

Chapter 6 – Nitrate and Chlorophyll

Having analyzed and understood about the variability of the upper ocean, the mixed layer and the barrier layer, it is important to analyze the water-column nutrients and biology to understand how they respond to these changes. Towards this, the nitrate and chlorophyll *a* at 10, 20, 50, and 100 m were analyzed and presented below. Surface values are not presented since the nitrate concentrations are generally in the undetectable levels. Only three seasons namely spring intermonsoon (March-April-May), summer monsoon (June-July-August), and winter monsoon (November-December-January-February) were considered as data in the fall intermonsoon (September-October) was very few as mentioned in Chapter 2. In addition, the satellite derived chlorophyll pigment concentrations were also analyzed during the four seasons to decipher the seasonal cycle.

6.1 Nitrate

6.1.1 Spring intermonsoon

During spring intermonsoon the nitrate concentrations at 10 m in most part of the basin was very low $\sim 0.5 \mu\text{M}$ (Fig.6.1.1.a). Along the northern and western Bay a high concentration was seen and the values were in excess of $1 \mu\text{M}$. The region around Sri Lanka as well as a large patch in the central Bay also showed nitrate concentrations in the range of $1-1.5 \mu\text{M}$. At 20 m high nitrate concentrations in the range of $1-2 \mu\text{M}$ were seen along the western and northeastern boundary (Fig.6.1.1.b). The highest nitrate concentration of $3 \mu\text{M}$ was noticed north of Sri Lanka. Except the regions south of Sri

Lanka and southeastern Bay, the nitrate concentrations were less than $0.5 \mu\text{M}$. The distribution pattern at 50 m depth was similar to that of 20 m, but concentration levels were much higher (Fig.6.1.1.1c). The nitrate concentrations ranged between 4 to $12 \mu\text{M}$ in the southwestern and northern Bay, with concentrations increasing towards the coast. Concentration in most part of the Bay was about $2 \mu\text{M}$. At 100 m depth nitrate varied between 8 to $24 \mu\text{M}$ (Fig.6.1.1.1d).

