nuclear-weapons test site before and after the alleged demolition of the site in May 2018.[5]

This is the first time that the open-source arms-control community has had access to SAR imagery. In order to help educate the crowd, Airbus shared a two-page background report on SAR, available on Geo4Nonpro's help page. Additionally, Airbus will provide a training webinar for Geo4Nonpro users at some point later this year.

Hyperspectral

Unlike traditional optical imagery that collects red, green, and blue wavelengths visible to the human eye, hyperspectral data represents many wavelengths which can be seen either as an image or as a spectral signal on any given pixel. Because light reflects differently on each individual surface, the spectral signature can be used to identify materials on the ground.

[5] Geoff Brumfiel and Elise Hu, "North Korea Demolishes Its Nuclear Test Site in a 'Huge Explosion'," NPR, May 24, 2018, https://www.npr.org/sections/parallels/2018/05/24/613465473/north-korea-demolishes-its-nuclear-test-site-in-a-huge-explosion

In September 2017, Catherine Dill, David Schmerler, and Melissa Hanham flew to Louisville, CO, to attend hyperspectral image-processing training on the Harris Geospatial campus. Harris's Zach Norman trained the class on how to receive and interpret imagery from aerial and space-based sensors.

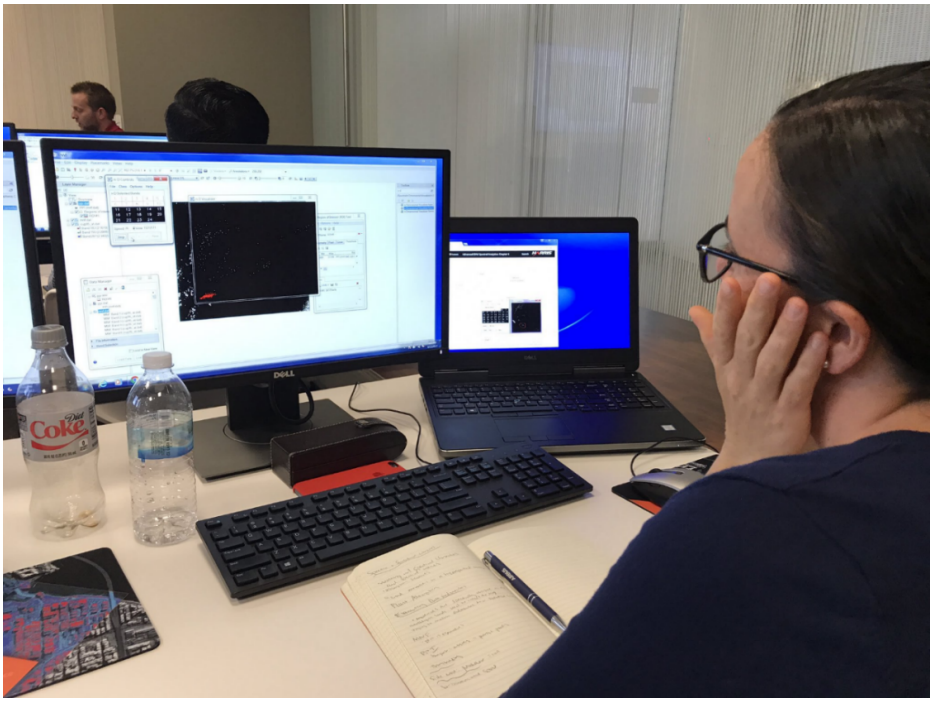

Figure 3: Catherine Dill training on hyperspectral imagery analysis using ENVI at Harris Geospatial in Louisville, CO. Dave Schmerler and Melissa Hanham also attended the training. Photo: Melissa Hanham

At this time, images from the Hyperion EO-1 satellite remain the best source of remotely sensed hyperspectral data. Although it was unfortunately decommissioned in 2017, Hyperion EO-1 offers 220 bands of data over a 30-meter spatial resolution. This data can be applied to identify surface materials. This may be particularly useful at mining and milling facilities.

While other commercial operators, such as Planetary Resources and HyperCubes, have expressed interest in commercial hyperspectral imagery, no company has yet put a hyperspectral sensor into space for commercial purposes. CNS has been collecting hyperspectral images of uranium mines and mills, as well as identifying mining equipment and buildings, to distinguish between copper, gold, and uranium mining, and to identify changes at a site that could indicate operation and throughput.[6] The team intends to host the images on Geo4Nonpro 2.0 as the collection is completed for the MacArthur Foundation.

[6] For more see: Jeffrey Lewis, et al., "Open Source Monitoring of Uranium Mining and Milling for Nuclear Nonproliferation Applications," CNS Occasional Paper #34, December 2017, http://www.nonproliferation.org/wp-content/uploads/2017/12/op34-open-source-monitoring-of-uranium-mining-and-milling-for-nuclear-nonproliferation-applications.pdf.

Rebuilding the Site

CNS began a contract with Harris Geospatial Solutions to migrate the domain host and data, set up a secure hypertext transfer protocol (HTTPS), and troubleshoot issues along the way. Harris Geospatial provided several iterations of wire frames. The map was removed from the landing page and is instead formatted in "cards." Each card provides a short description of the area of interest (AOI) and links to the campaign site. This design was meant to provide the user an intuitive point of navigation, while also removing the map from a public page, which can increase the risk of a distributed-denial-of-service attack. It will also open up the possibility for CNS to host additional non-map-based campaigns.

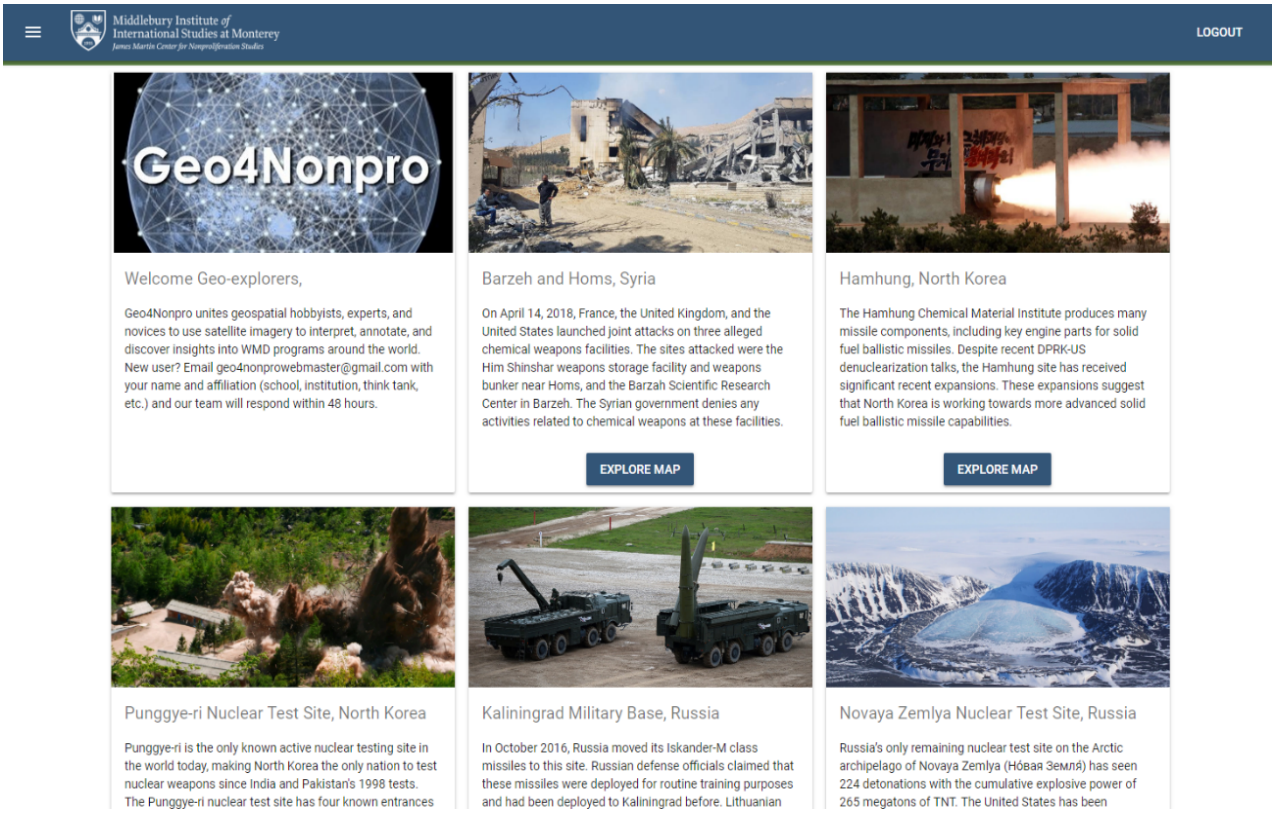

Figure 4: New home page at Geo4Nonpro.org.

