Application of IRS-P4 OCM data to study the impact of cyclone on coastal environment of Orissa

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The present study emphasizes on the impact of cyclone on the coastal environment of Orissa, using the IRS-P4 (OCM) satellite data. The study includes the analysis of IRS-P4 (OCM) data to generate chlorophyll, suspended sediment concentration (SSC) images for the coastal water and normalized difference vegetation index (NDVI) images for coastal vegetation in the pre and post-cyclonic stages. The effect on mangroves and change in distribution pattern of water constituents like chlorophyll and suspended sediments are brought out.

ORISSA coast was affected by a severe cyclone, with a high wind speed of above 200 km/h on 29 October 1999. This was probably the cyclone of highest intensity recorded during the last century. The coastline of Orissa covering districts Jagatsingh Pur, Kendrapara and Balasore was severely affected. The region most affected is the coastal habitation covering the areas around Paradeep and few blocks of Jagatsingh Pur, including Ersama, Kujang and Balikuda. These places were submerged with the tidal wave of height above 7 m which caused severe damage to the coastal terrestrial habitation as well as the habitats. In this paper, the impact of cyclone on coastal environment was studied. IRS-P4 OCM data were used to study impact on mangroves as well as on concentration and distribution of chlorophyll-a and suspended sediments.

The Ocean Colour Monitor (OCM) of the Indian Remote Sensing satellite IRS-P4 is optimally designed for the estimation of chlorophyll in coastal and oceanic waters, detection and monitoring of the phytoplankton bloom, studying the suspended sediment dynamics and other coastal and oceanic processes with respect to time and space. Attempt has been made to retrieve the normalized difference vegetation index (NDVI) for assessing the vegetation status of the cyclone-affected coastal districts of Orissa. The central wavelengths, the bandwidths and other major specifications of OCM sensor are given in Table 1.

The retrieval of ocean colour parameters such as phytoplankton pigment (chlorophyll-a) and suspended sediments in near-shore waters involves two major steps: (i) Atmospheric correction of visible channels to obtain normalized water leaving radiances (nLw); (ii) Retrieval of water constituents, such as chlorophyll and suspended sediments.

In the ocean remote sensing, the signal received at the satellite altitude is dominated by contribution of radiances through atmospheric scattering processes and only 8–10% signal corresponds to oceanic reflectance. Therefore it has been mandatory to correct the atmospheric effect to retrieve any quantitative parameter from space. The radiance received by a sensor at the top of the atmosphere (TOA) in a spectral band centred at a wavelength λ_i, $L_t(\lambda_i)$ can be divided into the following components:

$$L_t(\lambda_i) = L_a(\lambda_i) + L_r(\lambda_i) + T(\lambda_i)L_g(\lambda_i) + t(\lambda_i)L_w(\lambda_i),$$

where L_a and L_r are the radiance generated along the optical path by scattering in the atmosphere due to aerosol and Rayleigh scattering, L_g is the specular reflection or sun-glitter component which is being avoided by + 20° tilt angle of the sensor and L_w is the desired water leaving radiance. T and t are the direct and diffuse transmittance of the atmosphere, respectively.

The OCM scenes were corrected for atmospheric effects of Rayleigh and aerosol scattering. Rayleigh scattering component is computed by well-established theory[1]. Aerosol scattering is computed using an approach called long wavelength atmospheric correction method[2]. The approach used the two near infrared channels at 765 and 865 nm to correct visible wavelengths at 412, 443, 490, 510 and 555 nm[3]. The water-leaving radiances derived from atmospheric correction procedure were used to compute chlorophyll-a and suspended sediment concentration (SSC).

A number of bio-optical algorithms for retrieval of chlorophyll have been developed to relate measurements of ocean radiance to the *in situ* concentrations of phytoplankton pigments. An empirical algorithm (also known as Ocean Chlorophyll 2 or OC2) captures the inherent

