USE OF SATELLITE IMAGERY IN SUPPORT OF ON-SITE INSPECTIONS: LESSONS FROM A FIELD EXERCISE

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1. Introduction

1.1. About the experiment

In March 2023, the United Nations Institute of Disarmament Research (UNIDIR) conducted a field experiment, simulating an on-site inspection to verify the absence of nuclear warheads at a military site. As part of the experiment, UNIDIR, in collaboration with Open Nuclear Network (ONN), tested the applicability of commercially available satellite imagery to support the inspection. The acquired results from the experiment, as well as the methodology, monitoring arrangement and the discovered limitations and opportunities for future use of commercially available satellite imagery in support of on-site inspections, will be discussed in this paper.

The on-site inspection experiment is part of UNIDIR's continuous research on ways and means for disarmament verification. For the March experiment, the team tested a scenario that assumed an agreed arms control treaty between nuclear-weapon States. The treaty stipulates that all of the States' non-strategic nuclear warheads should be removed from sites where the means of their delivery are located. All such warheads should be securely stored at an appropriate facility, away from the possible launching sites. The verification efforts will then focus on ensuring no nuclear weapons are deployed at the launching military sites. UNIDIR calls such a scenario a 'zero-deployed' arrangement since neither party will have its non-strategic weapons ready for immediate use.[1]

1.2. Overview of satellite imagery use for verification purposes

The idea of using remote sensing for regime verification is not new. Exploration of the use of intelligence satellites for arms control verification started at least as early as the late 60s to the early 70s.[2] Such means of treaty verification, which were also referred to as 'national technical means' (NTM), were used, for example, in the Strategic Arms Limitation Talks Interim Agreement (SALT I) and the Anti-Ballistic Missile (ABM) Treaty.[3] Prior to developing the on-site inspection arrangement, the NTMs were almost the sole means of monitoring compliance with arms control treaties.[4] The 1987 Intermediate-Range Nuclear Forces (INF) Treaty created the first precedent in the arms control field for developing a comprehensive verification regime that combined NTM for monitoring and onsite inspections.[5]

NTMs, including military intelligence satellites, are capabilities that are only available to State actors. However, in the past several decades, the world has witnessed a rapid development of commercially available means of remote observation that can be applied for purposes of non-proliferation and disarmament verification.[6] Satellite imagery providers, such as Airbus, Maxar, and Planet Labs, offer their tasking and archive purchases to NGOs, academic institutions, and the private sector, thus eliminating the State-exclusive privilege for high-resolution remote sensing observation. Though such commercial solutions have not yet been used as a formal part of a verification regime of an arms control treaty, they are used for treaty verification by individual government entities, as well as a number of international organisations and their related bodies, such as the IAEA, OPCW and the UN Panel of Experts on the DPRK sanctions.

Furthermore, with the introduction of imagery with sub-one meter resolution and further democratisation of the satellite imagery field through platforms like Google Earth, non-State actors have started to contribute to verifying allegations regarding clandestine nuclear and missile-related facilities and activities.[7] However, more research is needed to test the applicability of commercially available satellite imagery to a real-life scenario of verification activity in support of an arms control agreement. The zero-deployed nuclear warheads experiment conducted by UNIDIR and ONN strives to contribute to addressing this research gap.

2. Methodology

For the on-site inspection experiment, UNIDIR developed a protocol, which broadly included the following stages: 1) pre-inspection preparations; 2) site lockdown; 3) on-site verification of the site diagram; 4) on-site inspection of an object of verification; 5) preparation of the inspection report. The satellite imagery use was envisioned for stages 1 and 2.

As part of the pre-inspection preparation phase, the team plans to acquire optical imagery as close to the inspection date as possible to serve as a reference point for all further detected activities. Furthermore, the reference image is planned to be used to verify the accuracy of the inspected site's diagram, which, according to the scripted scenario, is shared with the inspection team before the start of the inspection activities. The site diagram is also later to be verified by the inspectors as part of the on-site inspection activities, but as a preparatory step for that, the diagram is to be compared to the acquired reference imagery to pre-determine any apparent discrepancies that might be detectable with the available satellite imagery resolution.

For the second phase, after the arrival of the inspection team to the 'point of entry' in the inspected country, inspectors have to designate a particular site which becomes the site of inspection. From the moment of the site's designation until the moment when inspectors arrive at the site, which depending on the logistics in the inspected country, could take approximately 2-12 hours, the site goes into a 'lockdown.' During this phase, the host State is not allowed to move any closed vehicles or covered objects that are "large enough to contain an item of inspection" from or to the inspected site. Movements within the inspected site are also limited.