Geo4Nonpro's map server, hosting remote sensing and user-generated geographic information system (GIS) data continues to be hosted on Amazon Web Services (AWS). The site was moved from Wix to AWS for increased ease and customization. The log-ins were reconciled, making a single user log-in sufficient for both the site and the imagery, which was a major drawback to the previous site.

User Interface

Of chief concern was creating an inviting, user-friendly design with intuitive navigation. Geo4Nonpro is intended for "experts of all stripes" and should therefore be accessible for users at all levels. While some users may be proficient in imagery interpretation, others are chemists, area studies experts, or policy analysts. Geo4Nonpro 2.0 uses Mapbox web services to create a map that is familiar to many users who use navigation tools for driving or weather.

Users must create an account by sending an email to geo4nonprowebmaster@gmail.com and a G4N team member will do a basic vetting to verify the request. Geo4Nonpro considered using reCAPTCHA as a simple way to keep out bot traffic, but ultimately felt that a human-based vetting approach would be more thorough. As traffic to the site increases, this will need to be re-evaluated.

Once accepted, the user receives an email with a preset password, which they can change after logging in. In the email, the user is encouraged to explore the "Help" section if they are confused about any aspect of the site or to email any further questions. Other questions may be answered in our "Terms of Service" or "About" sections, which are both accessible in the general menu. The homepage displays different campaigns that the user can explore.

Each campaign is displayed on a card with an image and some text representing the information of the campaign. When a user logs into Geo4Nonpro, they are able to see the map corresponding to each campaign. Users also have the option to maneuver to the Menu located in the top left corner for additional pages. The bottom tool bar has links to the G4N social media pages. (See Rebuilding the Site).

Campaign pages

When a user first enters a campaign page, they can see all user-generated pins on the base map. All satellite image layers can be displayed by turning on the layer using the toggle switch. Users can turn on up to two layers at a time. Users can manipulate the transparency of each image using the slide bar.

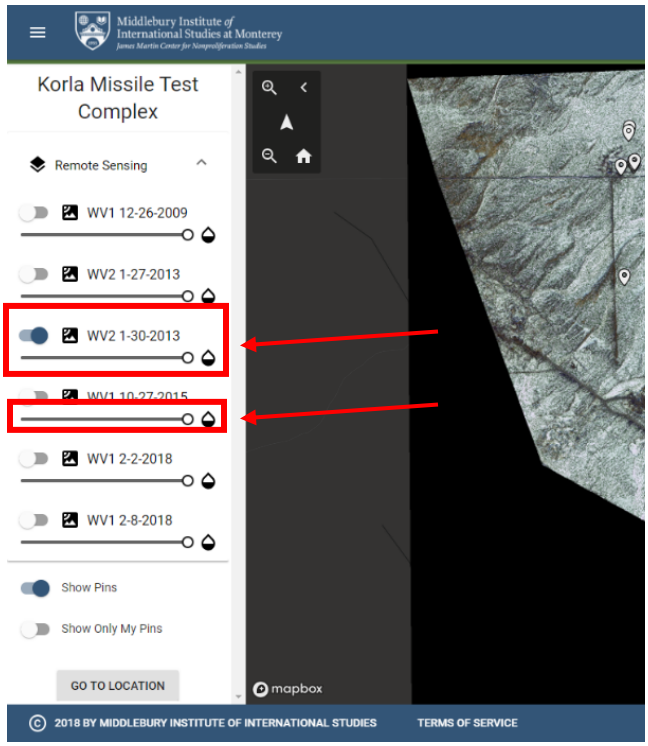

Figure 5: Zoom into slide bar and toggle switches to display pins.

Navigation

Once the desired images have rendered, the new, simplified button layout allows users to easily move around the image. The center arrow in the ToolBox points north and adjusts as the user rotates the map. Left-clicking changes the direction of the map; right-clicking and dragging with the mouse can change the angle and tilt. Users can zoom in or out with the magnifying glasses or by using a scroll wheel on their mouse. The "home" symbol in the ToolBox brings the user back to the base settings for the zoom and heading. The carrot on the top right of the ToolBox collapses the Layers pane to allocate more screen space for the satellite images.

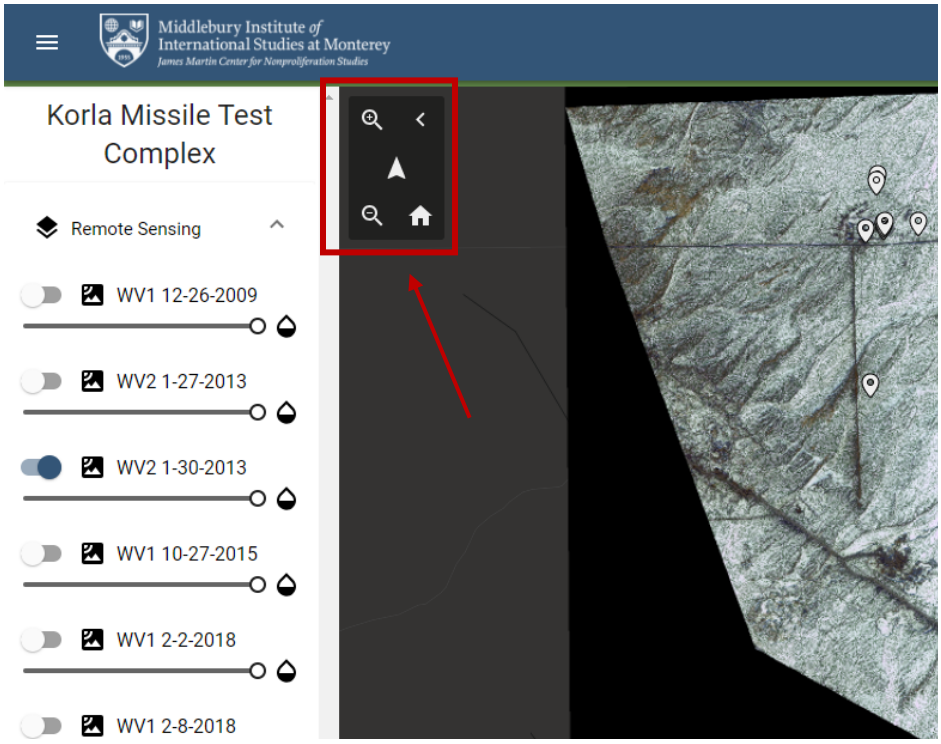

Figure 6: Zoomed view of the ToolBox in the Korla campaign.

Pins

Users can elect to turn off pins or show only their pins with the toggles on the left-hand toolbar. Users can drop a pin by clicking anywhere on the map and entering info after the prompt.

Currently the pinning tool only supports text information with options to add a hyperlink. We are also exploring the capability to directly add photos or videos to pins for Geo4Nonpro 3.0.

Geo4Nonpro in the Media

Geo4Nonpro serves as the primary host for CNS researchers to share and distribute satellite imagery for research. Many recent discoveries detected through this innovative crowdsourcing platform made the headlines in mainstream publications and platforms such as the *New York Times*, *The Diplomat*, National Public Radio (NPR), and the *Wall Street Journal*. CNS researchers working on Geo4Nonpro discussed the project in live interviews on television and radio, including the BBC and NPR.[7]

[7] For more information, see Jonathan Cheng, "North Korea Expands Key Missile-Manufacturing Plant," *Wall Street Journal*, July 2, 2018, www.wsj.com/articles/north-korea-expands-key-missile-manufacturing-plant-1530486907. Max Fisher, "Deep in the Desert, Iran Quietly Advances Missile Technology," *New York Times*, May 23, 2018, www.nytimes.com/2018/05/23/world/middleeast/iran-missiles.html.

