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SOUTH CHINA SEA MILITARY CAPABILITY SERIES

A Survey of Technologies and Capabilities on China's Military Outposts in the South China Sea

ELECTRONIC WARFARE AND SIGNALS INTELLIGENCE

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Introduction

This military capability (MILCAP) study focuses on electronic warfare (EW) and signals intelligence capabilities on seven Chinese island-reef outposts in the South China Sea (SCS). These SCS MILCAP studies provide a survey of military technologies and systems on Chinese-claimed island-reefs in the Spratly Islands, approximately 1,300 kilometers (700 nautical miles) south of Hong Kong (see Figure 1). These Chinese outposts have become significant People's Liberation Army (PLA) bases that will enhance future Chinese military operations in the SCS, an area where Beijing has disputed territorial claims (see Appendix B). The SCS MILCAP series highlights a PLA informationized warfare strategy to gain and maintain information control in a military conflict.

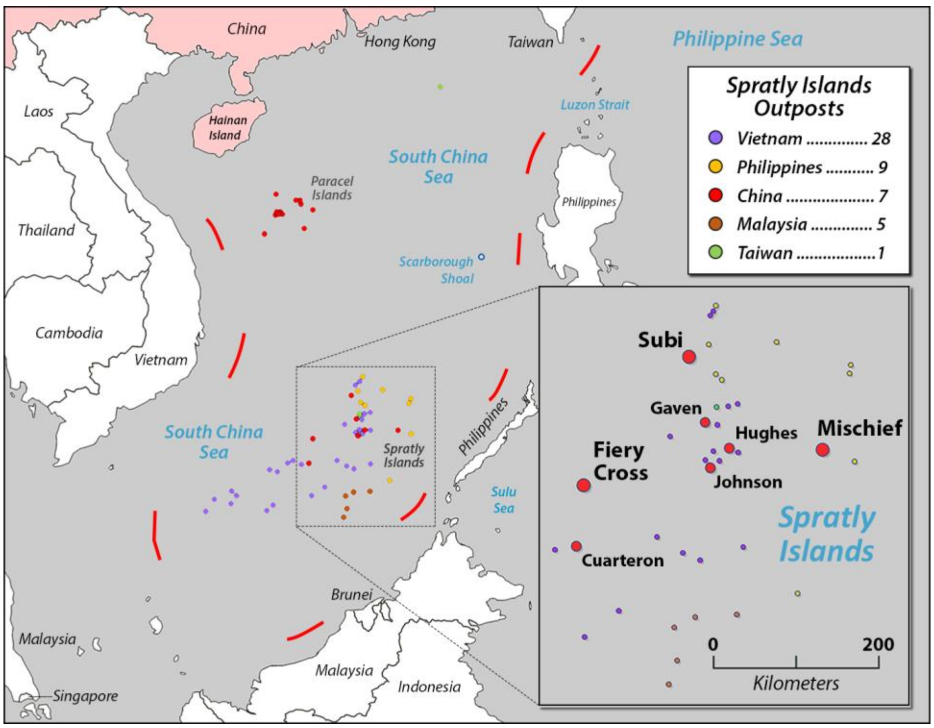

Figure 1. SCS Occupied Features

EW systems noted on Chinese-held island-reefs appear to be diverse and redundant, probably covering a broad swath of the electromagnetic spectrum. In addition to mobile ground-based EW systems, the PLA established a number of fixed signals intelligence facilities that include a high-frequency-direction-finding (HFDF) site and a likely site to monitor foreign satellite communications. EW aircraft with active jamming and passive signals collection capabilities will also contribute significantly to PLA efforts to manipulate and control the electromagnetic spectrum. Overview graphics of all capabilities noted on major outposts appear in Appendix C.

PLA Electronic Warfare Capabilities

Significant EW capabilities operate on or from the PLA's SCS island-reef bases. The PLA dedicated substantial effort to developing EW systems, controlling the electromagnetic spectrum, and operating in what the Chinese call a "complex electromagnetic environment (CEME)." PLA information-centric strategies reflect a major focus on CEME operations and controlling the electromagnetic spectrum using a range of electronic attack and signals intelligence (SIGINT) capabilities. Since the early 2000s, the PLA has pursued operational concepts centered on integrated network electronic warfare (INEW) that combines EW and cyber capabilities.[1] Chinese military computer hackers and cyber capabilities generated headlines around the world. However, at the operational level of war, the PLA's overarching focus on EW is vastly under-appreciated by many Western military analysts.

The PLA's overarching training guidance, the "Outline of Military Training and Evaluation (OMTE)," first directed a force-wide focus on CEME operations in 2001.[2] In a 2006 speech, Hu Jintao, then Chinese president and chairman of the Central Military Commission, observed, "information dominance is, in effect, electromagnetic dominance."[3] In 2008, the military commission issued "Opinions on Further Promoting the Transformation of Training under Informationized Conditions," which set a course for EW capability development and CEME training through 2020.[4] China's 2015 Military Strategy directed the PLA to "intensify training in complex electromagnetic environments."[5]

The Strategic Support Force (SSF) is responsible for management of INEW capabilities across the PLA. Created in December 2015, the SSF is a service-level organization with an institutional status similar to the PLA Air Force or Navy. The SSF

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[1] This study focuses on observable EW-related infrastructure in the SCS. Cyber effects that might otherwise be generated from the Chinese island-reefs are not subject to external observation. However, one would expect that because of the island-reefs' remote location, computer network operations would necessarily be initiated from the Chinese mainland, even if integrated with EW effects in the SCS.

[2] Bernard Cole, "China's Navy Prepared: Domestic Exercises, 2000–2010,"in *Learning by Doing, the PLA Trains at Home and Abroad*, ed. Roy Kamphausen, David Lai, and Travis Tanner (Carlisle, PA: US Army War College Press, 2012), 25–26.

[3] Zong Xun, "努力推动军事训练又好又快发展" [Strive to Promote the Good and Rapid Development of Military Training], *解放军报 [People's Liberation Army Daily]*, December 12, 2006, 6.

[4] Leng Feng, *Toward the Transformation of PLA Military Training under Conditions of Informationization* (Stockholm: Institute for Security and Development Policy, 2014), 23, 13, https://www.isdp.eu/content/uploads/images/stories/isdp-main-pdf/2014-leng-feng-toward-the-transformation-of-PLA-military-training.pdf.

[5] China Ministry of National Defense, 中国的军事战略 [China's Military Strategy]; see section V, "Preparation for Military Struggle," http://www.mod.gov.cn/regulatory/2015-05/26/content_4617812_6.htm.

brought military space, cyber, and EW capabilities under unified management. Assessments of the SSF often focus on space and cyber capabilities that align with Western military priorities and institutions (i.e., US Cyber Command and US Space Force). The SSF's substantial EW capabilities may be overlooked because there is no analogous EW institution in most Western militaries.[6]

The SSF, the military services, and probably each of the PLA's geographic theaters organize cyber and EW capabilities into technical reconnaissance bureaus (TRBs) responsible for SIGINT collection, as well as computer network operations.[7] Southern Theater command SSF forces are likely deployed to the SCS outposts alongside PLA Navy EW personnel.

Mobile Ground-Based Electronic Warfare Systems

Ground-based EW vehicles have been noted in commercial satellite imagery at locations on Subi and Mischief Reefs (see Figure 2). Observed truck-mounted systems are probably either electronic attack (i.e., jamming) or electronic intelligence (ELINT) collection vehicles. Satellite imagery resolution and camouflage netting on the deployed systems precludes a more detailed assessment.

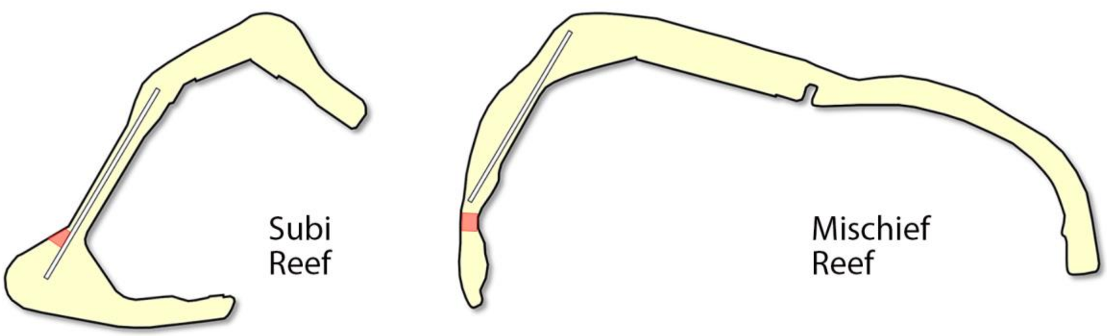

Figure 2. Locations of Prepared EW Sites on Subi and Mischief Reefs

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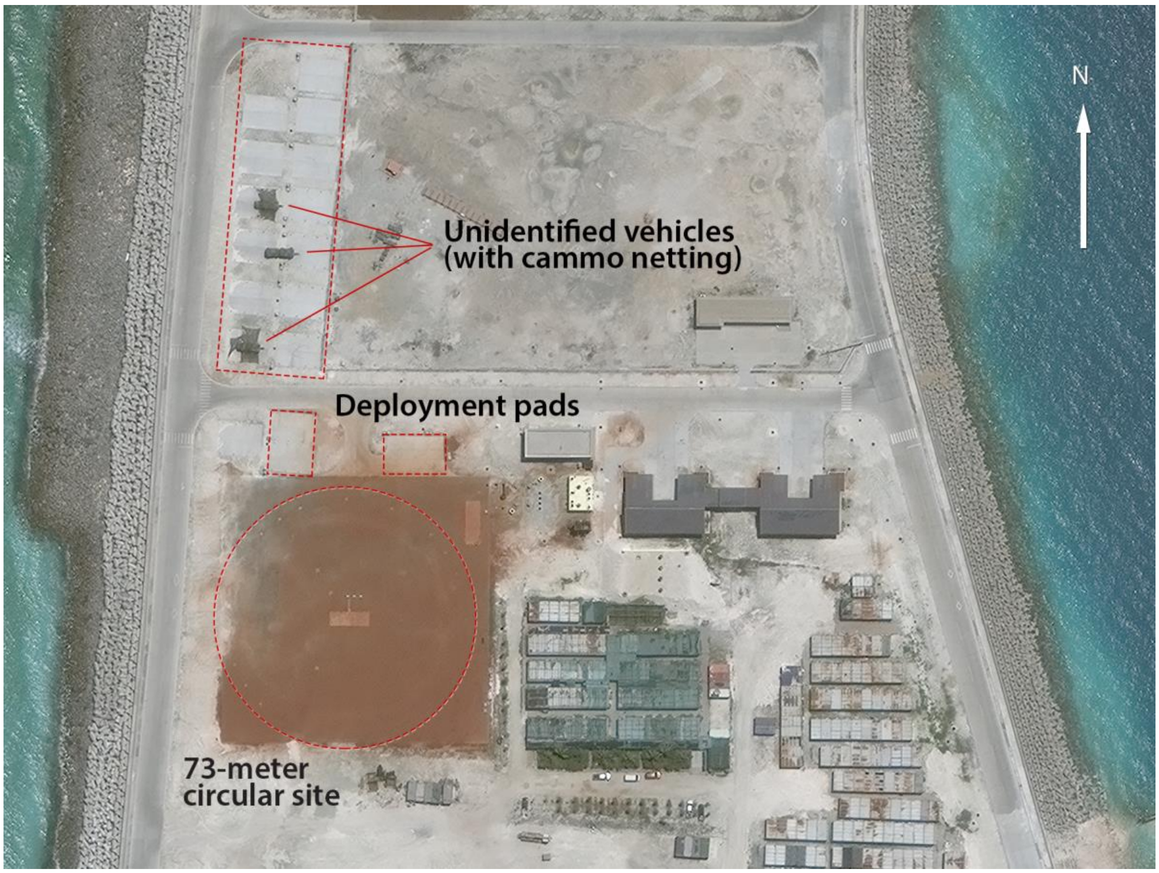
[6] For an excellent overview of the SSF, see Elsa B. Kania and John Costello, "Seizing the Commanding Heights: The PLA Strategic Support Force in Chinese Military Power," *Journal of Strategic Studies*, May 12, 2020, https://doi.org/10.1080/01402390.2020.1747444.

