Keeping an Eye on the Islands: 
Remote Monitoring in the South China Sea

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Abstract

This paper explores the utility and technical feasibility of aerial and commercial satellite imaging for cooperative monitoring of islands, islets, and reefs in the South China Sea — a region that has long been a source of conflict amongst the coastal states. We examine a subset of islands and reefs to test overhead imaging systems that may be useful for verifying possible future agreements designed to defuse the multilateral conflict. Moderate-resolution (5-10 meter) commercial satellite imagery was generally limited in utility, with the notable exception of Radarsat-1 imagery. Radar imagery proved to be an effective wide area search and detection tool, capable of detecting ships and structures independent of weather or lighting conditions. High-resolution (<1 m), aerial images provided a significant amount of information that was extremely useful for change detection analysis, ship identification, and infrastructure assessment. Based on this result, high-resolution satellite imagery should provide comparable detail from a higher vantage point, but only for limited time periods during daylight hours.

Our study concludes that a combination of aerial and satellite imaging can provide timely, substantive information on ships, structures, and activities in the South China Sea. Specific political agreements covering the area may be verifiable if the provisions are tailored to the imaging capabilities and limitations that were identified in this study. All of the necessary aerial and satellite imaging platforms for South China Sea monitoring will be in place by the year 2000. From that point onward, a formal monitoring regime optimized for the South China Sea will be technically feasible.
Keeping an Eye on the Islands: Remote Monitoring

in the South China Sea

Vipin Gupta and Adam Bernstein

Introduction

The Spratly islands in the South China Sea have long been a source of conflict and ill will among the states that surround them. Brunei, China, Malaysia, Philippines, Taiwan, and Vietnam have argued for decades about sovereignty over the islands, islets, and reefs in this region. China, Taiwan, and Vietnam claim the entire archipelago as their own while Brunei, Malaysia, and the Philippines lay claim to parts of it. Some of these states have had serious naval skirmishes in and around the South China Sea. More often they rely on less direct but still provocative means of controlling islands of interest. The methods range from occupation of the islands and construction of landing strips, markers, and other structures to more legalistic stratagems such as the sale of exploratory oil drilling rights, the release of maps indicating ownership, and the announcement of plans to develop certain islands.

Much of the conflict stems from the ambiguity of the claims. Countries often physically occupy or build structures on the islands without ever explicitly laying legal claim to the island or reef in question. Countries appear to be trying in this way to establish a de facto presence, which they hope may become de jure over time. Such tactics raise tensions when competitors discover the unannounced occupations, and have provoked naval battles, diplomatic protests, and the mass arrest of fishermen operating in disputed areas.

Unilateral efforts to patrol or otherwise locally monitor the islands are sporadic, made difficult by the sparse distribution of the islands and by the limited naval strength that most of the countries in the area have at their
disposal. Multilateral cooperation is largely confined to Indonesia-sponsored annual workshops on managing conflict in the South China Sea. The workshops, which began in 1990, have the goal of easing tensions and increasing cooperation among the contesting states. In the last several years, attendees have formed working groups devoted to scientific research, resource development, environmental protection, legal issues, and navigational and communication safety. However, the workshops have yielded little in the way of concrete results, and have not prevented continued unilateral attempts to take control of islands.

In this context, in which diplomatic efforts move slowly while unilateral occupation and development of the islands continues apace, it is worth considering new ways of monitoring this conflict. Sensor technologies, if used to observe the South China Sea in a systematic and non-intrusive manner, might provide the necessary technical underpinnings for verifiable agreements that could defuse the multilateral conflict. While such technologies may not make arms control and confidence building in this region probable, it might make it technically possible.

One monitoring approach that has been suggested for use in the South China Sea is overhead imaging. If changes could be seen remotely on islands and the information readily shared between the interested countries, the naval skirmishes and reprisals that have occurred in the past might be avoided or reduced in frequency. The states' knowledge that the region is under rigorous, multilateral remote surveillance could discourage the unilateral development or takeover of the islands in the future.

In this paper, we explore the usefulness and technical feasibility of cooperative monitoring of the Spratly Islands with aerial and commercial satellite images. We begin with a short résumé of the claims and conflicts in the territory. We then select islands for analysis based on their political significance and the availability of archived overhead imagery. We analyze the images to determine which features can be identified, and examine the
technical constraints placed on the regime by the small size and widespread distribution of the islands. We conclude with an assessment of both the risks and benefits of remote sensing in the context of the sovereignty disputes in the region.

**Claims and Conflicts in the Disputed Territory**

The Spratly Island chain (figure 1) consists of about 100 islands, reefs, and sea mounts with a total land area of less than 5 square kilometers. The small land masses are scattered across approximately 800,000 square kilometers of ocean. Guano (used for fertilizer) and fish are the principal natural resources. Some studies claim that the region has large oil and gas reserves, although the predictions vary widely and appear to be based on little hard data. Despite the uncertainty of the estimates, most of the countries in the region are interested in the Spratlys because of their potential as a source
for oil. The islands' geostrategic value is significant due to their proximity to major shipping lanes and to the mainlands of the Philippines, Brunei, Vietnam, and Malaysia. In addition, perhaps due to suspicions and nationalist sentiments raised by decades of low-level hostilities, the islands have acquired an import beyond their current economic and strategic value, turning them into emblems of sovereignty to many states in the region.  