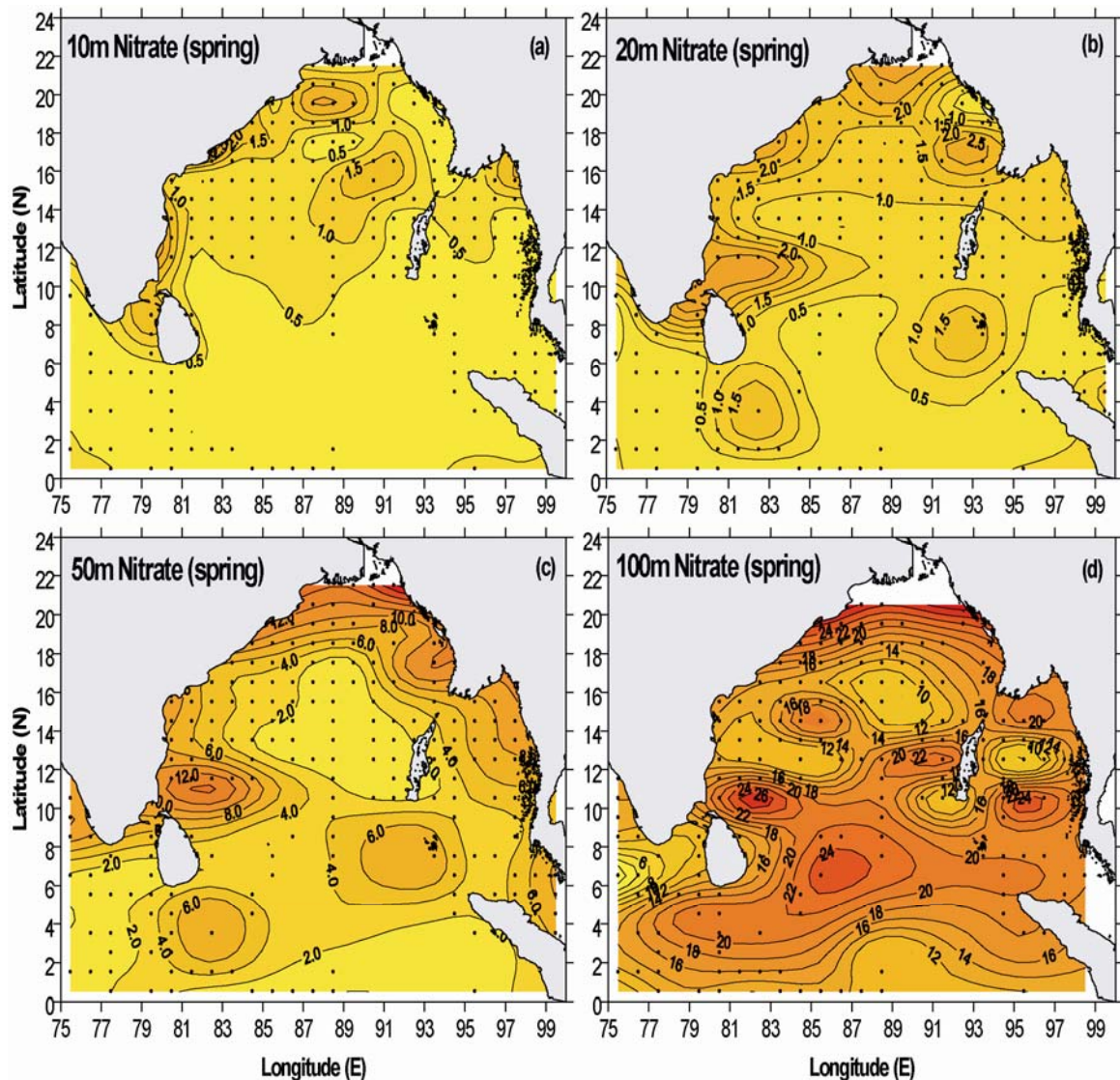


Fig.6.1.1.1 Spatial distribution of nitrate (μM) at (a) 10 m, (b) 20 m, (c) 50 m, and (d) 100 m during spring intermonsoon. Note the change in contour interval in (c) and (d).

6.1.2 Summer monsoon

The spatial distribution of nitrate at 10 m during summer showed very high concentrations in the Indo-Sri Lankan region where the values were as high as 6 μM near peninsular India and 3 μM off Sri Lanka (Fig.6.1.2.1a). Another region of high concentration, $\sim 2.5 \mu\text{M}$ was found near the head Bay. The rest of the basin had nitrate concentrations less than 0.5 μM . At 20 m the pattern was similar to that of 10 m, except