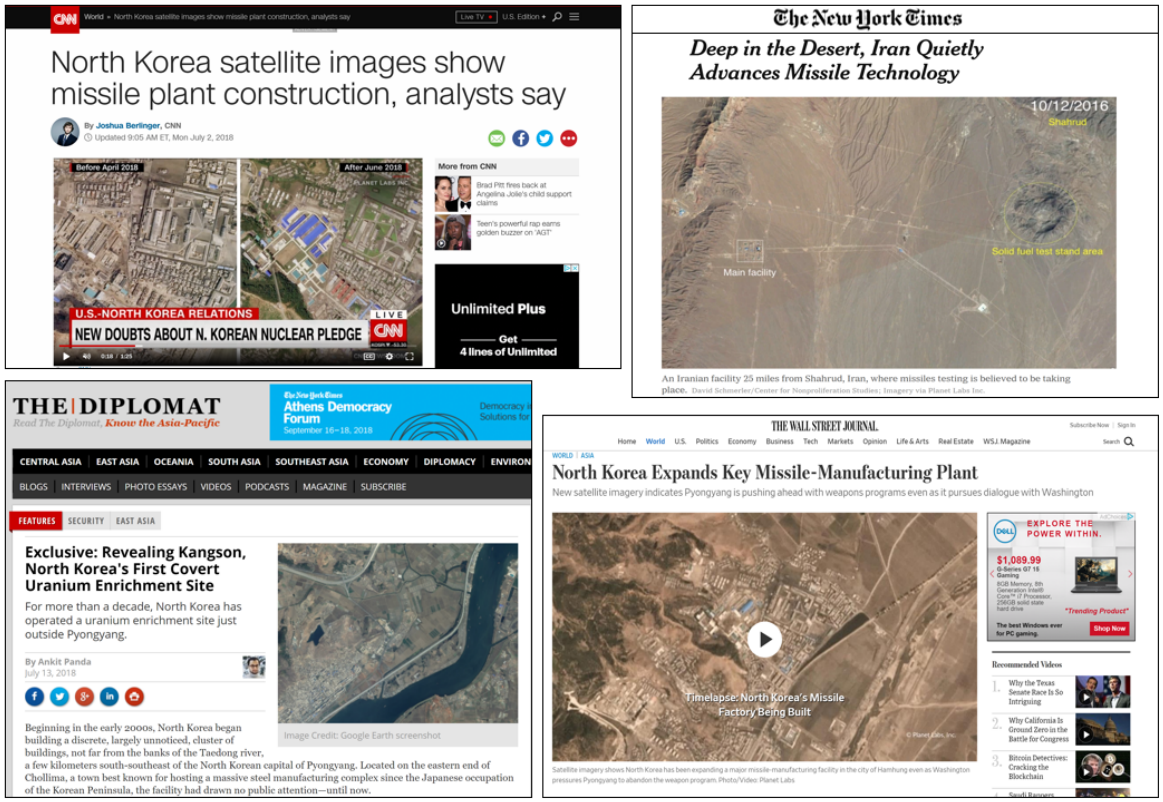

Figure 1: Screenshots of media articles that feature Geo4Nonpro

"Has North Korea Restarted Missile Production?" BBC, July 31, 2018, www.bbc.co.uk/programmes/w172w1fmcc4d6zj.
Scott Neuman, "North Korea Reportedly Expanding Ballistic Missile Production Facility," *NPR*, July 2, 2018, www.npr.org/2018/07/02/625267839/north-korea-reportedly-expanding-ballistic-missile-production-facility.
"North Korea Working on New Missiles, US Officials Say, Despite Thaw," BBC, July 31, 2018, www.bbc.com/news/world-asia-45015343.
Ankit Panda, "Exclusive: Revealing Kangson, North Korea's First Covert Uranium Enrichment Site," *The Diplomat*, July 14, 2018, www.thediplomat.com/2018/07/exclusive-revealing-kangson-north-koreas-first-covert-uranium-enrichment-site/.

Case Studies

Syria Chemical-Weapons Facilities

In early 2018 the US, UK, and French militaries identified the sites at Barzah and Homs as suspected facilities related to Syria's chemical-weapons program, although the Organisation for the Prohibition of Chemical Weapons (OPCW) concluded in November 2017 that there was no evidence that chemical or biological weapons were "developed, tested, or produced" at the site.[8] The facilities are officially known as the Barzah Scientific Research Center and the Him Shinshar weapons-storage facility. On April 14, 2018, US, UK, and French coalition forces launched airstrikes on both facilities in response to the use of chemical weapons against civilians in Douma a week prior.[9] Satellite images and ground photos show that the buildings at both sites were sufficiently damaged and were subsequently cleaned up.

The purchased satellite images show both sites before the airstrikes and shortly after. The images show the extent of damage to the facilities and the cleanup effort following the strikes. Both sites now lay empty.

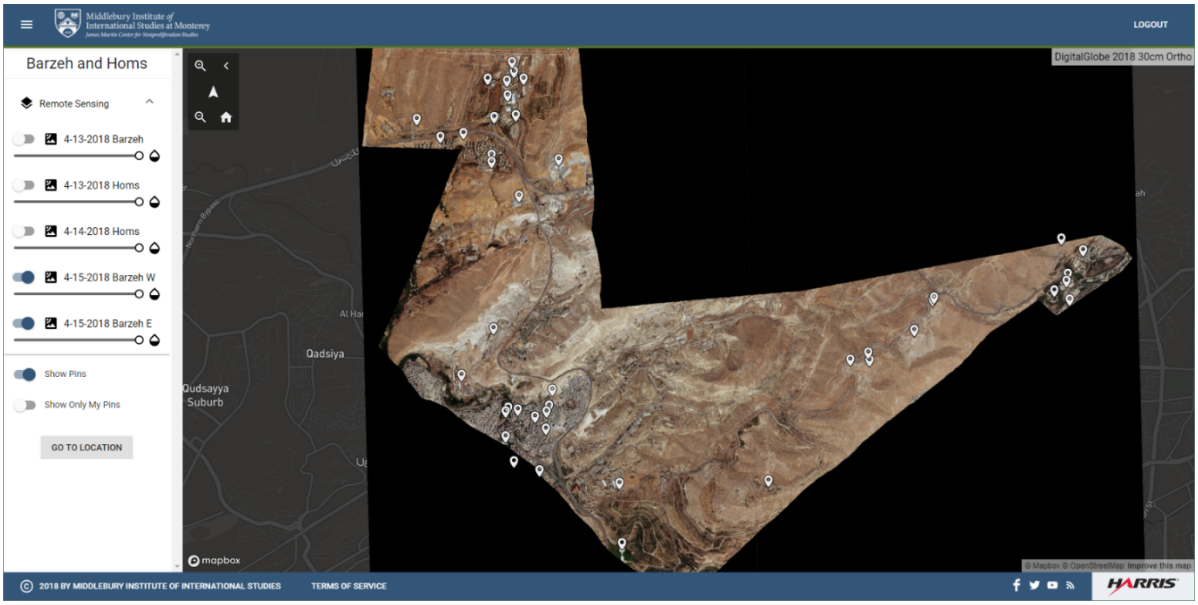

Figure 11: Screenshot of Homs imagery.

Crowd Analysis

One user pinned many interesting aspects at Barzah. The single user, who claims to be a junior in high school, pinned nearly 30 sites of interest and cited several other websites and resources related to some of the pins. These annotations were not limited to the site of the destroyed facilities but also expanded into the nearby towns and cities. The Homs image only received one pin pointing out the site of the missile strike.

[8] OPCW Executive Council, March 23, 2018, https://www.opcw.org/fileadmin/OPCW/EC/88/en/ec88dg01_e_.pdf
[9] Ben Hubbard, "Dozens Suffocate in Syria as Government Is Accused of Chemical Attack," *New York Times*, April 8, 2018, https://www.nytimes.com/2018/04/08/world/middleeast/syria-chemical-attack-ghouta.html

Offering satellite images that expand significantly beyond just one point of interest can be interesting for users and helps to put the AOI into the context of the environment: e.g., is the AOI in a highly populated area or is it isolated? What is the nearby terrain like? Are there several roads that lead to and away from the AOI?

Lessons

The media amply covered the airstrikes to the Barzah and Homs facilities at the time they occurred. But because the campaign launched nearly two months after the peak of the news coverage, it did not take advantage of the media coverage to direct traffic to the site. This may have impacted the number of people who were still interested in the site at the time of the campaign launch.

