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Demonstration of a Hybrid Space Architecture during RIMPAC 2020

Charlene Jacka
Air Force Research Laboratory
3553 Aberdeen Dr SE, Kirtland AFB, NM; +1 505 553 4150
Charlene.Jacka.1@us.af.mil

Sennen Peña
Space Dynamics Laboratory
1695 Research Park Way, North Logan, UT 8434; +1 505 225 6970
Sennen.Pena@sdl.usu.edu

Richard C. Ordonez, PhD
Naval Information Warfare Center Pacific
2293 Victor Wharf Access Road, Pearl City, Hawaii, 96782, 808-471-3911
richard.c.ordonez@navy.mil

David Lingard, David Neudegg, Victor Stamatescu. Michele Wilson
Defence Science & Technology Group
21L - 8, Third Ave, Edinburgh SA 5111; +61 (0) 8 7389 5289
David.Lingard@dst.defence.gov.au David.Neudegg@dst.defence.gov.au Victor.Stamatescu@dst.defence.gov.au
Michele.Wilson@dst.defence.gov.au

Pierre Lamontagne, Sacha Nandlall, Jeff Secker, Cdr Ted Parkinson
Defence R&D Canada (DRDC) Ottawa
3701 Carling Avenue Ottawa, ON K1A 0Z4 Canada; +1 613 998 6109
pierre.lamontagne2@forces.gc.ca, sacha.nandlall@forces.gc.ca, jeff.secker@forces.gc.ca,
ted.parkinson@forces.gc.ca

Jean-Pierre Ardouin, Robert Boucher, Vivian Issa, Daniel Lavigne, Josée Lévesque, Caroline Turcotte,
DRDC R&D Canada (DRDC) Valcartier
2459 route de la Bravoure, Quebec, QC, Canada G3J 1X5; +1 418-844 4000 ext 4077
jean-pierre.ardouin@drdc-rddc.gc.ca, robert.boucher@drdc-rddc.gc.ca, vivian.issa@drdc-rddc.gc.ca,
daniel.lavigne@drdc-rddc.gc.ca, josee.levesque@drdc-rddc.gc.ca, caroline.turcotte@drdc-rddc.gc.ca

Frank Schaefer
Fraunhofer Institute for High-Speed-Dynamics, Ernst-Mach-Institute, EMI
Ernst-Zermelo-Str. 4, 79110 Freiburg, Germany; +49 761 2714 421
frank.schaefer@emi.fraunhofer.de

Tobias R. Carman, Avyaya Kolhatkar, Sean Murphy
Defence Science and Technology Laboratory
Dstl Porton Down, Salisbury, Wiltshire, SP4 0JQ; +44 1980 95 7012
trcarman@dstl.gov.uk, akolhatkar@mail.dstl.gov.uk, SMURPHY1@dstl.gov.uk

Chiara Toglia
Thales Alenia Space Italy
Via Saccomuro, 24, 00131 Roma RM, Italy; +390641514686
chiara.toglia@thalesaleniaspace.com

Majoor ir J. Martin van de Pol
Royal Netherlands Air Force (RNLAF)
Luchtmachtplein 1, 4822ZB Breda, The Netherlands, +31765447323

TH.vd.Pol@mindef.nl

Mark van Persie
Royal Netherlands Aerospace Centre NLR
Anthony Fokkerweg 2, 1059 CM Amsterdam, The Netherlands, +31885114256
mark.van.persie@nlr.nl

William Coldicutt
Defence Technology Agency, New Zealand Defence Force
Jim Titchener Parade, Devonport, Auckland 0624, New Zealand; +64 9 445 5902
W.Coldicutt@dta.mil.nz

Øyvind Kinden Lensjø
Norwegian Defence Research Establishment
Instituttveien 20, 2007 Kjeller, Norway; +47 63 80 79 67
Oyvind-Kinden.Lensjo@ffi.no

ABSTRACT

The Micro-Satellite Military Utility (MSMU) Project Arrangement (PA) is an agreement under the Responsive Space Capabilities (RSC) Memorandum of Understanding (MOU) that involves the Departments and Ministries of Defence of Australia, Canada, Germany, Italy, the Netherlands, New Zealand, Norway, United Kingdom and United States. MSMU's charter is to inform a space enterprise that provides military users with reliable access to a broad spectrum of information in an opportunistic environment.

