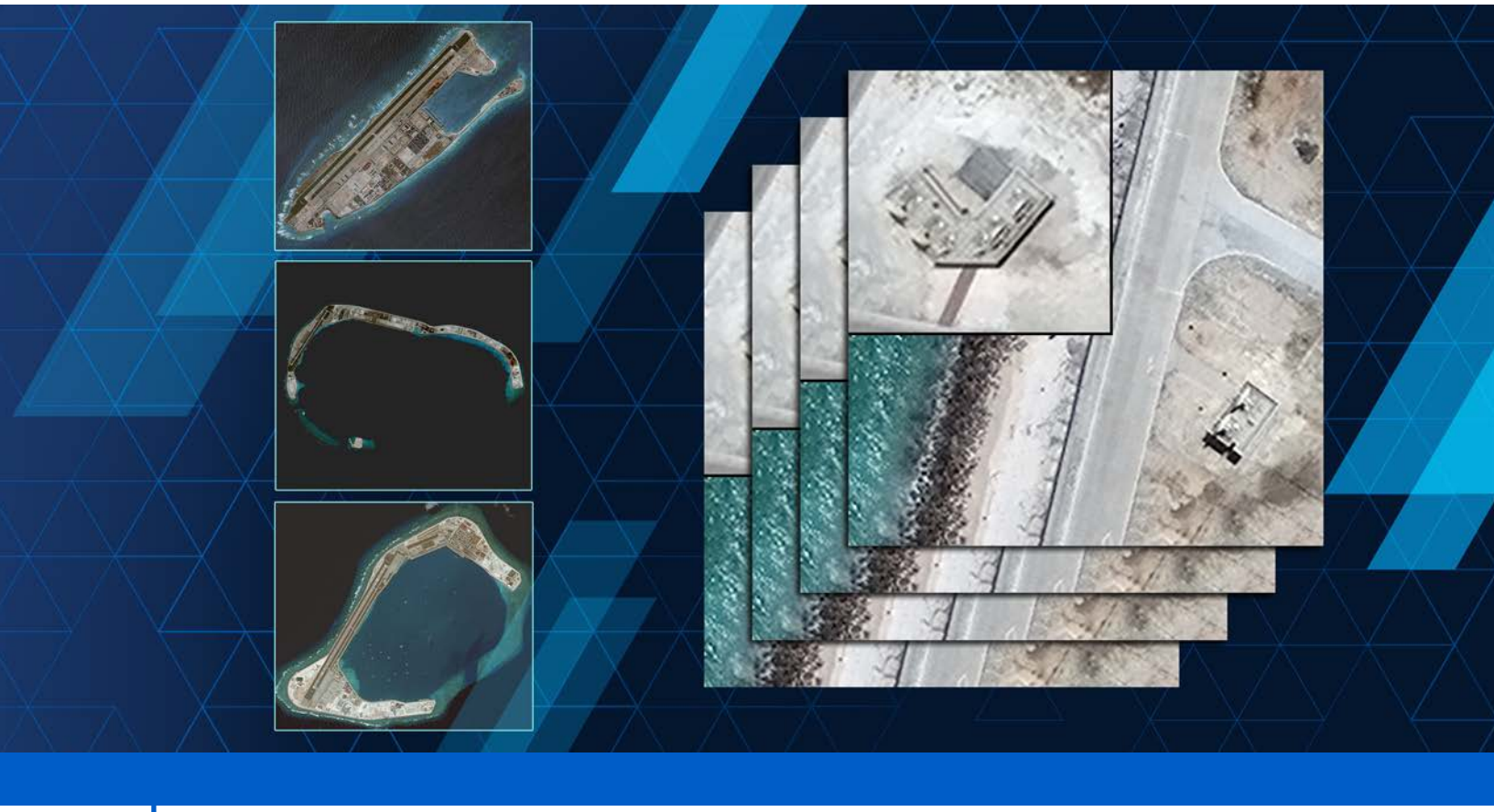
SOUTH CHINA SEA MILITARY CAPABILITY SERIES

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



INTER-ISLAND COMMUNICATIONS

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Introduction

This military capability (MILCAP) study focuses on inter-island communications capabilities among 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.

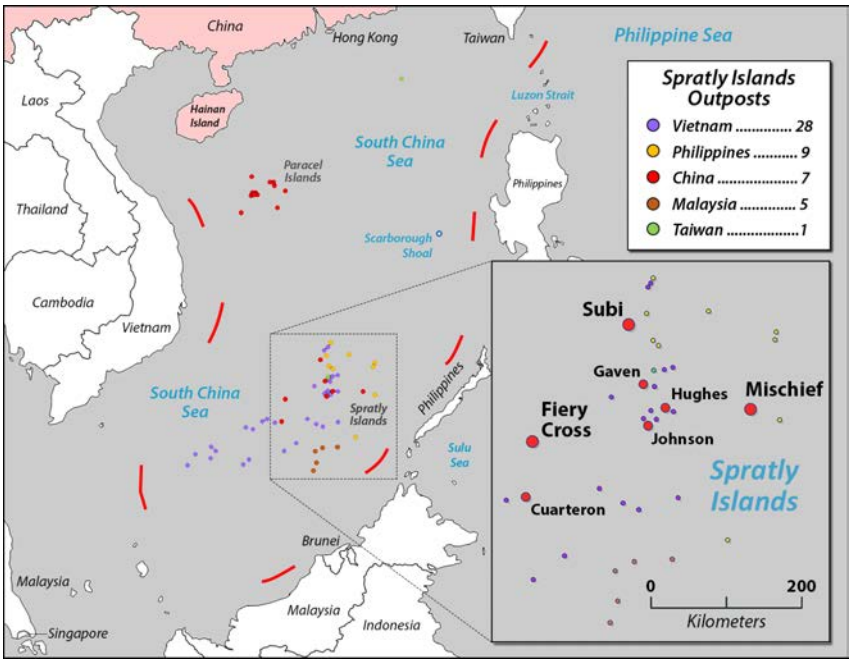

Figure 1. SCS Occupied Features

Inter-island communications on the PLA's SCS outposts include troposcatter, 4G (4th generation) cellular communications, and data links. Over-the-horizon troposcatter communications terminals were noted on four of the seven SCS outposts. Very-high-frequency (VHF)- or ultra-high-frequency (UHF)-band antennae are likely mounted atop island-reef buildings but are too small to detect in satellite imagery. A number of these antennae were noted on outpost communications towers. Long-range communications outlined in this SCS MILCAP series [e.g., satellite communications (SATCOM)] may also be used for inter-island communications. Overview graphics of all capabilities noted on major outposts appear in Appendix C.

