The determination of chlorophyll-a and suspended sediment concentrations

for EURASEP test site, during North Sea Ocean Colour Scanner experiment,

from an analysis of a LANDSAT scene of 27th June 1977.

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Abstract.

During the EURASEP "North Sea Ocean Colour Scanner Experiment" in
the summer of 1977 "sea-truth" data were collected simultaneously with the
overflight by an aircraft carrying a ten-channel multispectral scanner, the
Ocean Colour Scanner. A detailed comparison between the OCS results and
the "sea-truth" data has been made at the Joint Research Centre, Ispra, to
produce maps of suspended sediment and chlorophyll-a. In this paper we
describe the results of an analysis that we have made, using LANDSAT-2
multispectral scanner data obtained from a pass over the same area that
occurred on 27th June 1977, during the North Sea OCS experiment. We have
produced maps of suspended sediment and chlorophyll-a from the LANDSAT-2
data and the same "sea-truth" data already mentioned; we have made a de-
tailed comparison between the results of the Ocean Colour Scanner work and
of our LANDSAT-2 multispectral scanner work.

1. Introduction.

The NIMBUS-7 satellite was launched on 24th October 1978 and one of the instruments that it carries is the Coastal Zone Colour Scanner (CZCS). The EURASEP (European Association of Scientists for Experiments on Pollution) proposal was made by the JRC (Joint Research Centre) of the Commission of the European Community. The work of EURASEP is directed at the task of tackling problems involved in ocean colour monitoring from space. This includes the development of algorithms that would be relevant to the determination of turbidity and chlorophyll concentrations in European waters from satellite data.

The EURASEP "North Sea OCS (Ocean Colour Scanner) Experiment" was carried out in the Summer of 1977. This was envisaged as a pre-launch exercise in respect of the NIMBUS-7 satellite. The Coastal Zone Colour Scanner (CZCS), which is carried on NIMBUS-7, is similar to the Ocean Colour Scanner (OCS). The idea was that algorithms developed for the OCS would then subsequently be extended to be applicable to the CZCS data too. In this experiment 9 ships were on standby for two weeks at ports along the coast from Cap Gris Nez in France to Ijmuiden in the Netherlands. For the same period three aircraft were also on standby in the vicinity of that area. When clear weather was obtained these ships set out, on courses approximately normal to the coastline, to collect "sea-truth" data. At the same time the aircraft carrying multispectral scanners flew over the test site. An account of this data collection exercise is given in reference 1.

During the two-week standby period clear weather was obtained on less than half of the available working days. It so happened that there was a LANDSAT-2 pass over the test site on one of these clear days, namely 27th June 1977. In figure 1, we show an extract from the image obtained from the LANDSAT-2 multispectral scanner on that day. In this image one can see that there is a considerable variation in the reflected intensity from the water. This variation in the reflected intensity from deep waters must be considered to be due primarily to the presence of foreign materials floating on the surface of the water or suspended in the top few metres depth of water. In this area the water is generally deep enough that reflection from the bed of the sea can be ignored.

The concentrations of chlorophyll-a and of suspended matter, the so-called "sea-truth" data, obtained along the ship track B on 27th June 1977 are available from the published results of the North Sea OCS experiment (2,3). This ship set out from Bergsluis and its precise track is recorded in reference 3. The "sea-truth" data were collected between 09:10:00 hours and 11:24:00 hours (GMT) on that day and the centre of the LANDSAT-2 MSS scene we have used was recorded at 09:38:50 hours (GMT) on that day.

Very substantial efforts have been made at the Joint Research Centre, Ispra, to correlate the "sea-truth" data obtained, both on 27th June 1977 and on the other days of successful measurements, with the imagery obtained from the Ocean Colour Scanner (4,5). One of the objectives of the EURASEP experiment was to attempt to obtain algorithms for the determination of sea parameters, such as concentrations of chlorophyll-a, suspended sediment and yellow substance, etc. from the OCS data.