Additionally, because the airstrikes demolished most of these facilities and cleanup efforts removed the remaining debris, nothing presently sits at the sites. Since the sites are no longer active, this may also render this campaign less interesting to users than other active sites such as Hamhung or Novaya Zemlya.

Hamhung, North Korea, Solid-Fuel Motor Development

The Hamhung campaign features several sites related to North Korea's solid-fuel motor development and production. Site A is the Chemical Material Institute, where the North Koreans produce key missile components, such as motor parts for solid-fueled ballistic missiles. David Schmerler of CNS geo-located the site in 2016 and provided recent analysis on the Geo4Nonpo and Arms Control Wonk websites.[10]

Site B is the No. 17 Explosives Factory. This site received recent media attention in July 2018 when researchers at CNS noticed ongoing expansion, despite bilateral US–DPRK agreements to halt development of the North Korean nuclear program. The imagery includes both optical and near-infrared (NIR) images of the Hamhung solid-fuel motor testing stand.[11] Site C features a solid-fuel-motor test stand, sometimes called the Magunpo Solid Fuel Test Stand. NIR wavelengths constitute a portion of the electromagnetic spectrum that can deliver insights on a given area that cannot be seen with optical imagery alone. NIR data can carry information about temperature of an area relative to its surroundings, and can also distinguish live vegetation from non-biological, man-made sources. Using this capability at the solid-fuel test stand allows researchers to see burn scars on the ground, indicating if an engine was tested recently.

CNS researchers worked with reporter Jonathan Cheng of the *Wall Street Journal* to conduct the analysis of the site. Unfortunately, he did not include links to Geo4Nonpro in the article.[12]

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[10] David Schmerler, "North Korea Expanding Key Missile Site," Arms Control Wonk, July 2, 2018, https://www.armscontrolwonk.com/archive/1205558/north-korea-expanding-key-missile-site/.

[12] Jonathan Cheng, "North Korea Expands Key Missile-Manufacturing Plant," *Wall Street Journal*, July 1, 2018, https://www.wsj.com/articles/north-korea-expands-key-missile-manufacturing-plant-1530486907.

Figure 12: NIR images of Hamhung motor testing site.

Crowd Analysis

The team launched the Hamhung campaign on July 12. Even though this campaign was accompanied by a big news story, the campaign currently only has a handful of pins, one in the northern-most AOI and a few at the solid-fuel test stand.

Lessons

A potential contributing factor is that the widely popular Kangson campaign launched the very next day, which steered attention away from Hamhung.

Another reason why users may be hesitant to pin is that the NIR images have relatively poor resolution compared to three-band optical images, which makes ground features more difficult to identify. Users may also not be aware how to interpret NIR images. To help alleviate this issue, one G4N team member placed a pin pointing out a potential change in live vegetation in the NIR imagery. Another way to combat this issue is to add a section under the "Help" section explaining how to interpret NIR imagery, much like the explanation for SAR currently on the website.

Geo4Nonpro may also include a webinar on what NIR is and how to interpret it. CNS will complete this work by October with supplemental funding from the Skoll Foundation.

Shahrud Missile Test-Facility Update

The Shahrud missile-testing facility consists of five prominent features: a guarded entrance to the site, a large administrative complex, a horizontal assembly building, a mobile launch pad and gantry tower, and an additional complex that is partly underground in a large crater to the northeast of the facility. This site is roughly 35 square kilometers. The images show that the buildings within the large

administrative complex are connected by large underground tunnels. Four horizontal test stands appear to be located within the crater.

The Shahrud missile-testing facility first came to the public's attention when Jane's—a UK-based defense and intelligence clearinghouse—identified construction at the site in 2013.[13] There has been constant construction at the Shahrud missile-testing facility since 2010, and SAR imagery shows constant vehicle traffic and additional construction as recent as June 2018. In May 2018, CNS researchers, using Geo4Nonpro, identified possible horizontal solid-fuel testing stands, which was reported in the *New York Times*.[14]

Unlike other Iranian missile-testing sites, the Shahrud missile-testing facility does not appear to have large facilities dedicated to storing liquid fuel propellant. Since Iran currently possesses a limited arsenal of long-range solid-fuel ballistic missiles,[15] the construction of an apparent solid-fuel missile-testing facility may indicate that Iran is seeking to dramatically expand its solid-fuel missile program.

Crowd Analysis

The Geo4Nonpro team added seven new images of the Shahrud missile-testing facility since the relaunch in June. Two of these images, dated June 19 and June 27, 2017, appear to show a horizontal test stand before and after a possible solid-fuel engine test. Three other images from 2017 show continued construction at the site.

[13] Jane's Intelligence Review, "Space oddity – New developments in Iran's missile and space infrastructure," August 7, 2013, https://www.janes.com/images/assets/816/25816/Space_oddity_-_New_developments_in_Iran_s_missile_and_space_infrastructure.pdf

[14] Max Fisher, "Deep in the Desert, Iran Quietly Advances Missile Technology," *New York Times*, October 10, 2018, https://www.nytimes.com/2018/05/23/world/middleeast/iran-missiles.html.

[15] "Iran," Nuclear Threat Initiative Country Profiles, updated July 2017, http://www.nti.org/learn/countries/iran/delivery-systems/

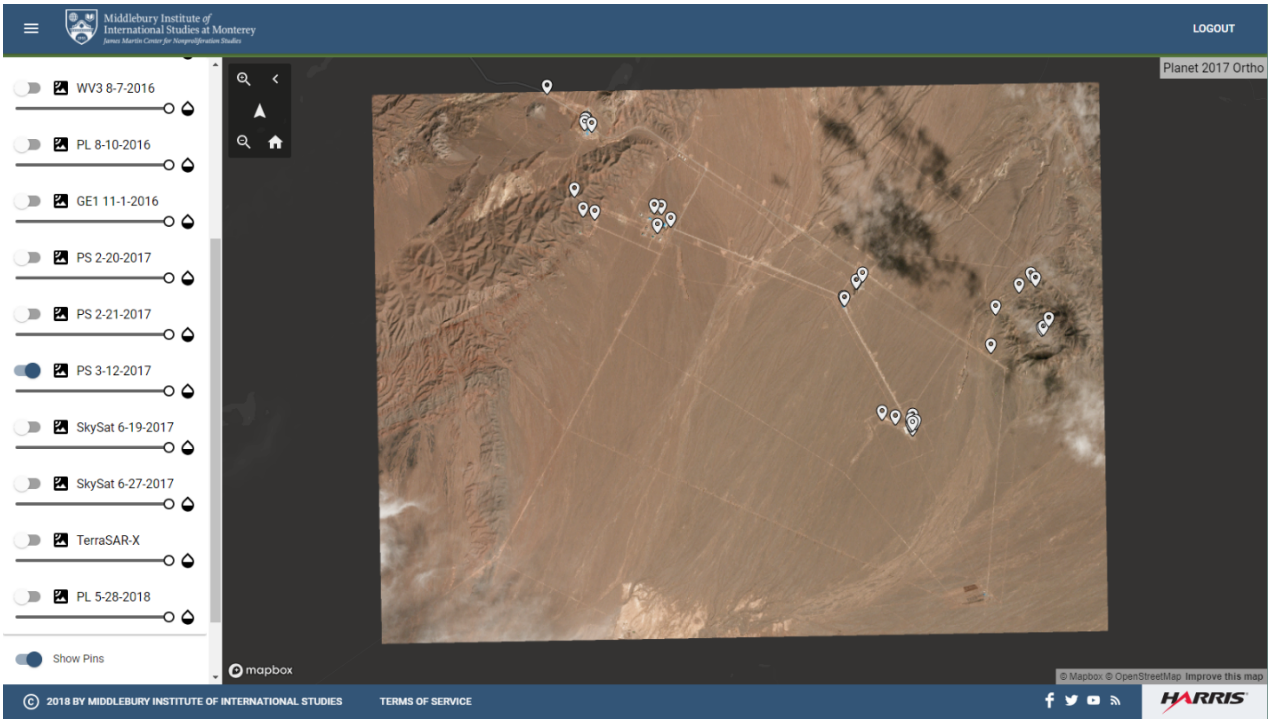

Figure 13: Screenshot of Shahrud imagery.