[7] In December 2015, the SSF assumed control of operational bureaus from 3PLA (computer network operations and electronic intelligence) and 4PLA (electronic attack and radar). For a pre-2016 analysis of PLA technical reconnaissance bureaus and electronic warfare regiments, see Mark Stokes, Jenny Lin, and Russell Hsiao, *The Chinese People's Liberation Army Signals Intelligence and Cyber Reconnaissance Infrastructure* (Washington, DC: Project 2049 Institute, 2011), 15, 31.

Electronic Warfare and Signals Intelligence

In early 2018, news articles citing unnamed US intelligence and Department of Defense officials indicated that PLA EW equipment was deployed to Fiery Cross and Mischief Reefs. Reports included commercial satellite imagery that showed possible jamming equipment deployed to the western shore of Mischief Reef.[8] Three purported EW vehicles imaged in April 2018 were still present in June 2018 satellite imagery. The large elevated antenna noted in the April 2018 satellite image was not raised in the June 2018 image (see Figure 3).



(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 3. Likely EW Deployment Site on Mischief Reef

This area on Mischief Reef appears to be a deployment area for road-mobile systems. Publicly available commercial satellite imagery, accessible through platforms like Google Earth, shows different numbers of vehicles occupying the site over time. The site could service any number of mobile systems, including radar or missile systems,

[8] Michael R. Gordon and Jeremy Page, "China Installed Military Jamming Equipment on Spratly Islands, U.S. Says," *Wall Street Journal*, April 9, 2018, https://www.wsj.com/articles/china-installed-military-jamming-equipment-on-spratly-islands-u-s-says-1523266320.

but the relatively isolated location makes it ideal for collecting discrete electromagnetic signals or generating electromagnetic interference. The area consists of several concrete pads to accommodate truck-size vehicles. Operating from a fixed location might seem to undermine the protection from attack afforded by mobile systems. These EW systems would certainly relocate elsewhere on the PLA outposts during a conflict. In routine operations, however, the pads offer a prepared site for extended operations and may provide island-reef generated electrical power, eliminating the need for generators. The prepared sites also probably offer communications connections (e.g., fiber-optic cable), eliminating the need for wireless transmissions to coordinate EW activities on or among the Chinese outposts.

The Mischief deployment site includes what appears to be a ring of anchor points or posts set 36.5 meters (120 feet) from a center pad. The function is unknown, but if the circle of dots are antennae, they might be used for calibration of EW equipment or serve a purpose related to signal direction finding. There is an identical 73-meter circular site at a similar deployment site on Subi Reef. The Subi Reef site does not have as many concrete pads as that on Mischief Reef. A probable EW vehicle covered with camouflage netting occupied one of the pads in June 2018 (see Figure 4).

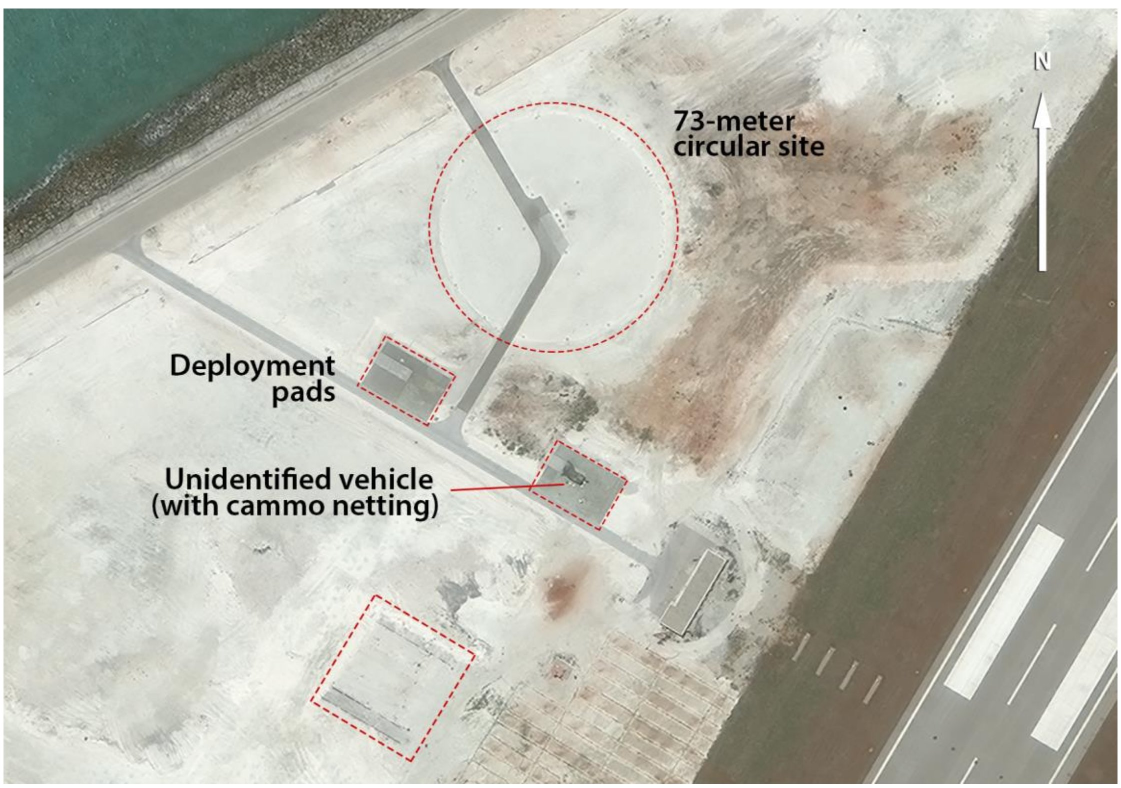


Figure 4. Likely EW Deployment Site on Mischief Reef

US media reports from early 2018 indicated that PLA EW equipment was also deployed to Fiery Cross Reef. However, no candidate vehicles that might be EW equipment were identified in June 2018 satellite imagery. No 73-meter circular site was noted on Fiery Cross Reef, nor was there a deployment area with concrete pads similar to those on the much larger Mischief and Subi Reefs. If EW vehicles were deployed to Fiery Cross Reef as reported in early 2018, the equipment could have been set up at any relatively isolated location on the island-reef to mitigate the effects of electromagnetic interference with other systems.

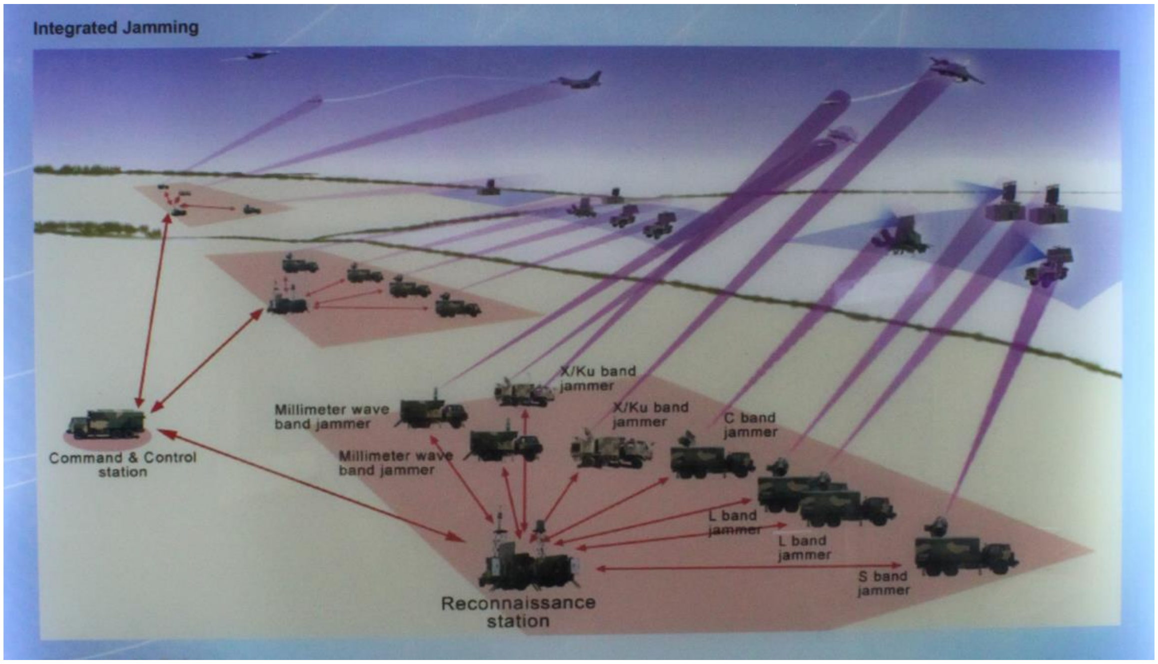
Whether at fixed, prepared sites or temporary locations elsewhere on the outposts, deploying mobile equipment to the SCS outposts allows the PLA to mix and match capabilities as necessary. Depending on the electronic attack, SIGINT, or other capabilities required to achieve a particular objective or counter a particular adversary threat, the PLA could rapidly deploy road-mobile equipment from hidden sites, such as garages or hangars on the outposts, or quickly deliver the systems to the island-reefs by ship or aircraft. This deployment capability may serve to keep an advancing adversary off balance, unable to anticipate and effectively counter the EW or intelligence, surveillance, and reconnaissance (ISR) capabilities dispatched to the Chinese outposts. For additional information on concealment and deception, see the SCS MILCAP study, "Hardened Infrastructure, Battlespace Environmental Management and Counter-Reconnaissance."