Our motivation in studying the LANDSAT-2 MSS data is not simply based on an academic wish to make comparisons with the OCS data. We have to acknowledge that the LANDSAT-2 multispectral scanner has two disadvantages. First, it has only four spectral channels (none of which is in the thermal infrared region of the spectrum) compared with the six channels of the CZCS. Secondly, the frequency of coverage of any given area by

LANDSAT-2 is much lower than the frequency of coverage by NIMBUS-7. On the other hand there are two points in favour of LANDSAT-2 in comparison with NIMBUS-7. First, the NIMBUS-7 satellite which carries the CZCS is only expected to have a relatively short lifetime compared with the time for which LANDSAT data have been available and can be expected to be available in the future. Secondly, the spatial resolution obtained with the LANDSAT-2 MSS data is about an order of magnitude better than that obtained with the NIMBUS-7 CZCS data. It has been estimated (reference 6,p.701) that LANDSAT-2 MSS data should be superior to CZCS data for determining chlorophyll concentrations larger than $2\mu g/1$, whereas the CZCS data should be superior to the LANDSAT data for determining chlorophyll concentrations lower than about $0.5\mu g/1$. Thus it seems that the study of the LANDSAT-2 MSS data is intrinsically interesting and important in this connection.

In this paper we shall, therefore, report on our calculations on (i) the correlation between the LANDSAT-2 MSS data and the chlorophyll-a and suspended sediment concentrations determined in situ on 27th June 1977, (ii) the calculation, or extrapolation, of these quantities from ship-track B to a much larger area in the LANDSAT scene, and (iii) the comparison of our results with the results of the analysis of the OCS data performed at Ispra and based on the same "sea-truth" data.
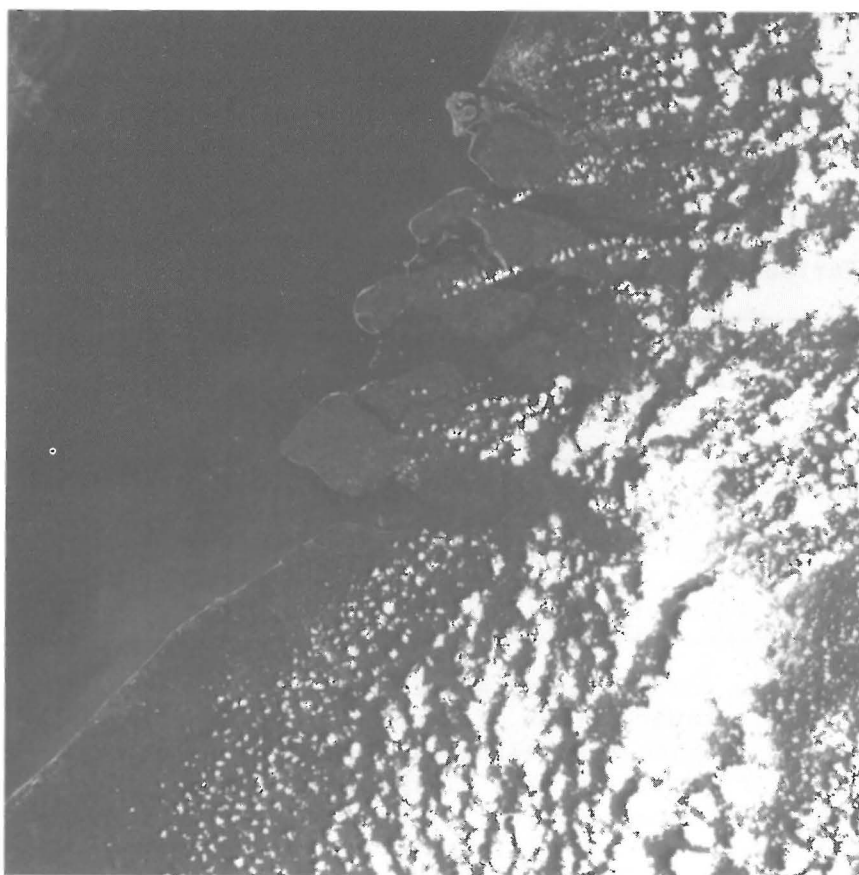

Figure 1. LANDSAT-2 multispectral scanner band-4 image of EURASEP test site, 27th June 1977.

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2. Geometrical Rectification.