The team added two sets of images from 2018: SAR images comparing February 28, 2018, and March 22, 2018, and a 50-cm optical image from the Pleiades satellite on May 28, 2018. To the team's knowledge, this is the first time that SAR imagery of a suspected WMD-related site is publicly available. The SAR imagery shows heavy-vehicle activity at night, likely cranes and heavy-duty moving equipment. The Planet imagery soon after shows disruption in the soil indicative of a solid-fuel motor test. Pairing the high-frequency imagery with the night-time SAR has proven to be very effective at monitoring this testing activity.

The crowd was able to identify the new ground scarring at the possible horizontal test stand. The user that identified the ground scarring was new to the site, and this was one of their first pins. The images that we updated of the ground scarring were restricted to the area within the crater and the first burn scar that had been identified previously.

Lessons

There are two lessons to take away from the updated images of the Shahrud missile-testing facility. First, uploading imagery of a small AOI constrains the area and therefore directs the crowd to more easily identify what is significant in a very short period of time. This is especially significant because there was a relatively short period of time between when we published the new image and the first pin identifying the new burn scar. Second, publishing satellite imagery of sites that are prevalent in the news attracts more traffic. The Shahrud missile-testing facility has received a fair amount of recent media publicity.

Kaliningrad Munitions Storage Facility

Dr. Hans Kristensen at the Federation of American Scientists published an article in June 2018 following the completion of renovations at a suspected nuclear-weapons storage bunker in Kaliningrad, Russia.[16] Dr. Kristensen has monitored the site using satellite imagery for more than a decade and noted in the article that previous renovations were carried out in 2002 and 2010. The site is constructed in an area with heavy vegetation, so the perimeter and the buildings stand out.

CNS collaborated with Dr. Kristensen to create the new campaign. During this discussion, he identified three additional munitions storage sites east of the initial bunker, which we included in the satellite imagery. There are not yet any signs of renovations at these alternate sites. This new article may have driven additional traffic to the Kaliningrad campaign as a whole. There are six additional pins in the two older AOIs.

CNS also received low-resolution JPG files from Airbus that indicate Russia has painted the roof of the deployment shelters identified in Geo4Nonpro 1.0 with radar-reflecting material. While the radar cannot penetrate the roof to see if Iskander missiles have been deployed, low-angle imagery can detect the opening and closing of garage doors, and initial passes of the site seem to indicate that the missiles are not deployed yet. Unfortunately, this imagery has not yet cleared export controls by the time of publication, so the imagery is not available for crowd analysis on the website.

Crowd Analysis

Within a couple days of adding the new images, a user tagged a security entrance. Another user noticed and tagged the other two secured facilities. Other than these pins, there has been no other activity on the updated AOIs of the campaign.

[16] Hans Kristensen, "Russia Upgrades Nuclear Weapons Storage Site in Kaliningrad," Federation of American Scientists, June 18, 2018, https://fas.org/blogs/security/2018/06/kaliningrad/.

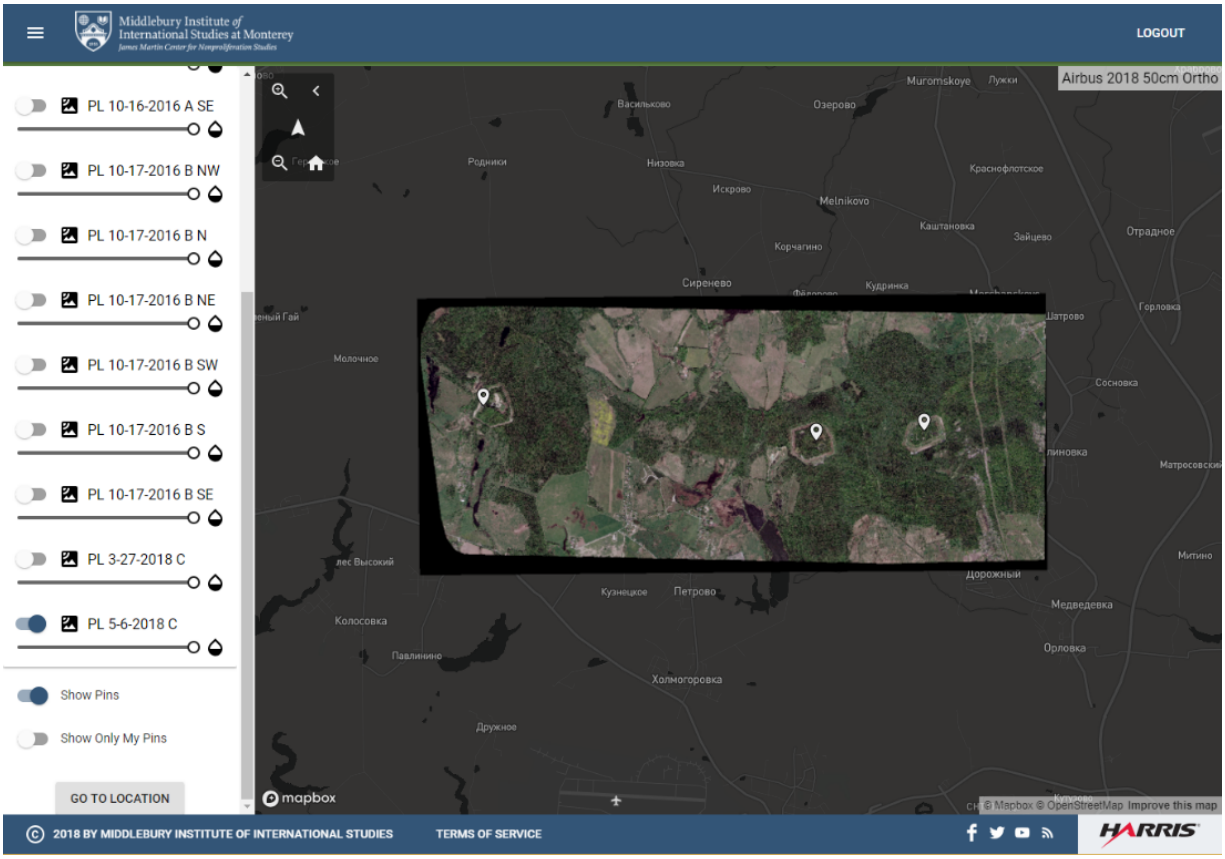

Figure 14: Screen shot from Kaliningrad campaign.

Lessons

Given Russia's recent developments in its nuclear activities—such as testing a nuclear-powered cruise missile and allegedly forward-deploying Iskander missiles in Kaliningrad[17]—monitoring Russian military sites may provide insight into developments of Russia's strategic forces. Activities that can be detected with remote sensing—renovations or vehicle traffic—can indicate the operational status of the base, help estimate the capacity of the bunkers, and indicate patterns of behavior at such sites.

Additionally, we are more likely to get traffic to the campaign when there is a related article or news story. Hans Kristensen shared our tweet announcing this campaign, which also drew more users to the site. This represents the first time we tried collaborating with another think tank in releasing a campaign.

This image also does not cover much other than the three suspected sites, meaning there is little context or nearby towns or cities for users to explore. This may cause viewers to lose interest more quickly than with images of more populated areas, which can lead to fewer pins. We are working with Airbus to provide a high-quality, recent, base-map for the entire site.

[17] Stubbs, Jack, "Russia Deploys Iskander Nuclear Capable Missiles to Kaliningrad," Reuters, February 5, 2018, https://www.reuters.com/article/us-russia-nato-missiles/russia-deploys-iskander-nuclear-capable-missiles-to-kaliningrad-ria-idUSKBN1FP21Y

Kangson Enrichment Facility

In May 2018, the *Washington Post* reported that North Korea was operating a covert uranium-enrichment site located near a place called "Kangsong [sic]."[18] This facility was originally described by a North Korean defector who reportedly worked at a nearby location. Amidst the process of creating a "denuclearization" deal with North Korea, reports of this alleged facility resurfaced in discussions for verifying the "denuclearization" process. In July 2018, researchers at CNS geo-located the site, using open-source information and high-resolution satellite imagery. The information was confirmed by an intelligence source of Ankit Panda of *The Diplomat*.[19]

Geo4Nonpro serves as the host for the satellite images that led to one of the most significant open-source discoveries. The four satellite images of the enrichment facility span from 2002—when the main facility building was in its initial stages of construction—to 2008. Over this timespan, we can also see construction of other auxiliary buildings, support structures, and roads.