Troposcatter Communications, 散射通信

Troposcatter communications capabilities on the SCS island-reefs are evidence of the PLA's requirement to maintain a robust, redundant, and resilient communications network in support of its informationized warfare strategy in the SCS. The Chinese term for troposcatter communications is "散射通信," which translates simply as "scatter communications." SCS troposcatter antenna locations as of June 2018 are depicted in Figure 2.

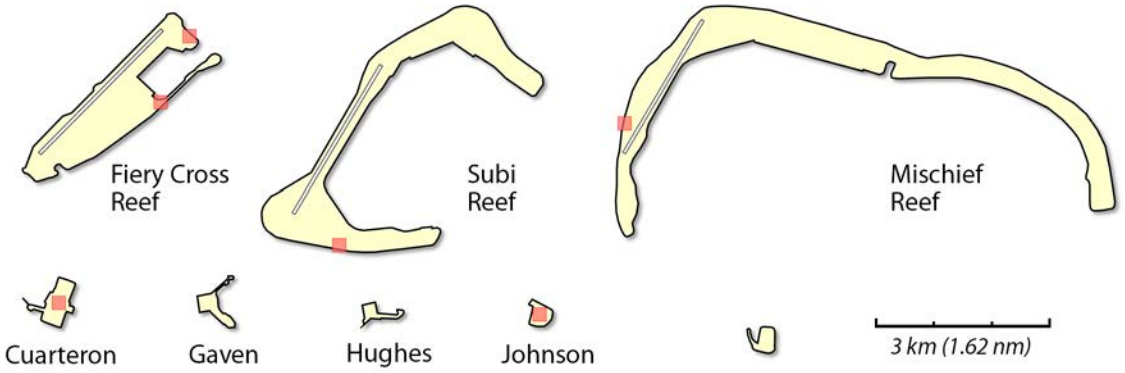

Figure 2. Observed SCS SATCOM Dish Locations, June 2018

Troposcatter communications links extend several hundred kilometers beyond line of sight. Pairs of transmit and receive antennae, aligned along reciprocal bearings, are pointed just above the visible horizon. Troposcatter microwave signals, generally above 500 megahertz, are scattered by dust and water vapor in the atmosphere and reflected back toward Earth from an altitude between 2,000 and 5,000 meters (~6,500 and 16,500 feet). Only a fraction of the transmission beam is reflected, requiring high-power transmitters, high gain antennae, and, to achieve high-bandwidth throughput, increasingly sophisticated signal processing (see Figure 3).

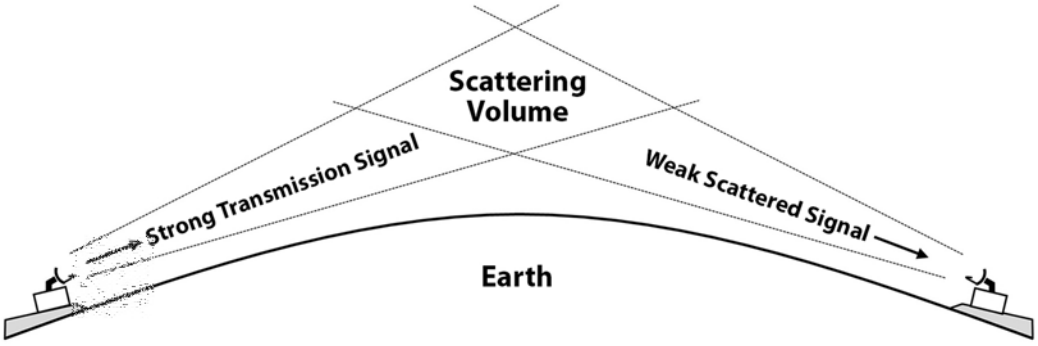

Figure 3. Troposcatter Communication Signal Propagation

The PLA improved on troposcatter technology that it adopted in the 1960s. The PLA built an extensive national-level troposcatter network in the 1970s.[1] It continues to deploy these communications throughout its military in support of operational- and tactical-level requirements. In contrast, the US military had largely abandoned troposcatter technology in favor of higher bandwidth satellite links for operational-level communications. Recently, however, the US Army appears to be reinvesting in troposcatter as a hedge against emerging threats to space-based communications.[2]

Engineers at the China Electronics Technology Group Corporation (CETC) 54th Research Institute (54th RI) asserted that troposcatter communications have a number of advantages for military communications. The 54th RI designs and builds a majority of PLA communication equipment. According to a 2014 article in the 54th RI's professional journal, *Radio Communications Technology*, troposcatter technology provides a reliable, cost-effective means for modern military communications. Troposcatter communications provide stable, single-hop, over-the-horizon communications over distances between 100 and 600 kilometers (54 and 324 nautical miles). The directional nature of the propagation also makes signals difficult to intercept or jam. Troposcatter is relatively unaffected by terrestrial or space weather (i.e., magnetic storms) and can provide greater capacity than high frequency (HF) communications, achieving throughputs of better than 8 megabits per second, according to the article.[3]

The PLA Navy established a fixed troposcatter communications network for its SCS outposts several years before land reclamation and artificial island building began in 2014. Large, parabolic troposcatter antennae oriented toward the horizon can be seen in handheld PLA Navy photos of the original outposts.[4] 2018 commercial satellite imagery indicates five SCS outposts have been linked by eight sets of troposcatter antennae on Fiery Cross, Subi, Mischief, Cuarteron, and Johnson Reefs (see Figure 4).

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[1] National Photographic Interpretation Center (NPIC), Chinese Troposcatter Communications Network (Washington, DC: NPIC, 1982), sanitized copy of document approved for public release February 1, 2010, https://www.cia.gov/library/readingroom/docs/CIA-RDP83T00574R000103000001-2.pdf.

[2] See, for example, "Network Modernization: Tropo," US Army Program Executive Office Command Control Communications-Tactical (PEO C3T), accessed August 26, 2019, https://peoc3t.army.mil/tn/tropo.php.

[3] Hao Yingchuan, Gan Qiguang, and Jia Mengyuan, "散射通信在岛屿中的应用及传播特性分析" [Application and Propagation Characteristics of Troposcatter Communications on Islands], 无线电通信技术 [Radio Communications Technology] 40, no. 2 (2014): 20.

[4] Qian Xiaohu and Gao Yi, "南海舰队远海训练编队巡航南沙" [South China Sea Fleet Far Seas Training Cruise Nansha (Spratly Islands)], 解放军报社海军分社 [PLA Newspaper Navy Branch], January 25, 2014, http://navy.81.cn/content/2014-01/25/content_5749997_3.htm.