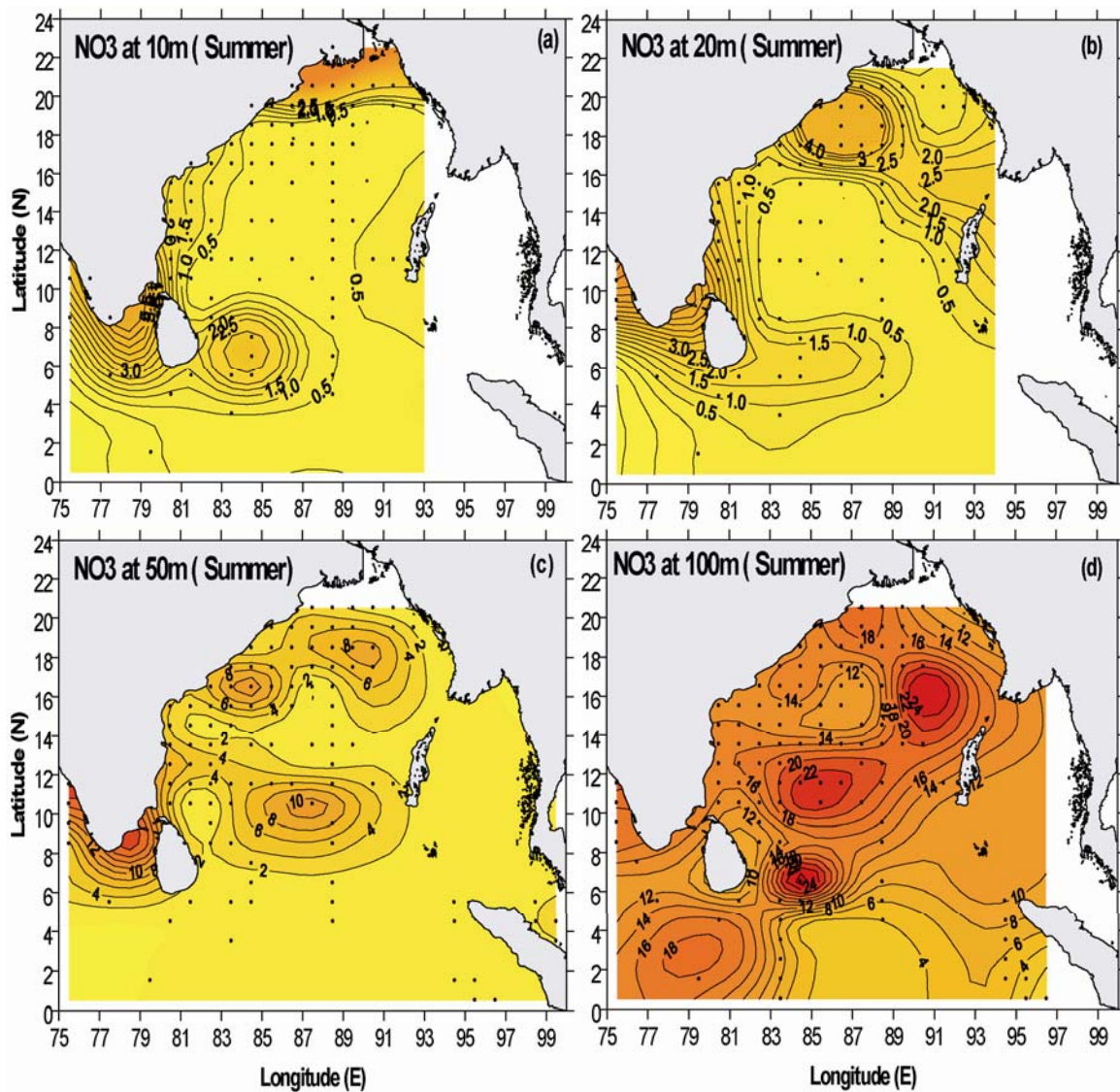


Fig.6.1.2.1 Spatial distribution of nitrate (μM) at (a) 10 m, (b) 20 m, (c) 50 m, and (d) 100 m during summer monsoon. Note the change in contour interval in (c) and (d).

that the high nitrate concentrations seen near the head Bay at 10 m shifted towards the northwestern Bay and the concentrations increased to $\sim 4 \mu\text{M}$ (Fig.6.1.2.1b). At 50 m the region of high concentrations of nitrate seen off east coast of Sri Lanka extended further to north and east and the core concentration was $10 \mu\text{M}$ (Fig.6.1.2.1c). The northern Bay north of 18°N showed high nitrate concentrations of $8\text{-}10 \mu\text{M}$. At 100 m the northwestern Bay showed higher concentrations while the southeastern Bay showed lower concentrations (Fig.6.1.2.1d). The maximum concentration of nitrate was $24 \mu\text{M}$.

6.1.3 Winter monsoon

The nitrate distribution at 10 m during winter season showed very less concentrations ($0.2\text{-}0.4 \mu\text{M}$) in the entire Bay except near the eastern equatorial region off Sumatra which had a maximum value of $2.5 \mu\text{M}$ (Fig.6.1.3.1a). At 20 m the nitrate concentrations near the eastern equatorial region off Sumatra reduced drastically to $0.8 \mu\text{M}$ (Fig.6.1.3.1b). This was one-third of the value seen at 10 m in the southeastern Bay indicating that the source of this is from the surface ocean. Near the head Bay as well as west of Sri Lanka the nitrate concentration showed slight enhancement. At 50 m the nitrate concentrations were in excess of $2 \mu\text{M}$ and the highest values were encountered near the southwestern ($12 \mu\text{M}$) and northeastern ($10 \mu\text{M}$) Bay (Fig.6.1.3.1c). At 100 m the nitrates over entire Bay showed high values and varied between $2\text{--}24 \mu\text{M}$ (Fig.6.1.3.1d).

