Detection of submerged reef banks in the Lakshadweep Sea using IRS-P4 OCM satellite data

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The coral reef systems of the Lakshadweep region are unique from an ecological perspective. The region around Lakshadweep Islands is characterized by shallow submerged reef banks. This study demonstrates the use of IRS-P4 OCM satellite data in deciphering information about the extent of submerged reef banks in this area. The short wavelength OCM spectral bands have been found to be useful in detecting submerged reef banks as deep as 50–60 m below the ocean surface. This information is useful for updating navigational charts and to minimize ecological losses for the reefs of this region.

Keywords: Coral reefs, IRS-P4 OCM, ocean colour, remote sensing.

THE Lakshadweep Islands lie in the southern Arabian Sea and consist of a chain of well-developed coral reefs. These islands are situated about 200–470 km westward off the Kerala coast, India. The reefs are of compound atoll type[1]. Almost all the atolls have NE–SW orientation with the low lying islands on the east, a broad well-developed reef on the west, and a lagoon in between, connected to the open ocean by one or more channels. Some of the Lakshadweep islands are characterized by shallow submerged reef banks, which can be classified as optically shallow waters. In the remote sensing of ocean colour, optically shallow waters are described as places where the reflectance of the bottom can be observed or detected from above the water surface[2].

Optically shallow water should not be confused with the more general term ‘shallow water’ commonly used in oceanography. There is an important distinction between shallow water and optically shallow water. Shallow water is defined as a ratio of vertical to horizontal length scales and therefore is fixed for a given region of the ocean. Optically shallow waters, on the other hand, are not simply defined by physical length scales, in this case bottom depth; they are also determined by optical properties of the water column and the benthic vegetation cover. The mapping of optically shallow water zones is important for navigation and monitoring of coral reef ecology. Depth information from remote sensing has been used to augment existing charts[3,4], assist in interpreting reef features[5] and map shipping corridors[6].

Satellite data of IRS-1B, 1C and 1D sensors have been extensively used to study geomorphology of coral reefs of the Lakshadweep region[7]. However, data from these sensors were not useful in detecting submerged reef banks at depths more than 8–10 m, owing to the absence of visible blue spectral bands and narrow bandwidth. IRS-P4 OCM sensor has eight spectral bands covering a spectral range of 412 to 865 nm, with 360 m spatial resolution and 20 nm bandwidth for the first six bands[8]. These technical specifications of the OCM data are most optimal for studying the optically shallow environments.

The hydrographic charts published by Naval Hydrographic Office, Dehradun show three significantly large submerged reef banks north of Chereapani Reef in the Lakshadweep Sea, namely Cora Divh, Sesostris Bank, and Bassas de Pedro (Figure 1). The geographical extent of these reef banks lies between lat. 12–14°N and long. 71–73°E. The bathymetry of these banks varies between 20 and 60 m. We have made use of OCM data to study these reef banks and characterize optically shallow waters around the study region. The cloud-free satellite data of OCM sensor for two

Figure 1. Naval hydrographic chart of part of Lakshadweep Sea. Box region in red colour shows study area.

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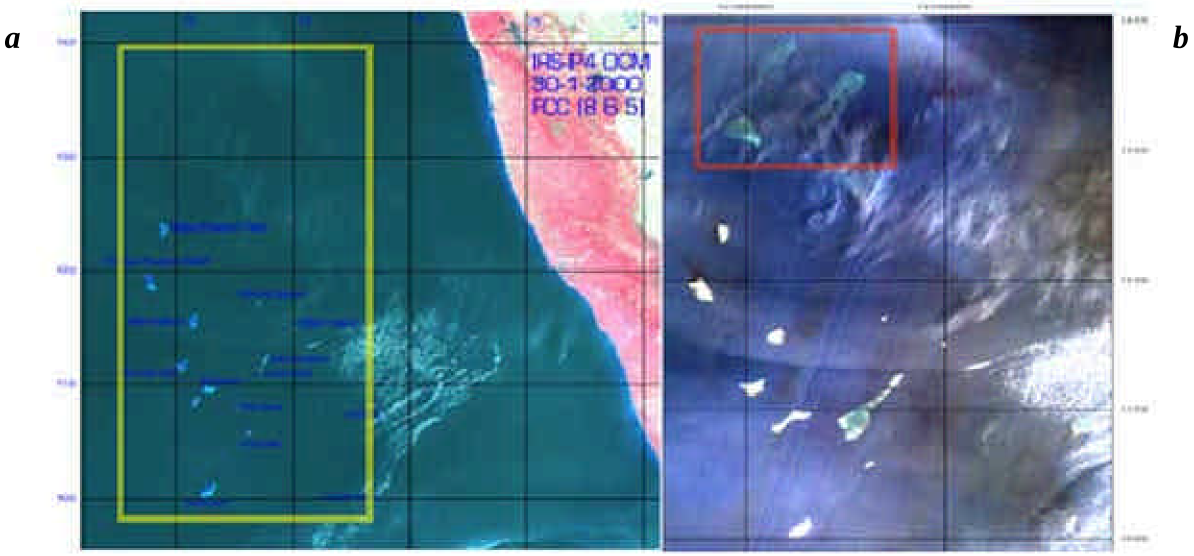