Inter-Island Communicaitons

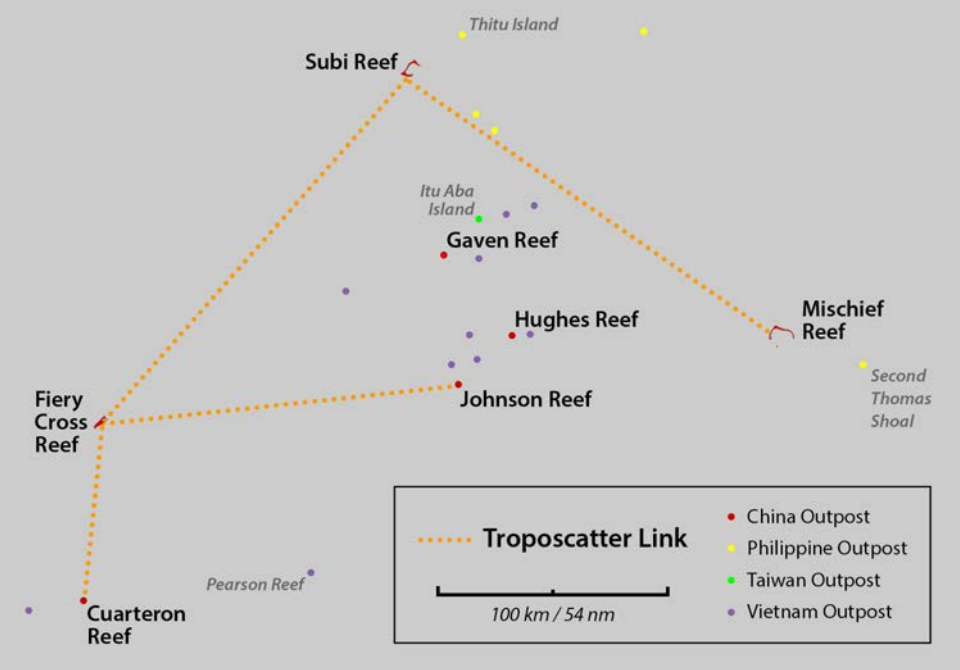

Figure 4. SCS Outpost Troposcatter Network

According to a 2017 article written by another author from the 54th RI, troposcatter communications equipment was deployed in the Paracel Islands and Spratly Islands for several years and was regarded as reliable and stable. He went on to write that, as of 2017, troposcatter communications on the island-reefs were being upgraded.[5] The upgraded, stand-alone troposcatter terminals, no longer mounted atop the old outpost buildings, are clearly visible in 2018 satellite imagery (see Figure 5 and Figure 6).

Pointing angles are difficult to determine for the northernmost troposcatter antenna set at the Fiery Cross east site due to image quality (see the right side of Figure 6). The antenna could conceivably point to Hughes, Johnson, or even Mischief Reef. No corresponding troposcatter transmit-receive site was identified on Mischief Reef. However, a transmit-receive site was identified on Johnson Reef in 2016 handheld imagery published by the Vietnamese *Thanh Nien News*. Two building-mounted troposcatter antennae can be seen in the photo pointing toward Fiery Cross Reef.[6]

[5] Cheng Hanlin, "散射通信海上应用研究" [Troposcatter Communications Offshore Application Research], 科学家 [Scientist], no. 13 (August 2017): 110.

[6] Mai Thanh Hai, "China's Illegal Construction in Vietnam's East Sea Reef," Thanh Nien News, June 08, 2016, http://www.thanhniennews.com/politics/chinas-illegal-construction-in-vietnams-east-sea-reef-62967.html. Note the second image captioned, "Guns deployed on roofs on Gac Ma Reef."

(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 5. Subi Reef (Left) and Mischief Reef (Right) Troposcatter Terminals

(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 6. Fiery Cross Reef North (Left) and Fiery Cross Reef East (Right) Troposcatter Terminals

The SCS island-reef troposcatter systems may be similar to commercial systems sold by CETC's 54th RI. The 54th RI markets the GS-504 fixed troposcatter system for offshore applications such as oil platform communications.[7] Each GS-504 station employs 2.4-meter dishes, similar to those observed on the SCS island-reefs. A version of the GS-504 is also marketed as the GS-504A by the Beijing Jiahangxin Electronics Company. Jiahangxin Electronics has ties to the PLA and incorporates domestic and foreign technologies, including US communications technology, to support petroleum industry customers such as the China National Offshore Oil Corporation.[8]

The GS-504 and GS-504A troposcatter communication systems have the following parameters:

- Operating frequency: 4,400–4,580 megahertz, 4,820–5,000 megahertz
- Transmission power: 200–1,000 watts
- Operating distance: greater than 200 kilometers
- Data rate: 256/512/1,024/2,048 kilobits per second, multiplexed to 8.45 megabits per second

The terminals connecting the SCS outposts may be a newer version of the GS-504, the GS-514 fixed troposcatter communications stations advertised by the 54th RI as of late 2018. The GS-514 is described in promotional literature as a large-capacity digital transmission station similar to the GS-504, supporting a data rate of up to 20 megabits per second.[9]

VHF/UHF and Other Line-of-Sight Communications

VHF-band (30 to 300 megahertz) or UHF-band (300 megahertz to 3 gigahertz) communications are probably used extensively on the Chinese SCS outposts. VHF and UHF antennae are employed for relatively short-range line-of-sight communications on the island-reefs and to ships, aircraft, and unmanned systems operating in the

[7] "GS-504 固定式散射通信系统" [GS-504 Fixed Troposcatter Communication System], 中国电子科技集团公司第五十四研究所 [China Electronics Technology Group Corporation 54th Research Institute], accessed October 24, 2018, http://www.cti.ac.cn/Products/system/network/Scatter/2013/0725/320.html.

[8] "对流层散射通信" [Tropospheric Scatter Communications], 北京佳航信电子有限公司 [Beijing Jiahangxin Electronics Co., Ltd.], accessed October 24, 2018, http://www.jhx-seatel.com.cn/cpjs12097.html. For information on the company's marketing and import of patented "US Navy mil-standard" technology, see http://www.jhx-seatel.com.cn/cpjs.html.

[9] "Troposcatter Communication," trade brochure (Communication Telemetry & Telecontrol Research Institute, CETC 54th RI, 2018), 5.

immediate vicinity of the outposts. These antennae are virtually impossible to observe with satellite imagery because of their small size. Southeast Asian media photos of some of the 50-meter (164-foot) communications towers reveals that, in addition to a variety of probable VHF-band whip antennae, rectangular UHF antennae used for cellular communications encircle the tops of the towers[10] (see Figure 7). These 50-meter towers, which are also present on Gaven, Hughes, and Johnson Reefs, enable line-of-sight communications between these smaller outposts that are less than 50 kilometers (27 nautical miles) apart.