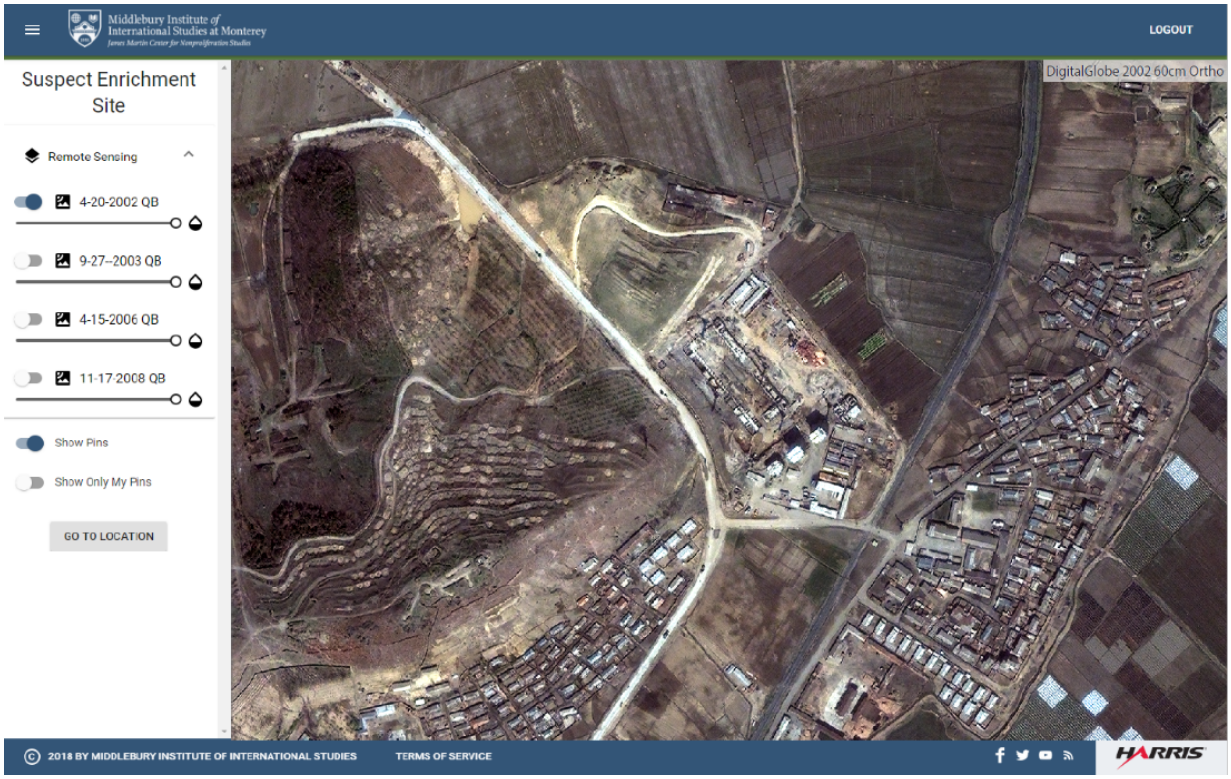

Figure 15: Screen shot from Kangson campaign

This is the first public identification of this covert facility. CNS wanted to make these images available in the open source, because Google Earth only has images from before the construction

[18] Joby Warrick and Souad Mekhennet, "Summit Collapse Foils Chance to Press North Korea on Suspicious Sites," *Washington Post*, May 25, 218, https://www.washingtonpost.com/world/national-security/summit-collapse-foils-chance-to-press-north-korea-on-suspicious-sites/2018/05/25/d5a14044-602d-11e8-9ee3-49d6d4814c4c_story.html.
[19] Ankit Panda, "Exclusive: Revealing Kangson, North Korea's First Covert Uranium Enrichment Site," *The Diplomat*, July 13, 2018, https://thediplomat.com/2018/07/exclusive-revealing-kangson-north-koreas-first-covert-uranium-enrichment-site/.

and after the facility was finished. Geo4Nonpro released the information at the same time as *The Diplomat* published Panda's report that used images and links from Geo4Nonpro.

Crowd Analysis

Panda's article mentions several features of the Kangson complex that G4N users had identified on the platform, including the security entrance, monuments, main building, and housing buildings. However, there are even more pins in the surrounding areas labeling other interesting markers. This includes the construction of a new road and building across the street from the facility, another secured building in the area, artillery, and activity along the river.

Lessons

This campaign has received the most traffic on Twitter and on the website. This is most likely due to the significance of the find and the prevalence of North Korea in the news. From this popularity, we also learned that the website may have some limits in terms of handling a large amount of traffic from users. Users were unable to pin on this campaign for a couple of days, which may contribute to the lack of pins, and we are currently working with the website developers to resolve this issue for future campaigns.

Korla Missile Test Complex

China tests its missiles and missile-defense technologies at the Korla Missile Test Complex in the northwestern region of the country. China has conducted five tests of its hit-to-kill interceptors from this facility. These five tests were conducted between January 2010 to February 2018. There is a large phased-array radar close to this site that is used to monitor these tests. Researchers at CNS noticed through high-frequency satellite imagery that this radar rotates shortly before tests. The G4N team is considering adding images of this radar to Geo4Nonpro to demonstrate the correlation between testing and radar use. The direction that the radar is pointing at the time of intercept is useful in understanding the type of test China is conducting.

Crowd Analysis

The crowd has annotated multiple points of interest throughout this campaign. Users have identified the launch pad, vehicle traffic (because of plowed snow), and new construction. Some users who pinned this site seem to be familiar with missile-test sites and the equipment and infrastructure that would be found at such sites. For example, one user identified a point as a possible sensor array. Other pins identify possible mobile radar trucks by the radar dishes that are fixed to the top of the vehicles.

Other pins signal that users are more familiar with Chinese culture. One pin speculates that signs on the side of a highway are "slogans." This would be consistent with signs that are present throughout the country, and especially in the region, that display pro-China and pro-Communist party language.

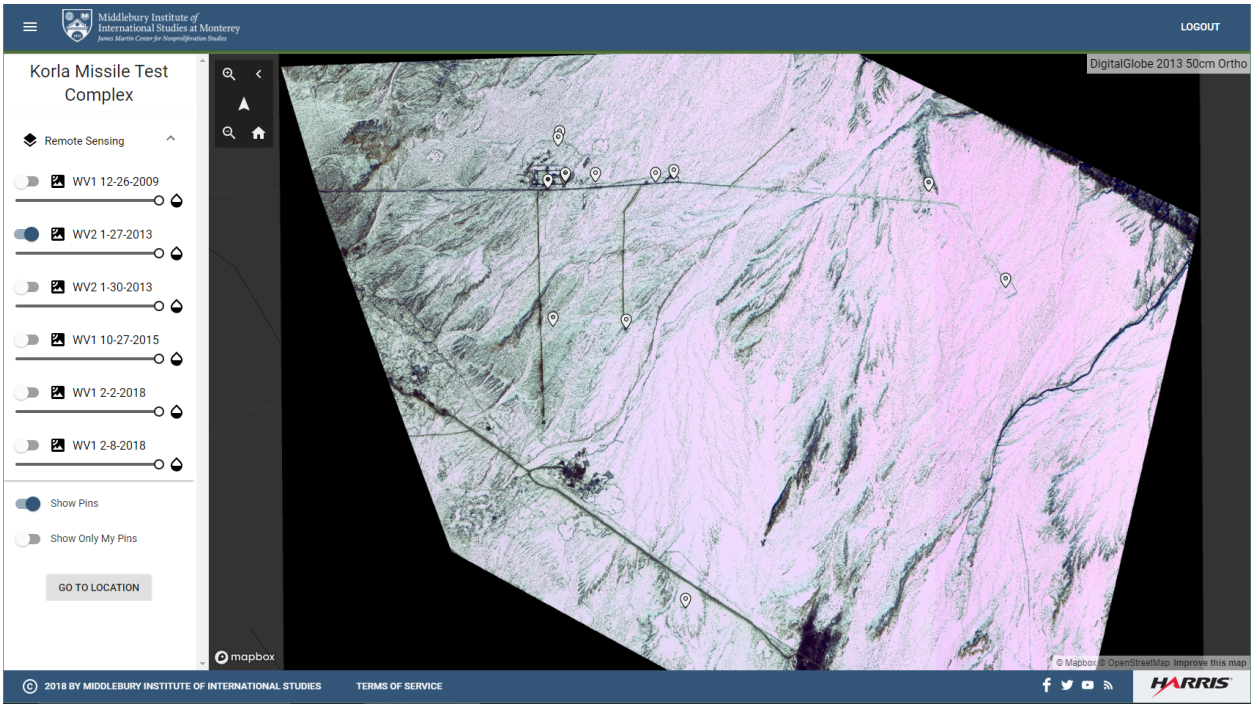

Figure 16: Screenshot of Korla campaign.