Table 1. Technical characteristics of IRS-P4 OCM payload

Spectral range	404–882 nm
No. of channels	8
Wavelengths (SNR*)	Channel 1 : 404–423 (340.5)
	Channel 2 : 431–451 (440.7)
	Channel 3 : 475–495 (427.6)
	Channel 4 : 501–520 (408.8)
	Channel 5 : 547–565 (412.2)
	Channel 6 : 660–677 (345.6)
	Channel 7 : 749–787 (393.7)
	Channel 8 : 847–882 (253.6)
Satellite altitude	720 km
Spatial resolution	360 × 236 m
Swath	1420 km
Repeativity	2 days
Quantization	12 bits
Equatorial crossing time	12 noon
Along track steering (to avoid sunglint)	k 20°
MTF (at Nyquist)	0.2
Transmission frequency	X-band
Data rate	20.8 Mbps

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sigmoid relationship between $R_{rs}490/R_{rs}555$ band ratio and chlorophyll concentration C (where R_{rs} is remote sensing reflectance)[4]. The algorithm was shown to retrieve low as well as high chlorophyll concentration (0.01–50.00 mg/m^3), which means it can be used for case 1 and case 2 waters. The algorithm operates with five coefficients and has the following mathematical form:

$$C = 10^{[0.341 - 3.001*X + 2.811*X^2 - 2.041*X^3]} + (-0.040),$$

where C is chlorophyll concentration in mg/m^3 and $X = \log_{10}[R_{rs}490/R_{rs}555]$. While comparing all available algorithms for Indian waters, it was observed that this algorithm provided best results for chlorophyll retrieval. This algorithm has been presently used for generating the