Figure 7. Fifty-Meter Communications Towers on Fiery Cross, Subi, and Mischief Reefs

4G Cellular Communications

State-owned China Telecom installed 4G cellular communications base stations on the Chinese-held island-reefs beginning in 2015.[11] These cellular base stations are purportedly for use by civilians and military personnel stationed on the Chinese island-reefs, as well as by nearby fishermen or transiting ships. Cellular networks are probably also used for military communications, even if the PLA maintains a network independent of the civil network.

[10] See, for example, image of tower in Trung Hieu, "Exclusive: China Nearly Finishes Illegal Building on East Sea Reef," Thanh Nien News, April 20, 2016, http://www.thanhniennews.com/politics/exclusive-china-nearly-finishes-illegal-building-on-east-sea-reef-61403.html.

[11] Liu Yuying, "中国电信 4G 信号覆盖南沙七个岛礁" [China Telecom's 4G Signal Covers Seven Island Reefs in Nansha [Spratly Islands]], 中国新闻网 [China News Network], July 16, 2016, http://www.chinanews.com/gn/2016/07-16/7941155.shtml.

Researchers at CETC's 28th Research Institute (28th RI), which manufactures command information systems for the PLA, [12] indicated that 4G LTE cellular communications have been used to create limited-area, high-speed broadband mobile networks for military units. The researchers recognize network security issues inherent in adapting commercial 4G cellular technology for military use. Still, they propose a variety of applications to improve battlespace situational awareness, command and control, and even positioning and navigation services.[13]

Assuming that network security issues are addressed, the cellular communications on the SCS island-reefs may provide the PLA with a high-speed wireless network that could service individual troop tasks or provide connectivity for equipment deployed to the island-reefs. Alternatively, the cellular network could serve as backup communication system if underground or overhead communications cables on the island-reefs are damaged or destroyed. The cellular network almost certainly affords civil authorities, including the Chinese paramilitary Maritime Militia forces, voice and high-speed data services when operating in the vicinity of the Chinese outposts.

Fifth-generation (5G) cellular service will significantly improve mobile communication data throughput on the SCS island-reefs with the potential for sophisticated encryption and Internet-of-things (IoT) functionality. In May 2019, China Mobile activated its first 5G cellular base station in the SCS on Fiery Cross Reef. The announcement touted a ten-fold increase in data rates over the outpost's 4G base station. China Mobile indicated that 5G services would be extended to the other SCS island-reefs but no timeline was provided.[14]

Airborne Communications Layer

If long-haul PLA communications are damaged or destroyed, unmanned aerial vehicles (UAVs) or aircraft based on the SCS island-reefs may be used to create an "airborne layer" for contingency communications. Many Chinese UAVs are advertised as capable of carrying communications relay packages. To complement SATCOM or HF communications, UAVs or manned aircraft could automatically relay line-of-sight

[12] The 28th RI is also known as the Nanjing Electronic Engineering Research Institute. It should not be confused with the 14th RI, also located in Nanjing and known as the Nanjing Electronic Technology Research Institute.

[13] Luo Mingxin, Chang Junjie, and Zhou Hui, "4G 移动通信技术及其军事应用" [4G Mobile Communication Technology and its Military Application], 指挥信息系统与技术 [Command Information System and Technology] 5, no. 2 (April 2014): 56–60.

[14] "中国移动 5G 再次南伸！南沙永暑礁 5G 基站开通" [China Mobile's 5G Extends South Again, Nansha Yongshu Jiao (Spratly Islands Fiery Cross Reef) 5G Base Station Opened] *人民网讯 [People's Daily Online]*, May 24, 2019, https://www.sohu.com/a/316172783_354877.

communications, such as voice or data link, to surface ships or other platforms operating over-the-horizon, far from the SCS outposts. Aircraft that might act as communications relays include the KJ-500 airborne early warning and control (AEW&C) aircraft or the BZK-005 UAV (see Figure 8).[15] In November 2019, commercial satellite imagery noted a tethered aerostat flying over Mischief Reef.[16] In addition to extending reconnaissance ranges, aerostats or balloons might also relay and extend line-of-sight communications. For additional information about these airborne capabilities, see the SCS MILCAP study, "Special Mission Aircraft and Unmanned Systems."

(Japanese Ministry of Defense Photos)

Figure 8. KJ-500 AEW&C Aircraft and BZK-005 UAV

Data Link, 数据链

While not subject to observation in imagery, multilevel military data links that allow for information exchange among the island-reefs and nearby military forces are certainly used by the PLA in the SCS. "Data links" may refer to a specific data protocol that travels over a variety of different communications networks. The term "data link" may also refer to a specific communications system consisting of matching data link terminals that form a unique communication network.

[15] Joint Staff, 中国機の東シナ海における飛行について [Chinese aircraft flying in the East China Sea], press release (Tokyo: Japanese Ministry of Defense, March 23, 2020), http://www.mod.go.jp/js/Press/press2020/press_pdf/p20200323_01.pdf. Also, Joint Staff, 推定中国機の東シナ海における飛行について [Presumed Chinese aircraft flying in the East China Sea], press release (Tokyo: Japanese Ministry of Defense, April 30, 2018), http://www.mod.go.jp/js/Press/press2018/press_pdf/p20180418_01.pdf.

[16] Ankit Panda, "Imagery Suggests China Deployed Surveillance Aerostat to Mischief Reef in the South China Sea," *The Diplomat*, December 3, 2019, https://thediplomat.com/2019/12/imagery-suggests-china-deployed-surveillance-aerostat-to-mischief-reef-in-south-china-sea/

Chinese Military Data Link Development

In the early 2000s, the Chinese military services began to field different data link systems and standards. By 2010, the PLA ground force, Air Force, and Navy acquired different data link systems that were not interoperable across the services.[17] The PLA Navy, for example, developed the HN-900 air- and surface-data link. The original HN-900-series data links were very similar to (if not based on) the US Navy/NATO Link-11 that operates in the HF- and UHF-bands. PLA Air Force dedicated data links included the "485/484 Anti-Interference Data Transmission System" ("485/484 抗干扰数据传输系统").[18]

By 2007, the PLA began fielding a joint data link system that Chinese sources indicated was similar to (if not based on) the US Link-16/Joint Tactical Information Distribution System (JTIDS) data link. At the time, this VHF-band Chinese data link was called the Tri-service Tactical Information Distribution System (三军战术数据分发系统), abbreviated by Chinese sources in English as TIS. TIS appeared to be very similar to Link-16, employing frequency-hopping spread spectrum (FHSS) techniques to resist jamming and operating between 960 and 1,215 megahertz.[19] Whether TIS operated within or beyond this frequency range, 960 to 1,215 megahertz is the frequency range set aside for Link-16-type data link operation by the United Nations International Telecommunication Union (ITU).[20]

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[17] Kevin Pollpeter, "Towards an Integrative C4ISR System: Informationization and Joint Operations in the People's Liberation Army," in The PLA at Home and Abroad: Assessing the Operational Capabilities of China's Military, ed. Roy Kamphausen, David Lai, and Andrew Scobell (Carlisle, PA: US Army Strategic Studies Institute, 2010), 205.