Actual claims to the Spratlys are variously based on historical evidence, existing occupation, and limits defined by treaties and unilateral decrees. China and Taiwan claim all features in the Spratly Islands both above and below sea level. China occupies or has placed markers on seven to ten reefs in the Spratlys, while Taiwan occupies one of the largest islands, known as Taiping or Itu Abu. Vietnam claims everything above sea level in the Spratlys as its own; it has outposts on about 23 islands or reefs. The Philippines occupies eight islands or cays in an area it refers to as the Kalayaan region, or "Freedomland." Malaysia claims all six islands within a continental shelf limit defined in 1979, and occupies three of these; the other three are occupied by Vietnam and the Philippines. Brunei's claim is most conservative, restricted to the seas surrounding Louisa Reef, apparently not even including the reef itself.  

Over the past few decades, China, Malaysia, the Philippines, Taiwan and Vietnam have all fought over sites in contested areas. Some of the salient disputes have occurred within the past ten years. These recent incidents show distinct patterns of confrontation in 1988, early 1995, and late 1998 separated by periods of tense calm:

- In 1988, China began construction on Fiery Cross Reef, also claimed by Vietnam. Vietnam then engaged in a battle near the reef with China in which three Vietnamese ships were sunk and 72-75 Vietnamese killed.  
- In 1992, China announced an oil exploration deal near the Spratlys with the US company Crestone. In 1994, Vietnam built a drilling rig in the Crestone area, even as China claimed sovereignty over Vietnam's nearby 'Blue Dragon' exploration area.  
- In early 1995, China began construction of several buildings on Mischief Reef that the Philippines described as "military structures." The Philippines reacted by removing
Chinese markers from the island and bringing journalists to the reef to observe China's activities.11

- In March 1995, the Philippine navy arrested Chinese fisherman near Alicia Reef that it claims along with China.12 Filipino forces also arrested 62 Chinese fishermen at Half Moon Shoal.13

- In late March 1995, Taiwanese forces fired warning shots at a Vietnamese cargo vessel that violated a Taiwan-declared exclusion zone around Itu Abu, an island it occupies in the Spratlys.14 In the same week, Filipino forces fired warning shots at Chinese fishing boats that came within one mile of its occupied position on Thitu Island.15

- On 8 September 1998, China formally protested Vietnam's sudden occupation of Orleana Shoal and Kingston Shoal. China claims sovereignty over both of these shoals.16

- On 6 November 1998, the Philippines released a public statement calling for China to terminate intensified construction activities at Mischief Reef. The Philippines accused China of building more permanent, fortified structures on Philippine territory.17 Chinese officials claimed that they were merely repairing fishing shelters that were damaged by storms.18

**Islands Selected for Analysis**

We chose specific islands for image analysis through an iterative process. First, we selected a set of islands for study based on their political significance and topographic features. We then searched for suitable commercial aerial and satellite images of those islands. In situations where no images were found, we substituted other islands into the study set and searched the archives again.

The searches of the satellite archives concentrated on high-resolution (<10 m), panchromatic imagery. Since published aerial photos and media reports indicated that island activities and infrastructure were small-scale and rudimentary, the imagery with the highest spatial detail had the best chance of providing observable evidence of island occupations. The need for high spatial resolution focused the data search on four satellite archives: declassified US CORONA images, declassified Russian KVR-1000 images, Indian IRS-1C and IRS-1D images, and Canadian Radarsat images.19

Table 1 shows the initial set of islands that were selected for detailed examination. The table gives the geographic location of each island and
Table 1: Initial Selection of islands in the South China Sea for detailed image analysis.

<table>
<thead>
<tr>
<th>Island</th>
<th>Present Occupants</th>
<th>Geographic Location</th>
<th>Significance of Island</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mischief Reef</td>
<td>China</td>
<td>9° 53' N, 115° 32' E</td>
<td>China took control of the reef in early 1995, triggering ASEAN to protest the surprise occupation. Aerial photos indicate that China constructed several octagonal structures on the reef. Philippines, Taiwan, and Vietnam also have claims to the reef.</td>
</tr>
<tr>
<td>Thitu Island</td>
<td>Philippines</td>
<td>11° 03' N, 114° 17' E</td>
<td>Thitu Island is the largest Philippine-occupied island. The island reportedly has an airstrip, lighthouse, and power plant. China, Taiwan, and Vietnam also have claims to the island.</td>
</tr>
<tr>
<td>Itu Abu</td>
<td>Taiwan</td>
<td>10° 23' N, 114° 21' E</td>
<td>This island is one of the larger land masses in the area. It reportedly has a marine garrison, helicopter pad, meteorological center, and a communications facility is reportedly under construction and an 1800 meter airstrip is apparently under consideration. China, Vietnam, and the Philippines also claim the island.</td>
</tr>
<tr>
<td>Southwest Cay</td>
<td>Vietnam</td>
<td>11° 26' N, 114° 20' E</td>
<td>Occupied by different countries, these two islands are only 4 km away from each other. The SW and NE Cays illustrate how two countries that do not border each other can create a potential frontline in the S. China Sea.</td>
</tr>
<tr>
<td>Northeast Cay</td>
<td>Philippines</td>
<td>11° 27' N, 114° 21' E</td>
<td></td>
</tr>
<tr>
<td>Fiery Cross Reef</td>
<td>China</td>
<td>9° 40' N, 113° 02' E</td>
<td>China began construction on this reef in early March 1988. Vietnam tried to disrupt this construction, which resulted in an armed conflict. The reef reportedly holds a large Chinese observation post along with a helicopter pad and pier.</td>
</tr>
<tr>
<td>Spratly Island</td>
<td>Vietnam</td>
<td>8° 39' N, 111° 55' E</td>
<td>Vietnam reportedly built a lighthouse, 600 m airstrip, harbor, power plant, and radio station. China and Taiwan also claim this island.</td>
</tr>
</tbody>
</table>

Table 1: Initial Selection of islands in the South China Sea for detailed image analysis.

