Lights on the Water? Accumulating VIIRS boat detection grids in Southeast Asia spanning 2012–2021

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It has been known since the 1970s that heavily lit fishing boats can be detected with nighttime visible low-light imaging data collected by polar-orbiting meteorological sensors (Croft, 1979). The two-sensor series having low-light imaging capabilities include the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) and the NASA/NOAA Visible Infrared Imaging Radiometer Suite (VIIRS). These sensors use light intensification to enable the detection of moonlit clouds at night—to satisfy a requirement from meteorologists for day and night visible and thermal imagery of clouds. The OLS digital archive extends from 1992 to the present and collects relatively coarse resolution (2.7 km ground sample distance) global data. The VIIRS sensor provides key improvements (Elvidge *et al*., 2013) in low-light imaging from 2012 to the present and the pixel resolution (742 m × 742 m) is finer and has in-flight calibration to radiance units. In 2015, the Earth Observation Group (EOG) developed the VIIRS boat detection (VBD) algorithm (Elvidge *et al*., 2015a; Elvidge *et al*., 2018; Hsu *et al*., 2019) with support from NOAA's Joint Polar Satellite System (JPSS) proving ground program and United States Agency for International Development (USAID). The VBD data were produced in near real-time and the nightly record extends back to April 2012 in Asia. In addition to the nightly product, the EOG also made monthly and annual summary grids. These temporal compilations reveal spatial patterns that are not evident in data from single nights. In this article, the cumulative VBD images during 2012–2021 for the SEAFDEC Member Countries are reviewed.

Fishery agencies could rely on VIIRS boat detection (VBD) data in implementing regulations and management measures. VBD data could provide up-to-date information on the activities of fishery vessels such as indications of illegal fishing activity in restricted areas and incursions across exclusive economic zones (EEZ). Also, VBD could enable the authorities to identify "dark vessels" that lack a vessel monitoring system (VMS) or automatic identification system (AIS) operating in fishery closures, restricted waters, or EEZ boundary zones. Another potential VBD data application is the identification of offshore transshipment events. While the data are unable to discern the ownership of a fishery vessel, several ways the data can be used to enhance fishery management and combat illegal, unregulated and unreported (IUU) fishing are summarized in **Box** (Elvidge *et al*., 2015a; Hsu *et al*., 2019).

Box. Applications of VIIRS boat detection data

- Cross-reference with location data from a vessel monitoring system (VMS) or automatic identification system (AIS) to identify fishery vessels that are not operating a location beacon
- Overlay with outlines of marine protected areas or seasonally restricted fishing grounds to identify illegal fishing
- Identify possible incursions of foreign fishery vessels across EEZ borders
- Identify fishery vessels that are exceeding wattage limits placed on lighting
- Track spatial and temporal shifts in fishing grounds and identify stationary boats that may be storage boats collecting catch from a cadre of fishing boats by using monthly summary data
- Target enforcement efforts and inspections in areas with concentrated fishery vessel activities

In Southeast Asia and several other regions, VIIRS is a widely used practice. In Indonesia, 32 months of VMS data was segmented into fishing and transit activity types and then cross-matched with the VBD record. The cross-matching indicated that 96 % of the matches occur while the vessel is fishing. There was an indication that VMS vessels using submersible lights could be identified based on consistently low average radiances and match rates under 45 %. Overall, VIIRS detected large numbers of fishing boats under the 30 GT level set for the VMS requirement and the cross-matching could be used to identify "dark" vessels that lack AIS or VMS (Hsu *et al*., 2019).

Moreover, a VIIRS closure index (VCI) was developed to rate the effectiveness of three types of closures: *ad hoc* fishery closure associated with toxic industrial discharge in Viet Nam, seasonal fishery closure in Palawan, Philippines, and permanent closure in restricted coastal waters in Negros Occidental, Philippines (Elvidge *et al*., 2018). The VCI results indicated that it was possible to rank the effectiveness of different closures, year-to-year differences in compliance levels, and identify closure encroachments that may warrant additional enforcement effort. For the closure in Viet Nam, the VCI registered a modest level of compliance with a range of 13–44 % which indicated that a substantial amount of fishing occurred during the closure months. In the Philippines, VIIRS boat detection alerts were running for more than 900 fishery closures with email and short message service (SMS) transmission modes which are being actively used to plan enforcement actions and there was a growing list of apprehensions that occurred based on tip-offs from VIIRS.