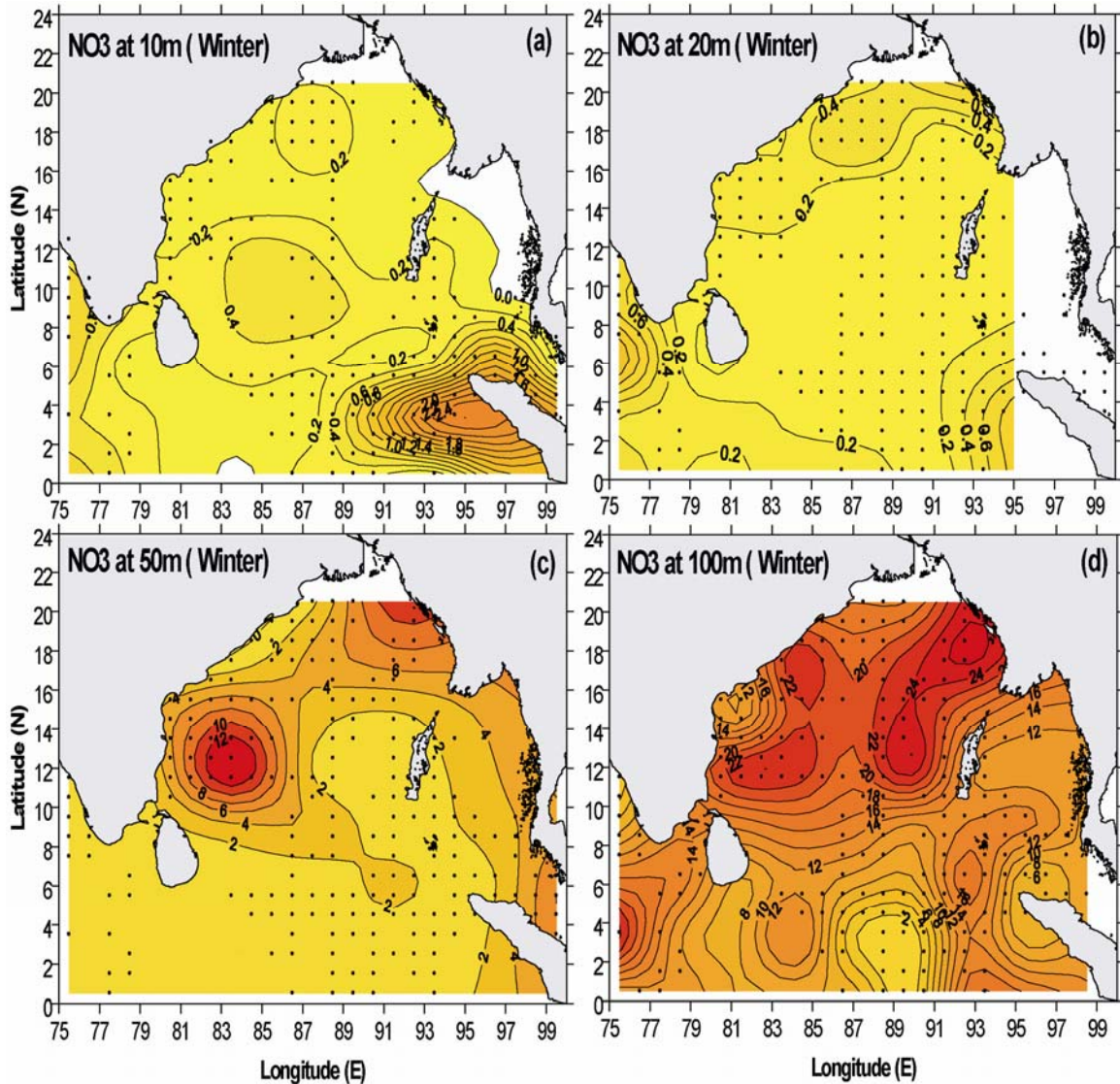


Fig.6.1.3.1 Spatial distribution of nitrate (μM) at (a) 10 m, (b) 20 m, (c) 50 m, and (d) 100 m during winter monsoon. Note the change in contour interval in (c) and (d).

6.2 Chlorophyll *a*

6.2.1 Spring intermonsoon

The chlorophyll *a* concentration at 10 m during spring intermonsoon was high along the southern tip of India, along the western boundary and also along the northeastern Bay

(Fig.6.2.1.1a). The region between 91 to 98°E and 4 to 10°N also showed highest chlorophyll *a* concentrations with maximum value of 0.7 mg/m³. In the central and southern Bay the chlorophyll *a* was least and the value varied between 0.1 – 0.2 mg/m³.