explains why each was selected for image analysis. Every island that was chosen for detailed study was either a significant base of operations or a flashpoint with a documented history of threats and conflict between two or more countries. Our subsequent search found high-resolution satellite images for only two of the six selected islands: Mischief Reef and Thitu Island. Aerial
imagery was found for four of the six selected islands, but only 12 photos were publicly available. This result was quite revealing. It indicated that declassified and commercial satellite imagery have not been used on a sustained, systematic basis to monitor the principal conflict areas in the South China Sea. It also indicated that aerial imagery of these same areas was either limited or generally kept secret by the respective conflicting parties.
As a result, the selected set of islands was revised to accommodate the limited archive of suitable images of the study area. Table 2 and Figure 2 show the revised set of islands that were ultimately analyzed with aerial and commercial satellite imagery. Each island was selected by considering its relative size and significance along with the availability of archived images. Preference was given to islands imaged by commercial satellite platforms because this particular technology has not been tested for South China Sea monitoring.

**Analysis of Aerial and Satellite Imagery**

We analyzed images of each island listed in Table 2 for infrastructure, ongoing activities, and natural phenomena. We searched for manmade and natural changes as well as evidence that could confirm or refute accounts in
published articles about specific islands. The image analysis enabled us to assess the technical capabilities and limitations of the various imaging systems that were used, and gauge the likely utility of imaging satellites that are planned for deployment within the next few years.

**Mischief Reef**

In early 1995, the appropriately named Mischief Reef emerged as a major flashpoint in the South China Sea when China began constructing and occupying buildings on the reef. Filipino fishermen reportedly discovered the Chinese occupation, were detained by Chinese personnel at Mischief Reef, and subsequently notified Philippine authorities after being released. Philippine naval and air force reconnaissance confirmed that the Chinese had taken control of the reef located 215 km west of undisputed Philippine territory. The Philippine government perceived the Chinese action as a direct challenge to their own sovereignty claim over Mischief Reef.

The Philippine Department of National Defense reported that several Chinese naval ships were sighted in close proximity to the reef, including a Yukan-class amphibious warfare ship and a Dazhi-class submarine support ship. As evidence, the Philippines released aerial photos showing Chinese activities in the area. Plate 1 is an aerial photo of an armed Chinese ship that was reportedly at Mischief Reef in early 1995 (Note: the annotations on all plates are based on our image interpretation). Plate 2 shows aerial photos of two armed ships that the Philippines identified as Chinese. Both of these ships were photographed in the spring of 1997 near Philippine-occupied areas in the South China Sea.

In addition to the ship activity, the Philippines presented aerial photos of four permanent building clusters on Mischief Reef that had been built by China. Each cluster was constructed on top of steel pylons because the reef submerges at high tide. Plates 3 and 4 show two of the four building clusters in great detail. Acquired a few months after China took control of the reef, the
Plate 1: Philippine aerial photo acquired on 1 February 1995 showing a ship that was reportedly located at Mischief Reef. The photograph has a spatial resolution of .2 meters. Our analysis revealed that this is a Chinese Yannan-class ship, an armed survey and research vessel. The inset is a reference image of a Chinese Yannan-class ship from Jane’s Fighting Ships, 1995-1996. The connected circles show the features in the overhead image that match the reference image. Because of the overhead view, neither the flag nor the identification marks along the bow could be seen. (Overhead aerial image courtesy: Agence France-Presse, Reference image courtesy: Jane’s Information Group)

Plate 2: Philippine aerial photos acquired in the spring of 1997. These two armed ships were reportedly photographed in the South China Sea and identified as Chinese. In the large photo, the flag is not identifiable, but the ship’s pennant number (‘420’) is legible. The class of the ship is not known for certain although it may be a variant of Yenlai-class. The inset shows a Chinese Yannan-class ship with a pennant number of ‘24’ or ‘124’ (see Yannan-class reference image in Plate 1 inset). (Aerial images courtesy: Agence France-Presse)
Plate 3: Aerial photo showing one of four building clusters that China constructed and occupied. The photo was taken a few months after China took control of the reef. Many features in the image were identified. The inset shows an individual standing on a platform scrutinizing the observation aircraft and a second possibly armed individual positioned behind one of the armor shields along the periphery of the building cluster. (Courtesy: Agence France-Presse)

Plate 4: Aerial photo showing another Chinese building cluster on Mischief Reef. As in Plate 1, many features in the image were identified. In both clusters, the huts were deliberately built away from the octagonal buildings which suggests the storage of items that need to be kept away from the living quarters for safety or hygienic reasons. The inset shows an individual with binoculars watching the observation aircraft as it flies by. (Courtesy: Agence France-Presse)
Plate 5: 4 September 1997 IRS-1C satellite image of Mischief Reef. The IRS-1C panchromatic sensor acquired the image at a six meter ground sample distance. The image was then resampled so that each pixel covers a 5 m x 5 m ground area. The four reported building clusters could not be identified, but four distinct blips along the north, south, east, and west perimeter were detected. In addition, a 68±5 meter long feature inside the lagoon was found that could be a naval vessel. The feature could not be conclusively identified because its shape was blurred and its shadow was not visible in the lagoon (see inset).

Photos show the personnel at the building clusters carefully observing the observation aircraft as it flies by. Both photos also show the deployment of armor shields along the periphery of the building clusters. The Plate 3 inset shows a possibly armed individual behind one of the armor shields facing the observing aircraft.