Research and Development teams from MSMU partner nations supported Exercise Rim of the Pacific (RIMPAC) 2020 which took place 17 to 31 August 2020 in the Hawaiian region. RIMPAC 2020 provided an opportunity to explore the military utility of a Hybrid Space Architecture (HSA) of satellites including traditional government and commercial satellites, as well as micro-satellites and nanosatellites, by leveraging contributions across the MSMU partner nations. The objective was to continue testing the hypothesis that an HSA, mostly composed of small satellites, can bring significant value to the operational theatre. The MSMU PA partner nations have leveraged several multi-national exercises, with the first being the Exercise RIMPAC 2018. Previous exercises enabled multinational technology advancements, interoperability testing, process refinement, and capability developments to make advancements towards MSMU's goal to address the warfighter's need for diverse ISR capabilities. The most recent accomplishment was a major integration effort across mission planning tools, space-based Intelligence, Surveillance and Reconnaissance (ISR) data providers, and exploitation tools.

The MSMU team accessed ~256 space-based sensors (EO – Electro Optical, SAR – Synthetic Aperture Radar, AIS – Automatic Identification System) to collect maritime domain and ISR data over a harbor, airfields and open sea. Data was exploited via international channels in order to determine the success rate of capturing pertinent data to be later exploited and disseminated. This paper describes results from the experiment and offers insights into the HSA military utility.

INTRODUCTION

The aim of this paper is to present the results of the experiment conducted during the RIMPAC 2020 within the framework of the RSC MOU through the MSMU PA. Description of RSC MOU and MSMU PA can be found in [RD1].

Hybrid Space Architecture (HSA)

A Hybrid Space Architecture is defined as a constellation of government-owned (military and civil), allied and commercial satellites equipped with different phenomenologies that are capable of collecting ISR data needed to produce the Common Intelligence Picture (CIP) that assists the Warfighters' decision-making process. See Figure 1.

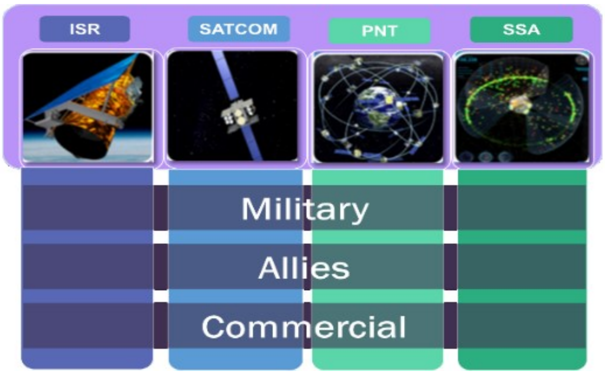

Figure 1: HSA Concept

As a result of previous years' experience, the MSMU PA adopted a more iterative experimental method to emphasize both analysis and demonstration efforts toward a more thorough evaluation of the military utility of the HSA. The experimental method is as follows:

- Conduct enterprise explorations which are defined as analyses efforts that aim to characterize the HSA capability.
- Conduct an S&T demonstration to test capabilities and evaluate challenges.
- Demonstrate best performing capabilities to military users and gather feedback.
- Evaluate utility based on performance and feedback stemming from demonstrations.

EXERCISE RIMPAC 2020

RIMPAC 2020 presented an opportunity for MSMU PA to conduct its own S&T demonstration. It allowed the MSMU PA team to directly exploit well scripted events, rich target sets, and access to planning and ground truth information for structured capability testing anchored on real world data. The at-sea-only construct allowed MSMU PA to leverage existing live training scenarios and objectives to validate and automate the MSMU PA capabilities through modeling, simulation, and value-based metrics involving tactical level air, land, and sea elements with minimal cost. RIMPAC 2020 also provided a series of opportunities to collect hybrid data sets in the maritime and land domain.

EXPERIMENT DESCRIPTION

MSMU PA implemented the following integration approach, which proved to be robust in introducing space-based unclassified tactical ISR products into exercises:

- Test aggregate capability of MSMU coalition.
- Integrate space data into simulated operational scenario.
- Educate operational users on current and future space capability.
- Engage with Military community on needs and elicit feedback.
- Learn from experience and document lessons learned.

The MSMU PA member nations conducted the following:

- Tasked and exploited a multinational HSA constructed of dedicated and contributing ISR space-based sensors, comprised of commercial and government owned satellites, to attempt to collect static and moving targets over land and sea.
- Fused ISR products based on a globally distributed Tasking, Collection, Processing, Exploitation and Dissemination (TCPED) cycle, with a goal of significantly reducing cycle latency.
- Utilized advanced modeling and simulation capabilities to assess mission planning options of live training events during RIMPAC 2020 and carried out post-RIMPAC 2020 analysis of the collected ISR data with the objective of improving the automated tools, compressing the TCPED cycle by reducing the time necessary to responding to an information request, improving the effectiveness of multinational efforts in space-based ISR collection and documenting other key lessons learned in RIMPAC 20.