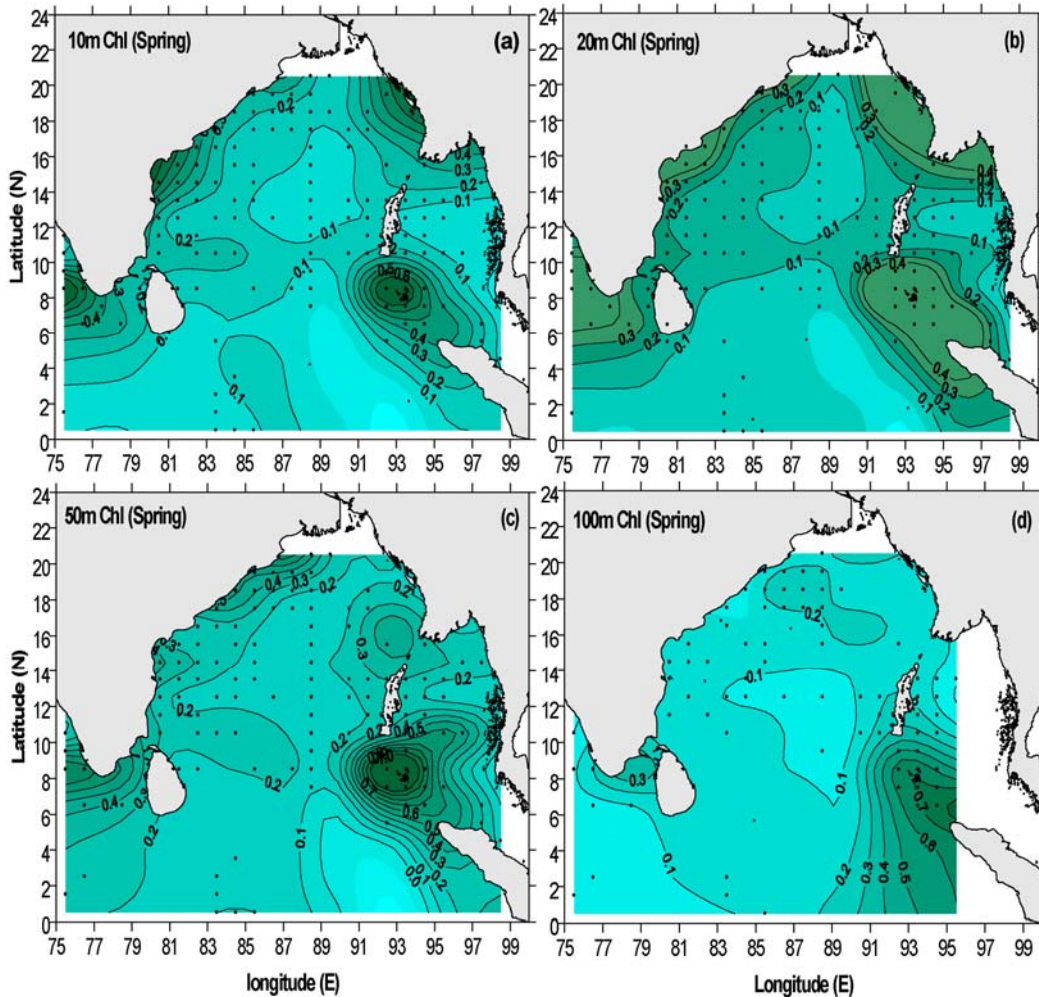


Fig.6.2.1.1 Spatial distribution of chlorophyll *a* (mg/m³) at (a) 10 m, (b) 20 m, (c) 50 m, and (d) 100 m during spring intermonsoon.

At 20 m the chlorophyll showed the same pattern as that at 10 m with increased concentrations (Fig.6.2.1.1b). At 50 m the chlorophyll *a* along the western boundary and southern tip of India was high and showed an increase towards the coast (Fig.6.2.1.1c). The value varied between 0.2 – 0.7 mg/m³. At 100 m the chlorophyll *a* concentrations in

the entire Bay was less than 0.2 mg/m^3 except in the southeastern Bay where it showed an increase from 0.2 to 0.7 mg/m^3 (Fig.6.2.1.1d).

6.2.2 Summer monsoon

The spatial distribution of chlorophyll *a* during summer monsoon at 10 m showed highest concentration of 0.5 mg/m^3 in the northern Bay compared to all other season (Fig.6.2.2.1a). The chlorophyll *a* concentrations along the southern part of the western