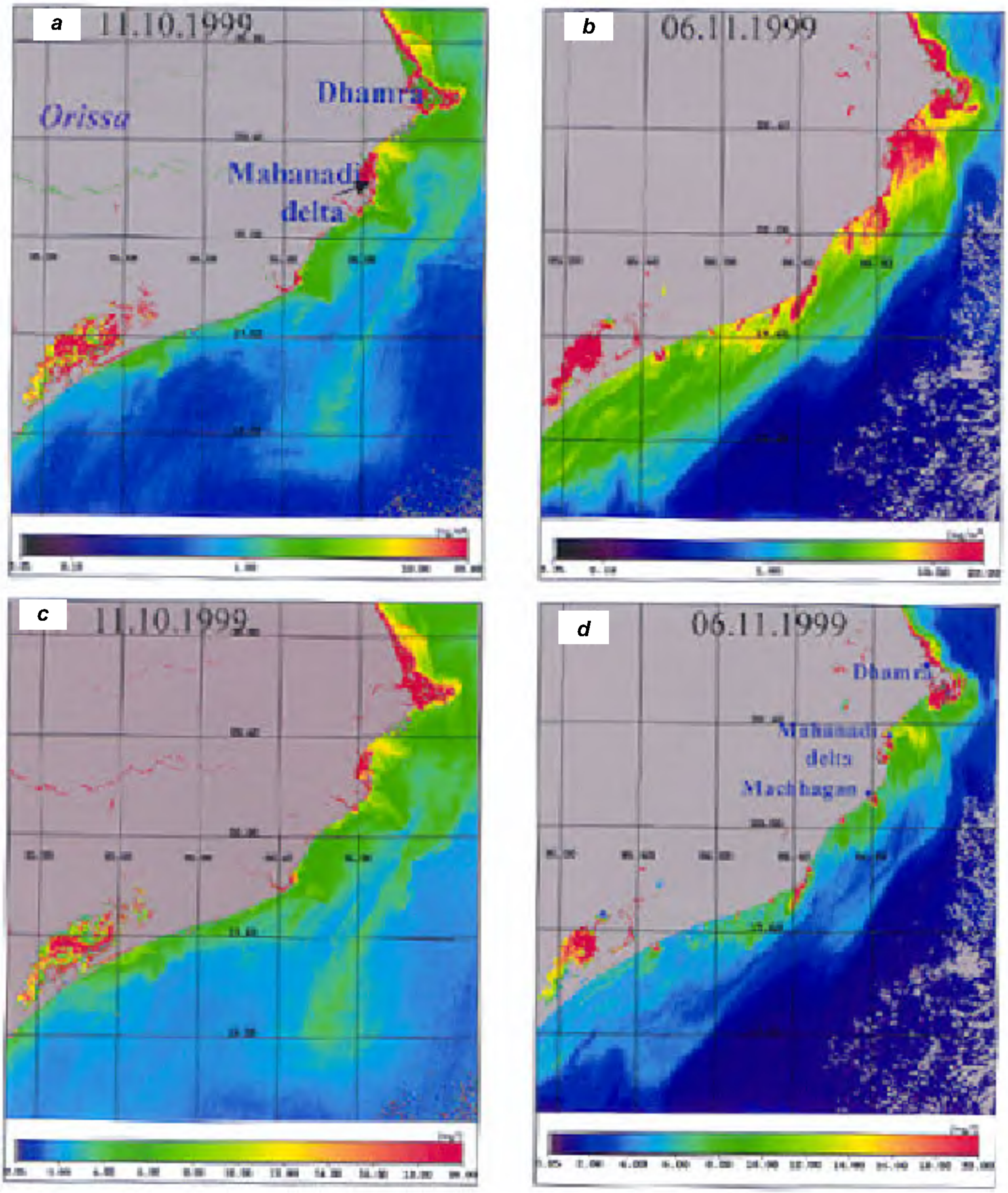

Figure 1. IRS-P4 OCM derived chlorophyll-*a* images (***a*** and ***b***) and suspended sediment concentration images (***c*** and ***d***) for the pre- (11.10.1999) and post-cyclone (06.11.1999) period around Orissa coast.

chlorophyll maps, using IRS-P4 OCM-derived water leaving radiances. The chlorophyll images were generated using the above algorithm for the pre-cyclone date (11, 13 and 15 October 1999) and the post-cyclone date (6, 8, 10, 12 and 14 November 1999). The above images were geometrically corrected and grided with one-degree latitude and longitude interval.

The suspended sediment concentration in the coastal areas have been derived using water leaving radiances in bands 490, 555 and 670 nm. The algorithm[5] that has been used to compute suspended sediments from OCM data has the following mathematical form:

$$\log S = 1.83 + 1.26 \log X_s,$$

where S is suspended sediment concentration in g/m^3 and X_s is a variable defined as:

$$X_s = [R_{\mathrm{rs}}(555) + R_{\mathrm{rs}}(670)]*[R_{\mathrm{rs}}(490)/R_{\mathrm{rs}}(555)]^{-0.5},$$

where R_{rs} is remote sensing reflectance in the respective wavelengths.

The data are analysed for both the pre-cyclone (11, 13 and 15 October 1999) and post-cyclone (6, 8, 10, 12 and 14 November 1999) periods to generate the SSC images using the above algorithm.

The NDVI is related to the condition of vegetation[6]. Healthy vegetation reflects very well in the near infrared part of the spectrum. Green leaves have a reflectance of 20 per cent or less in the 0.5 to 0.7 micron range (green to red) and about 60 per cent in the 0.7 to 1.3 micron range (near infrared)[7]. The value is then normalized to the range $-1 \le \mathrm{NDVI} \le +1$ to partially account for differences in illumination and surface slopes[8].

It is calculated using a simple formula from the two (red and infrared) channels of a sensor. If one band is in the visible region (VIS) and one in the near infrared (NIR), then the NDVI is (NIR – VIS)/(NIR + VIS)[9]. In our present study the channels used for NDVI calculation are band 8 (865 nm–NIR) and band 6 (670 nm–red) of the IRS-P4 OCM sensor.

NDVI provides a good estimation of vegetation health and a means of monitoring changes in vegetation over time. The possible range of values is between about – 0.1 (NIR less than VIS for a not very green area) and 0.6 (for a very green area)[10].

In pre-cyclone period the chlorophyll image shows the moderate range (around 1.0 mg/m^3). Chlorophyll patches are seen in a scattered manner. In the pre-cyclonic period image (during October), which falls in the monsoon period, the scattered patches in the coastal water may be due to frequent rainfall and mixing of pigments in the water column. The seasonal monsoon wind gives rise to surface currents, which ultimately influence the spatial pattern of chlorophyll. The same concentration of chlorophyll patches which are pushed parallel towards the coastline is due to surface wind stress and cyclonic wind from continental shelf towards coastal water (Figure 1 *a*).