IRS-1C satellite images of Mischief Reef show the entire landscape as well as the surrounding sea. In both Plates 5 and 6, one can readily see the reef structure, lagoon with a passable opening to the sea, small reef islets inside the lagoon, and the ephemeral beach along the northern periphery.
Plate 6: 10 November 1997 IRS-1C satellite image of Mischief Reef. The IRS-1C panchromatic sensor acquired the image at a six meter ground sample distance. The image was then resampled so that each pixel covers a 5 m x 5 m ground area. Two blips were detected along the north and east periphery and one naval vessel was identified. The vessel is 71±5 meters long and it has a distinct, blurred appearance (see inset). Its class could not be determined, but several ship classes were eliminated from consideration based on the length measurement.

Acquired 2.5 years after the Chinese occupation, these panchromatic images show significantly less detail than the aerial photos.

The 4 September 1997 IRS-1C image shows the reef with four noticeable blips along the north, south, east, and west perimeter (Plate 5). These blips may be part of the four building clusters described in the media reports on the Chinese occupation. However, it is not possible to be certain about this because the individual buildings within each cluster are not visible. Inside the lagoon, there is a 68 ± 5 meter long feature that could possibly be a naval vessel. Unfortunately, a more definitive identification could not be made.
because the feature's shape is blurred and its shadow could not be discerned in
the lagoon. In the 10 November 1997 IRS-1C image, two of the four blips along the
reef periphery could not be seen, but a feature inside the lagoon could be
positively identified as a naval vessel (see Plate 6). The Plate 6 inset clearly
shows its shape and size. Although the satellite image was too blurred to
identify the class of the vessel with certainty, the feature's measured length of
71 ± 5 meters did eliminate some ship classes from consideration. If the
vessel was Chinese, it was too small to be a destroyer, frigate, or ballistic
missile submarine and too large to be a coastal patrol boat. The vessel was
also too small to be either a Yukan-class supply ship (120 meters long) or a
Dazhi-class support ship (107 meters long). Both ship classes have been
observed at Mischief Reef on earlier occasions. Thus, based on a process of
elimination, the imaged ship was probably either a replenishment ship (e.g.,
Fulin Class), a survey and research ship (e.g., Yannan Class), a cable ship
(Yudian Class), or a civilian transport/fishing ship.

Moderate resolution, panchromatic satellite imagery provided a
synoptic view of Mischief Reef as well as conclusive evidence of a ship
deployment. These initial results suggest that this type of commercial
imagery can be used under favorable weather conditions to detect large
warships and supply ships. If compared with an overhead imagery database
of known ships, the class of the imaged ships may also be identifiable.

However, this same imagery failed to reveal the building clusters
shown in the aerial photos. This suggests that higher resolution imagery is
required to detect smaller scale features such as the manned outposts shown
in Plates 3 and 4. Such high resolution imagery is also likely to be required to
determine the nature and purpose of specific activities.

The importance of high resolution imagery was concretely
demonstrated in late 1998, when the Philippine government announced
renewed Chinese construction on Mischief Reef. The Philippines accused
China of a substantial military buildup. China responded that the activity
Plate 7: This aerial photo was released by the Philippine Department of National Defense on 10 November 1998. The photo shows significant construction activity at one of the four Chinese-occupied areas on Mischief Reef. Working adjacent to octagonal structures that were built in early 1995, the construction workers can be seen placing metal rods into position for the foundation of a large, reinforced concrete structure.

The inset shows the concrete structure near completion just two months later. The inset picture of the five story building was acquired on 15 January 1999 from an aircraft flying at an altitude of 300 feet. It was imaged from a camera bearing offset by 90° from the camera bearing of the main photo. The different perspective views of the small hut visually shows this difference in bearing. (Aerial images courtesy: Agence France-Presse)

merely involved the repair of existing structures damaged by heavy storms. The conflicting accounts could have lingered on as an unsubstantiated factual dispute, but high-resolution photographic evidence helped to clarify the type of activity that was taking place.

Aerial photos acquired by Philippine reconnaissance show significant construction activity around the existing building clusters (see Plates 7 and 8). Plate 7 shows approximately 40 construction workers laying out the skeletal frame for a new, large concrete structure. The Plate 7 inset shows the five story concrete structure nearly completed just two months later. Plate 8 shows approximately 65 workers building a truss structure adjacent to the existing platforms. The photo also shows shrouds covering portions of the platform and a probable anti-air or anti-ship system surrounded by sandbags.
Plate 8: This aerial photo shows new construction activity at a second Chinese occupied area on Mischief Reef. It was also released by the Philippine Department of National Defense on 10 November 1998. In the foreground, the octagonal structures built in early 1995 can be seen with portions of the platform covered by shrouds. In the background, the construction workers can be seen erecting a large, truss structure. On the central platform, personnel can be seen around a large, black object surrounded by sandbags. The object appears to be an anti-aircraft or anti-ship weapon system. However, the type and operational status of the probable weapon system is not evident. (Aerial image courtesy: Agence France-Presse)

In addition to the aerial photos of the construction activity, the Philippines released aerial photos of Chinese naval ships that supported the operation. Plate 9 shows two Chinese amphibious warships at Mischief Reef on 7 November 1998. Both of these large ships are Yuting-class equipped with bow doors and helicopter decks. Plate 10 shows three Chinese naval ships positioned next to each other at Mischief Reef on 10 December 1998. The middle ship is a Dayun-class support ship, and the ships on either side of it are Yuting-class.