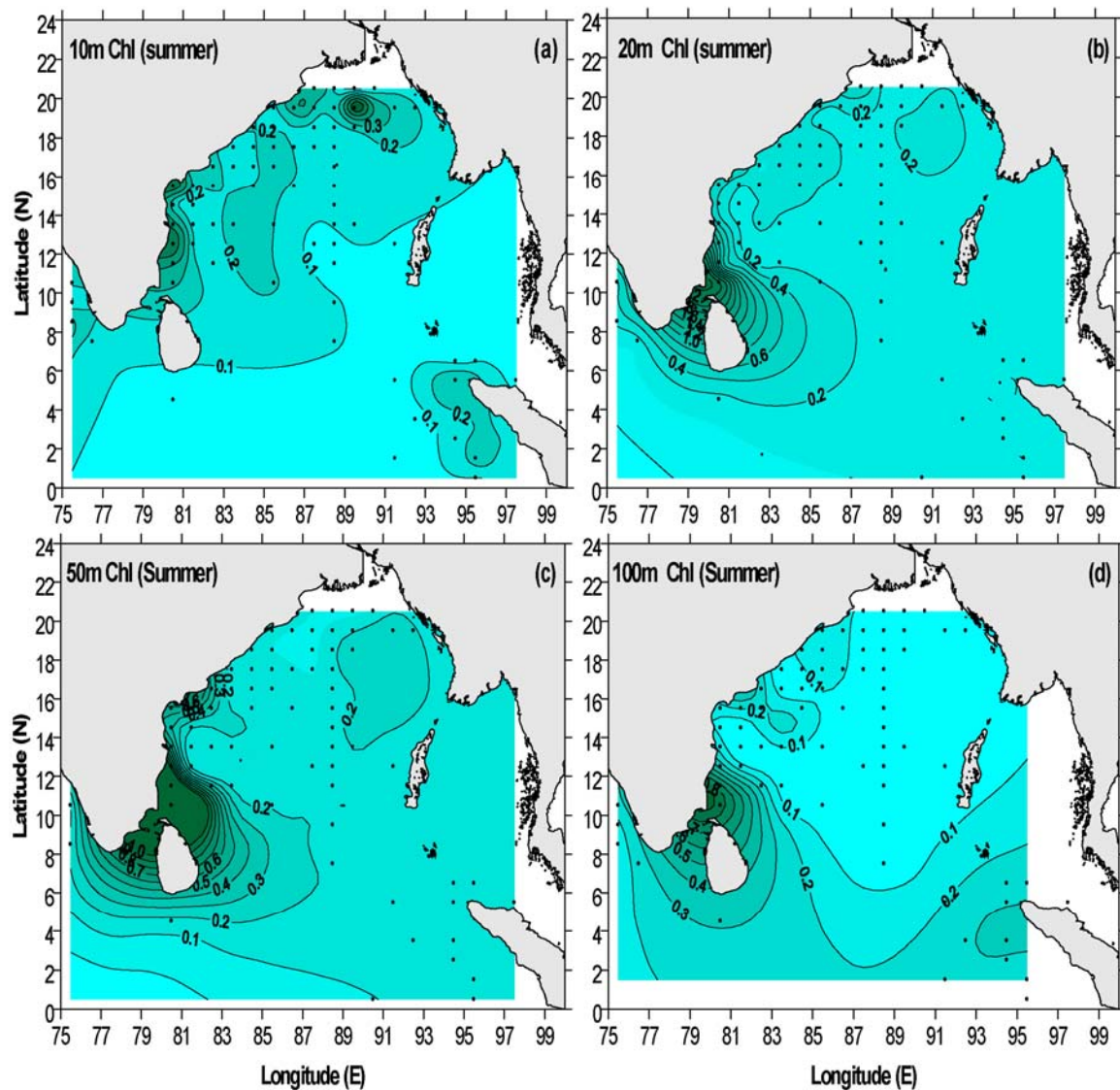


Fig.6.2.2.1 Spatial distribution of chlorophyll *a* (mg/m^3) at (a) 10 m, (b) 20 m, (c) 50 m, and (d) 100 m during summer monsoon. Note the change in contour interval in (b).

boundary also showed a value of about 0.5 mg/m^3 close to the coast, while in the rest of the Bay the chlorophyll *a* was between 0.1 to 0.2 mg/m^3 . At 20 m the chlorophyll was the highest in the Indo-Sri Lanka with a value of $\sim 2 \text{ mg/m}^3$ (Fig.6.2.2.1b). In the rest of the Bay the chlorophyll *a* was less than 0.2 mg/m^3 . At 50 m (Fig.6.2.2.1c) and 100 m (Fig.6.2.2.1d) chlorophyll *a* distribution was similar to that at 20 m with higher concentrations around Sri Lanka and very less concentrations in the rest of the Bay.

6.2.3 Winter monsoon

During winter the chlorophyll *a* at 10 m in the Bay varied between $0.2 - 0.4 \text{ mg/m}^3$ except in the southeastern Bay where it was less than 0.1 mg/m^3 (Fig.6.2.3.1a). The highest concentration of 0.4 mg/m^3 occurred close to the western boundary. At 20 m the distribution of chlorophyll *a* showed a similar pattern as that of 10 m, except that the values along the western boundary was higher and varied between $0.3 - 0.6 \text{ mg/m}^3$ (Fig.6.2.3.1b). At 50 m the chlorophyll *a* over the Bay varied between 0.1 to 0.3 mg/m^3 except along the western boundary where it was more than 0.4 mg/m^3 (Fig.6.2.3.1.c). At 100 m most of the Bay showed low chlorophyll *a* with concentrations was about 0.1 mg/m^3 , except a patch near the southern part of the western Bay where the concentration was $\sim 0.5 \text{ mg/m}^3$ (Fig.6.2.3.1d). Similarly near Sumatra coast the value was 0.3 mg/m^3 .