In the chlorophyll image of the post-cyclonic stage, the moderate concentration range chlorophyll patches are pushed towards the coastal waters, seen parallel to the coastline (Figure 1 *a* and *b*).The coastal waters around Dhamra show high concentration of chlorophyll (5.0–10.0 mg/m^3) patches compared to the pre-cyclonic chlorophyll composite image. This may be due to terrestrial nutrient flux to sea from land run-off and had enhanced the productivity of the coastal water. The chlorophyll distribution in the image of 6 November shows very high concentration of (around 20 mg/m^3) water off the cyclone-affected districts of Orissa, which appears as bloom-like high concentration patches. It is not unusual to get high chlorophyll values in the coastal waters[11,12]. The coastal water chlorophyll zonation which is seen parallel to the coastline with high concentration range (1.0–5.0 mg/m^3), may be due to the effect of along-shore wind (Figure 1 *b*). Like Dhamra, the coastal waters around Mahanadi delta show very high chlorophyll concentration of around

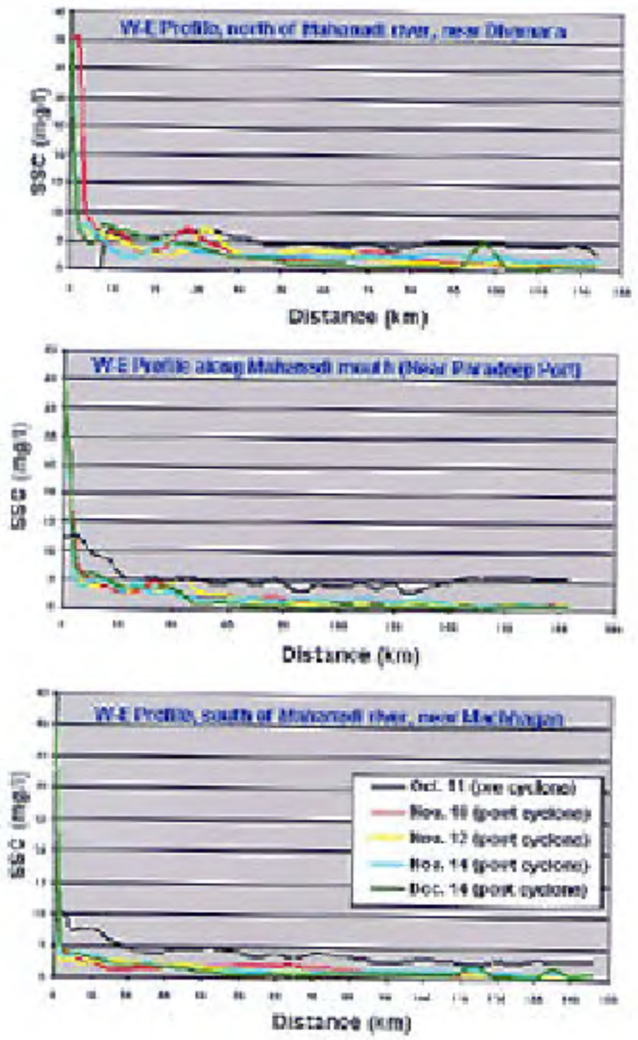

Figure 2. Suspended sediment distribution patterns observed in the cyclone-affected coastal waters around Mahanadi delta for the data retrieved from IRS-P4 OCM images.

20 mg/m^3 in post-cyclone image than the pre-cyclone image and the patterns are seen as compressed in comparison with pre-cyclonic stage.

The changes in the suspended sediment patterns and concentration due to the impact of cyclone are distinctly observed while analysing pre- and post-cyclone IRS-P4 OCM data. Figure 1 *c* and *d*, shows SSC images of pre- and post-cyclone period.

The SSC map derived from OCM data of 11 October 1999 is the first available cloud-free data just before the first cyclone struck the Orissa coast on 16 October 1999. The pattern of the sediment plumes observed at Dhamra and Paradeep (Mahanadi) shows dispersion influenced by NE to SW currents prevailing during this season in the region under study. The Dhamra and Mahanadi estuaries show very high SSC seen as red colour in the imagery. This is expected due to the high monsoon rainfall in the catchment area of these rivers. It may be seen that on 6 November 1999 we could get the first cloud-free OCM data after the super cyclone struck the Orissa coast on 29 October 1999. The derived SSC image shows that the entire region has abnormally low values seen as dark blue colour on the imagery, in spite of the continued supply of very high sediment influx from the terrestrial region during the prevailing monsoon season. This is very peculiar and probably the very severe wind and wave action during the super cyclone period have transported sediments towards the coast, following severe cyclonic