Understanding the Features of VBD

In defining the types of features that can be seen in the ten-year VBD accumulation grid, **Figure 1** shows a **diffuse cloud** of VBD detections south of Aru Island, Indonesia. There are spots embedded in the cloud with many more detections than the surroundings which are called **recurring detection sites**. Near major ports and heavily trafficked straits, there can be dense clusters of detections associated with anchorages that serve as vessel parking lots with the example presented in **Figure 2** is a set of anchorages east of Singapore. While vessel freighters, tankers, and passenger vessels are only occasionally detected by VBD, there are some places exhibiting faint linear traces of detections from vessels in **transit lanes** (**Figure 3**)

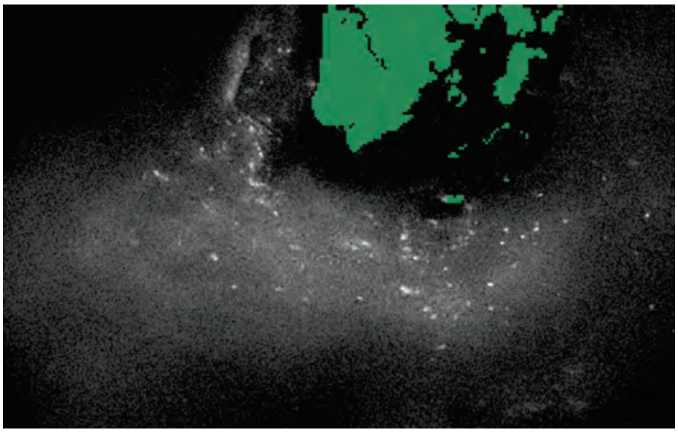

Figure 1. Diffuse cloud of VBD detections defining the outline of the fishing ground. Embedded in the clouds are spots having many more detections called **recurring detection sites**