[18] Zhao Rui, Zhong Bang, and Zhu Zuli, "战术数据链发展现状" [Tactical Data Link Development Status], 期四川兵工学报 [Sichuan Military Engineering Journal] 33, no. 12 (December 2012): 61. PLA Navy dedicated data links had included HN-900-series data links such as H/TJN-901, H/TJN-902, and H/TJN-903. These PLA Navy data links are possibly being phased out (as Link-11 has been in the West). Recent articles have highlighted a new PLA Navy data link, H/TJN-906, which is described as a "high-speed broadband data link" (高速宽带数据链). See, for example, "中国新型 054B 舰竟如此高端" [Chinese New Type-054B Ship is so High-End], 新浪军事 [Sina Military], June 3, 2017, http://mil.news.sina.com.cn/jssd/2017-06-03/doc-ifyfuzny2872787.shtml.

[19] Xu Lei, Wang Rong, and Yao Minli, "TIS 系统的弱实施多任务网管的设计" [Windows NT-Based Research on Soft Real-time Multi-Task Gateway of TIS], 电光与控制 [Electronics Optics and Control] (August 2007): 16, cited in Pollpeter, "Towards an Integrative C4ISR System," 204–205.

[20] "Frequency Allocations, Article 5, 5.328," in Radio Regulations Articles (Geneva: International Telecommunications Union, 2016), 99, http://search.itu.int/history/HistoryDigitalCollectionDocLibrary/1.43.48.en.101.pdf. China would likely want to appear to comply with the ITU-established worldwide frequency allocation for "aeronautical radionavigation services" and Link-16-type data links.

The Chinese joint data link, TIS, evolved into JIDS, the "Tri-Service Joint Information Distribution System," simplified as the "Joint Information Distribution System" (三军联合信息分发系统 or 联合信息分发系统). As with TIS, JIDS appears to be very similar to Link-16/JTIDS, possibly with additional modifications.[21] Chinese sources describe JIDS as a data link that connects Army, Navy, Air Force, and SATCOM networks, integrating different service-level tactical data links into a single joint network.[22]

The PLA may also be integrating a next-generation data link in its operational forces. The DTS-03 tactical data link is described as a follow-on to the Chinese JIDS data link.[23] According to CETC, the manufacturer of the DTS-03 terminals, this data link has a significantly higher data exchange rate at much lower latency than Link-16. The new data link incorporates ad-hoc technology to create a mesh network that is not dependent on a fixed network topology but dynamically reconfigures itself based on the performance and availability of different DTS-03 terminals. DTS-03 is also advertised to support a "cooperative engagement capability," presumably similar to the US Navy Cooperative Engagement Capability (CEC) that integrates sensors with fire control systems for seamless weapons engagements. DTS-03 was first mentioned at the 2014 China Air Show as a new data link under development.[24] At the 2018 China Air Show, CETC displayed DTS-03 terminals and other hardware, indicating that the PLA may be fielding the new-type data link (see Figure 9).

Data Link Employment

According to a 2014 journal article, PLA data links may be categorized into three levels, all of which are likely used to some extent on the SCS outposts. These data links include 1) weapons collaborative data links (武器协同数据链), 2) tactical collaborative data links (战术协同数据链), and 3) theater collaborative data links (战区协同数据链).[25]

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[21] Zhao, Zhang, and Zhu, "战术数据链发展现状" [Tactical Data Link Development Status], 61.

[22] Fu Jizong, Huo Lei, Feng Xiaoqin, Chen WenXing, and Fan Haiwen, "基于数据链的联合作战技术" [Data Link-Based Joint Warfare Technology], 火力与指挥控制 [Fire Control & Command Control] 39, Supplement (July 2014): 13.

[23] DTS may be an acronym for Data Terminal Set (数据终端设备 or 数据终端机).

[24] "官媒曝新型数据链装备歼-11 技术已超越美军" [Official Media Exposes New J-11 Data Link Equipment Technology that has Surpassed the U.S. Military], 凤凰视频 [Phoenix Video], June 20, 2016, http://inews.ifeng.com/yidian/49197315/news.shtml?ch=ref_zbs_ydzx_news. See also Mu Keshuang, "是雄鹰，就去天空寻找胜利答案" [As Eagles, Go to the Sky to Find the Answer for Victory], 解放军画报 [People's Liberation Army Pictorial], June 17, 2016, http://photo.81.cn/pla/2016-06/17/content_7105998_4.htm.

[25] Fu et al., "基于数据链的联合作战技术" [Data Link-Based Joint Warfare Technology], 13.

Weapons data links are specific to different weapons and weapon systems. Tactical data links, that probably include JIDS or DTS-03, contribute to maintaining a joint common operational picture (COP) and common intelligence picture (CIP) among operational units, ships, and aircraft. Theater data links provide "cross-war zone coverage" (跨战区覆盖), distributing data within a particular theater of operations (e.g., the PLA's southern theater, responsible for the SCS outposts). In addition to distributing a COP and CIP, theater collaborative data links transmitted over SATCOM or other long-haul communications may also exchange imagery, combat plans, and other high-level command and control information.[26]

(JHU/APL Photo)

Figure 9. DTS-03 Data Link Type-I and Type-II Terminals on Display at Air Show China 2018

Conclusions

Inter-island communications, such as other communications or reconnaissance capabilities on China's SCS island-reefs, are diverse and redundant. Troposcatter communications provide over-the-horizon links up to 20 Mbps among four of the seven Chinese outposts. Line-of-sight communications, which may include VHF- or UHF-band communications, connect the smaller outposts in the center of the island-reef network. Line-of-sight communications also provide voice communications or data link connectivity to nearby ships or high-flying manned aircraft or UAVs

[26] Fu et al., "基于数据链的联合作战技术" [Data Link-Based Joint Warfare Technology], 15.

operating several hundred kilometers from the island-reef airfields. Airborne platforms may also create an airborne communications layer, relaying line-of-sight communications beyond the surface horizon. Cellular base stations provide service on each island-reef and afford cell phone and data service to ships operating within sight of the Chinese outposts. The advent of 5G cellular services promises to improve mobile communications on the SCS island-reefs, a development that may have significant military utility given 5G's improvements in data volume and speed.