Given publicly known information about PLA combat systems such as ships, aircraft, and missiles, comparatively little is known about PLA EW equipment, especially ground-based EW systems. EW equipment only rarely appears in Chinese military parades and even then is only identified generically as "a new type of radar jamming vehicle" or "a new type of communication jamming vehicle."[9]

The PLA probably covers most of the electromagnetic spectrum with a range of EW equipment for detection and jamming. This is consistent with the PLA's approach to radar and communications diversity on the island-reefs, laying claim to a wide swath of the frequency spectrum. The state-owned China Electronics Technology Group Corporation (CETC) displayed a graphic at a recent arms exhibition showing the notional composition of ground-based electronic confrontation units (i.e., electronic countermeasures regiments). While this graphic is generic, it depicts an EW command and control vehicle communicating with EW reconnaissance stations that feed information to individual specialized jammers, each covering a different part of

[9] Mei Changwei, Fan Yongqiang, Chen Yu, Mei Shixiong, Wang Yushan, Li Bingfeng, Wang Jingguo, Chen Yu, Wang Xiang, and Zhang Wei, "9个作战群,空地一体受阅" [9 Operations Groups, Surface-to-Air Missiles All Receive Inspection], 新华每日电讯5版 [*Xinhua Daily Telegraph* 5th Edition], July 31 2017, http://www.xinhuanet.com//mrdx/2017-07/31/c_136487232.htm.

the electromagnetic spectrum. Individual jammers are shown creating interference in the millimeter-wave band, X/Ku-band, C-band, L-band, and S-band in support of an air defense mission (see Figure 5).



(JHU/APL Photo/CETC)

Figure 5. Chinese CETC Graphic Depicting EW Group Equipment

Determining the effective range of a ground-based, ship-based, or airborne electronic attack capabilities is a complicated endeavor. Jamming effectiveness necessarily involves the interaction between friendly and enemy electronic systems; radiated power, range, and geometry. Barrage or noise jamming overwhelms an antenna trying to receive communications signals or radar reflections. Ground-based systems or large aircraft that can generate high-power jamming signals may be used in noise jamming roles. Deceptive jammers that mimic or modify signals have much lower power requirements and may be employed in self-protect jammers or on smaller platforms such as unmanned aerial vehicles (UAVs). In any case, placing ground-based or airborne collection systems and jammers in the center of the SCS significantly enhances PLA EW capabilities that might otherwise be limited to shipborne EW systems. With the exception of high-frequency (HF) waves that travel over-the-horizon, higher frequency jamming or signal collection is limited to line of site. Line-of-sight ranges from ground-based EW systems are shown in Figure 6. These ranges will ultimately be limited by factors such as radiated power and geometry between the jammer and target.

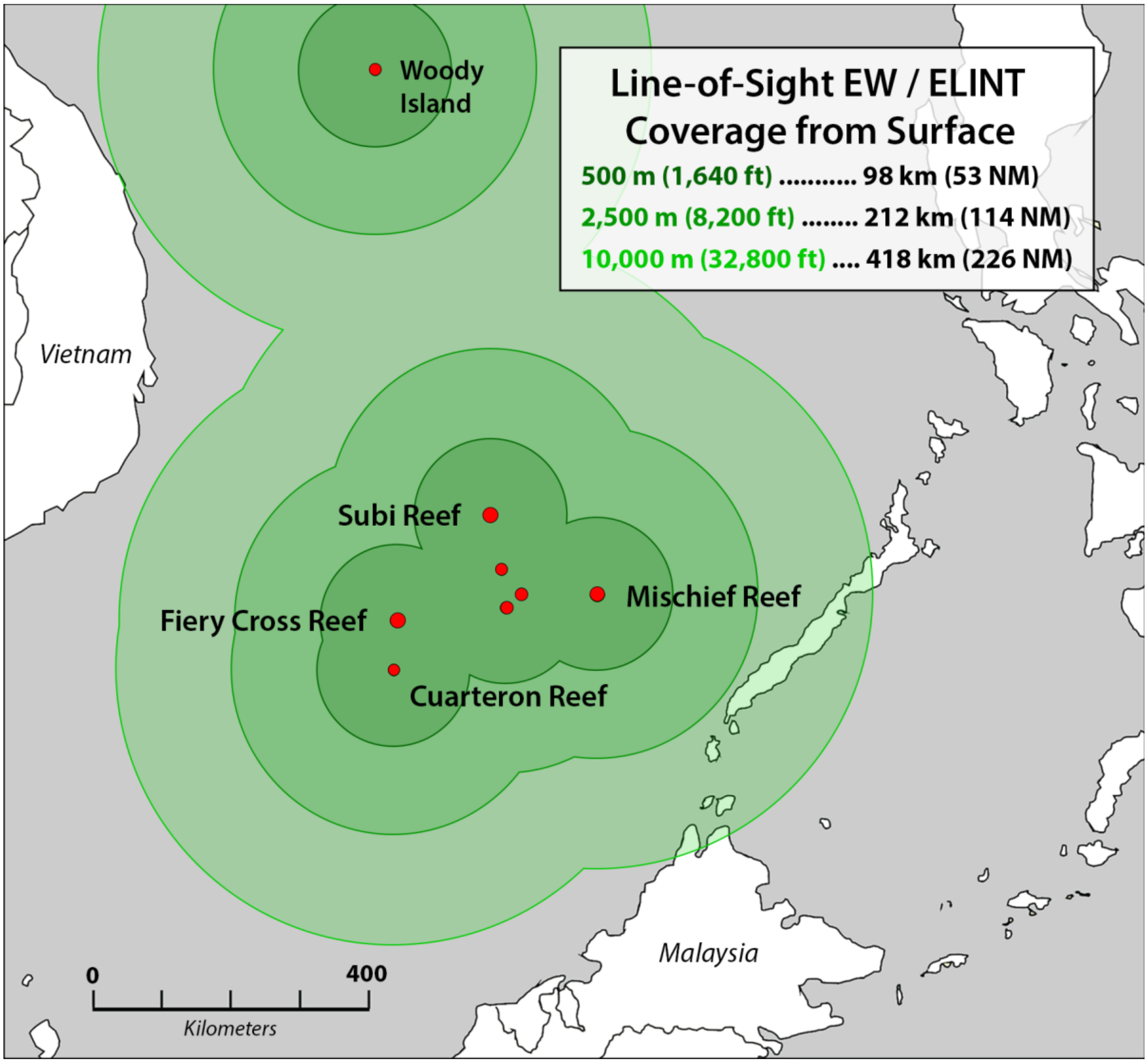


Figure 6. Line-of-Site EW / ELINT Coverage

Fixed Signals Intelligence Sites

Using only commercial satellite imagery to differentiate between communications arrays and signals intelligence collection arrays is inherently difficult. Practically any antenna capable of receiving a transmission could also be used to monitor foreign signals of interest. For example, large HF communications arrays, identified in the SCS MILCAP study "High-Frequency Communications," could be used for communications intelligence (COMINT), a category of signals intelligence that monitors communications "internals," the content of a transmission.

ELINT sites capture signal "externals" and serve to detect, identify, and geolocate signals of interest. Generally, ELINT capabilities focus on radar signals, but may also include identifying and locating communications transmissions even if signal contents are indecipherable or encrypted. There are certainly a variety of ELINT sites on each of the Chinese-held island-reefs. These are difficult to identify and could appear as innocuous as a single antenna. However, several large arrays have been identified through commercial satellite imagery, including a possible satellite communications (SATCOM) surveillance site, an HFDF site, and a suspected ELINT array consisting of two pairs of identical radomes (see Figure 7).

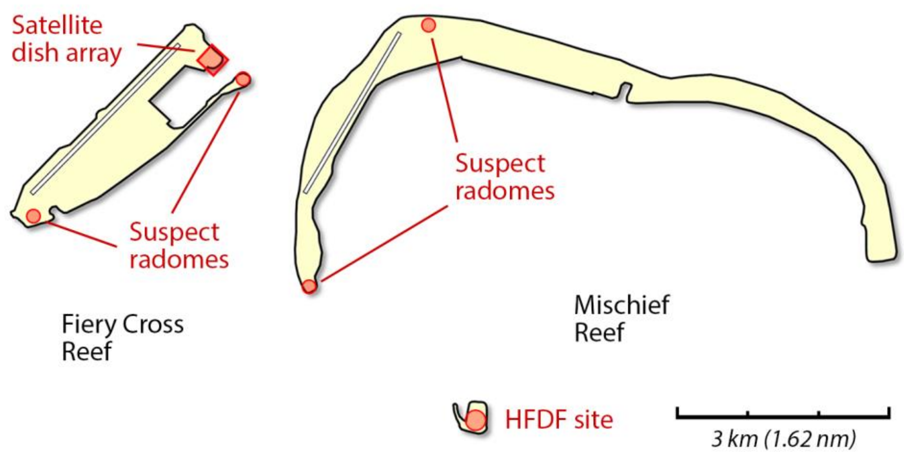


Figure 7. Locations of Fixed Signals Intelligence Sites on Fiery Cross and Mischief Reefs

SATCOM Surveillance and Geolocation

The set of eleven radomes on the northern end of Fiery Cross Reef may be able to monitor or geolocate foreign SATCOM transmissions. As discussed in the companion SCS MILCAP study, "Undersea Fiber-Optic Cable and Satellite Communications," the seven-radome SATCOM set grayed-out in Figure 8 is common to each major island-reef and is probably the SATCOM gateway for each major outpost. The function of the remaining eleven radomes unique to Fiery Cross Reef is unknown. It may simply represent greater SATCOM capacity. Fiery Cross Reef is a civil-military command and control node and likely has a higher military status than the other outposts. In April 2020, the Chinese State Council established Fiery Cross Reef as the seat of civilian government for a newly created SCS administrative district (南沙区人民政府).[10]

[10] Sun Shaolong, "国务院批准海南省三沙市设立市辖区" [State Council Approves the Establishment of a Municipal District in Sansha City, Hainan Province], *Xinhua News Agency*, April 18, 2020, www.mod.gov.cn/topnews/2020-04/18/content_4863771.htm