Figure 2. ***a***, FCC image of OCM bands 8,6,5 showing locations of Lakshadweep Islands. ***b***, FCC image (yellow box region in (***a***)) of OCM data from bands 4,3,2 using visible blue and green spectral bands. Image shows presence of three large submerged reef banks (see red box) when short-wavelength data are used.

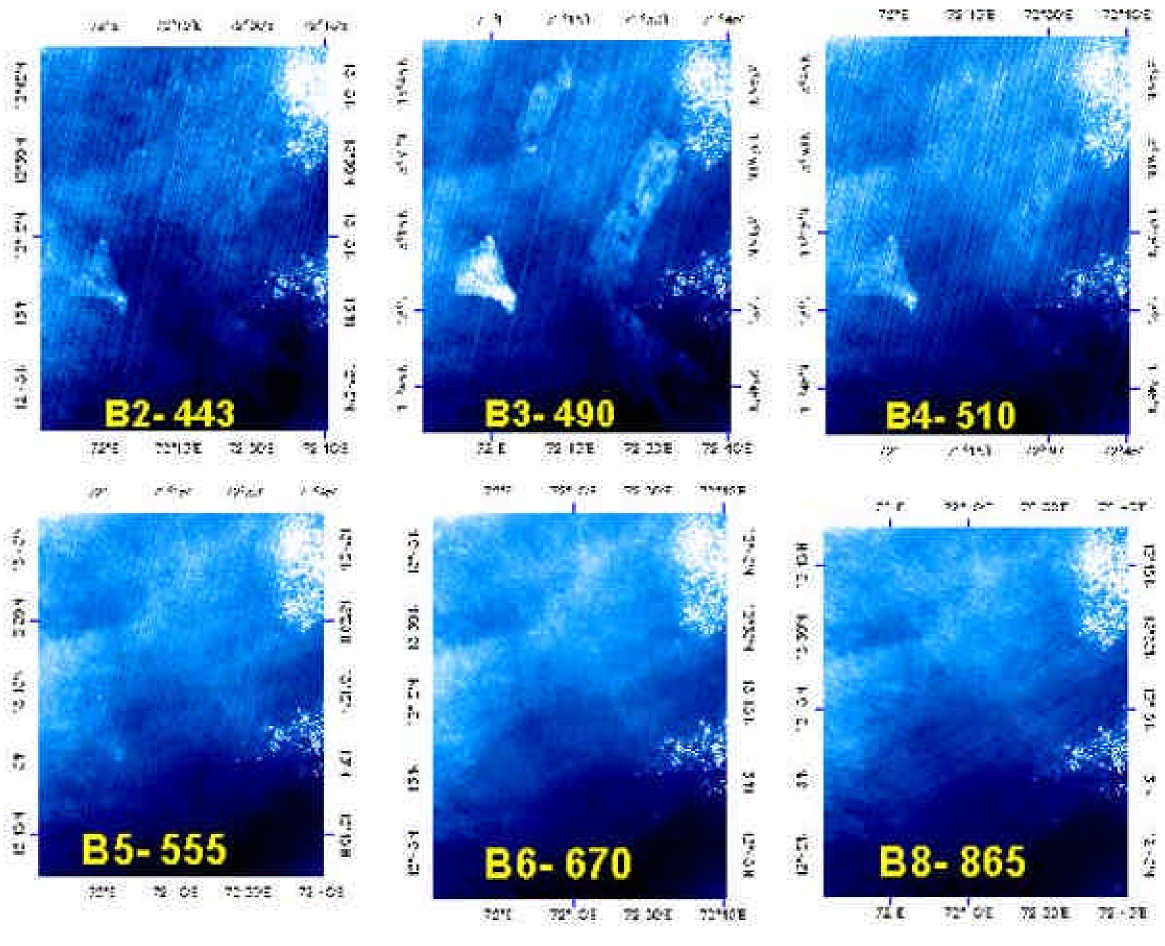

Figure 3. Band 2 to 8 images of OCM data (24 March 2000) for study area in different wavelengths. Image of band 3 (i.e. 490 nm) provides maximum information about submerged reef banks. No details of these features could be seen in red and infra-red bands (i.e. bands 6 and 8).