Shorter range, inter-island communications capabilities on China's SCS outposts are complementary to long-range communications capabilities, such as undersea fiber-optic cable or SATCOM, that may also provide inter-island connectivity. The redundancy and structure of the PLA's SCS communications offer dozens of different combinations to support a self-healing network. In a conflict, as different communications are jammed or physically damaged, battlespace information as well as command and control may be rerouted from one link to the next through ships, aircraft, and the island-reefs until communications reach their intended destination (see Figure 10).

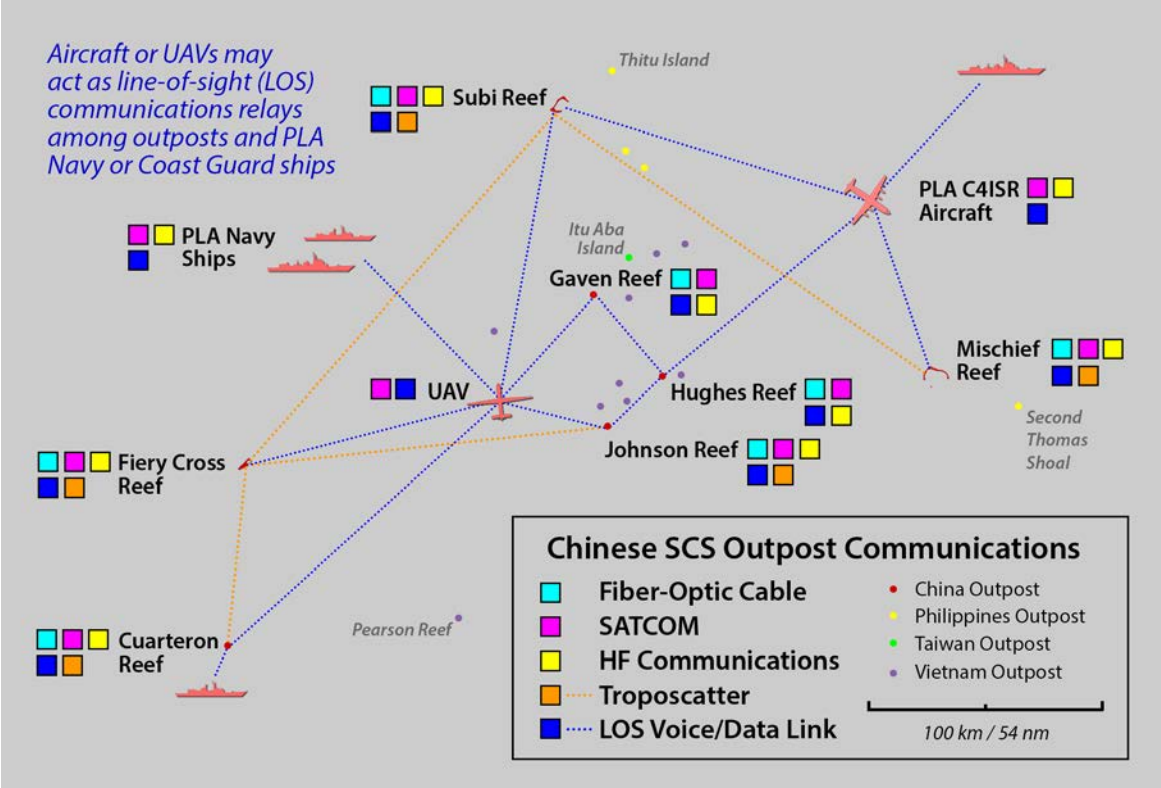


Figure 10. Chinese SCS Outpost Communications

Inter-Island Communicaitons

The Chinese investment in inter-island communications among the PLA outposts demonstrates an informationized warfare strategy that emphasizes information control. Inter-island communications capabilities contribute to robust and redundant communications that utilize different phenomenologies and cover a broad swath of the electromagnetic spectrum. Countering the PLA's ability to communicate in a conflict will involve simultaneously interfering with or destroying a number of Chinese communication 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).[27] 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.

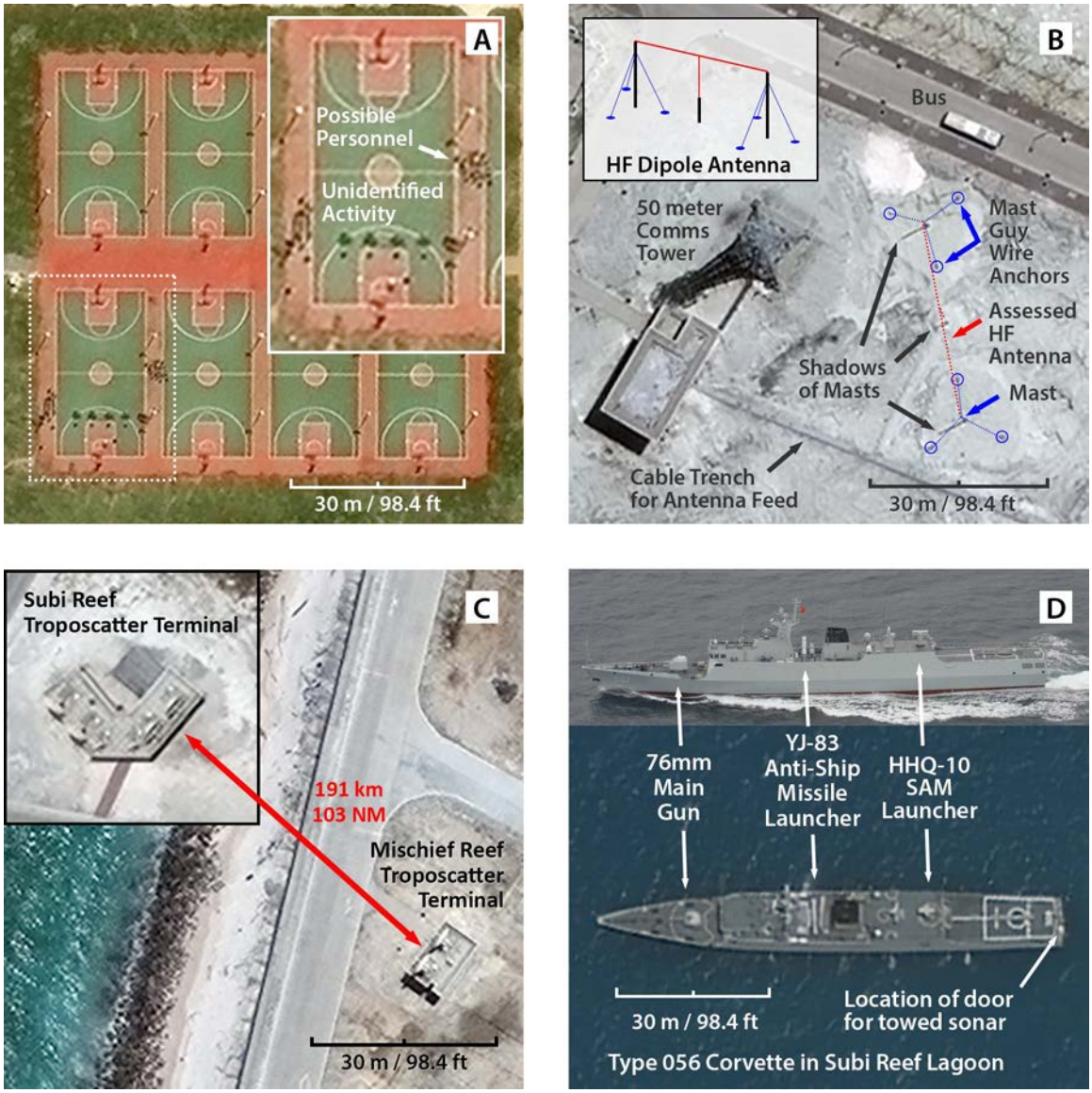
Table 1. DigitalGlobe Inc. WorldView-3 Satellite Imagery Details