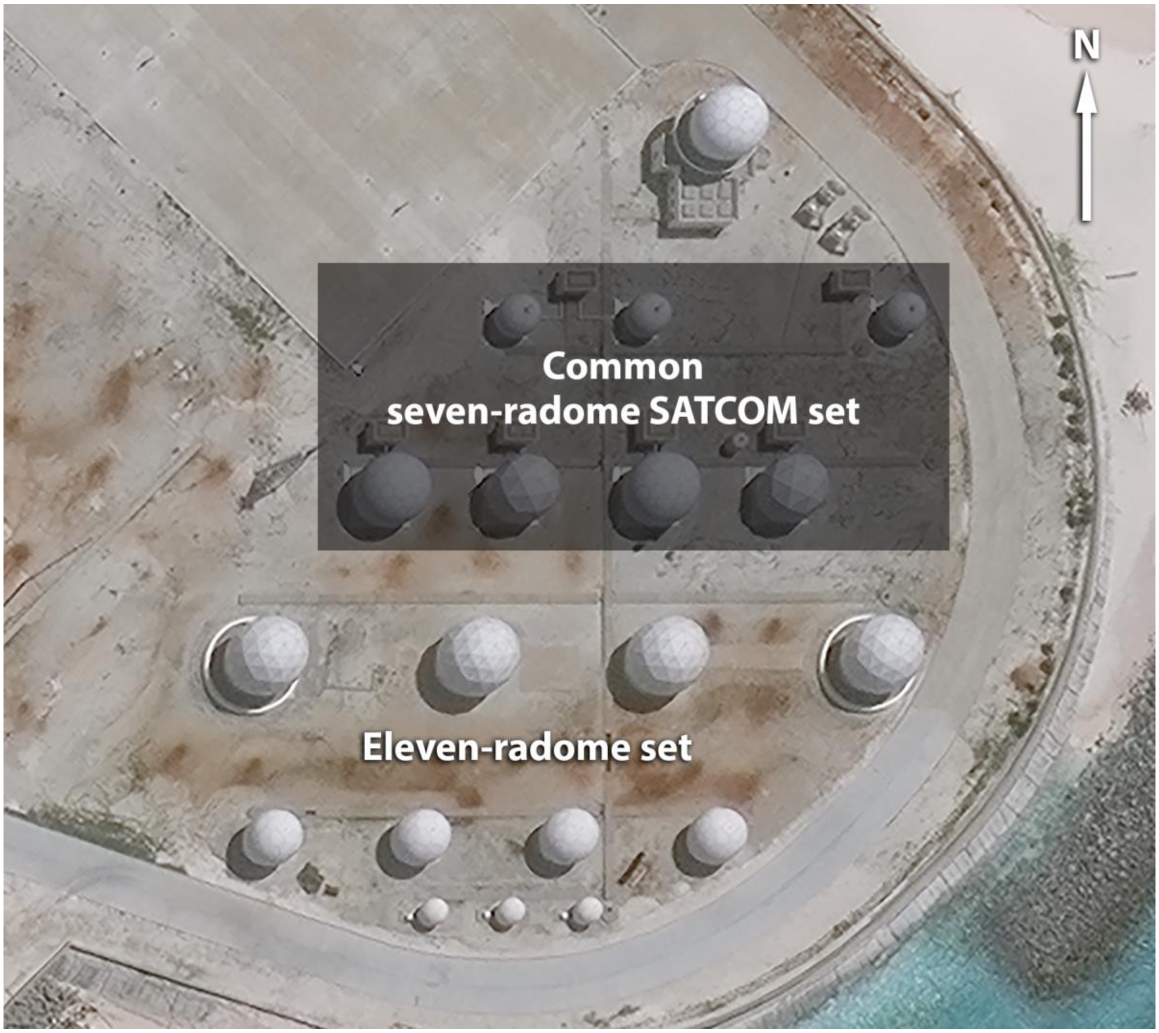


Figure 8. Satellite Dish Radome Array on Fiery Cross Reef

Some or all of the additional eleven satellite dishes could be used to geolocate foreign SATCOM signals using time difference of arrival (TDOA) or frequency difference of arrival (FDOA) techniques.[11] Signals of interest might originate from adversary ships, submarines, aircraft, or unmanned systems. TDOA/FDOA techniques analyze SATCOM uplink signals reflected off one or more geostationary communications satellites. Higher frequency military communications satellites in X- or Ka-band have shapeable beam footprints or spot beams that are used to mitigate threats from

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[11] See, for example, Cao Yalu, Peng Li, Li Jinzhou, Yang Le, and Guo Fucheng, "A New Iterative Algorithm for Geolocating a Known Altitude Target Using TDOA and FDOA Measurements in the Presence of Satellite Location Uncertainty," *Chinese Journal of Aeronautics* 28, no. 5 (September 2015): 1510–1518.

signals intelligence collection or jamming.[12] To counter these beam-shaping techniques, PLA SATCOM signal intercept must occur from a ground station within the footprint of those satellite shape or spot beams. If adversary satellite transponder beams are shaped away from PLA collection sites on the Chinese mainland, a SATCOM collection array on the island-reefs may allow for PLA collection of downlinks or geolocation of uplinks of foreign military SATCOM (see Figure 9).

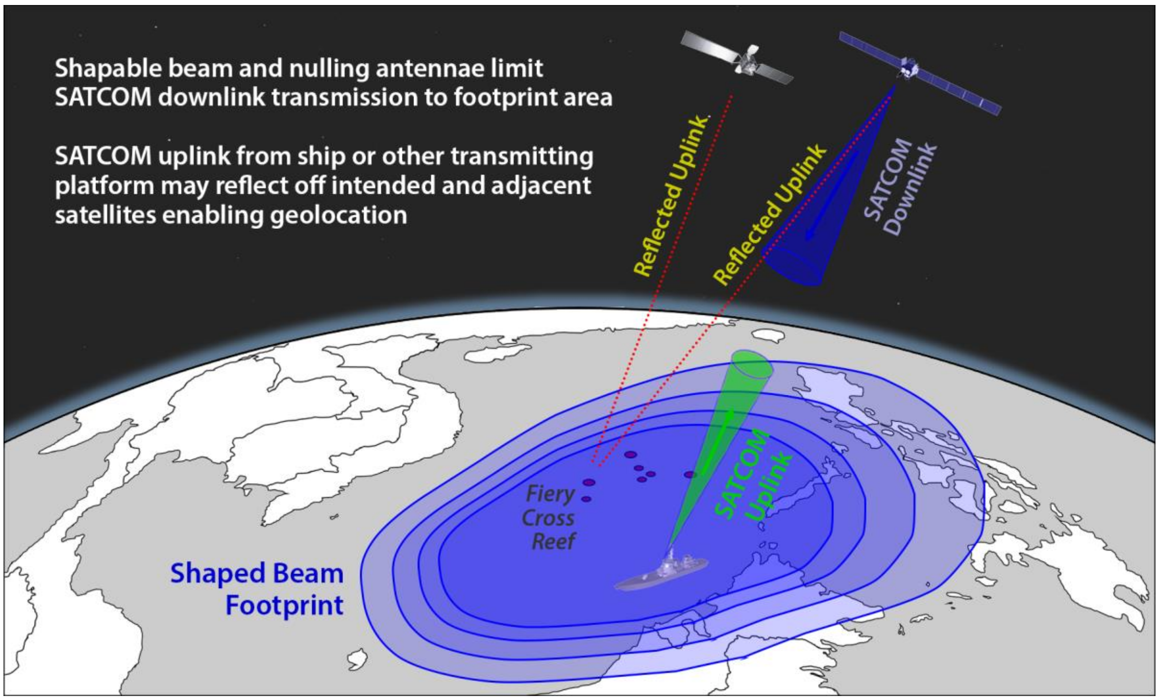


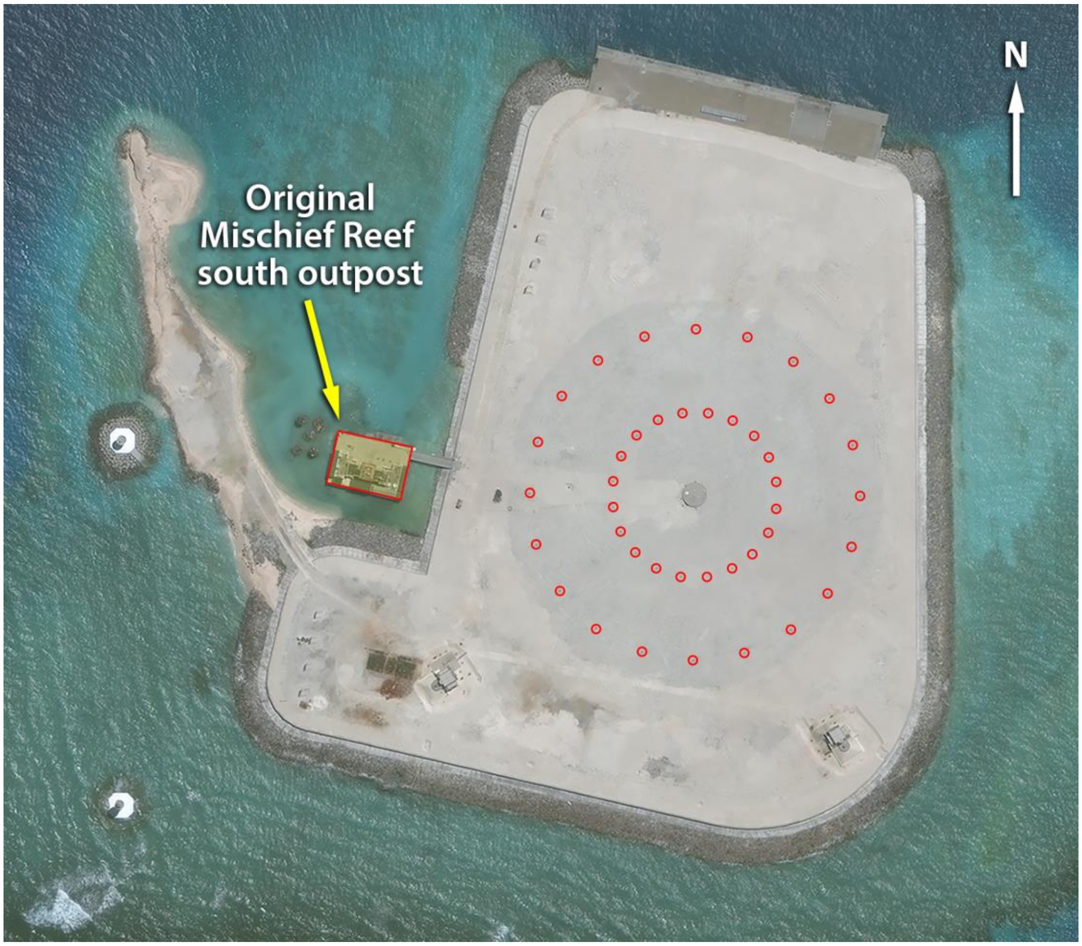
Figure 9. Potential Geolocation of SATCOM Uplinks in the SCS

High-Frequency Direction Finding

An HFDF site takes up most of the artificial islet on the southern end of Mischief Reef. The type of HFDF site on Mischief Reef is commonly referred to as a "Fixed 20-20" because of the twenty internal and twenty external monopole antennae that form the array's two rings (see Figure 10). This array can determine a line of bearing to an HF transmission coming from ships, aircraft, or land-based communications systems. Information from the array is then compared with target lines of bearing from other HFDF sites, in this case, probably on Hainan Island or in mainland China. Two or more lines of bearing from the HFDF sites can be used to triangulate the location of the

[12] The US military Wideband Global Satellite (WGS), for example, has eight steerable and shapeable X-band beams and ten steerable Ka-band spot beams. See Headquarters, Department of the Army, "Techniques for Satellite Communications," ATP 6-02.54 (Washington, DC: Army Publishing Directorate, June 2017), 20.

target HF signal. The Mischief Reef HFDF site, located 1,400 kilometers (750 nautical miles) south of the Chinese mainland, significantly enhances Chinese HFDF capabilities. Greater geographic separation between HFDF sites means potentially greater angles between intercept lines of bearing and, therefore, more accurate triangulations of HF signals originating in the SCS, Pacific Ocean, or Indian Ocean.