The high-resolution aerial images of the 1998 construction and ship activity at Mischief Reef clearly show a rapid buildup of fortified structures.
Plate 9: Philippine aerial photo acquired on 7 November 1998 showing two ships reportedly anchored at Mischief Reef. Our analysis of this photo revealed that these are Chinese Yuting-class ships. These ships are armed and designed for amphibious warfare. With a full load displacement of 4,800 tons and a length of 130 meters, each ship can carry 250 troops along with 10 tanks. The inset is a reference image of a Chinese Yuting-class ship from Jane's Fighting Ships, 1995-1996. Interestingly, the ship in the foreground appears to be the exact same ship as the one shown in the reference image — both are marked with pennant number '991'. The ship in the background is marked with pennant number '934'. Ships '991' and '934' were the first and second Yuting-class ships to be commissioned into the Chinese PLA navy. (Aerial image courtesy: Agence France-Presse, Reference image courtesy: Jane's Information Group)

Plate 10: Philippine aerial photo acquired on 10 December 1998 showing three ships reportedly anchored at Mischief Reef. Our analysis of this photo revealed that the middle ship is a Chinese Dayun-class support ship, and the ships on either side of it are Chinese Yuting-class ships. The Yuting-class ship in the foreground is marked with pennant number '935'; it was the third such ship to be commissioned into the Chinese PLA navy. The inset is a reference image of a Chinese Dayun-class ship from Jane's Fighting Ships, 1995-1996. The connected circles show the features of the middle ship that match the reference image. (Aerial image courtesy: Agence France-Presse, Reference image courtesy: Jane's Information Group)
with logistical support and protection provided by the Chinese PLA navy. The construction of new multi-story, concrete buildings on the reef indicates that the activity went well beyond the repair of existing shelters.

The aerial images also show a marked increase in Chinese capability on Mischief Reef. China established an expanded, fortified presence that enables deployed personnel to better withstand harsh weather and resist attack. The fortifications can also be used to project naval power into the surrounding area and serve as a sanctuary for Chinese fishing vessels operating in disputed waters. The naval forces that have been observed at the reef demonstrate a capability to quickly reinforce China's occupation with more personnel, material, and heavy weaponry.

The images of Chinese activities at Mischief Reef provide some working experience on what can and cannot be done with overhead imagery to monitor the South China Sea as a whole. The lessons drawn from such experience can be expanded further by analyzing images of other areas and activities in the South China Sea.

**Thitu Island**

Thitu Island is the English name for the largest Philippine-occupied island in the South China Sea. Its Filipino name is Pagasa. Philippine forces took control of the island in the 1970s. Since China, Taiwan, and Vietnam also claim this relatively large island, the Philippines established a substantial military presence there to reinforce its claim, deter attempts by others to take over the island, and defend itself in case of attack. The approximately 100-man military force on Thitu Island can also be used to project power in other parts of the South China Sea — particularly air power.
Plate 11: 4 September 1997 Radarsat-1 image of Thitu Island. This synthetic aperture radar image was acquired in the C-Band (5.6 cm wavelength) at approximately eight meter ground sample distance. Although the radar image has the characteristic speckle appearance, the runway is clearly visible and measurable: 1294±5 meters long and 96±5 meters wide. The wave barrier at the end of the runway and portions of the reef can also be seen.

In contrast with the fortified outposts at Mischief Reef, Thitu Island is one of the few islands in the South China Sea with an airfield (known as Rancudo Airfield). Plate 11 shows a Radarsat-1 satellite image of Thitu Island. The radar image provided information on the large-scale infrastructure, but little detail on the small-scale features such as aircraft, vehicles, and buildings. The runway is clearly evident. Built on top of the island's coral base, it is substantially wider than the island itself. The image also shows the wave barrier at the end of the runway as well as portions of the island's surrounding reef structure. Scattered throughout the island are a few bright blips that could not be identified, but are most likely vehicles, buildings, and other parts of the island infrastructure.
Plate 12: Aerial photo of Thitu Island. This image was acquired in February 1998 from a C-130 transport plane. In addition to the runway, the image shows buildings amongst the lush vegetation and the aircraft parking area. An observation tower next to the taxiway can also be seen.

The inset is a close-up view of the runway which appears to consist of grass, coral, and concrete. The photo was taken from the C-130 cockpit while on landing approach from the west. Notice the wave barrier at the end of the runway. This same barrier can be clearly seen in the Radarsat-1 image in Plate 11.

Aerial photos of Thitu Island show the runway surface composition and significantly more detail on the island vegetation and support infrastructure. Plate 12 shows several buildings surrounded by natural vegetation as well as an observation tower and aircraft parking area. The photo shows that the island's coral foundation extends well beyond the beaches. Thus, there is available space to enlarge the operations at the island. Indeed, that is reportedly what the Philippines intend to do.

In early 1999, Philippine government officials announced plans to expand and upgrade the infrastructure at Thitu Island. To accommodate a wider array of military and civilian aircraft, it plans to cement the entire airstrip. There are also unconfirmed reports of extending the runway.
although that may not be necessary because its current length is capable of handling large transport aircraft.

The air operations are planned to be upgraded further with the construction of "temporary" hangars to house Air Force planes. These planes are reportedly OV-10 aircraft needed for increased surveillance activities as well as increased visibility of the Philippine Air Force in the South China Sea. In addition to the expansion of the air operations, the Philippines also plan to construct a pier, causeway, and base operations center.

The Philippines plan to open the island for tourism as well. To attract visitors to the remote area, they intend to construct at least 10 housing units that would be used by fishermen and tourists. The use of the island by civilians could help defray the cost of the occupation and solidify the Philippines' claim of sovereignty over the islands in this area.

The facilities at Thitu Island and the announced plans to improve the infrastructure make this site ripe for continued aerial and satellite monitoring. Overhead imagery could be used to determine whether such plans ever get implemented and how the changes would impact existing agreements and declarations. As illustrated in Plates 11 and 12, the moderate-resolution satellite imagery will most likely be useful for detecting and tracking large-scale changes, while one-meter resolution aerial and satellite imagery will probably be most useful for analyzing new construction activity and monitoring the air traffic to and from the island.