Figure 2 illustrates the data providers, exploitation tools, planning tools, and enterprise explorations as organized by the contributing nations to the RIMPAC 2020 experiment. The satellites were comprised of approximately 256 sensors (EO, AIS, and SAR) that were tasked throughout the events to develop/add to maritime domain awareness, and collect maritime intelligence data. Moreover, there were a total of 12 exploitation tools. Participating nations retained national control and tasking authority over their collection assets throughout the experiment.

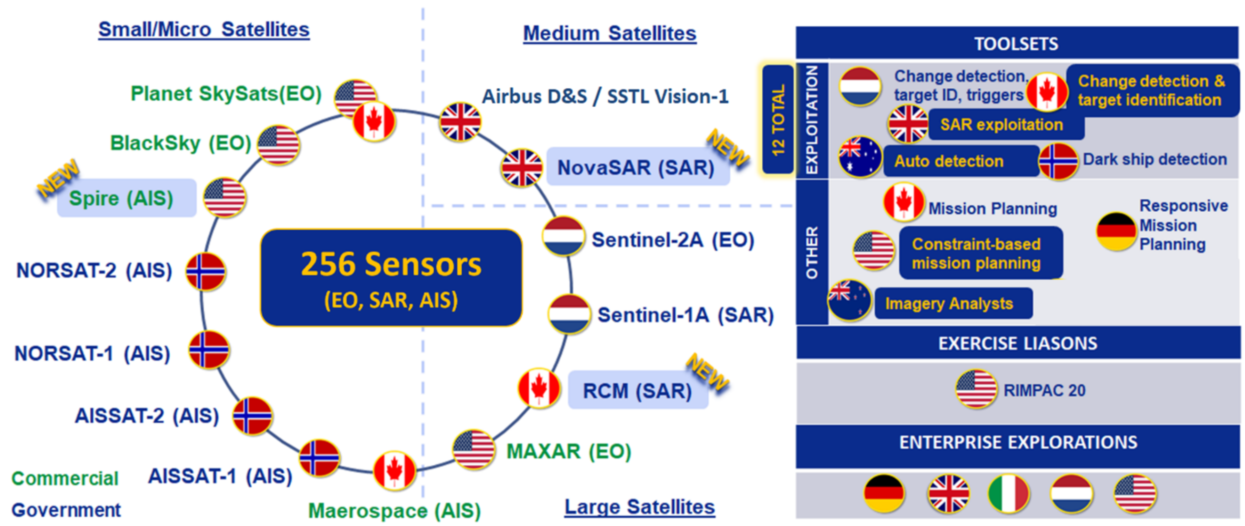

Figure 2: MSMU Contributions for RIMPAC 2020

Figure 3 illustrates the simplified execution process as based on a modified version of the Intelligence Requirements Management and Collection Management (IRM&CM) process used by NATO and which has become the cornerstone for the MSMU PA experimental framework. Being at the center of the Intelligence cycle, the IRM&CM process ensured that the Intelligence Requirements (IR) were answered and the intelligence assets available were focused and prioritized to answer user requests.

The Collection Management (CM) process was based on the NATO TCPED cycle and was therefore based on a 96-hour planning cycle.

The Collection Management Board (CMB) chaired by the MSMU PA designated nation met daily to review and prioritize all received request for information RFIs. The RFIs were then used to generate RFCs. To ensure the execution of each RFC, the CMB discussed the collection opportunities daily and verified the collections could be executed utilizing the Rapid Sensor Contact Assessment Tool (RASCAT), Cognitive Inference Tasking for Satellite Command Coordination and Control (CNTIENT-SPACE), and the Commercial Satellite Imagery Acquisition Planning System (CSIAPS). From here, collection tasks were then forwarded to commercial providers and data was disseminated internally to the MSMU Team and exploiters.

The CMB provided updates and context on the newly submitted RFCs and updates on processed RFCs. The CMB continued to be an effective and necessary activity to synchronize multinational constellation TCPED efforts but there is a continued need for increased automation to reduce required human in the loop.