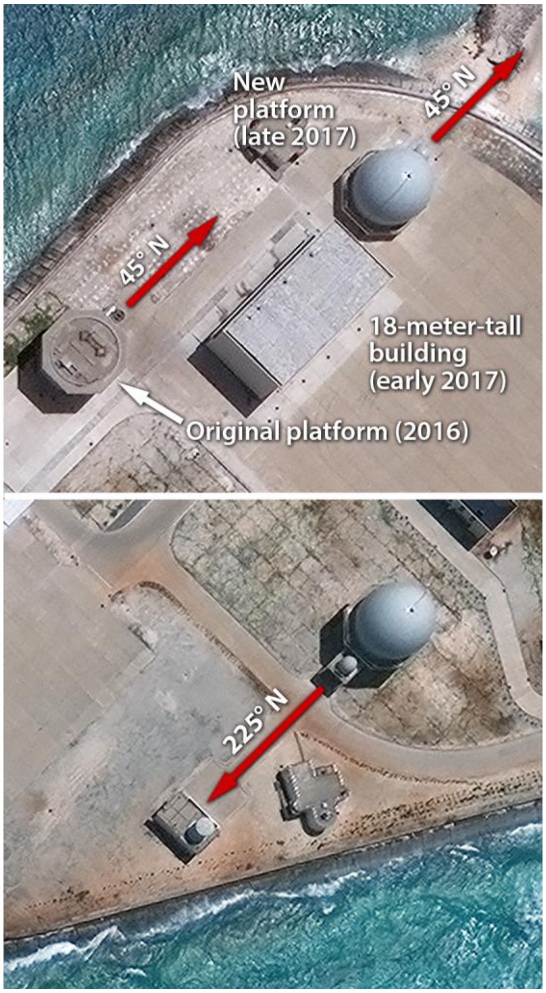


(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 10. Mischief Reef HFDF Site

Possible Electronic Intelligence Array

Four radomes located on Fiery Cross Reef and Mischief Reef may be an ELINT array or some other type of passive ISR system. One dome is located at the far northern and southern ends of each outpost. The individual arrays each have a smaller radome (4 meters/13 feet), presumably in front of a larger radome (19.5 meters/64 feet). The domes on each outpost are oriented on reciprocal bearings (see Figure 11 and Figure 12).



(Images © 2020 Maxar/DigitalGlobe, Inc.)

Figure 11. Fiery Cross Reef North-South Radomes on Reciprocal Bearings

(Images © 2020 Maxar/DigitalGlobe, Inc.)

Figure 12. Mischief Reef North South Radomes on Reciprocal Bearings

Historical imagery indicates these domes with hexagonal bases were constructed in early 2016; however, the northern Fiery Cross dome was moved to the northeast, possibly because an 18-meter-tall building was constructed in early 2017, blocking the field of view at the original site. A probable antenna mount on top of the old Fiery Cross platform indicates that a fixed antenna, as opposed to a rotating antenna, may be inside the radomes. Commercial satellite images taken in November 2017 show the antenna under construction before the dome was put in place. The image shows two dark, angular objects positioned at the front of the dome (see Figure 13).[13]

[13] Google Earth Pro 7.3.3.7721, (November 15 and 18, 2017), Fiery Cross Reef, 09°33'25"N 112°54'20"E. Maxar Technologies 2020.

(Image Google Earth/© 2020 Maxar Technologies)

Figure 13. Fiery Cross Reef North Array Under Construction, November 2017

The radomes, each located on relatively low platforms, might house a fixed, high-power, phased-array radar. In that case, the northern antenna may have been moved to mitigate the radiation hazard that such a radar poses to personnel and equipment in the building constructed nearby. However, the presence of low-lying buildings directly in front of the southern Fiery Cross Reef site suggests that electromagnetic radiation may not be a concern and that whatever is covered by these domes is, in fact, a passive, receive-only collection system.

Taken together, the characteristics of the sites indicate these radomes probably house an ELINT collection system or another type of ISR system. The small antenna in front may aid in signal direction finding or provide detection and cuing for the larger antenna. The reciprocal orientation indicates that the arrays are aligned for some collaborative purpose. Assuming a 180-degree field of view for each antenna, the line-of-sight coverage for the four arrays appears to provide overlapping coverage for the Chinese-held island-reefs. Figure 14 depicts line-of-sight coverage from each radome to various altitudes.

Ultimately, the function of these radome sets cannot be conclusively determined based on the limited information available. Whether an active or passive system, the four radome sets are very likely an ISR system providing overlapping, broad-area coverage in the SCS.

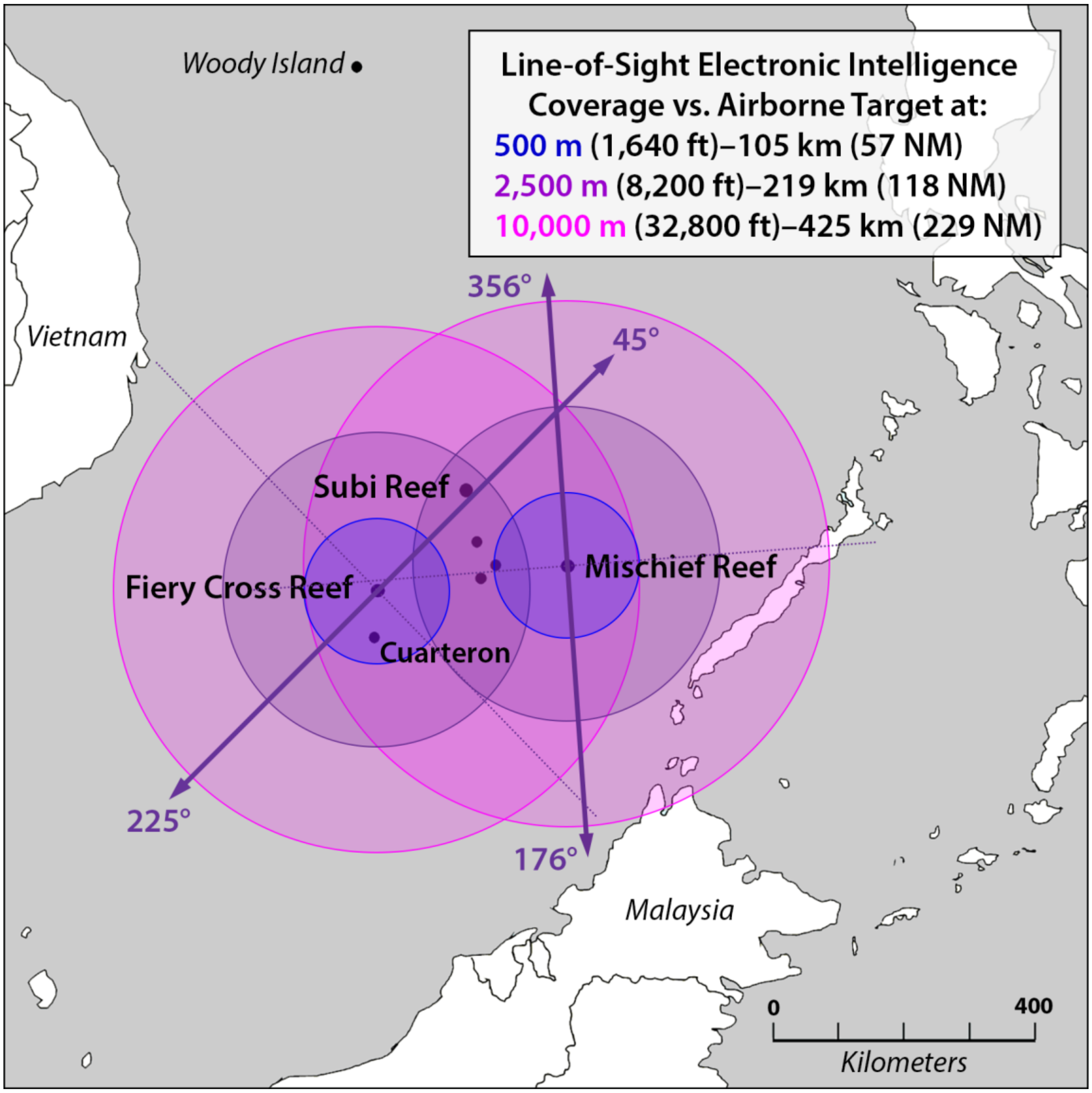


Figure 14. Orientation and Altitude-Dependent Coverage of Fiery Cross and Mischief Reef Electronic Intelligence Arrays

Electronic Warfare Aircraft

PLA EW capabilities generated from the island-reefs are not limited to ground-based units or fixed elements and will include deployed EW aircraft. The most capable of these platforms for overwater ELINT operations is the relatively new Y-9JB aircraft. Electronic attack aircraft that might be stationed on the Chinese island-reefs include the Y-8G and its follow-on, the Y-9G. Chinese aviation enthusiasts sometimes refer to the Y-8G as "mumps" because of the antenna housings that protrude from the left and right sides of the forward fuselage (see Figure 15).[14] The Y-8G likely generates substantial electronic interference across a broad frequency range in a standoff jamming role. Fighter-size aircraft deployed to the island-reef airfields may also carry KG-600 or KG-800 jamming pods for electronic attack/standoff jamming missions.[15]

(JSDF Photos)

Figure 15. Y-9JB ELINT Aircraft (Left) and Y-8G EW aircraft (Right)

According to Chinese defense industry promotional literature, seemingly all large Chinese unmanned aerial vehicles (UAVs) are also capable of carrying jamming pods or signals intelligence packages. COMINT, ELINT, or electronic attack pods enable a broad range of flexible, UAV-based EW capabilities. The Chinese Wing Loong II UAV, similar to the US Predator UAV, is reportedly equipped with an "integrated electronic warfare mission system" (see Figure 16).[16] EW aircraft and UAVs that may operate from SCS island-reef airfields are detailed in the SCS MILCAP study, "Special Mission Aircraft and Unmanned Systems."

(JHU/APL Photo)

Figure 16. Wing Loong II UAV

[14] Joint Staff, 中国機の東シナ海及び太平洋における飛行について [Chinese aircraft flying in the East China Sea and Pacific Ocean], press release (Tokyo: Japanese Ministry of Defense, December 9, 2017), http://www.mod.go.jp/js/Press/press2017/press_pdf/p20171209_01.pdf.

[15] Tiago Machado, "Silencing the Airwaves: Chinese SEAD Capabilities," *Janes Defense Weekly*, September 20, 2018, https://janes.ihs.com/Janes/Display/FG_1056438-JDW.

[16] "翼龙II 无人机系统" [Wing Loong II UAS], trade brochure (中国航空工业集团公司 [Aviation Industry Corporation of China, Ltd.], 2018), 1.

As with ground-based systems, airborne EW jamming effectiveness or ELINT detection will generally be limited by line-of-site range from the jammer or sensor to the target. Range will be further limited by factors such as radiated power and the geometry of the EW aircraft to the target. Example line-of-site ranges from airborne ELINT or EW platforms are shown in Figure 17.