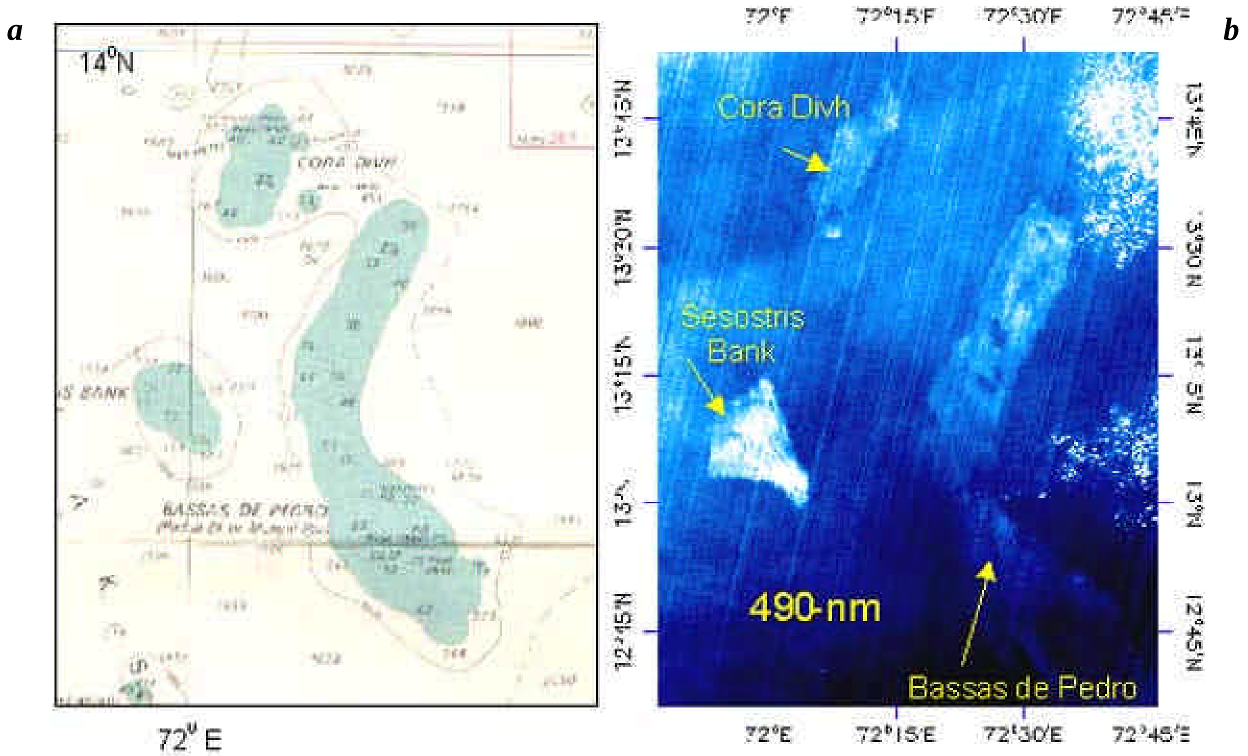

Figure 4. Comparison of hydrographic chart of the region (***a***) with OCM image of 490 nm spectral band (***b***) Geographic extent of submerged reef is better mapped using OCM data.

different dates (i.e. 27 February 2000 and 24 April 2000) were used to study the area.

A False Colour Composite (FCC) of OCM data from pass 9 and row 14 of 27 February 2000 for bands 8 (865 nm), 6 (670 nm) and 5 (555 nm) was prepared over the Lakshadweep Islands and their surrounding oceanic regions. Figure 2 *a* shows this conventional FCC using near infrared (NIR), red and green spectral bands. Many of the islands in Lakshadweep can be mapped onto this FCC (Figure 2 *a*). In this conventional FCC, the earlier mentioned submerged reef banks could not be delineated. However, it is well known from the fundamental principle behind using remote sensing to map bathymetry, that different wavelengths of light will penetrate in water to varying degrees[6]. When light passes through water, it gets attenuated by interaction with the water column. Red light attenuates rapidly in water and does not penetrate more than about 5 m in clear water. In contrast, blue light penetrates much further and in clear water, the seabed can reflect enough light to be detected by a satellite sensor. The penetration depth of light also depends on water turbidity, suspended sediment particles, phytoplankton and dissolved organic compounds.