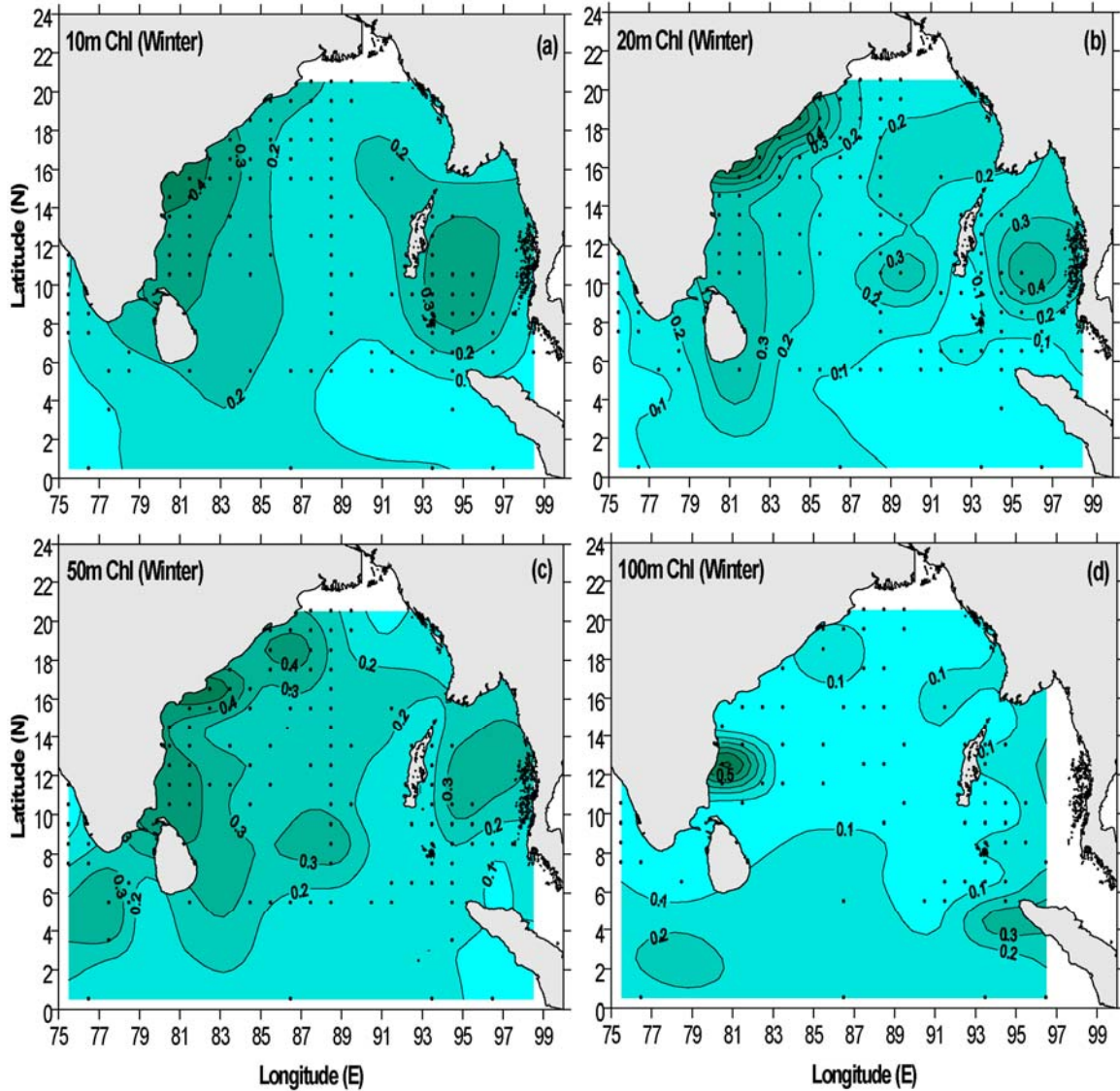


Fig.6.2.3.1 Spatial distribution of chlorophyll *a* (mg/m^3) at (a) 10 m, (b) 20 m, (c) 50 m, and (d) 100 m during winter monsoon.

6.3 Satellite-derived chlorophyll pigment concentrations

The satellite-derived chlorophyll pigment concentrations showed the least value during spring intermonsoon compared to the rest of the 3 seasons (Fig.6.3.1a). The pigment concentrations within the Bay varied over a very narrow range of 0.1 to 0.2 mg/m^3 , except in the head Bay and close to peninsular India and Sri Lanka where it marginally

increased to 0.3 mg/m^3 . The chlorophyll pigment concentrations were the highest in the Bay during summer monsoon around Indo-Sri Lanka region as well as in the northwestern Bay (Fig.6.3.1b). These values were comparable with the *in situ* concentrations seen in the earlier section. The Northern Bay showed a maximum value of