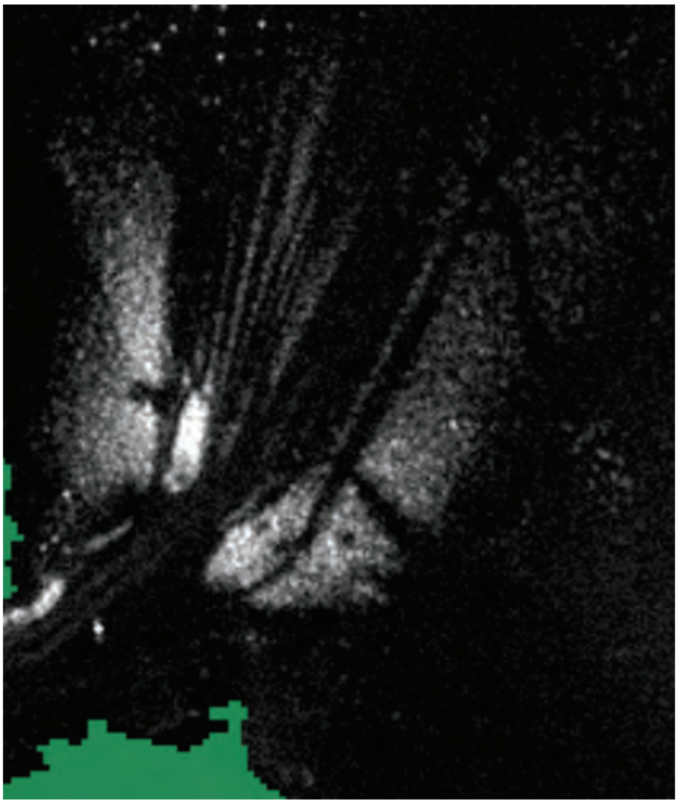

Figure 2. Anchorages east of Singapore

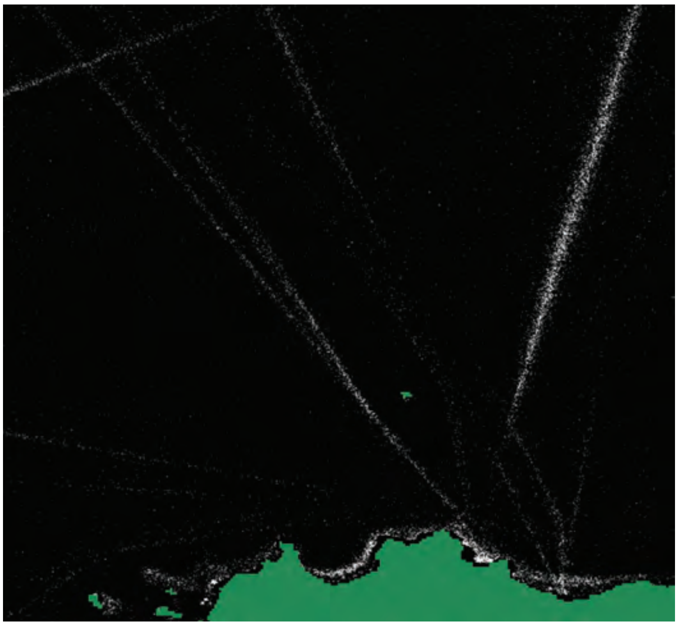

Figure 3. Transit lanes north of Sicily, Italy which are the result of lit passenger ferries transiting in largely straight lines between ports in the Mediterranean Sea

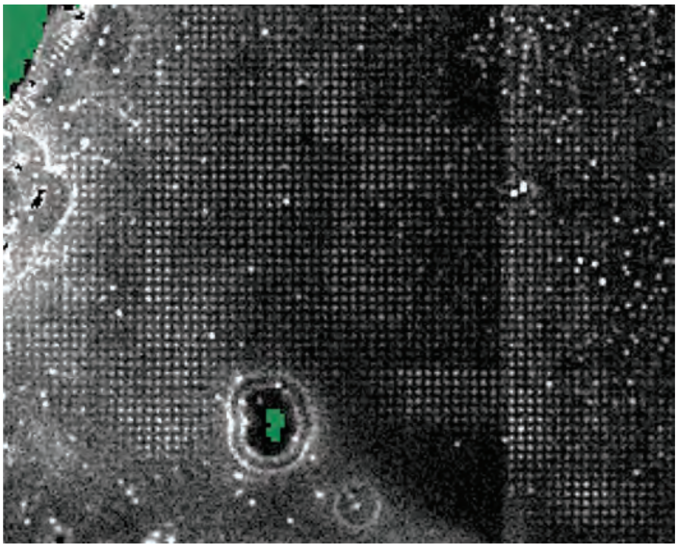

Figure 4. The Gulf of Thailand features excellent examples of regular **grid patterns** in the placement of recurring VBD detection spots. Ko Tao Island in Thailand is surrounded by two rings indicating that fishing boats are adhering to an **exclusion buffer** surrounding the shoreline. The double ring indicates a change occurred in the buffer distance

when VBD are accumulated for ten years. In some areas, the recurring detections form regular **grids and linear features** and good examples of this can be found in the Gulf of Thailand (**Figure 4**). **Figure 4** also shows the result of the effective exclusion of fishing boats near high-value islands, in this case, Koh Tao has two **exclusion rings** indicating at least two distance buffers for fishing boats have been active from 2012 to 2021. Finally, there are also aquaculture areas where sufficient lighting is deployed to produce VBD detections. The example here is the **ribbon** of offshore detections in Uchiura Bay, Hokkaido, Japan (**Figure 5**).

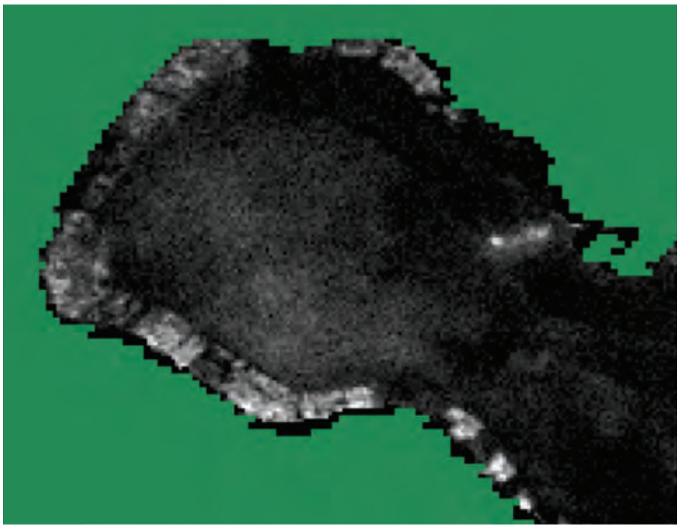

Figure 5. There is a **ribbon** of lit aquaculture parallel to the shore in Uchiura Bay, Hokkaido, Japan

Cumulative VBD images in SEAFDEC Member Countries

Brunei Darussalam

There are multiple recurring detections and several anchorages near the port in Brunei Darussalam (**Figure 6**).