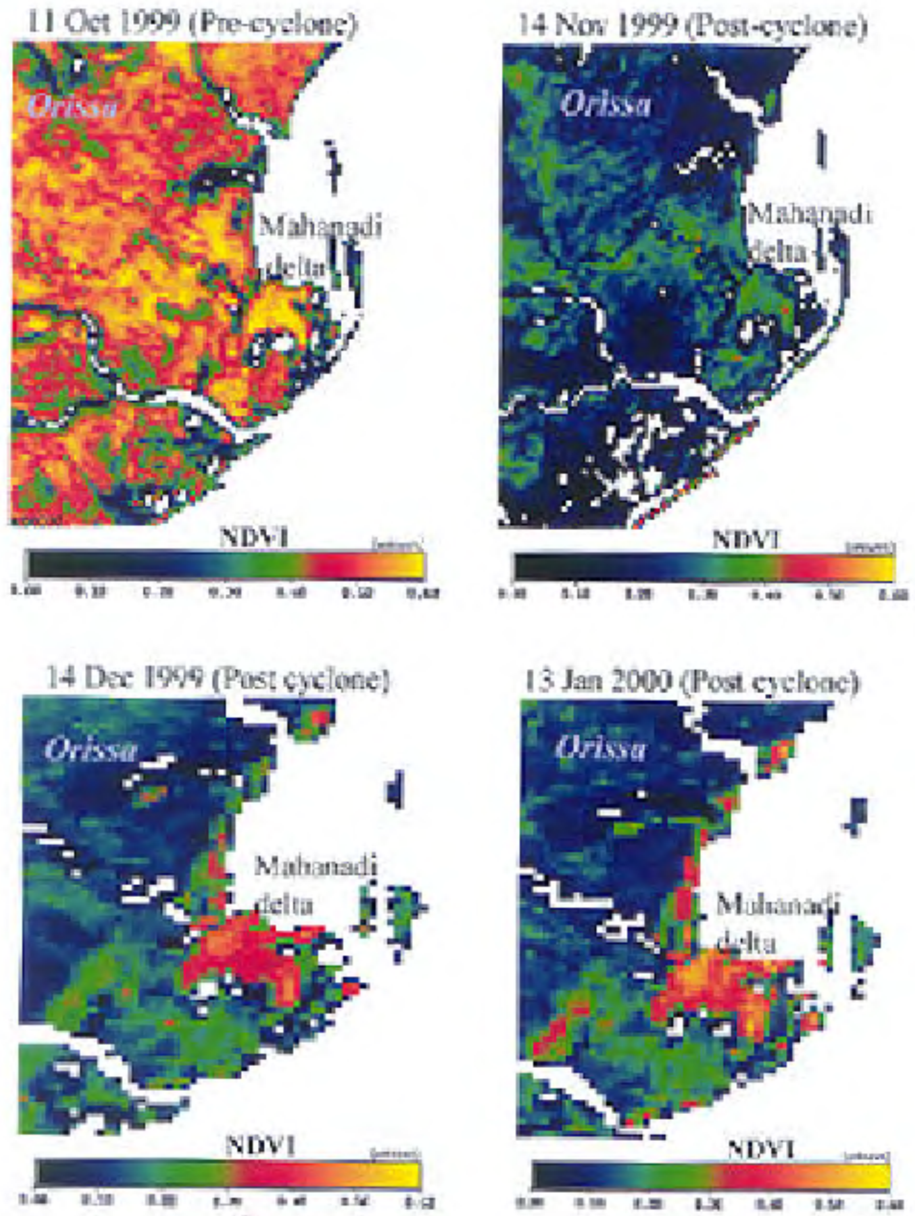

Figure 3. IRS-P4 OCM-derived normalized difference vegetation index (NDVI) images for the pre- and post-cyclone periods showing the vegetation status around Mahanadi delta.

wind stress and storm surge activity. Very high SSC is observed in the Mahanadi estuarine and deltaic regions and near Dhamra coast (Figure 2). The subsequent SSC images retrieved after analysing IRS-P4 OCM data of 8, 10, 12 and 14 November 1999 show that SSC in the offshore region has started gradually increasing. The width of the SSC along the Orissa coast has increased. It is also noted that plume at Dhamra is showing N-S dispersion and gradually the SSC has reduced within the Chilka lagoon and around Paradeep region. The area north of Dhamra up to Hoogli estuary shows disappearance of red colour, indicating reduced SSC near the coast in this particular region.