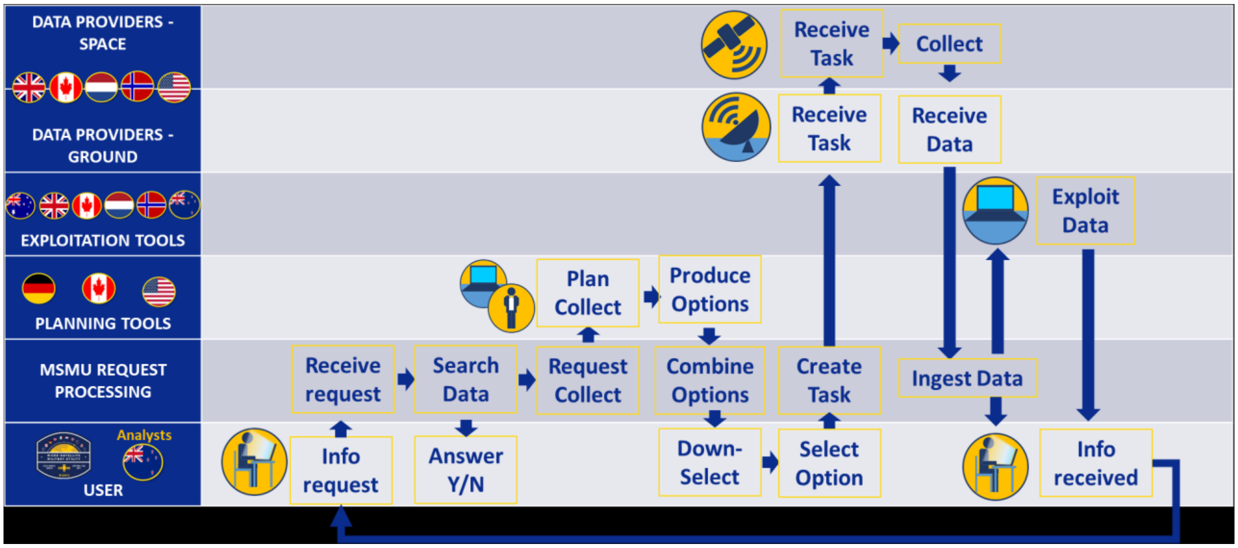

Figure 3: Organization of Participating Nations in terms of TCPED

EXPERIMENTS OBJECTIVES

Hereafter is a summary of the objectives of the MSMU PA experiment at Exercise RIMPAC 2020:

1. Static Target Point/Pattern of Life Vignette:
   Understand the value and capability of MSMU HSA multi-temporal and multi-phenomenology (EO/SAR/AIS) observations and exploitation for automated monitoring of military activities in a defined static target area, including pattern of life determination and anomaly detection and inspection.
2. Monitor Force Buildup/Pattern of Life Vignette:
   Demonstrate how automated site monitoring tools and deep learning can be adapted for detection and classification of aircraft and monitoring airfield activities.
3. Battle Damage Assessment Vignette:
   Examine the capability and utility of MSMU HSA to support a battle damage assessment of a vessel with low latency using high frequency multiple EO, SAR, and AIS collections.
4. Rendezvous/Dynamic Bounded Target Vignette:
   Understand the value of using AIS data for real-time anomaly detection, including automated detection of close interactions, in order to cue collection by high resolution imaging capabilities to determine activity.
5. Dynamic Trajectory Target Vignette:
   Understand the value of multi-int pervasive collection to aid in anomaly detection.
6. Dynamic Trajectory Target/Track Custody of Fleet Vignette:
   Examine the ability of the HSA to track and maintain custody of fleet of ships while in transit from California to Hawaii.
7. Detect and Track uncooperative Dark Vessel Vignette:
   Understand the value of systematic multi-temporal and multi-phenomenology observations and exploitation for automated detection of dark ships and the potential tipping and cross cueing of dynamic collection assets to identify and track the target.
8. TCPED Process and Metrics:
   Examine the RFI/RFC and TCPED processes associated with the fundamental MSMU core processes as they relate to and support Analysis Objectives 1-7.

AGGREGATED RESULTS

Objective 1 – Static Target Point/Pattern of Life Vignette

Overall Results: fully realized, successful semi-automated mission planning, consistent daily and sub-daily collections of Pearl Harbor and MCBH Kaneohe Bay across multiple phenomenologies, resulting in semi-automated generation of exploitation products.

A representative subset of the data collected in support of the objective is reported in Figure 4 to 6. Satellites differ in size, phenomenology, provider.

An example of Situation Update Report describing the number of detected ships compared to the derived trend from the year before is reported in Figure 7.