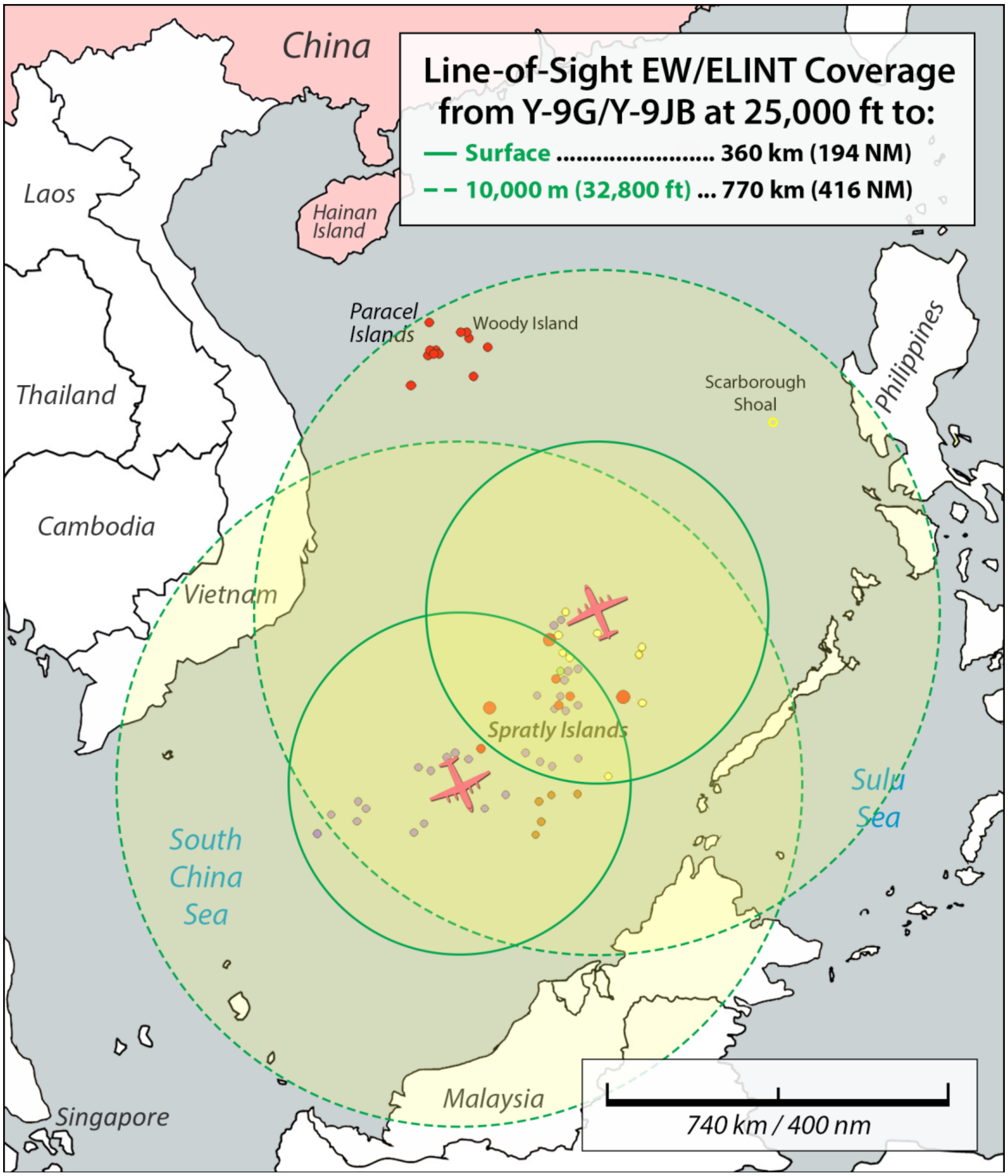


Figure 17. Line-of-Sight Ranges from Airborne ELINT or EW Aircraft

Conclusions

Determining specific EW capabilities present on the PLA's SCS outpost is inherently challenging since such capabilities may reside in a single, relatively small antenna that is difficult to discern from commercial satellite imagery. Using the PLA's imperative to control the electromagnetic spectrum as a prompt, a number of EW capabilities appear to be resident on the island-reefs. These capabilities include a diverse array of specialized mobile ground-based vehicles deployed on the island-reefs to address a variety of jamming or SIGINT collection requirements. Fixed signals intelligence facilities include sites that may be used to monitor, locate, or jam foreign SATCOM signals and an HFDF site that enhances the PLA's regional HF triangulation capabilities. A substantial ELINT array or some other type of passive ISR system consisting of a pair of radomes set on reciprocal bearings are located on Fiery Cross and Mischief Reefs. Aircraft or UAVs flying from island-reef airfields also provide significant EW capabilities to complement island-reef based systems.

The PLA has been focused on developing EW capabilities and training to operate in a complex electromagnetic environment since the early 2000s. EW capabilities that cover large parts of the frequency spectrum is consistent with the PLA's design approach to other complex systems-of-systems such as communications and radar capabilities outlined in other SCS MILCAP studies. Redundant communications and radar capabilities are defensive measures—frequency diversity preserves PLA access to the electromagnetic spectrum in the face of threats from enemy jamming or destruction. PLA EW capabilities are the corresponding offensive effort—capabilities to deny an adversary use of the electromagnetic spectrum either through jamming or the threat of detection and subsequent attack. The diverse EW capabilities observed on the island-reef outposts are integral components of a Chinese strategy to control battlespace information.

PLA investments in diverse and redundant EW systems demonstrates a Chinese informationized warfare strategy that emphasizes battlespace information control. The jamming or ELINT detection threat to foreign militaries operating in the SCS is not from a single EW system but from the sum total of different EW systems—ground-based, airborne, or ship-based. Electronic jamming may be synchronized with other ELINT detection and kinetic attack. Countering complex Chinese EW networks will require an integrated system-of-systems approach that integrates kinetic and non-kinetic means to deny PLA designs to gain and maintain battlespace information advantage.

Appendix A. Sources and Methods

Observations and analysis of the Chinese SCS outposts in these MILCAP studies rely on commercial satellite imagery licensed to JHU/APL and collected by the Maxar/DigitalGlobe Inc. WorldView-3 satellite (see Table 1). WorldView-3 can collect images up to 30-centimeters resolution, which translates to image quality between 5.0 and 6.0 on the National Imagery Interpretation Rating Scale (NIIRS).[17] For these studies, software like Google Earth Pro and Adobe Photoshop were used to interpret imagery, measure features, and adjust image color and balance. These images were not subject to any special processing or proprietary enhancements.

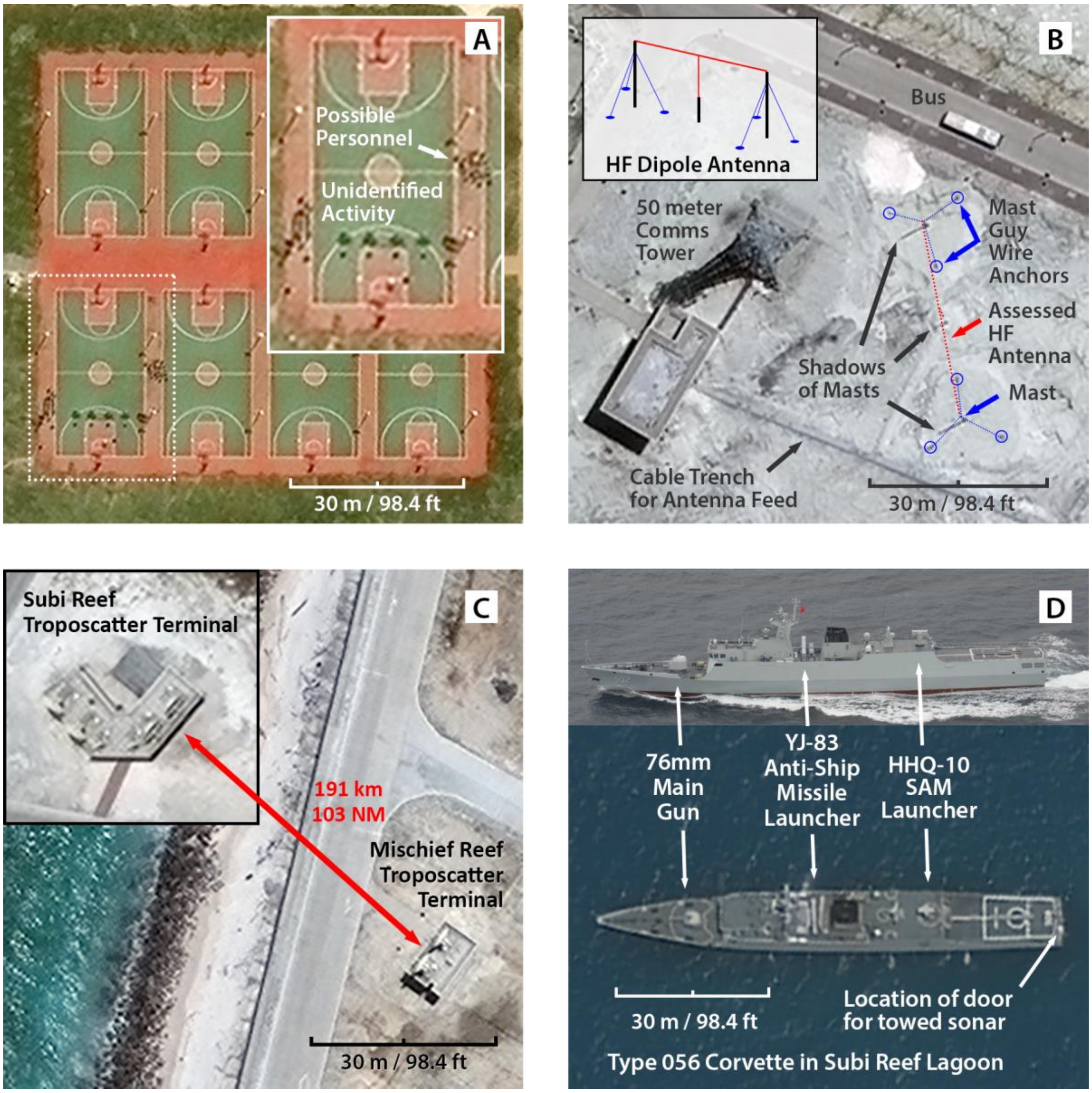
Table 1. DigitalGlobe Inc. WorldView-3 Satellite Imagery Details

Island-Reef	Location	Date	DigitalGlobe Image ID
Fiery Cross Reef	09°33′00″ N, 112°53′25″ E	June 14, 2018	104001003C49BB00
Subi Reef	10°55′22″ N, 114°05′04″ E	June 19, 2018	104001003E841300
Mischief Reef	09°54′10″ N, 115°32′13″ E	June 19, 2018	104001003D964F00

Reference images published in these studies cover hundreds of square meters, which necessarily obscures many specific features used in making assessments. Zoomed-in examples of details available in these satellite images are shown in Figure 18. The dots made up of only a few pixels in Figure 18(A) cannot be readily identified. However, their location on the basketball court leads to a conclusion that these may be personnel. As shown in Figure 18(B), observing shadows and other features may reveal structures such as a common HF dipole antennae, even if the fine-gauge wires cannot be seen in the image. Shadow length may be translated into object height using satellite image metadata and simple trigonometry. Figure 18(C) is an example that indicates the likely connection between two widely separated troposcatter terminals based on antenna pointing angles. Figure 18(D) demonstrates that positive identification of detailed features may be possible with a much higher quality reference image. The PLA Navy Type 056 corvette in the satellite image may be an anti-submarine warfare variant (Type 056A) based on the light colored feature seen where the door for a towed sonar array should be located.[18]

[17] Leigh Harrington, David Blanchard, James Salacain, Stephen Smith, and Philip Amanik, *General Image Quality Equation; GIQE version 5*, (Washington, DC: National Geospatial-Intelligence Agency (NGA), 2015), https://gwg.nga.mil/ntb/baseline/docs/GIQE-5_for_Public_Release.pdf.