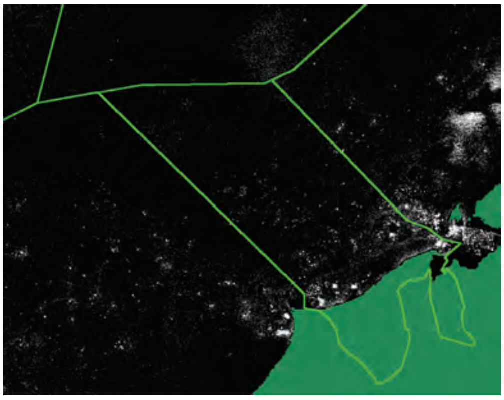

Figure 6. Cumulative VIIRS boat detections for Brunei Darussalam in 2012–2021

Indonesia

As shown in **Figure 7**, there are clusters of fishing grounds with embedded recurring detection in the Arafura Sea. In Sulawesi, near-shore fishing ground clusters with embedded recurring detections are primarily found in the south. Meanwhile, diffuse and dense fishing ground clusters with embedded recurring detections could be found in the Java Sea. There are several diffuse and dense fishing ground clusters with clouds of evenly spaced recurring detections in the Natuna Sea. The Straits of Malacca displayed diffuse and dense fishing ground clusters plus large numbers of evenly spaced recurring detections. In West Sumatra, diffuse fishing ground clusters with multiple recurring detection sites were found.

Japan

Multiple diffused to dense fishing grounds and close-to-shore ribbons of aquaculture were detected in Uchiura Bay, Hokkaido anchorages near major ports (**Figure 8**).