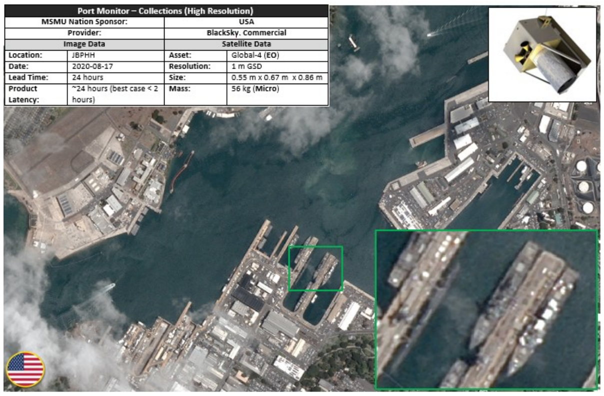

Figure 4: Commercial satellite (BlackSky, microsat) - Port Monitoring (EO)

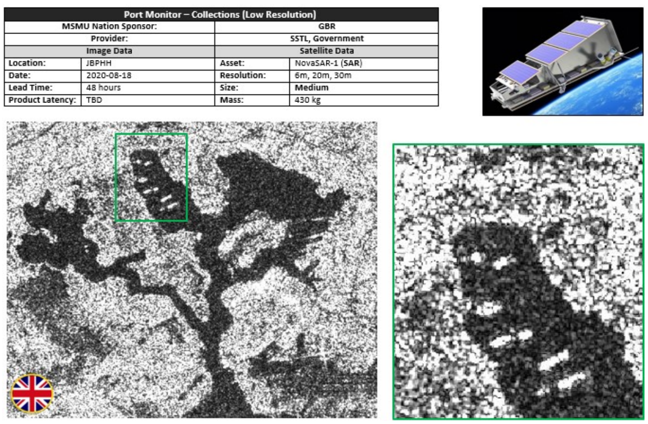

Figure 5: Commercial satellite (NovaSAR-1, medium class satellite) - Port Monitoring (SAR). Image credits: SSTL

Figure 6: European Commission satellite (Sentinel 2, large class satellite) - Port Monitoring (EO)

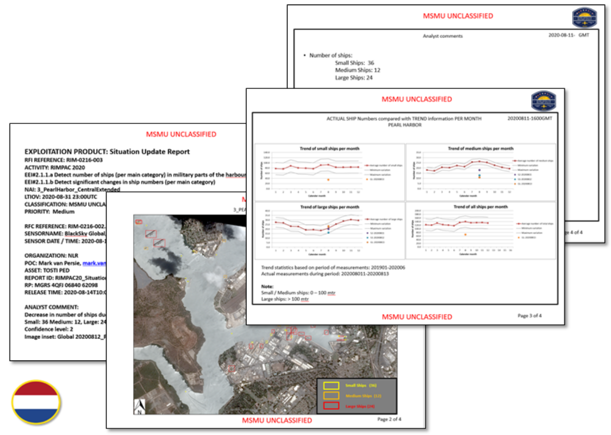

Figure 7: Example of Situation Update Report

Objective 2 – Monitor Force Buildup/Pattern of Life

Overall Results: Realized, successful semi-automated mission planning, consistent daily and sub-daily collections of Pearl Harbor and MCBH Kaneohe Bay across multiple phenomenologies, resulting in semi-automated exploitation. More development is needed for automated detection of specific behavior and more complex events.

Figure 8 shows a representative data collected in support of the objective. Figure 9 shows the New Zealand Geospatial Intelligence Analyst (GIA) product, providing an ORBAT assessment of the V-22 Ospreys stationed at Kaneohe Bay. In a detail a V-22 has been assessed to be placed under heavy maintenance as it is in a stowage configuration with its engines removed. This product highlights the value of the analyst to provide a deeper level insight.

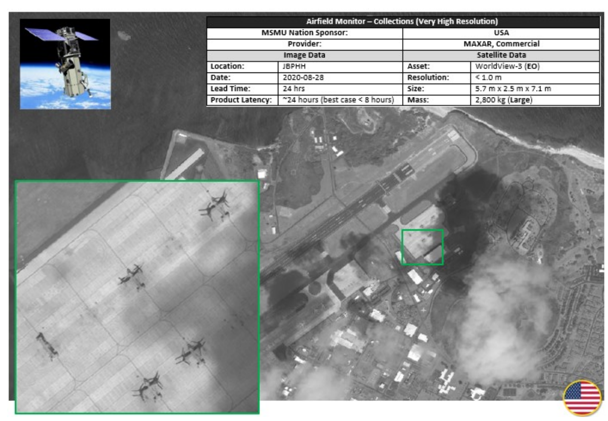

Figure 8: Commercial satellite (MAXAR, large class satellite) - Airfield Monitoring (EO)