[18] See close-up images of the towed array door in "'Sanmenxia,' First Type 056A ASW Corvette (Jiangdao Class), Commissioned in Chinese Navy (PLAN)," *Navy Recognition*, November 19, 2014, accessed July 1, 2020, http://navyrecognition.com/index.php?option=com_content&view= article&id=2189.



(Images © 2020 Maxar/DigitalGlobe, Inc. Photograph of ship courtesy of Japan Self Defense Force)

Figure 18. Detailed Image Examples. (A) Mischief Reef Basketball Courts, (B) Mischief Reef HF Antenna, (C) Troposcatter Terminals, (D) Type 056 Frigate

Publicly accessible satellite imagery, available on Google Earth or from organizations like the Asia Maritime Transparency Initiative, provides historical images that may show changes to island-reef features over time. Official or semi-official Chinese sources discussing military capabilities on the SCS outposts complement imagery analysis and help qualify imagery observations. Where appropriate, these studies also reference secondary sources such as credible media reporting on China's SCS island-reefs or public U.S. government statements about PLA capabilities in the SCS.

Appendix B. South China Sea Maritime Territorial Claims

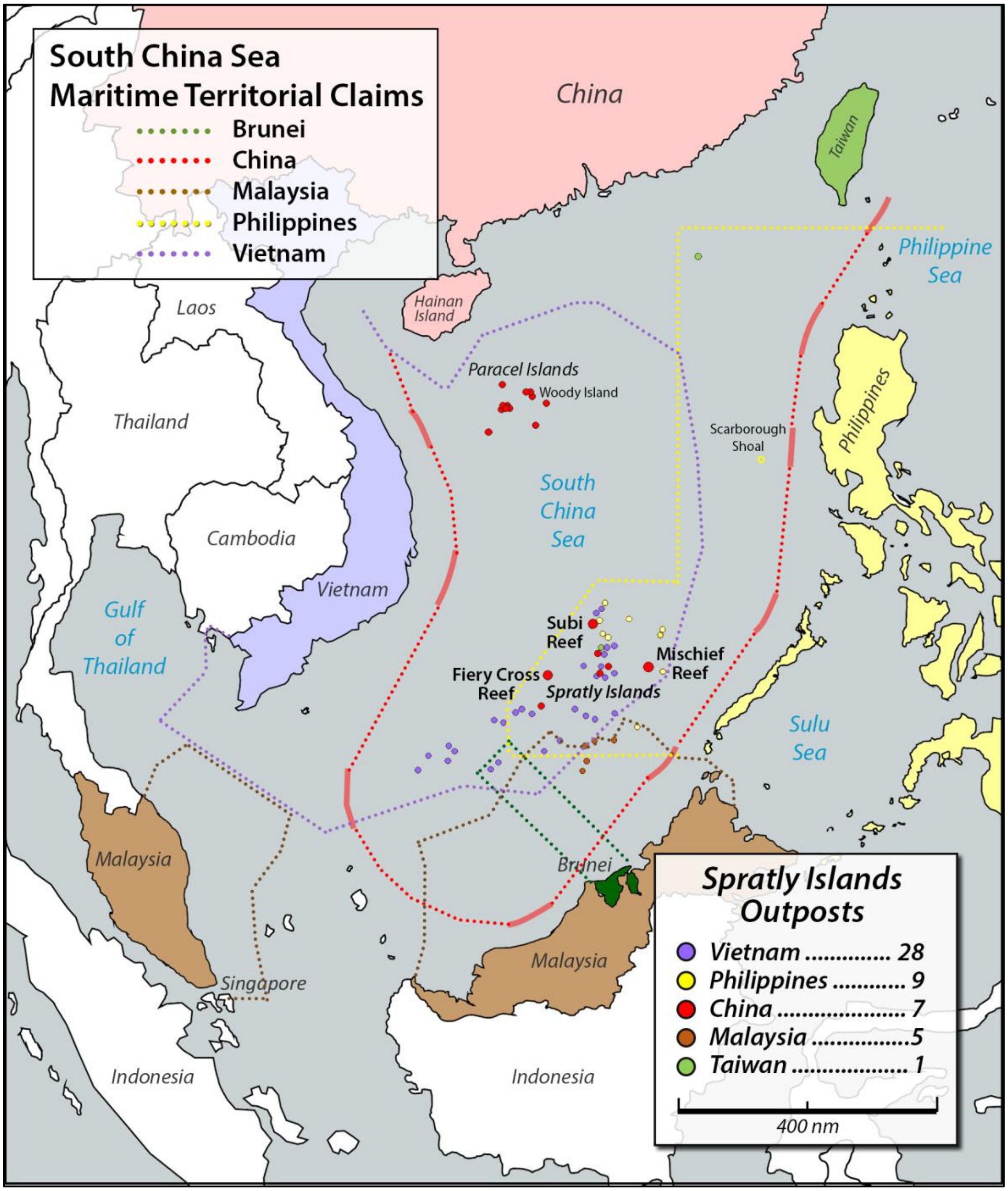
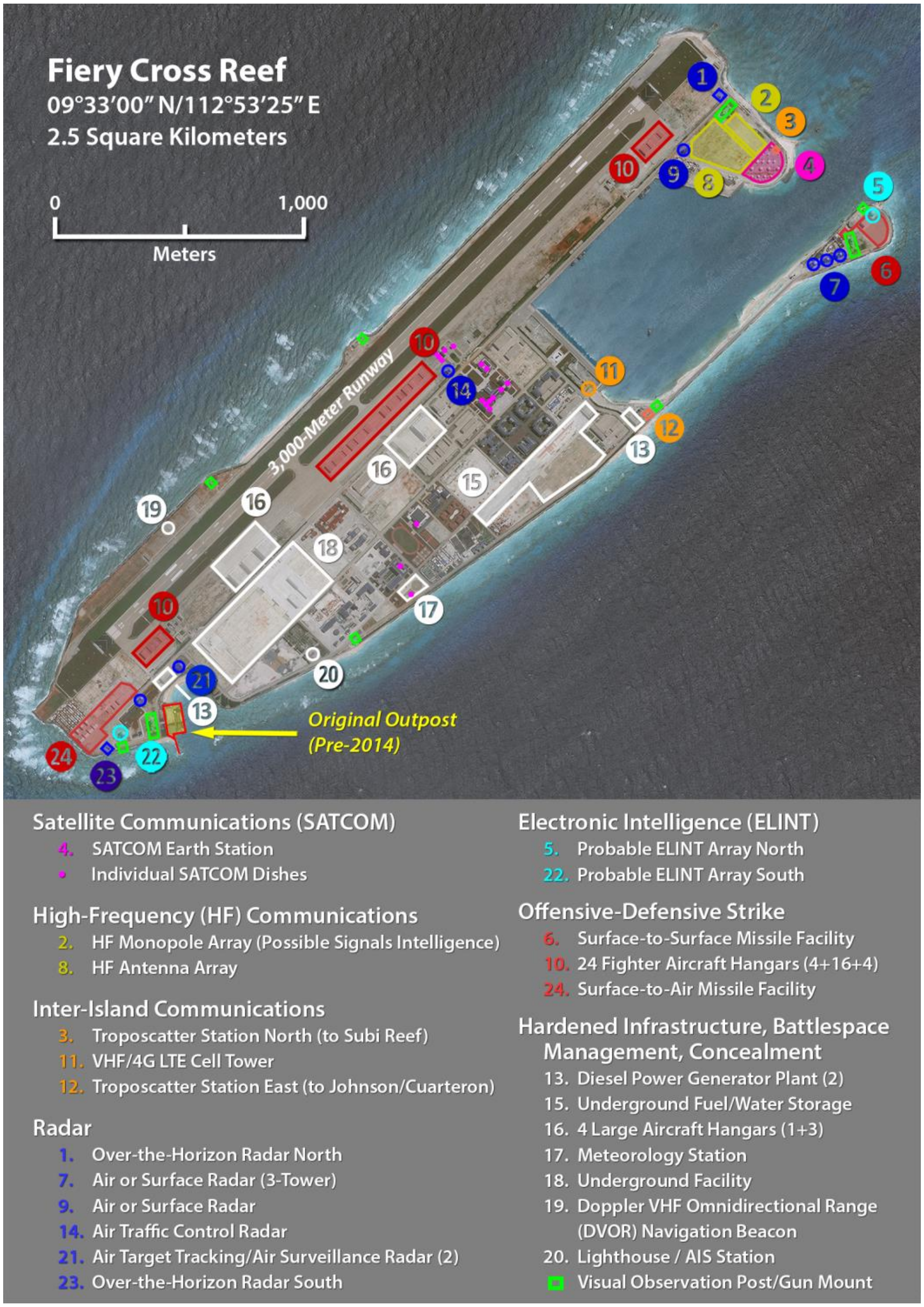