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 11. The dots made up of only a few pixels in Figure 11(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 11(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 11(C) is an example that indicates the likely connection between two widely separated troposcatter terminals based on antenna pointing angles. Figure 11(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.[28]

[27] 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.

[28] 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 11. 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

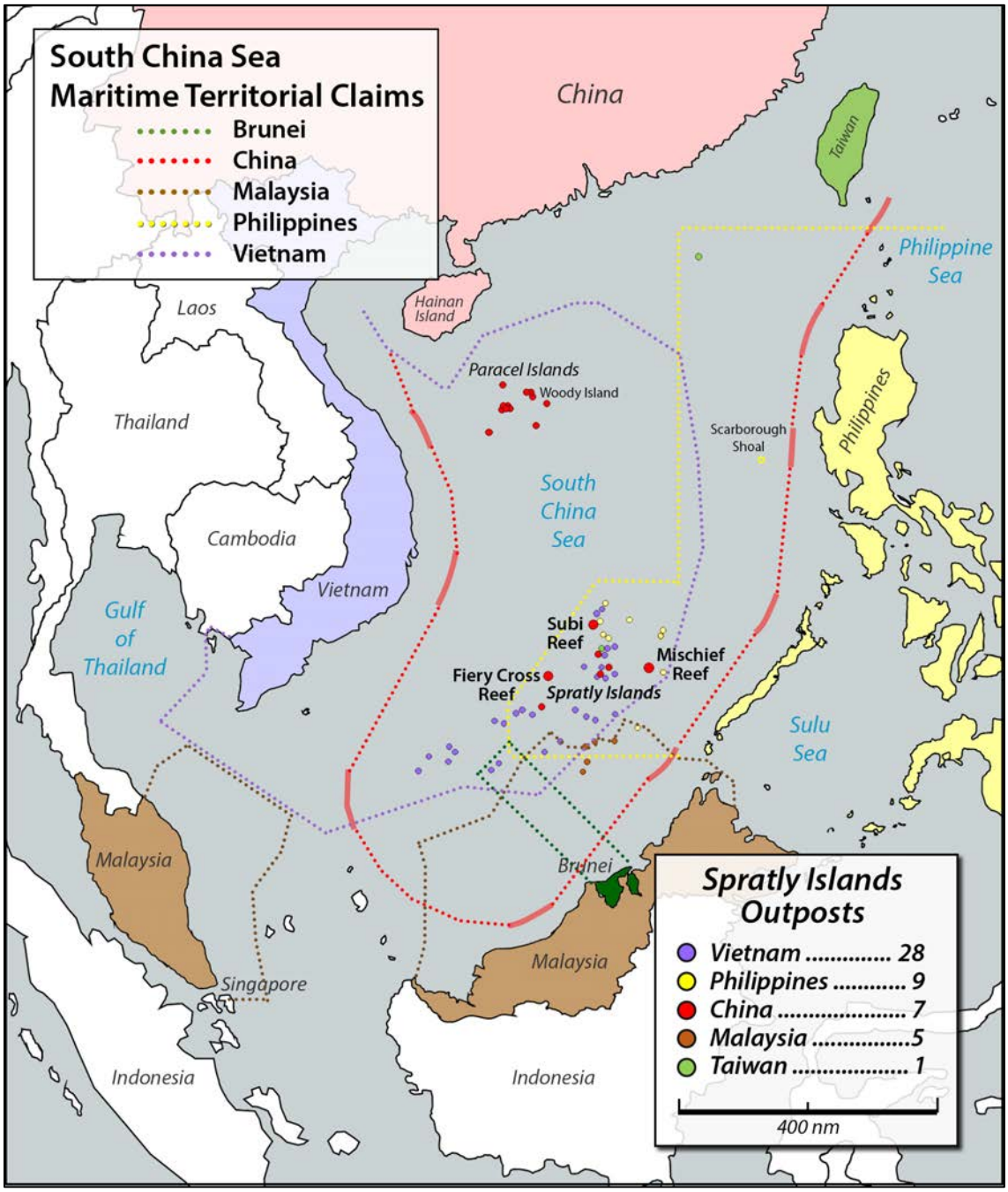