Lessons

The Korla campaign, along with other sites that focus on missiles and rocket launch sites, seem to be generally more popular than sites that are more geospatially ambiguous. This may be because signatures related to launch sites are easier to see and identify. For instance, a rocket launch pad or gantry tower is generally a very large, easily identifiable object.

The Korla test site also features images with snow on the ground, which can also highlight vehicle traffic and other changes in terrain. This makes it easier for people to see differences between two images and deduce the cause of the changes. Featuring more images in other locations with snow or differing ground conditions could be interesting for users and provide another frame of analysis.

Punggye-ri Nuclear Test Site

North Korea tested nuclear devices at this site in 2006, 2009, 2013, twice in 2016, and in 2017. In May 2018, the North Korean government invited reporters to the site to witness explosions that would collapse testing tunnels and demolish support facilities. CNS continued its previous campaign to examine what happened at the site during the September 2017 nuclear test, and the May 2018 demolition of the associated facilities.

CNS acquired optical and SAR images of the test site before and after the final nuclear test on September 2, 2017. Planet, with its high-frequency orbits, was the first company to produce imagery of the site. The website 38 North published a report by a few analysts who, after taking a cursory

look at the site after the explosion, noted evidence of landslides at Mt. Mantap.[20] CNS concurs with this initial analysis, but collaborated with Airbus to do a more comprehensive analysis of the nuclear test using SAR from TerraSAR-X.[21]

Figure 17: Airbus processed SAR imagery from 8/26 2016. See animated GIF of before and after nuclear test at: https://www.armscontrolwonk.com/files/2017/09/TSX_20170826_20170906.gif

Airbus tasked their SAR sensor to collect imagery after the nuclear test. The x-band microwaves of about 3.1 cm wavelength bounced off the mountain at a resolution of about 1m. Pairing an image from August 26, 2017, with an image from September 6, 2017, the researchers saw major subsidence at Mt. Mantap. An area of about 85 acres dropped several meters from the explosion. Because the site is covered with trees of different heights, it is not possible to know the exact displacement.

In May 2018, North Korea invited journalists from major new outlets to watch the demolition of its nuclear-testing tunnels and some support facilities at Punggye-ri. CNS collected optical imagery before the demolition, which included viewing stands for the journalists. In the days after, additional optical imagery clearly showed the demolition of log buildings at the site, corroborating videos and

[20] Frank Pabian, Joseph Bermudez, Jack Liu, "North Korea's Sixth Nuclear Test: A First Look," 38 North, September 5, 2017.

[21] Catherine Dill, Melissa Hanham, Catherine Hartley, Jeffrey Lewis, Lars Petersen, Allison Puccioni, and David Schmerler, "SAR Image of Punggye-ri," Arms Control Wonk, September 13, 2018, https://www.armscontrolwonk.com/archive/1203852/sar-image-of-punggye-ri/; see media coverage of the analysis: Michelle Ye Hee Lee, "North Korea's Latest Nuclear Test was so Powerful it Reshaped the Mountain Above it," *Washington Post,* September 14, 2017, https://www.washingtonpost.com/news/worldviews/wp/2017/09/14/orth-koreas-latest-nuclear-test-was-so-powerful-it-reshaped-the-mountain-above-it/?utm_term=.12de6f12ede1.

images produced from the site. Reporters were unable to enter or inspect the tunnels to determine how deep detonation devices were rigged.

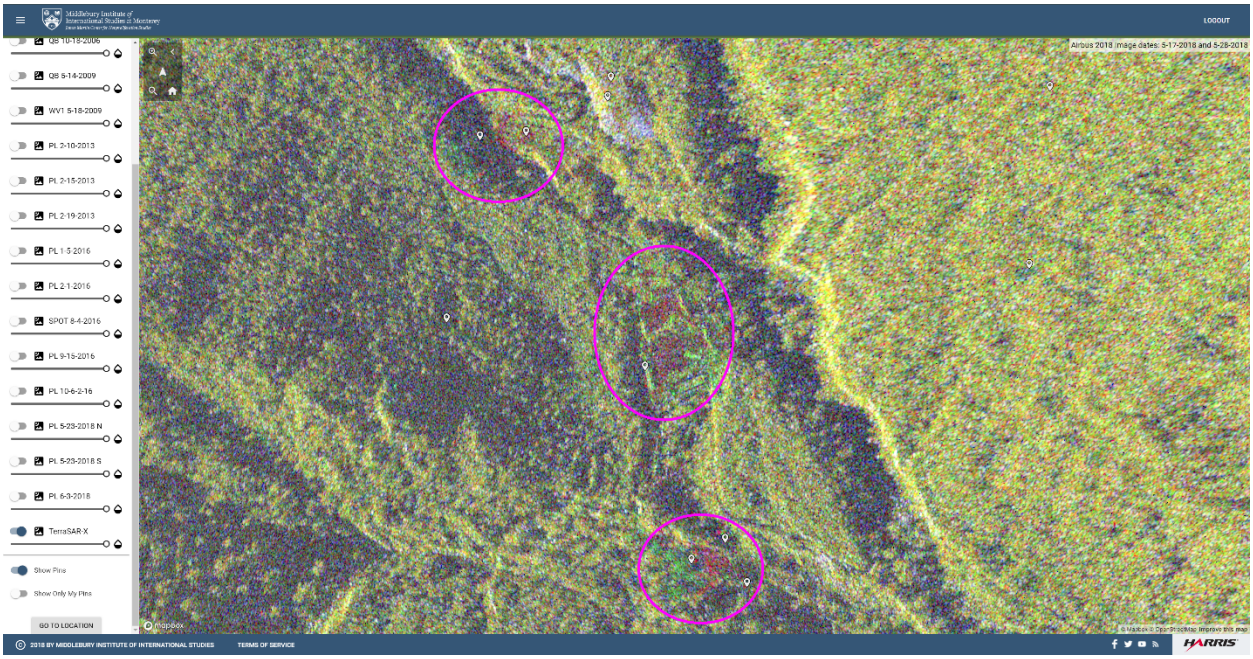

Figure 18: Airbus used ACD and CCD to show areas of greatest disturbance after the demolition at Punggye-ri

CNS worked with Airbus TerraSAR-X to collect and analyze SAR data from the Punggye-ri test site again. This time, TerraSAR-X developers processed the imagery with amplitude and cohesion-change detection software and false colored the imagery to illustrate changes. Red indicates reflectance that was apparent on May 17, 2018, but that had disappeared by May 28, 2017. Green indicates radar reflectance that was not present on May 17, 2018, but appeared by May 28, 2017. Yellow indicates low cohesion between the two dates, meaning that a higher level of change occurred, while white indicates high cohesion.

In this paring of images, the evidence of explosions at the tunnel entrances is much more obvious than in optical imagery. While the SAR pairing clearly shows the facilities that were demolished, it also shows the displacement at the entrances of the west and south tunnel entrances. Unfortunately, the trees prevent SAR from taking an accurate measurement of any explosion that occurred deeper in the tunnels.

Crowd Analysis

Punggye-ri was one of the popular sites for users to visit and drop pins. Users were able to use the optical imagery to identify shelters at the site.