From the derived SSC values for different dates, three profiles at different locations from the Orissa coast to offshore region (around 170 km) showing distribution of SSC during pre-cyclone (11 October 1999) and post-cyclone (10, 12, 14 November and 14 December 1999) were plotted. The locations are: (i) W-E profile north of Mahanadi river (near Dhamra); (ii) W-E profile along Mahanadi mouth (near Paradeep port); (iii) W-E profile south of Mahanadi river (near Machhagan).

The profiles are shown as Figure 2. The profiles reconfirm that the observation made on the basis of SSC patterns that the large surge of sea water (7 m high) coupled with very high wind speed has brought all sediments near the coast. Additionally, the receding flood water (up to 8–9 km inland) brought silt and large sediment particles (eroded from land) along with it. This led to heavy sedimentation near the coast. After the cyclone the silt particles were dispersed towards the open sea and in the south-east direction, due to predominant south-easterly current during this season. However, it is very likely that large sediment particles have settled near the coast. It should have consequent impact on near-shore bathymetry. The changes in near-shore bathymetry influence wave approach direction, magnitude and the littoral drift. This could result in rapid shoreline changes. The regional study of suspended sediments and their dispersal is being followed by study of high resolution IRS-1C/1D LISS-III and PAN data to understand shoreline changes brought by the Orissa cyclone.

NDVI images were studied for the pre-cyclonic period (on 11 October 1999) and post-cyclonic period in the 3 successive 3 months on 14 November 1999, 14 December 1999 and 13 January 2000 (Figure 3). The pre-cyclonic image of 11 October 1999 shows healthy vegetation status. The NDVI value varies between 0.40 and 0.60 in the Mahanadi delta. But for the post-cyclone image (14 November 1999), the same area shows NDVI range of 0.20–0.40 (Figure 3). The low NDVI range indicates damage to mangroves during the cyclone, which has been observed during ground truth, apart from water stagnation over mangroves.

The NDVI image of the 14 December 1999 shows the improvement in condition of mangrove forest along the coastline. In the image of 13 January 2000 the vegetation shows the NDVI range of 0.40–0.60 for the mangroves around Mahanadi delta. This suggests that mangroves were not totally uprooted but had shed their leaves only. Within two months, the mangroves have reached their original state. This indicates that as shelter belt, mangroves should be planted wherever possible.

The above study gives the results of the pre- and post-cyclonic changes in the coastal environment of Orissa, with respect to the coastal vegetation and constituents of coastal water. The chlorophyll concentration in the coastal waters of the cyclone-affected areas shows rapid change with very higher concentration (> 10 mg/m^3) in post-cyclone images than the pre-cyclone images derived from the IRS-P4 OCM data. Similarly the SSC image shows higher values (> 20 mg/l) in the coastal water along Paradeep, Dhamra and other cyclone-affected areas in the post-cyclone image. These are due to the effect of the cyclonic wind stress and the land influxes. The synoptic view and higher temporal resolution (2 days) of the IRS-P4 OCM data were found to be extremely useful in understanding the impact of the Orissa cyclone on coastal sediments. Orissa coast has undergone rapid changes due to abnormally high sediments settling near it brought by both high surge from offshore as well as receding flood water. This is indicative of change in near-shore bathymetry and consequent shoreline changes. The coastal vegetation status of the cyclone-affected areas shows severe damage to mangroves, which improves in the temporal series NDVI images for December 1999 and January 2000. The above work proves the potential of the IRS-P4 OCM sensor for assessment of the coastal environment with respect to the super cyclone which struck the Orissa coast on 29 October 1999.

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ACKNOWLEDGEMENTS. We thank Dr R. R. Navalgund, Deputy Director, Remote Sensing Application Area and Director, Space Applications Centre for providing necessary guidance and facilities for carrying out the work.