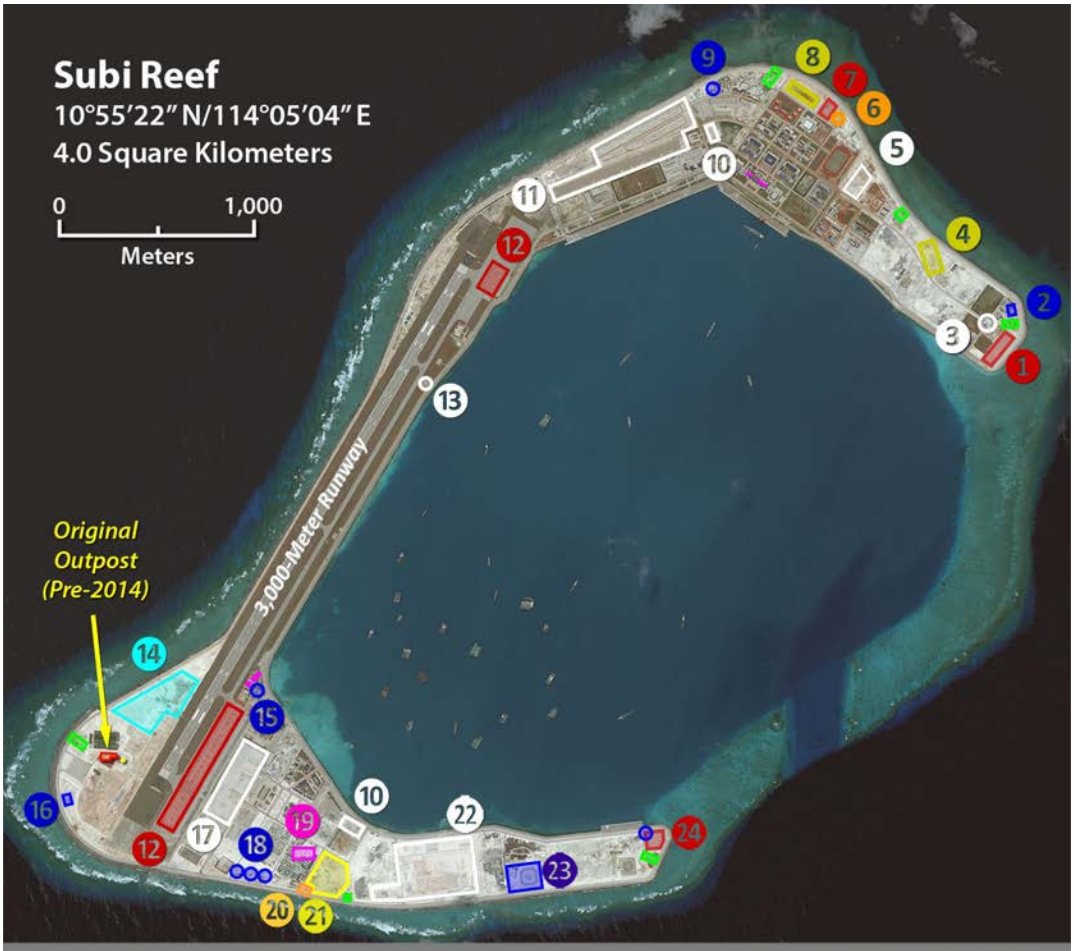
Figure 12. South China Sea Maritime Territorial Claims

Appendix C. Island-Reef Capabilities Overview Graphics

(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 13. Fiery Cross Reef Overview

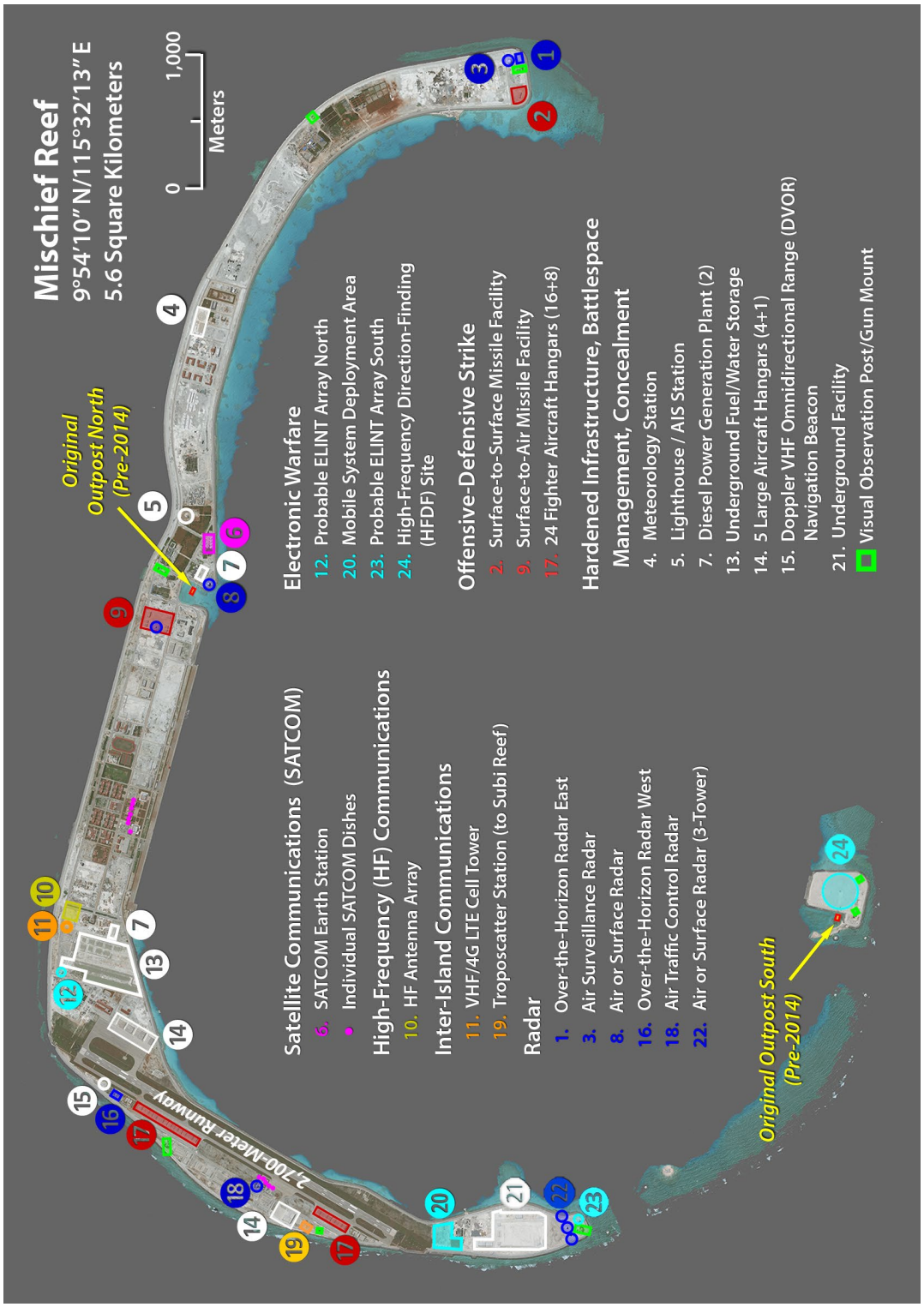
Inter-Island Communicaitons



(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 14. Subi Reef Overview

Inter-Island Communicaitons



(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 15. 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

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

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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