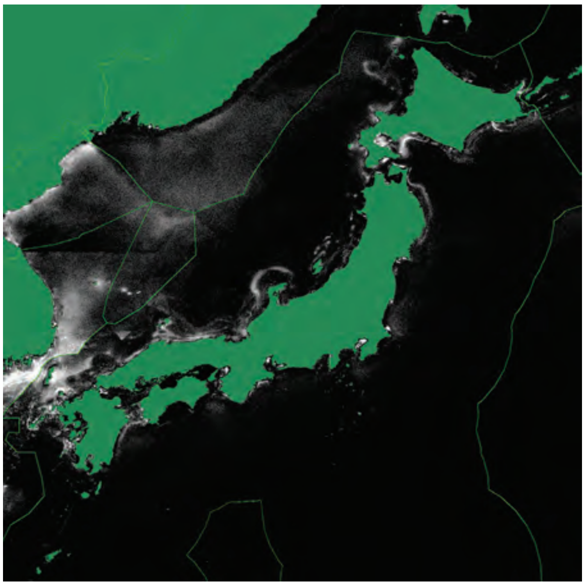

Figure 8. Cumulative VIIRS boat detections for Japan in 2012–2021

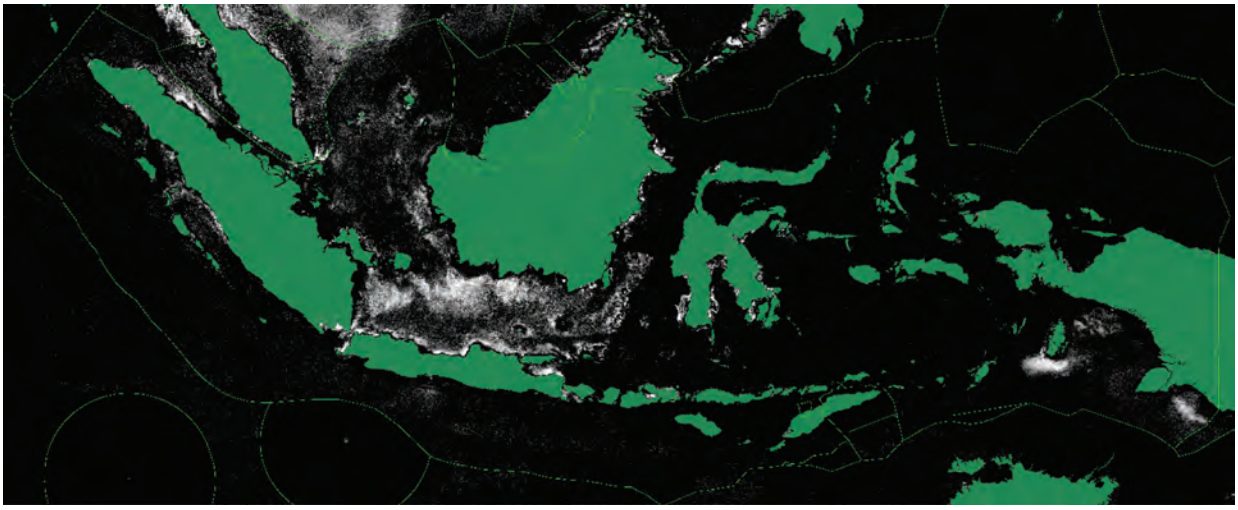

Figure 7. Cumulative VIIRS boat detections for Indonesia in 2012–2021

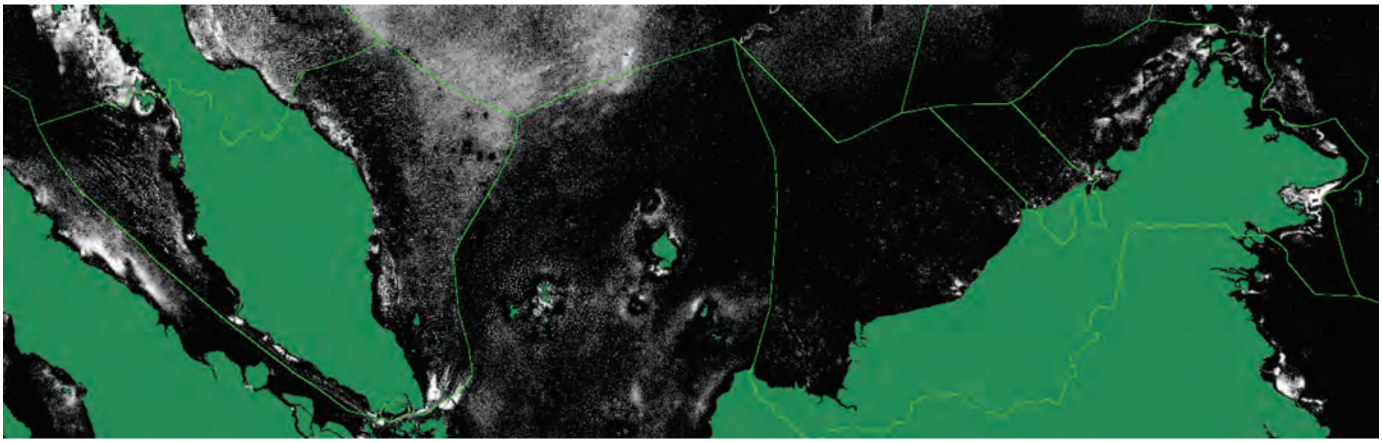

Figure 9. Cumulative VIIRS boat detections for Malaysia in 2012–2021

Malaysia

Figure 9 shows that in Malacca Strait there were curved and diagonal strings of regularly spaced recurring VBD detection, an anchorage near Kuala Lumpur, multiple anchorages near the shore northwest of Singapore, and faint tracks of detections in transit lands approaching Singapore. Moreover, in the East of Peninsular Malaysia, east-west linear and curved strings of recurring VBD detections; diffuse detection clouds centered on the exclusive economic zone (EEZ) junctions of Malaysia, Thailand, and Viet Nam; several nearshore fishing grounds; and large anchorages near Singapore were perceived. In Sarawak, there were numerous randomly spaced recurring detections across the EEZ and several dense anchorages near Bintulu. In Sabah, multiple irregularly shaped fishing ground clusters were sensed.

Myanmar

There is a 100 km wide ribbon of fishing boat detections in southern Myanmar along the Andaman Sea. In northern Myanmar, there are several dense fishing boat clusters indicating fishing grounds (**Figure 10**).

Philippines

Figure 11 shows that the northern part of Luzon Island is largely devoid of VBD. Nevertheless, there are several anchorages associated with Manila. From Manila to the south, there are multiple dense VBD clusters in the southern part of Luzon extending through the Visayas. Furthermore, dense clusters of fishing boats were also found in Palawan and Zamboanga Islands.