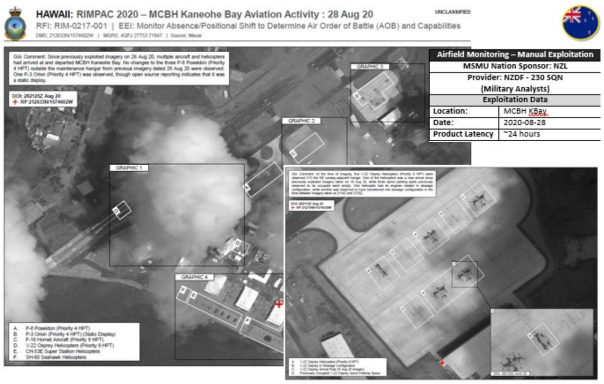

Figure 9: Military Analysts (NZDF) data for Airfield Monitoring

Figure 10 shows an automated exploitation on an EO composite imagery of Hickam Airbase from the MAXAR provider collected on August 27, 2020. The ADSS automated exploitation tool was used to detect the number of aircraft in the AOI from MAXAR imagery [RD3]. ADSS automatically successfully identified aircraft detections with confidence of 0.1 or higher, producing a human-readable PDF report of most confident (up to 50) detections as well as all detections in GeoJSON format, which could then tip the analyst when viewed on top of imagery using GIS software. The detector operating threshold was set low in order to have high Probability of Detection, at the expense of higher false alarm rate (e.g. duplicate detections, clutter). Exploitation was conducted automatically from the AUS ADSS system (in less than ~3 hours).

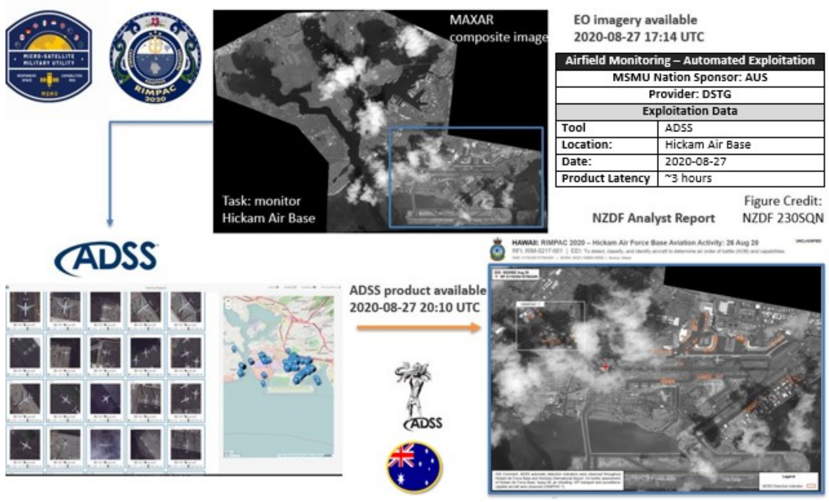

Figure 10: Military Analysts (DSTG) data for Airfield Monitoring

Objective 3 – Battle Damage Assessment (BDA)

Overall Results: Not realized, limited collection opportunities for the short duration of the planned SINKEX event, in combination with real-time execution which differed from the planning information resulted in limited collection of open water without expected maritime activity.

Figure 11 illustrates two pictures expecting to report the target vessel location in the center of the image, but the vessel drifted out of the frame due to exercise execution deviations from the previous plan, thus not captured.

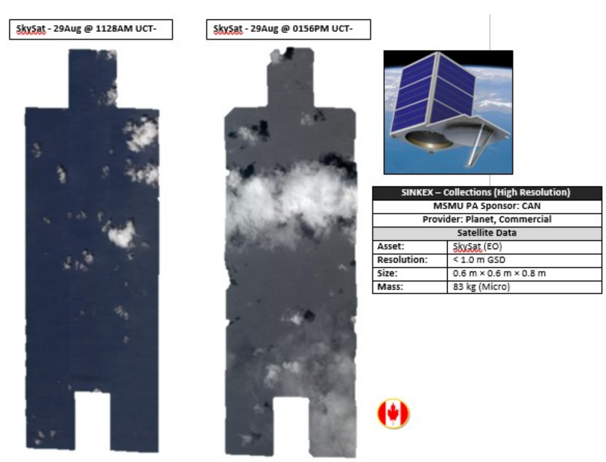

Figure 2: Commercial satellite (Planet, microsat) picture for BDA (EO asset)