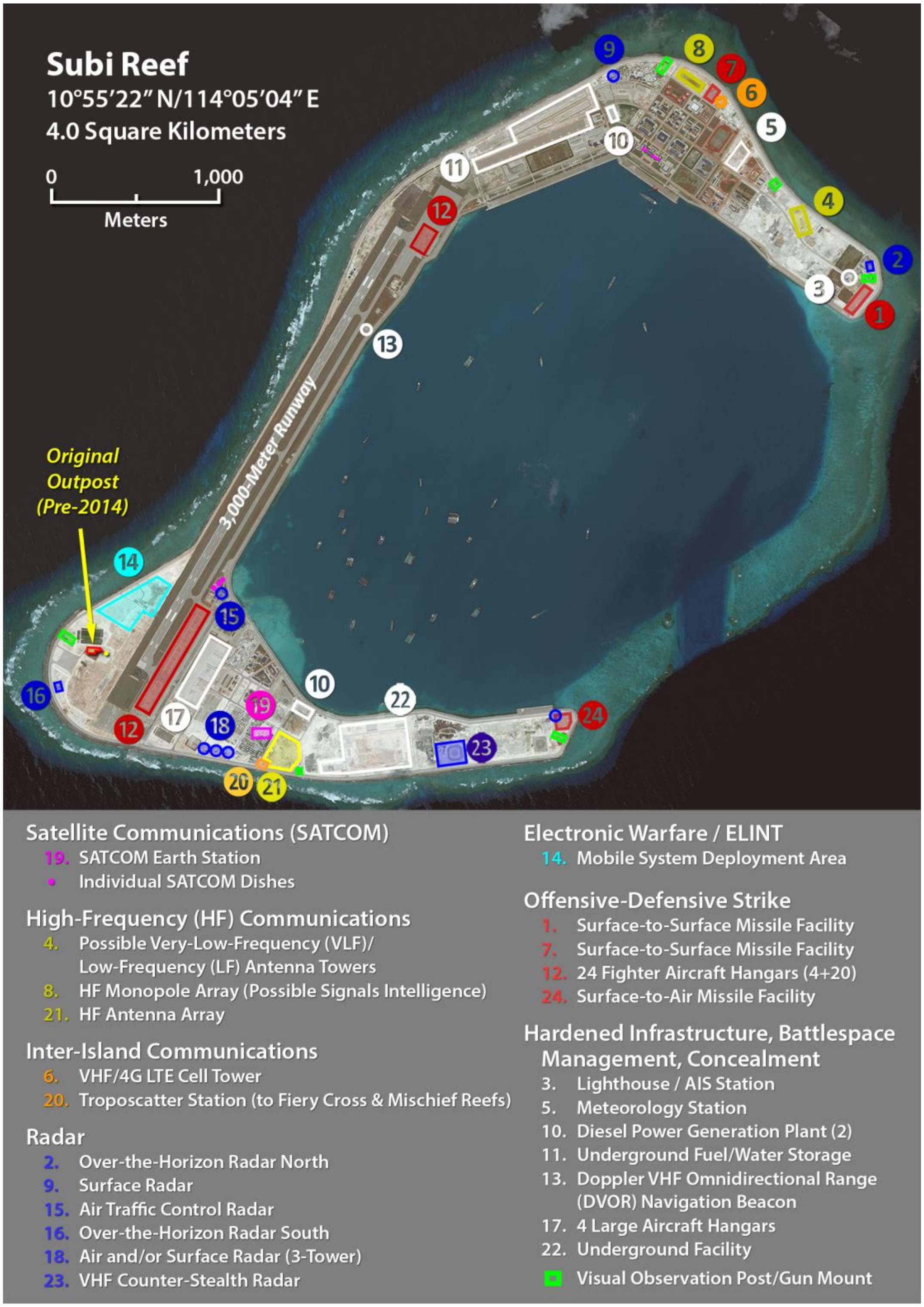
Figure 19. South China Sea Maritime Territorial Claims

Appendix C. Island-Reef Capabilities Overview Graphics



(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 20. Fiery Cross Reef Overview



(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 21. Subi Reef Overview

Electronic Warfare and Signals Intelligence

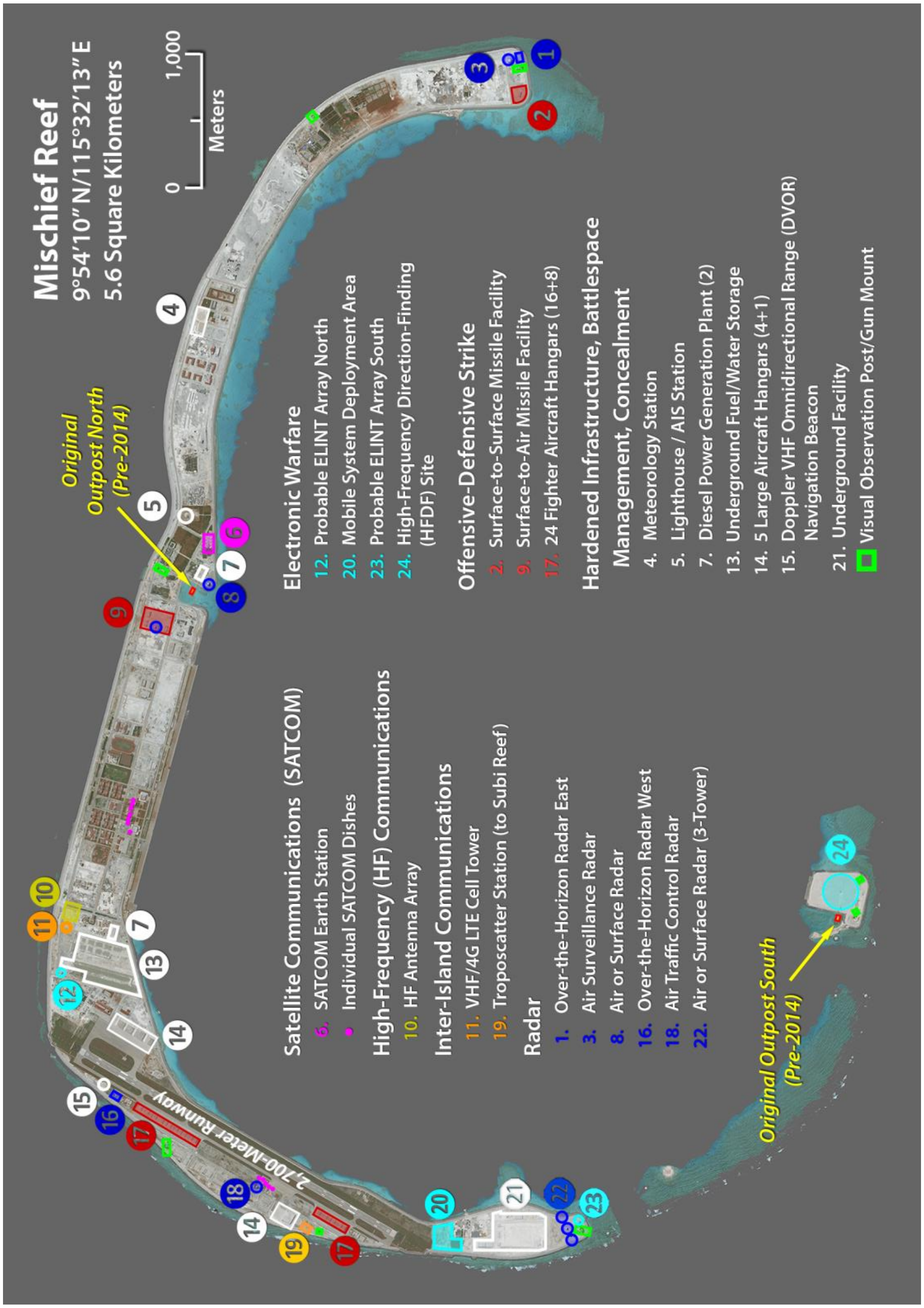


Figure 22. Mischief Reef Overview

Appendix D. Definitions and Abbreviations

AIS—Automatic identification system; tracking system used by large ships

4G LTE—Fourth-generation long-term evolution; cellular communications

ASCM—Anti-ship cruise missile

C4—Command, control, communications, and computers. Sometimes rendered C3, dropping "computers" or C2, "command and control"

C4ISR—Command, control, communications, computers, intelligence, surveillance, and reconnaissance. Sometimes C5ISR or C5ISRT, including "cyber" and "targeting"

CCD—Camouflage, concealment, and deception

ELINT—Electronic intelligence

EMS—Electromagnetic spectrum; common frequency bands are shown in Table 2

Table 2. Radio and Radar Frequency Bands

<table>
<tr><th>ITU Radio Bands</th><th>Band Name</th><th>Frequency Range</th><th>IEEE Radar Bands</th><th>Frequency Range</th></tr>
<tr><td>VLF</td><td>Very-low frequency</td><td>3-30 kHz</td><td></td><td></td></tr>
<tr><td>LF</td><td>Low frequency</td><td>30-300 kHz</td><td></td><td></td></tr>
<tr><td>MF</td><td>Medium frequency</td><td>300-3000 kHz</td><td></td><td></td></tr>
<tr><td>HF</td><td>High frequency</td><td>3-30 MHz</td><td></td><td></td></tr>
<tr><td>VHF</td><td>Very-high frequency</td><td>30-300 MHz</td><td>VHF</td><td>30-300 MHz</td></tr>
<tr><td rowspan="2">UHF</td><td rowspan="2">Ultra-high frequency</td><td rowspan="2">300-3000 MHz</td><td>UHF</td><td>300-1000 MHz</td></tr>
<tr><td>L</td><td>1-2 GHz</td></tr>
<tr><td rowspan="5">SHF</td><td rowspan="5">Super-high frequency</td><td rowspan="5">3-30 GHz</td><td>S</td><td>2-4 GHz</td></tr>
<tr><td>C</td><td>4-8 GHz</td></tr>
<tr><td>X</td><td>8-12 GHz</td></tr>
<tr><td>Ku</td><td>12-18 GHz</td></tr>
<tr><td>K</td><td>18-27 GHz</td></tr>
<tr><td rowspan="2">EHF</td><td rowspan="2">Extremely-high frequency</td><td rowspan="2">30-300 GHz</td><td>Ka</td><td>27-40 GHz</td></tr>
<tr><td></td><td></td></tr>
</table>

EW—Electronic warfare

HFDF—High-frequency direction finding

Information power—信息力 (*xìnxī lì*)—A Chinese term referring to the capability of a military force to achieve information superiority, ensuring the use of information for friendly operational forces while simultaneously denying adversary operational forces the use of information

Informationized warfare—信息化作战 (*xìnxī huà zuòzhàn*)—The prevailing "form of war" (战争形态, *zhànzhēng xíngtài*) in Chinese military theory.

Island-reef—岛礁 (*dǎo jiāo*)—A Chinese term for an islet or an island of sand that has built up on a reef. China's military outposts in the Spratly Island group were formerly rocks or high-tide features that do not have the international legal status of island that might otherwise define territorial waters or an exclusive economic zone

ISR—Intelligence, surveillance, and reconnaissance

PLA—People's Liberation Army; Refers to the entire Chinese military

PLAN—People's Liberation Army Navy

PNT—Positioning, navigation, and timing

SATCOM—Satellite communications

SAM—Surface-to-air missile

SCS—South China Sea

SoS—System-of-systems.

Southern Theater—One of five PLA theater commands created in 2016 Chinese military reorganization. Area of responsibility includes southern China, Hainan Island, the SCS, and Paracel and Spratly island-reef bases

SSF—PLA Strategic Support Force

SSM—Surface-to-surface missile

Troposcatter— Troposcatter or tropospheric communications are microwave signals, generally above five hundred megahertz, scattered by dust and water vapor in the atmosphere, allowing for over-the-horizon communication links

UAV—Unmanned aerial vehicle

USV—Unmanned surface vehicle

UUV—Unmanned underwater vehicle

About the Author

J. Michael Dahm is a senior national security researcher at the Johns Hopkins University Applied Physics Laboratory where he focuses on foreign military capabilities, operational concepts, and technologies. Before joining JHU/APL, he served as a US naval intelligence officer for over 25 years. His most recent assignments included senior analyst in the USPACOM China Strategic Focus Group, assistant naval attaché at the US embassy in Beijing, China, and senior naval intelligence officer for China at the Office of Naval Intelligence.

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