Figure 10. Cumulative VIIRS boat detections in Myanmar in 2012–2021

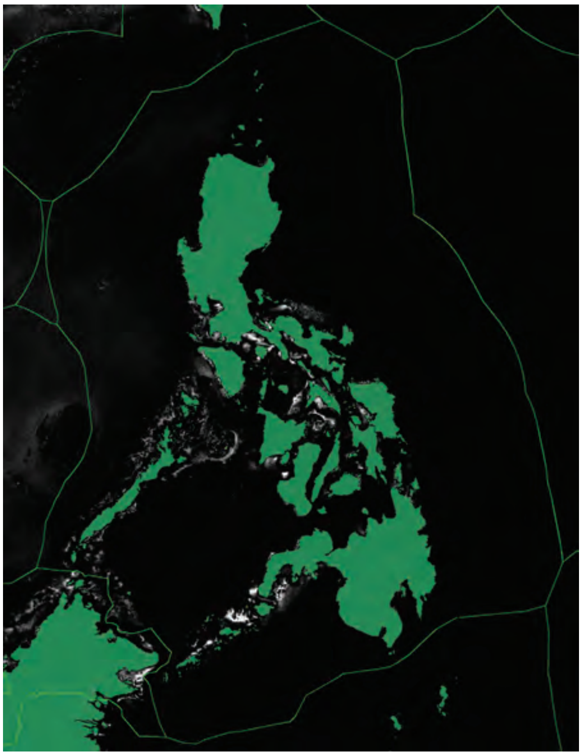

Figure 11. Cumulative VIIRS boat detections in the Philippines in 2012–2021

Singapore

Near Singapore, there were multiple large anchorages and evidence of transit lanes. Further south, there were several dense fishing ground clusters in Indonesia (**Figure 12**).

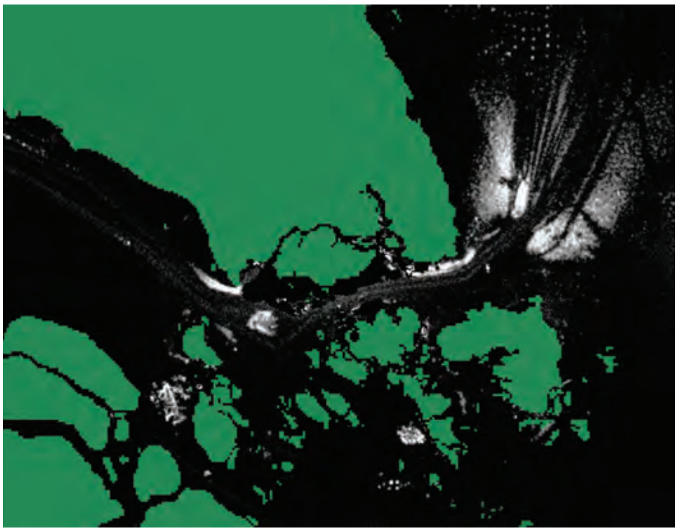

Figure 12. Cumulative VIIRS boat detections in Singapore in 2012-2021

Thailand and Cambodia

The Thailand portion of the Gulf of Thailand has numerous adjoining grids of recurring VBD detecting points (**Figure 13**). In the southern part of the gulf, the grid patterns begin breaking up into linear strings of recurring detections. There was a wide ribbon with a diffuse cloud of VBD detections which is overprinted by grids of recurring detections. This ribbon extends 100 km into the Andaman Sea. on the other hand, Cambodian waters feature a diffused cloud of VBD detections and extensions of the grid pattern of recurring detection spots along the boundary with Thailand waters.

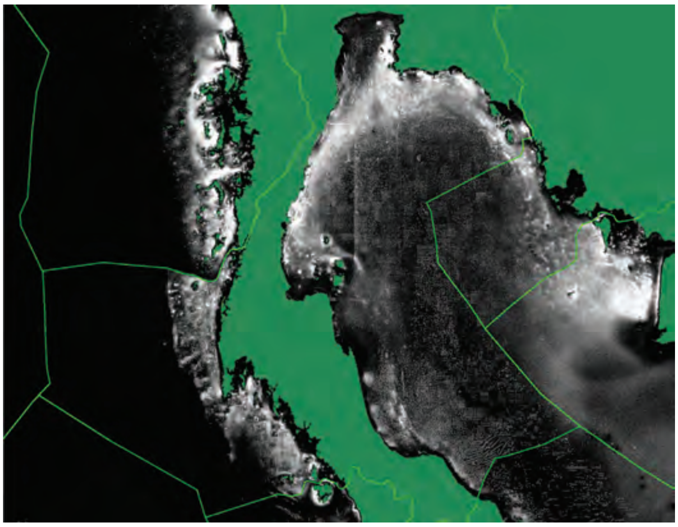

Figure 13. Cumulative VIIRS boat detections for Thailand and Cambodia in 2012-2021