**Subi Reef**

Just 26 kilometers southwest of Thitu Island, China occupies Subi Reef. China took control of the reef in 1988. Although it is only above water at low tide, it is centrally located within the archipelago (see Figure 2). It is the northernmost Chinese-fortified position in the Spratlys, and it is relatively
Plate 13: 4 September 1997 Radarsat-1 image of Chinese-occupied Subi Reef. This image is from the same full Radarsat-1 scene that shows Thitu Island (see Plate 11). It shows the faint outline of the submerged reef with several bright blips located inside the reef perimeter (see inset). The blips are not identifiable, but it is reasonable to infer that the features are ships and/or fixed structures. The circled set of three blips (see inset) correlate with the orientation of the structures shown in the aerial photo of Subi Reef (see Plate 14). Thus, it is reasonable to deduce that this blip cluster represents the fort, platform, and connecting bridge shown in the aerial photo (see Plate 14).

Plate 13 is a Radarsat-1 image of Subi Reef. While analyzing the full Radarsat scene of Thitu Island, we accidentally discovered that the satellite

... close to other strategic islands such as Taiwan-occupied Itu Abu and Philippine-occupied Thitu Island. Consequently, Subi Reef is well suited as a way station and as a monitoring post for observing Taiwanese, Philippine, and Vietnamese activities in the immediate area (see Figures 1 and 2).

Plate 13 is a Radarsat-1 image of Subi Reef. While analyzing the full Radarsat scene of Thitu Island, we accidentally discovered that the satellite
Plate 14: Aerial photos of the fortified Chinese structures on Subi Reef. Both photos were acquired by the Philippine Air Force and released in May 1997. The annotation in the overhead photo was done by Filipino image interpreters (and it appears to be accurate).

The inset is a perspective view of the same structures shown in the overhead aerial image. The perspective view was acquired using an aerial camera that was pointing south. (Aerial images courtesy: Philippine Armed Forces)

had also imaged China’s occupied position on Subi Reef. The discovery was made from the observation of several bright blips inside the reef perimeter. The blips were too coarse to be identifiable, but their bright appearance indicated that the features were distinctively shaped and probably metallic.
The high radar backscatter from these objects suggested that these were manmade structures.

Aerial images of Subi Reef confirmed the Radarsat detection. Plate 14 shows two aerial photos of the fortified Chinese position there. Acquired by the Philippine Air Force, the photos show a round platform, a connecting bridge, and a three-story, concrete fort built on top of a raised foundation. The overhead photo also shows four naval guns and a communications dish.

These specific features could not be identified in the Radarsat image because the resolution was too coarse. However, using the aerial photos, it was possible to identify the blips that corresponded with the fort, platform, and bridge. This was done by comparing the orientation of the blips with respect to north to the orientation shown in the overhead aerial photo. From this comparison, the structures shown in the aerial photos were matched with the corresponding blips in the Radarsat image (see Plate 13 inset).

The analysis of Subi Reef demonstrated how image information from different sensor platforms could be combined to provide a clearer overall picture. The satellite image showed the layout and level of activity at the reef while the aerial photos provided details on the fortifications. The satellite image was useful for detecting the structures as part of a wide area sweep while the aerial photos were useful for identifying the "dots" that were detected. Each sensor platform compensated for the principal technical limitations of the other sensor platform.

Commodore Reef

Commodore Reef is located in the southeastern quadrant of the Spratly archipelago (see Figure 2). Located 110 km west of the Philippines' Palawaan island and 125 km northwest of Malaysia, Commodore Reef is claimed by China, Malaysia, the Philippines, and Vietnam. The Philippines took control of the reef in the 1970s, although one report states that they deserted it in the mid-1980s.49
Plate 15: 4 September 1997 IRS-1C satellite image of Commodore Reef. The IRS-1C panchromatic sensor acquired the image at a six meter ground sample distance. The insets are enlargements that show a total of five distinct blips with connecting linear features. These features may be evidence of human occupation. However, because of the coarse resolution of the image, it is not possible to establish with a high degree of confidence that the reef is occupied.

Commodore Reef was the site of one major incident. In April 1988, the Malaysian navy detained Philippine fishermen operating near the reef. The Philippine government protested the detention, and Malaysia ultimately released the fishermen as a gesture of goodwill. However, they explicitly noted that the release was done without prejudice to Malaysia’s claim over Commodore Reef.\textsuperscript{50}

Plate 15 is an IRS-1C panchromatic image of Commodore Reef. The ‘Figure 8’ shaped reef consists of two, separate lagoons. It is one of the larger reefs in the South China Sea, with portions of it remaining above water at high tide.\textsuperscript{51} The satellite image shown in Plate 15 shows little detail on human occupation of the reef. Careful examination of the image revealed five distinct blips connected by linear features that could be evidence of manmade structures (see Plate 15 insets). However, because of the coarse resolution of the image, it was not possible to verify the reported Philippine presence on the reef with a high degree of confidence. Nor was it possible to determine whether there were any inhabited sites on the portions of the reef that were obscured by cloud cover (see Plate 15).
The IRS-1C satellite image of Commodore Reef illustrates two strengths and two weaknesses of moderate resolution, panchromatic imagery. It can show the geographic layout of a reef in more detail than existing maps. It can also detect blips that may be evidence of human occupation. On the other hand, it cannot, in itself, provide conclusive evidence of a small-scale military presence, nor can it be used to search for features obscured by clouds.

Alicoa Annie and Yuan Anha

Alicoa Annie (also known as Alicia Annie) and Yuan Anha are two large reefs in the South China Sea that have no known occupants. However, both are in relatively close proximity to other reefs and islands that are occupied by various claimant states. Alicoa Annie is just 56 kilometers south-southwest of Chinese-occupied Mischief Reef. Yuan Anha is less than 75 kilometers from reefs that are occupied by the Philippines, Malaysia, and Vietnam (see Figures 1 and 2).