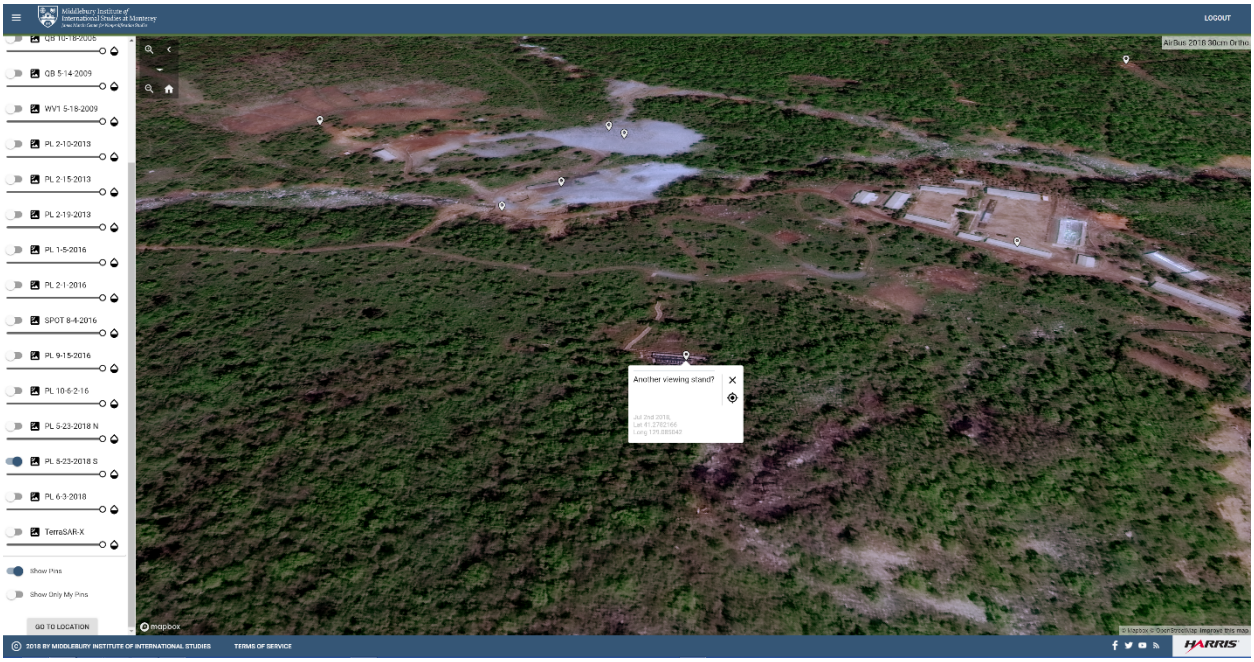

Figure 19: Screenshot of Punggye-ri campaign

SAR imagery was only uploaded in August of 2018. Melissa Hanham placed a few pins on the Punggye-ri site to help users who are new to SAR. No independent experts have annotated the image yet. CNS will host a webinar with Airbus data scientists on October 2, 2018 who will explain how SAR data is collected, processed, and analyzed. They will use Punggye-ri as an example, and then invite users to drop pins on the Shahrud campaign.

Lessons

As was the case with previous campaigns, users are increasingly comfortable dropping pins on this well-known location. They can manipulate and annotate optical imagery, and are keen to do so likely because of its prevalence in the news. SAR data is still new to most open-source researchers, including CNS staff. CNS is grateful to Airbus for the opportunity to learn train on SAR analysis.

Next Steps

CNS will continue Geo4Nonpro 2.0 with funding through October 2018. Several campaigns are underway, including uranium mining and milling analysis using multispectral, hyperspectral, and thermal bands of Landsat. In addition, we are collecting Planet and TerraSAR-X imagery near Sverny, Russia, of a possible nuclear cruise-missile test site.

CNS will continue to work with Airbus to release SAR files that can be used on the site layered with optical imagery. Airbus/TerraSAR-X scientists have agreed to provide a webinar for users on how to "read" the imagery on October 2, 2018. In addition, CNS will receive digital elevation models and other forms of remote sensing data. As soon as Mapbox offers 3D rendering of topographies, we will offer 3D terrain on the site.

Several sites would benefit greatly from the ability to add photos and/or videos to pins. CNS would also like to add a feature that allows users to comment on each other's pins in a "thread" format.

Uploading files from users is inherently risky from a security standpoint, but we would like to add the capability for Geo4Nonpro administrator accounts. CNS is also exploring the possibility of sharing pins directly to social media as a fun and competitive way to engage new users and draw traffic to the site. In addition, we plan to add social media and trade data widgets to the site, which will update in near-real time.

Last, we will continue to promote the site in social and traditional media in order to expand the crowd. The broader public benefits from diverse expertise when approaching WMD research and analysis.

About the Authors

Melissa Hanham is a senior research associate at the James Martin Center for Nonproliferation Studies (CNS) at the Middlebury Institute of International Studies at Monterey (MIIS). She studies East Asian security, with particular focus on North Korean WMD capabilities, procurement and proliferation networks, and China's nuclear posture. Hanham is an expert on open-source intelligence, incorporating satellite and aerial imagery, and other remote sensing data, large data sets, social media, 3D modeling, and GIS mapping. She is particularly focused on the monitoring and verification of international arms-control agreements using open-source evidence. She also uses open-source information to study export-control systems and proliferation finance activities. She is an affiliate of Stanford University's Center for International Security and Cooperation. Hanham teaches "Geospatial Tools for Nonproliferation Analysis" at the Middlebury Institute of International Studies and is a regular contributor to Arms Control Wonk, the leading blog and podcast on disarmament, arms control, and nonproliferation. In 2018, she was awarded the Paul Olum Grant Fund for being one of the most inventive scientific and technical minds working to reduce the threat of nuclear weapons. She previously worked with the Mixed-Methods, Evaluation, Training & Analysis (META) Lab and the International Crisis Group in Seoul and Beijing.

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Catherine Dill is a senior research associate at CNS with a broad research portfolio that includes extensive work on satellite imagery and remote sensing analysis on nuclear nonproliferation-related issues, including open-source research, satellite-image processing, and geospatial analysis. In addition, Ms. Dill researches illicit trafficking networks in Asia and developments in strategic trade control systems in East Asia. Her work incorporates geospatial analysis and mapping, foreign-language research, and archival research. Previously, Ms. Dill worked as a senior consultant at Booz Allen Hamilton as a radiological and nuclear threats analyst in Washington, DC. She holds a Master's in Nonproliferation and Terrorism Studies from the MIIS and a Bachelor of Science in Foreign Service from Georgetown University's School of Foreign Service.

Grace Liu is a research associate in the East Asia Nonproliferation Program at CNS. She translates Korean and Chinese sources, conducts geospatial analysis, and uses 3D-modeling techniques to assess North Korea's WMD and ballistic-missile capabilities. Her research focuses on applying open-source intelligence to verify arms control treaty compliance. Ms. Liu served as an all-source intelligence officer in the armed forces. She holds a Master's in Nonproliferation and Terrorism Studies from MIIS, a Master's of Business Administration in International Management, and a Bachelor's in Military Science from the University of New Mexico.

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Octave Lepinard is an undergraduate at Middlebury College studying Geology and Computer Science, with a focus in remote sensing. During the summer of 2018, he was a research assistant at CNS, where he worked with satellite imagery and various image-processing software to track developing and growing WMD programs around the world. He also sought to use new technologies such as hyper-spectral analysis to develop methods for identifying covert uranium mines.

Olivia Hallam is a graduate research assistant in the East Asia Nonproliferation Program at the CNS, where she supports research on China's nuclear developments and capabilities using open-source techniques, translates Chinese sources, and conducts geospatial analysis. During the summer of 2018, Ms. Hallam interned at the Center for Global Security Research at Lawrence Livermore National Laboratory (LLNL) where she conducted open-source research and analysis on China's Grand Strategy and assisted LLNL's N-program on radiological security project in conjunction with the National Nuclear Security Administration's Office of Radiological Security. Ms. Hallam is currently working toward a Master's in Nonproliferation and Terrorism Studies while continuing her Chinese studies at MIIS. She earned her BA in Chinese and Political Science and minor in International Relations from the University of Rhode Island in 2017, where she also received her Chinese Flagship Certificate from the Language Flagship and graduated magna cum laude.

Ben McIntosh is graduate student at MIIS and a graduate research assistant at CNS. He focuses on the methods of diplomatic engagement and open-source monitoring of Northeast Asian countries, most notably North Korea. Before coming to Monterey, Mr. McIntosh was appointed to the US Department of Agriculture from 2015 to 2017 and worked on multiple congressional and presidential campaigns. Ben received his BA in International Studies from the University of Oregon in 2013.

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