Objectives 4 – Rendezvous/Dynamic Bounded Target

Overall Results: Partially realized, successful collection of AIS data likely including rendezvousing ships. Automated exploitation techniques (e.g. Anomaly Detection using Bayesian Networks – ADBN in the Processing & Exploitation section [RD02]) were developed to determine track summary models of rendezvousing ships, however, exploitation techniques will need to be developed to verify rendezvous events with Truth data (Schedule of Events). We could not collect EO or SAR on rendezvous events due to limited collection opportunities in the specified windows as well as large collection areas.

Objective 5 – Dynamic Trajectory Target

Overall Results: Realized, excellent collection of AIS data. A SAR image of the target was collected, but limited collection opportunities for the specified time window prevented successful EO collection.

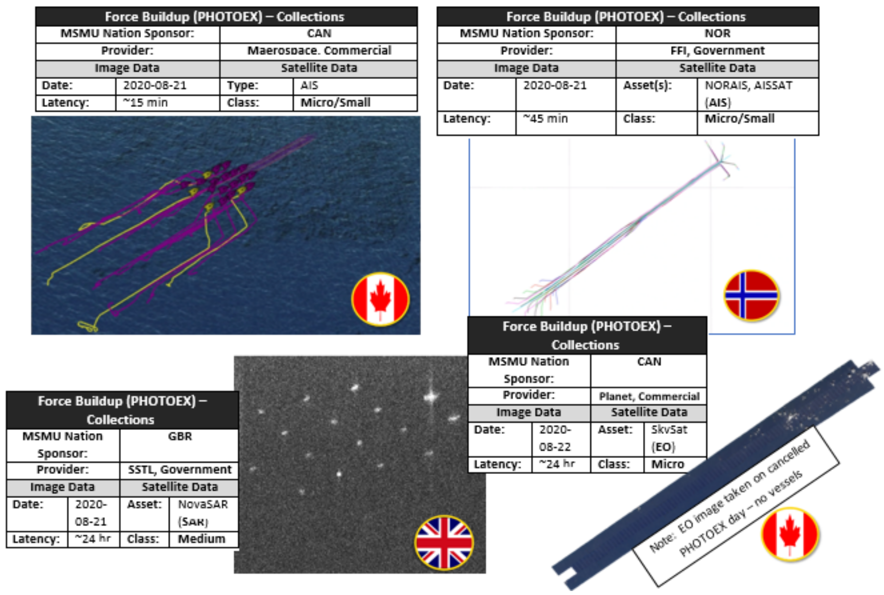

Figure 12: Images collected for Dynamic Trajectory Tracking. NovaSAR image credits: SSTL

Objective 6 – Dynamic Trajectory Target/Track Custody of Fleet

Overall Results: N/A – Event did not occur due to down-scoping as a result of COVID-19 impacts.

Objective 7 – Detect and Track uncooperative Dark Vessel

Overall Results: Partially Realized: The USNS Sioux towing the EX-Durham to its SINKEX location was used as the uncooperative Dark vessel scenario. A dynamic tasking on the tow ship using AIS detections to determine planned trajectory was attempted. Based on the ship location, prediction using AIS tracking was conducted 12 hours in advance of a Planet SkySat collection opportunity.

Objective 8 – TCPED Process and Metrics

Overall Results: Realized. There were some challenges experienced with regards to data discovery due to the large amount of data collected during the exercise. Manual processes significantly influenced the timeliness of metrics captured. Semi-automated mission planning significantly reduced the time to plan collections.

Table 1 illustrates a snapshot of the RFIs which comprised the various objectives of the experiment. The collection opportunities (CO)s were automatically generated when the RFC was published. Tasks were created by the user and products are either raw data or exploitation data. Note: Planet SkySat data is not included in any metric due to data releasability issues.