Although the Spratly conflict has sometimes been intense, Alicoa Annie and Yuan Anha have been relatively peaceful. There have been no documented confrontations at Yuan Anha and one at Alicoa Annie. On 25 March 1995, the Philippine navy captured four Chinese fishing boats near Alicoa Annie and arrested 62 fishermen. The detention of the Chinese fishermen took place just two months after China took control of Philippine-claimed Mischief Reef. The arrests were consistent with a pattern of seizing fishing vessels of a claimant state shortly after it occupies another Spratly reef or island.

Plates 16 and 17 are IRS-1C panchromatic images of Alicoa Annie and Yuan Anha. Both were acquired in March 1998 and both are almost completely cloud free. Alicoa Annie and Yuan Anha are appreciably larger in size than the other selected islands and show no evidence of human occupation whatsoever.
Plate 16: 15 March 1998 IRS-1C satellite image of Alicoa Annie. The IRS-1C panchromatic sensor acquired the image at a six meter ground sample distance. The reef is comparable in size with Mischief Reef.

Plate 17: 10 March 1998 IRS-1C satellite image of Yuan Anha. The IRS-1C panchromatic sensor acquired the image at a six meter ground sample distance. This was the largest of the six islands and reefs that were selected for detailed study.
Careful examination of Plates 16 and 17 failed to reveal any blips, paths, or structures that could be attributed to the physical occupation of the reefs. This suggests that moderate-resolution images may have limited utility not only for detecting possible inhabited structures, but also for verifying the absence of such structures on disputed reefs.\textsuperscript{53}

Conclusions

Our study used a variety of aerial and satellite sensors to analyze the selected islands and reefs in the South China Sea. Each study site revealed at least one capability or limitation associated with overhead imaging. The analysis of Mischief Reef demonstrated how high-resolution aerial images were needed to detect and assess the controversial activities there. Moderate-resolution, panchromatic imagery from satellites proved to be limited in monitoring specific activities at Mischief Reef, but it was useful for ship detection and synoptic analysis. The study of Thitu Island demonstrated the value of radar imagery for detecting large-scale infrastructure independent of light conditions or cloud coverage. The aerial photos showed smaller structures such as the individual buildings and observation tower. The accidental discovery of Chinese-occupied Subi Reef in the Radarsat-1 image was a realistic example on how radar imagery could be used as a detection tool. In addition, the analysis showed how coarse resolution features from satellite imagery could be correlated with high-resolution aerial images of the same feature.

The examination of Commodore Reef highlighted the limitations associated with the exclusive use of moderate-resolution, panchromatic imagery. Even though the IRS-1C satellite provided a unique bird's eye view, it was partially obscured by cloud cover and it did not offer enough spatial detail to verify human occupation of the reef. It did, however, show a few "blips" of possible human occupation that could be examined more closely with higher resolution imagery. Alicoa Annie and Yuan Anha served as
controls for the study. The image analysis of these two large reefs with no known occupants came up with no evidence of physical occupation. This suggests that such imagery may be useful for dispelling false allegations of physical occupation and verifying the absence of structures on disputed reefs.

In addition to obtaining empirical results from the study of selected islands and reefs, we also derived results from the different types of remote sensing systems that were used. Table 3 charts the strengths and weaknesses of four general types of aerial and satellite imaging sensors. The assessment is based on the technical and operational utility of each sensor for monitoring the South China Sea specifically. The fourth type, high-resolution satellite imaging, was not used in this study, but its strengths and weaknesses can be extrapolated from high-resolution aerial imaging and moderate-resolution satellite imaging.

From Table 3, we can devise an imaging strategy optimized for monitoring the South China Sea. The overall technical objective would be to monitor all civilian and military activity in the area without provoking an armed incident. To do this, the imaging strategy would have to rely on satellite imaging as much as possible; it is the only platform that can scan the entire South China Sea on a routine basis for ship and island activity. And in contrast with aircraft, imaging satellites can operate from a safe altitude without the risk of being misinterpreted as a fighter-bomber.

Moderate-resolution, radar imaging satellites are the best space-based system for performing routine search missions over the South China Sea. Unaffected by adverse weather, radar imaging satellites are the only systems capable of searching for controversial activities that may deliberately use cloud cover as a screen. Radar images from satellites such as Radarsat-1 are well suited for detecting the large ships and outposts that have been observed in the South China Sea. If the images are delivered within 8-72 hours of acquisition, these images could provide early warning of controversial or prohibited activity, whether civilian or military.
Remote Imaging Strengths | Weaknesses
--- | ---
## Technology
Low Altitude (<5000 ft) Aerial Imaging
- Can acquire perspective views of ships, structures, and activity with very high spatial detail, approximately 2-5 m resolution (see Plates 2-4, 7-10, 12)
- Can be cued to examine suspect sites at any time of day
- Acquires images with very small fields of view and thus do not show the surrounding area
- Cannot be used effectively to search for activity throughout the entire South China Sea
- Cannot be used in adverse weather conditions
- May be interpreted as hostile and are highly vulnerable to anti-aircraft fire

High Altitude (>5000 ft) Aerial Imaging
- Can acquire overhead images of ships, structures, and activity at high spatial resolution, approximately 1-5 meter resolution (see Plates 1, 14)
- Can acquire perspective views at 1-5 meter resolution
- Can be used to monitor a limited set of specific islands and reefs
- Can be cued to examine suspect sites at any time of day
- Acquires images with small fields of view and thus do not show much of the surrounding area
- Cannot be used efficiently to search for activity throughout the entire South China Sea
- Cannot be used in adverse weather conditions
- May be interpreted as hostile