Received 10 October 2000; revised accepted 18 January 2001

Genetic analysis of somaclonal variation among callus-derived plants of tomato

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Genetic stability in tissue-cultured tomato plants was examined by randomly amplified polymorphic DNA (RAPD) analysis. Picloram was used for the first time as alternative auxin, along with benzyladenine (BA) for callus induction in tomato. Calli were induced from leaf explants on Murashige and Skoog's (MS) medium supplemented with 8.88 µM BA and 4.13 µM picloram. Regeneration was obtained after culturing freshly-induced calli on MS medium containing 17.7 µM BA alone. Microshoots were rooted in the presence of 10 µM indole-butyric acid (IBA) on MS medium. DNA samples from the mother plant and 11 randomly selected regenerated plants, obtained from a single callus, were subjected to RAPD analysis for the detection of putative somaclones. Six arbitrary decamer primers produced polymorphic amplification products. In this set of experiments, fifteen non-parental bands were observed, of which three were shared and twelve unique. The estimation of genetic similarity coefficient based on RAPD band-sharing data indicated that ten regenerated plants were more than 95% similar to the mother plant, except one, LS5, which was found to be distinctly different. This report demonstrates the feasibility of easy induction of regenerative calli by using combination of picloram and BA and the possibility of detecting genetic variation through RAPD analysis among callus-regenerated plants in tomato at an early stage of growth.

IDENTIFICATION of possible somaclonal variants at an early stage of development is considered to be very useful for quality control in plant tissue culture, transgenic plant production and in the introduction of variants. Somaclonal variability often arises in tissue culture as a manifestation of epigenetic influence or changes in the genome of differentiating vegetative cells induced by tissue culture conditions[1,2]. Any genetic change induced by *in vitro* conditions of tissue culture is expected to generate stable plants carrying interesting heritable traits. However, such random changes are not desirable in plant transformation experiments. Therefore, their early detection is considered to be very useful in plant tissue culture and transformation studies. Randomly amplified polymorphic DNA (RAPD) based detection of genetic polymorphism[3,4] has found successful application in describing somaclonal variability in regenerated individuals of several plant species[5–7]. In the present paper, we report successful induction of regenerative calli from tomato leaf explants, cultured on Murashige and Skoog's (MS) medium supplemented with picloram (4-amino-3-5-6-trichloropicolinic acid, a common herbicide) (as an auxin) and benzyladenine (BA; as cytokinin), and the extent of genetic variability in the plants regenerated from one of these calli as examined through RAPD analyses.

Lycopersicon esculentum Mill cv. Sakthi procured from Agricultural College, Thiruvananthapuram was used in this study. Leaf explants, from a field-grown plant (mother plant), were sequentially washed under running water and with 0.1% labolene (Qualigens, India) for 10 min each. Their surface was disinfected with 70% ethanol for 2 min and then treated with 0.1% w/v mercuric chloride solution for 3 min. Finally, they were washed 3–4 times with sterile distilled water and inoculated aseptically on MS basal medium[8] containing combinations of BA (4.2–17.7 µM) and picloram (4.13–8.26 µM). Regeneration of calli was attempted on MS medium containing BA alone, picloram alone and combinations of both. The pH of all media was adjusted to 5.8 and 0.8% (weight/volume) agar was added prior to autoclaving at 103 kpa for 20 min. Cultures were incubated under a 12 h photo-period with light intensity of 3000 lux at 26 ± 1°C.

DNA was extracted from fresh *in vitro* leaves of regenerated tomato plants and the mother plant by cetyltrimethyl ammonium bromide (CTAB)-based procedure[9]. RAPD was performed as described by Williams *et al.*[4] using random decamer primers (M/s Operon Inc, USA). Polymerase chain reaction (PCR) was carried out in presence of 1X Taq DNA polymerase buffer (10 mM Tris-HCl, pH 8.3, 50 mM KCl, 1.5 mM $MgCl_2$, 0.001% gelatin), 100 µM dNTPs, 5 picomole single random primer, 25 ng template DNA, 0.5 unit of Taq DNA polymerase (Bangalore Genei, India) in a total volume of 20 µl overlayed with mineral oil (Sigma Chemical Co). PCR amplification was performed in automated thermal cycler (PE480) programmed for 45 cycles of 1.0 min denaturation at 94°C, 1.0 min annealing at 37°C and 2 min polymerization at 72°C, followed by a final extension step at 72°C for 10 min. The amplification products were resolved by electrophoresis in 1.2% agarose (USB) gels in 0.5X TBE buffer at 5 V/cm for 3 h and documented on Gel Doc 1000 (Bio-Rad).

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