Table 1: Snapshot of Data by Type and RFI produced on August 5

RFI ID	RFI Name	Num COs	Num RFCs	Num Tasks	Num Products
_NO_RFI_	_NO_RFI_	-	-	-	8395
GLU-0223-001	Coalition Service Support Readiness Level	55	11	8	11
GLU-0223-002	Track Custody of Fleet	118	13	20	300
GLU-0224-006	Current Maritime Situation (WASEX)	285	4	-	8
RIM-0216-002	Vign_HarbMon_01	1227	51	20	326
RIM-0217-001	Airfield Monitoring	616	46	65	144
RIM-0217-004	Activities of Non-Participating Vessels	596	2	-	10
RIM-0218-001	Naval Task Force Collection	82	16	9	34
RIM-0218-002	Battle Damage Assessment - SINKEX	10	2	8	5
All		**2989**	**145**	**130**	**9233**

Table 2 illustrates a snapshot of the various datatypes collected (note: 1 product = one collection, a single collection may be represented in more than 1 product).

Note: Planet SkySat data is not included in any of the metric data due to data releasability issues.

Table 2: Collection Files/Products Per Provider w/ Sensor Type produced on August 5

Provider Name	Sensor Type	AIS	EO	SAR	All
	BlackSky	-	42	-	42
	DRDC-RDDC	7881	-	-	7881
	MAXAR	-	65	-	65
	NORAIS	444	-	-	444
	R-NLR	-	19	17	36
	SSTL	1	-	2	3
	All	**8326**	**126**	**19**	**8471**

Table 3 illustrates an example of some of the data inconsistencies resulting from manual operation of the system. Task categories were not consistently used or accurately reflected for all collections.

The majority of data was collected without an accompanying RFI (AIS data from Canada). Efforts were also focused on the first two objectives, or data was only successfully collected and uploaded for the first two objectives, see Table 4.

The MSMU HSA had consistent collections throughout the exercise. This consisted of tasked sensors (EO, SAR) as well as untasked data sources (AIS)

Table 3: Tasks by Status and RFI produced on August 5

		Task Status								
RFI ID	RFI Name	Accepted	Cancelled	Completed	Failed	New	Provider Received	Rejected	Uplinked	All
GLU-0223-001	Coalition Service Support Readiness Level	-	-	-	-	7	1	-	-	8
GLU-0223-002	Track Custody of Fleet	-	1	5	3	4	2	5	-	20
RIM-0216-002	Vign_HarbMon_01	-	-	4	3	-	11	2	-	20
RIM-0217-001	Airfield Monitoring	-	2	15	7	11	19	10	1	65
RIM-0218-001	Naval Task Force Collection	-	-	2	-	-	7	-	-	9
RIM-0218-002	Battle Damage Assessment - SINKEX	1	-	-	-	-	6	-	-	7
All		**1**	**3**	**26**	**13**	**22**	**46**	**17**	**1**	**129**

Table 4: Products by Provider and RFI produced on August 5

providerName	BlackSky	CNTIEN T-SPACE	DRDC-RDDC	DST Group	FFI	MAXAR	NORAIS	NZDF - 230 SQN	R-NLR	RASCAT	SDL	SSTL	All
rfiId													
GLU-0223-001	2	4	-	-	-	-	-	-	-	4	-	1	11
GLU-0223-002	10	12	-	250	1	21	-	-	-	5	-	1	300
GLU-0224-006	-	6	-	-	-	-	-	-	-	2	-	-	8
RIM-0216-002	12	95	-	54	-	17	-	4	36	107	-	1	326
RIM-0217-001	16	32	-	40	-	22	-	9	-	24	-	1	144
RIM-0217-004	-	4	-	-	-	-	-	-	-	6	-	-	10
RIM-0218-001	3	14	-	3	-	1	-	-	-	13	-	-	34
RIM-0218-002	-	2	-	-	-	-	-	-	-	3	-	-	5
_NO_RFI_	-	-	7889	8	1	4	444	4	2	-	8	35	8395
All	**43**	**169**	**7889**	**355**	**2**	**65**	**444**	**17**	**38**	**164**	**8**	**39**	**9233**

The majority of the products were from raw collected AIS data. Exploitation was received primarily from the AUS ADSS system with an end-to-end latency ~3 hours. Processing took place locally at DSTG, rather than where imagery resided. ADSS exploitation product latency ranged 1-3 hours during stable operation, including the imagery download.

CONCLUSIONS

The HSA was designed to accommodate a large sensor diversity amongst participating nations assets, thereby maximizing their utility. MSMU's HSA's research continues to improve capability development and increase partner nations interoperability. The level of interoperability accomplished via the MSMU-constructed HSA during Exercise RIMPAC 2020 was adequate to facilitate fully remote support to despite COVID-19 impacts. This year's results, including analyst tipping by fully automated exploitation results, demonstrates the potential impact of solutions that enhance the utility of the HSA, ultimately to address the warfighters need to vastly increase ISR sources using both commercial and government assets across allied nations.

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