Mod-Resolution (5-10 m) Satellite Imaging
- Can use radar imagery to search for ships and structures throughout the South China Sea independent of weather or lighting conditions (see Plates 11, 13)
- Can use panchromatic or multispectral imagery to search for possible occupied sites and cue aerial sensors to suspect sites (see Plates 5-6, 15)
- Operates at an altitude of 500-1000 km; the observed do not see the satellite that is imaging them
- Are invulnerable to anti-air weaponry
- Cannot provide enough spatial detail to determine the nature of observed activity
- Cannot acquire panchromatic or multispectral images of islands at night or during bad weather conditions
- Cannot be used to image suspect sites at any time of day

High-Resolution (1-2 m) Satellite Imaging
- In addition to all the strengths of moderate resolution satellite imaging, can show high spatial detail of ships, structures, and activity
- Cannot acquire panchromatic or multispectral images of islands at night or during bad weather conditions
- Cannot be used to image suspect sites at any time
- Cover a smaller area than moderate resolution satellite images

<table>
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<th>Strengths</th>
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<td>Low Altitude (&lt;5000 ft) Aerial Imaging</td>
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<tr>
<td>- Can acquire perspective views of ships, structures, and activity with very high spatial detail, approximately 2-5 m resolution (see Plates 2-4, 7-10, 12)</td>
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<tr>
<td>- Can be cued to examine suspect sites at any time of day</td>
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Table 3: The strengths and weaknesses of aerial and satellite imaging for monitoring the South China Sea.
Any activity detected in a radar image would most likely appear as a fairly coarse blip. Consequently, higher resolution images would be needed to investigate further. To facilitate the creation of a stable monitoring regime, commercial imaging satellites would be the preferred "close look" platform because the images could be acquired from a safe, remote vantage point, transmitted to a central image archive, and shared with all claimant states and other interested parties.

If such images are unavailable in a timely fashion due to the orbital position of the satellite, the tasking load, or cloud coverage, aerial imaging would be the next viable option for investigating any suspect features found in the radar satellite sweep. To minimize the risk of vulnerability and armed confrontation, the aerial imaging should be done using visibly unarmed aircraft flying around the suspect site at maximum possible stand-off distances. To maximize the degree of transparency in the South China Sea, the aerial data should be shared in a cooperative manner so that claimant states and interested parties can independently assess the observed activity. Such sharing could build on the precedent established by the Philippines' routine release of aerial images of South China Sea sites.

Our remote sensing study shows that aerial and satellite imaging can provide timely, substantive information on ships, structures, and activities in the South China Sea. With the devised optimal monitoring strategy, future studies can now consider verification provisions for specific political agreements tailored to the capabilities and limitations of aerial and satellite imaging. All of the necessary aerial and satellite imaging platforms for South China Sea monitoring are scheduled to be in place by the year 2000. From that point onward, a formal monitoring regime optimized for the South China Sea will be technically feasible. Whether such a regime will be realized will ultimately depend on multilateral agreement to an interim or permanent solution to the Spratly conflict.
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8 Thomas and Dzurek, "The Spratly Islands Dispute," p. 306.
9 "Conflict in Spratlys Spurs Rift Between Hanoi and Moscow," Christian Science Monitor, 14 June 1988. This article and others from the time refer to five Vietnamese dead and 74 missing. Later reports refer to from 72 to 75 Vietnamese dead.
15 Botbol, p. 78.
19 Radarsat archives were included in the image search because the imagery offered not only relatively high spatial detail, but also structural information on the imaged features (e.g., surface roughness, metallic composition, etc.).
28 Branigin, p. A18. It is possible the Yukan-class ship was actually a Yuting-class amphibious warship. Both types of ships have similar profiles, and both operate in the South China Sea.
31 The feature’s shadow could not be seen because it blended with the dark lagoon water. The cloud shadows could not be seen in the lagoon either. The high sun elevation (69°) also reduced the shadow’s size.
36 Yuting-class ships ‘991’ and ‘934’ were commissioned on September 1992 and September 1995 respectively. Both were built at the Zhonghua Shipyard. Sharpe, Jane’s Fighting Ships: 1997-1998, p. 129.
37 Yuting-class ship ‘935’ was commissioned in December 1995. It was built at the Zhonghua Shipyard. Sharpe, Jane’s Fighting Ships: 1997-1998, p. 129.
39 There has already been one publicized case where a Chinese fishing vessel has reportedly fled to Mischief Reef to elude the Philippine Navy. ‘China Demands Fishers’ Release,” Manila Times, 2 December 1998.
42 The C-130 propellers can be seen in another photo that was taken by the photographer. See Tracy Dahlby, “South China Sea: Crossroads of Asia,” National Geographic, Vol. 194, No. 6, December 1998, p. 9.
45 Ibid. The OV-10 aircraft was built by Rockwell for the US Marine Corps. It is widely used for reconnaissance, but it also can be configured as a fighter-bomber. Jane’s All the World’s Aircraft 1986-87 (London: Jane’s Publishing Company Limited, 1986), pp. 492-493.
46 Villaviray, “RP Eyes Expansion of Spratlys Facilities.”
47 “Philippines Plan to Open Spratly Island to Tourism,” Asia Pulse, 18 February 1999.
50 Dzurek, “The Spratly Islands Dispute,” p. 25.
51 Valencia et al., p. 228.
53 If camouflage is used to blend the appearance of structures with the surrounding reef, high resolution imagery or radar imagery would most likely be required to detect such structures or verify the absence of such structures.