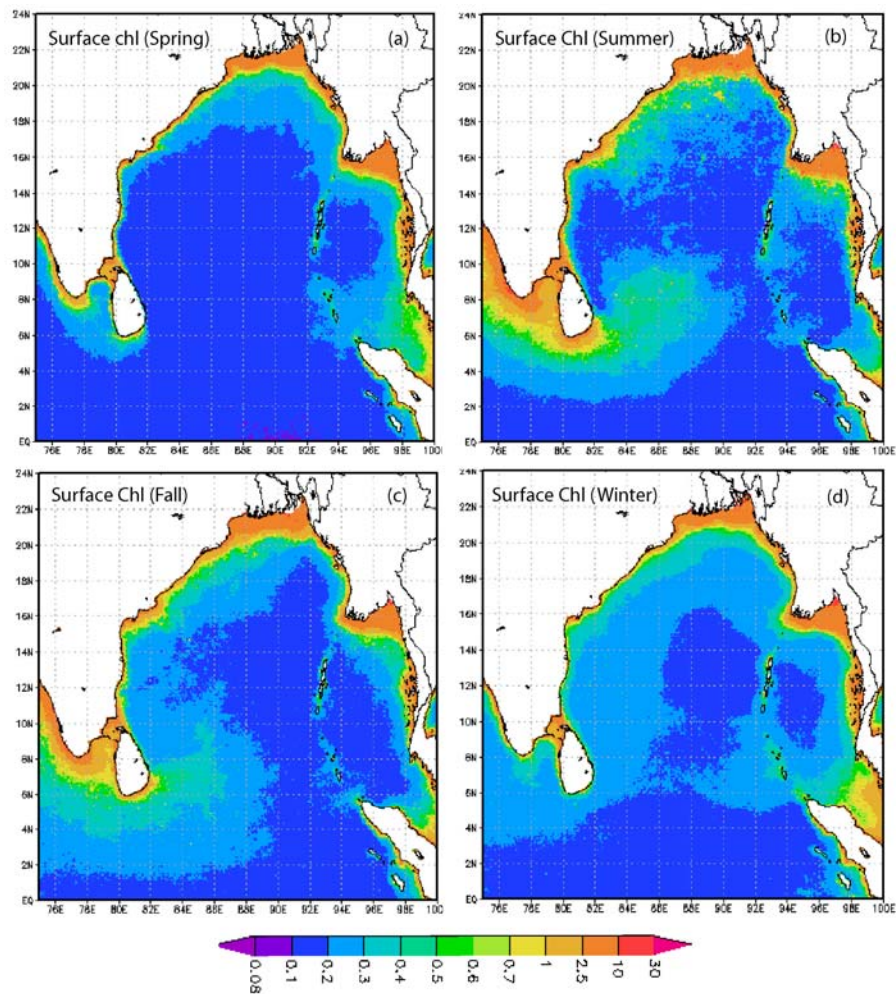


Fig.6.3.1 Seasonal mean climatology of chlorophyll pigment concentrations (mg/m^3) derived from SeaWiFS during (a) spring intermonsoon, (b) summer monsoon, (c) fall intermonsoon, and (d) winter monsoon.

about 1 mg/m^3 , while near the Indo-Sri Lanka region it varied between $0.5 - 10 \text{ mg/m}^3$. In fall intermonsoon the chlorophyll pigment concentrations showed a reduction in their concentration, but the pattern remained similar to that of summer monsoon. The pigment

concentrations varied between 0.1 to 2.5 mg/m³ (Fig.6.3.1c). During winter the chlorophyll pigment concentration showed a further reduction with most of the basin the values ranging between 0.1 to 0.3 mg/m³ (Fig.6.3.1d). However, close to the western and eastern boundary the values varied between 0.3 – 2.5 mg/m³.

In summary, the nitrate concentrations of the upper layer were the least during spring intermonsoon compared to the rest of the seasons. The highest concentrations in spring intermonsoon were along the western boundary. Consistent with this, the chlorophyll *a* concentrations, both in situ as well as satellite-derived, were also the least. The nitrate concentrations during summer monsoon were the highest and it occurred in the region of peninsular India and Sri Lanka and near the northern Bay. Accordingly, the chlorophyll concentrations were the highest. In fall intermonsoon, though the nutrient data and in situ chlorophyll *a* data were not available, the satellite-derived chlorophyll pigment concentrations showed pattern similar to that of summer monsoon with a reduced concentration indicating the tapering effect of summer monsoon. In winter, both the nitrate concentrations and the chlorophyll *a* concentrations were high along the western boundary. It is to be noted that the number of chlorophyll *a* data for any given season is much less in comparison with the nitrate data. Also the spatial coverage of chlorophyll *a* data also is less adequate compared to nitrate data. Hence it is quite possible that this data were unable to resolve all the characteristics of the seasonal variability. Nevertheless, the salient features such as summer monsoon high concentrations in the northern Bay as well as near the Indo-Sri Lanka region, the comparatively high concentrations along the western boundary and the lowest concentrations during spring intermonsoon were all captured.