Viet Nam

Figure 14 shows that Viet Nam had an extended dense to diffuse cloud of VBD detections in the north with embedded recurring detection points. This northern cloud straddled the EEZ boundary with China. In central Viet Nam, the VBD detection cloud was denser nearshore and more diffuse further out, with several linear density changes. In the south, there was a large diffuse to a dense cloud of VBD detections with large numbers of recurring detection sites, but lacking the grids and linear alignments typical in Malaysian and Thai waters.

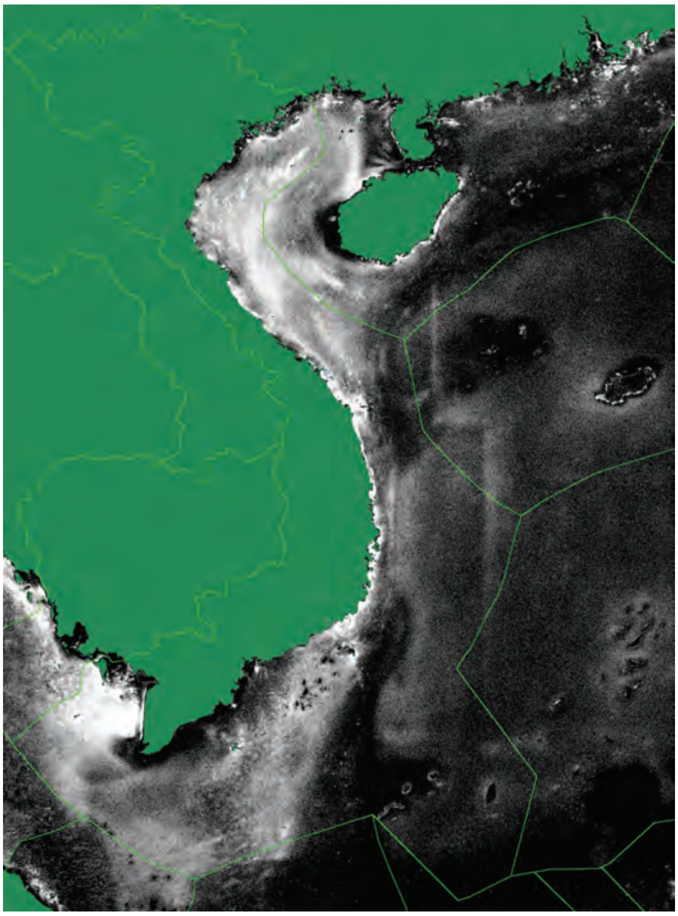

Figure 13. Cumulative VIIRS boat detections in Viet Nam in 2012-2021

Conclusion

The VIIRS day/night band has a remarkable capability to detect electric lighting present at the Earth's surface. Onshore, the lighting is primarily from human settlements, industrial sites, and transportation corridors. Offshore, the majority of lighting comes from fishery vessels using lights to attract fish. However, several other types of sites have been found in a ten-year accumulation of VBD data. This includes anchorages, transit lanes, and aquaculture. One of the features found in the ten-year compilation remains a mystery which is the recurring detection points. These may be solitary, in regular grids, or equally spaced lines and curves. It was checked that the recurring detection sites with the mapping of offshore gas flares and a small number of the sites aligned with known flares (Elvidge *et al*., 2015b). But the function filled by the vast majority of the recurring sites has yet to be determined. Though it was suspected that they were a combination of fishing platforms and anchored fish aggregating devices.

Way Forward

For fishery agencies and other relevant stakeholders that are interested to learn more about VBD data and potentially use it for offshore monitoring, please contact the lead author by email. In the past, his team has given 1–2-day training courses to several fishery agencies and their local collaborators in several countries.

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