The lockdown phase is arguably the most challenging stage of the verification process. This is likely to be the opportune moment for the host State to hide any evidence of its potential non-compliance with treaty obligations. To address this issue, the treaty specifies that the lockdown phase will be verified through remote sensing. The possibility of being watched and caught red-handed should serve as a deterring factor. Nevertheless, for the purposes of the experiment, the organisers decided to assume a possible scenario when the inspected State chooses to cheat, and inspectors attempt to detect such activity during the lockdown phase through commercially available satellite imagery. In a real-world scenario, the inspectors would have the possibility to use both NTMs and commercially available imagery, so the State's chances of catching any suspicious activity would be even higher.

3. Results

To acquire suitable images for both stages, ONN engaged six different commercial providers for tasked high-resolution optical imagery and synthetic aperture radar (SAR) data. However, only two providers were able to provide adequate tasking windows within the study period, especially for the lockdown phase.[1]

Acquiring imagery for the preparatory phase was challenging due to near-permanent cloud coverage during the days preceding the inspection date. All high-resolution tasking attempts returned images with zero visibility of the site. As such, an archived medium-resolution Planet Scope image from the most recent day without cloud coverage had to suffice for the purposes described above. The 3-meter resolution of the image was sufficient for assessing that no significant infrastructural discrepancies were present between the existing site layout and the current status of the site.

Figure 1: 3-meter Planet Scope image with an overlay of the site layout on the left (red: objects of verification; green: auxiliary buildings). Image © 2023 Planet Labs Inc. All Rights Reserved. Reprinted by permission.

Only one day after the inspection took place, the weather conditions improved, and a high-resolution optical image was taken successfully. While it was not used for the preparatory phase, the following 0.5-meter resolution Planet SkySat image may serve to illustrate what additional observations can be made with a higher resolution. Most importantly for the purposes of this experiment, it is possible to assess and count the vehicle presence at the site at that particular time.

[1] Commercial providers have to prioritize various tasks from different customers that may not be compatible with each other. Typically this prioritization process takes place within the week preceding a tasking date, and, depending on the provider, customers can pay a premium for a higher chance that the task will be executed within a particular period. Nonetheless, providers do not usually provide an absolute guarantee that an acquisition at a particular date and/or time will take place.

Figure 2: 0.5-meter Planet SkySat image. Image © 2023 Planet Labs Inc. All Rights Reserved. Reprinted by permission.

For the lockdown phase, all optical imagery tasking attempts were similarly unsuccessful due to cloud coverage. The dual approach of tasking for both optical and SAR images thus proved to be critical, and two SAR spotlight acquisitions by ICEYE took place during the lockdown period, namely at 14:12 and 20:56 local time. In comparison between each other and separately with the most recent optical images available, no significant discrepancies were discernible.

However, the application of a SAR processing technique that allows for the detection of moving targets showed that a possible vehicle may have been driving on an exit ramp on the site within the 10-second acquisition duration of the 20:56 task. Due to the synthetic aperture configuration of SAR acquisition geometry, moving targets in azimuth direction can be identified and visualized as such.[8] Depending on the precise terms of the lockdown agreement, this could have been considered a possible violation.

Figure 3: Illustration of a moving target identified based on ICEYE SAR data; overlaid on Planet SkySat image. Image © 2023 Planet Labs Inc. All Rights Reserved. Reprinted by permission.

4. Implications and Conclusion

Several lessons can be drawn from the satellite imagery component of the experiment. Overall, it is clear that commercial satellite imagery can play an important, non-invasive mechanism that helps to verify the terms of arms control agreements. In particular, it can assist inspectors in the preparatory phase of an inspection and also verify that there are no discrepancies between known or declared features and tasked images that show the current status of the site in question. Furthermore, tasking commercial satellites for acquisitions during a lockdown period can help in ascertaining whether a State may have attempted to conceal or remove any verification-relevant objects.

With satellite imagery alone, may it come from NTM or commercial sources, it is not possible to have complete certainty that no activity in violation of a lockdown period has occurred. However, a certain level of confidence can be reached with a higher temporal resolution that can be achieved with a sufficient budget and as the technological offerings of commercial providers continue to improve. A State acting in bad faith may also be sufficiently deterred from non-compliance knowing that remote observations are actively taking place, or may have to go through additional efforts to conceal any observable activity.

The experiment showed that the utility of optical imagery acquisitions is highly weather dependent and can not be relied upon by itself. On the other hand, the utility of SAR acquisition is highly dependent on good knowledge of the site and its current status and/or a current optical image for reference purposes. A combined approach is most advisable. Furthermore, applying a moving target detection technique can be useful to assess whether any vehicular movement occurred during the acquisition process itself. While, for this particular experiment, getting any SAR acquisitions within the lockdown period was prioritized over getting acquisitions with a similar imaging geometry, the continuous growth of commercial constellations should allow for reliable coherent change detection analysis in future applications.

5. References

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