Making use of this principle, a FCC comprising visible green and blue spectral bands of OCM data (i.e. 510, 490 and 443 nm) was prepared (Figure 2 *b*). It is seen from Figure 2 *b* (region within the red box) that the submerged reef banks are clearly delineated, as they are more illuminated in the shorter wavelengths. Figure 3 shows detailed images of these submerged features in different spectral bands (i.e. 443, 490, 510, 555 , 670 and 865 nm) of the OCM data. It is clear from Figure 3 that maximum information about the submerged features is available from band 3, i.e. 490 nm of the OCM data, while the red and near-infrared bands of OCM data do not show any details about the submerged features.

The coefficient of light attenuation in the sea depends on wavelength. Longer wavelength light has a higher attenuation coefficient than short wavelengths. Therefore, red light is removed from white light passing vertically through water, faster than blue light. There will, therefore, be a depth at which all the light detected by band 6 (visible red, 670 nm) of the OCM sensor has been attenuated. However, not all wavelengths would have been attenuated to the same extent – there will still be shorter wavelength light at this depth, which is detectable by bands 4, 3 and 2 of the OCM sensor (visible green, 510 nm and visible blue, 490 and 443 nm respectively). This is most easily visualized if the same area is viewed with images consisting of different bands (Figure 3).

In order to validate the findings obtained from OCM satellite data, a comparison of the OCM images was carried out with the naval hydrographic charts of this region. Figure 4 *a* shows a portion of the naval hydrographic chart of part of Lakshadweep Sea corresponding to the study area. As seen in Figure 4 *a*, *b*, ocean-colour data of OCM provide details about the extent and morphology of these three submerged reef banks. The Sesostris Bank (Figure 4 *b*) is the

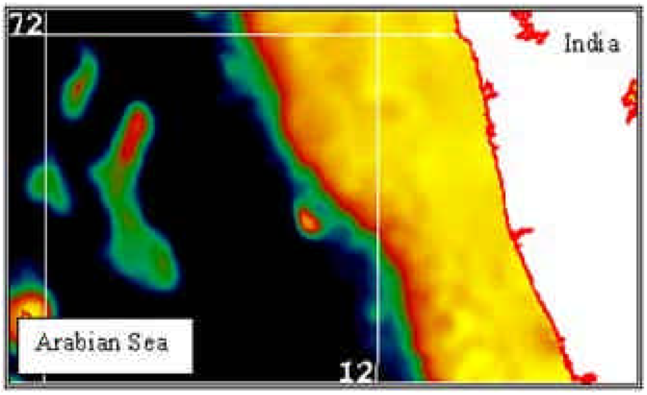

Figure 5. Global bathymetry data of study area at 5 min resolution available from SeaWiFS project of NASA. Global bathymetry data also confirm the observations made on reef band morphology using OCM sensor.

most shallow reef bank having a depth range around 20–25 m. This feature has been captured well in band 3 data of OCM. Comparison of hydrographic chart and OCM imagery shows that shape of Sesostris Bank and Cora Divh reef banks has significant differences.

Further, OCM observations were compared with the global bathymetry data available on 5 min spatial resolution from the United States Geological Survey (USGS). Figure 5 shows the USGS bathymetry image of the study area. The data on 5 min resolution also clearly indicate the presence of the submerged reef banks. The morphology of the Sesostris Bank and Cora Divh appears more closer to the observation made by OCM sensor, rather than the naval hydrographic chart.

The results of this study show the importance of ocean-colour data in mapping and charting the submerged reef features and subsequent upgradation of hydrographic charts. Efforts are being initiated to accurately map the bathymetry of these reef features. There is a need to plan ship campaigns for further validation.

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Population density, microhabitat use and activity pattern of the Indian rock lizard, *Psammophilus dorsalis* (Agamidae)

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The rock lizard, *Psammophilus dorsalis* is found in rocky hills in southern India. We estimated the population density of *P. dorsalis* in three sites, each measuring ~ 0.5 ha, area around the village Hampi (Karnataka). The density of rock lizards was found to be ~ 90 per ha. The population of adults is characterized by a female-biased sex ratio. Males are larger than females and gorgeous with nuptial colours during breeding season, while females are mottled and difficult to distinguish from the stones. The species exhibits a clear sex-specific niche separation. Males occupied higher perches than females; the latter were generally found at lower heights or on ground. The daily activity pattern of the lizards of both sexes typically involves basking in the morning hours (up to 0930 h) followed by other activities such as foraging, moving, and searching for mates and oviposition sites (during breeding season). The lizards were sighted in large numbers during their peak activity period, the morning phase. The sightings declined in the afternoon (1300–1545 h) with a rise in air temperature, as they retreated to shady areas and crevices. However, during the breeding season the lizards continued their activity even during afternoons, possibly associated with the reproductive events. In the late afternoon (1600–1700 h), with a decline in ambient temperature, the lizards once again appeared in the open for foraging and

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