One of the standard techniques (6,7) for LANDSAT image rectification was used in order to relate the easting (E) and the northing (N) co-ordinates of discrete points along the ship track B to the MSS data in terms of the scan line number (L) and the column number, or pixel (picture element) number, (P). The E and N coordinates of the points at which the "sea-truth" data were obtained are available from the EURASEP OCS experiment. A number of ground control points (GCPs) along the coastline were identified manually both on the map and in the LANDSAT image. This enables one to assign two sets of coordinates to each of the GCPs, namely, the (E,N) coordinates and the (L,P) coordinates. The transformation from one coordinate system to the other coordinate system was achieved through the following non-linear relations:

$$L = a_0 + a_1E + a_2N + a_3E^2 + a_4N^2 + a_5EN \left.\rule{0cm}{1cm}\right\} \quad (1)$$
$$P = b_0 + b_1E + b_2N + b_3E^2 + b_4N^2 + b_5EN$$

$$E = a_0' + a_1'L + a_2'P + a_3'L^2 + a_4'P^2 + a_5'LP \left.\rule{0cm}{1cm}\right\} \quad (2)$$
$$N = b_0' + b_1'L + b_2'P + b_3'L^2 + b_4'P^2 + b_5'LP .$$

Using these relations and the coordinates of the GCPs, multi-variable regression analysis was performed. The results are shown in table 1. The entries in column 1 indicate which of the above relations was considered.

Table 1.

Dependent Variable	Coefficient of multiple correlation		Standard error of estimate	
	non-linear	linear	non-linear	linear
L	0.9999	0.9998	3.5 lines	4 lines
P	0.9996	0.9994	5 columns	5.5 cols.
E	0.9996	0.9998	24"	15"
N	0.9999	0.9998	12"	13"

The entries in columns 2 and 4 are the coefficient of multiple co-relation and the standard error of estimate. We have included the entries in columns 3 and 5 which were obtained by retaining only the linear terms in equation (1) and equation (2). Inspection of the values in this table shows that there has been a slight improvement of the least squares fit in going from the linear transformations to the non-linear transformations of second order. Thus, it seems obvious that in order to achieve the transformations with a high degree of accuracy, higher degree transformation relations must be used; this in turn demands that a larger number of uniformly distributed GCPs must be used. To identify a large number of uniformly distributed GCPs on the map as well as in the LANDSAT image is not an easy task.

The above analysis enables one to compute the sample (ship track) coordinates in terms of the scan line number and the column number of the

MSS data. Therefore, the LANDSAT-2 MSS data at these sample coordinates are available.

3. Algorithm for Chlorophyll-a and Suspended Matter Concentrations

We have attempted to correlate these "sea-truth" data with the LANDSAT-2 MSS digital data using a number of simple functional forms:

3.1. A simple ratio

We have considered the ratio

$$\frac{I_5}{I_4} = a + b \ln x \tag{3}$$

where I_4 and I_5 are the MSS digital data for band 4 and band 5 respectively, X stands for the "sea-truth" data (either chlorophyll-a or suspended matter) and a and b are constants which are determined by the regression analysis. This form of relation has been used (6) for chlorophyll-a determination. However, equation (3) resulted in poor correlations both for chlorophyll-a and for suspended matter, namely, $R_c = 0.58$ and $R_s = 0.60$, where the subscripts c and s on the correlation coefficient (R) stand for chlorophyll-a and suspended matter respectively.

3.2. Simple power laws.

We have considered two forms:

$$I_B = a X^b \tag{4}$$

$$I_B = a b^X \tag{5}$$

where I_B stands for the LANDSAT-2 MSS digital data for any particular band B (B = 4,5,6 and 7). The correlations given by equations (4) and (5) were, however, poorer than those given by the relation (3).

3.3. A linear transformation

We have considered a general linear relationship:

$$X = c_0 + c_1 I_4 + c_2 I_5 + c_3 I_6 + c_4 I_7 \tag{6}$$

where X has the usual meaning and I_4, I_5, I_6 and I_7 are the LANDSAT-2 MSS digital data for band 4,5,6 and 7 respectively. This type of algorithm has been suggested in reference 8. The correlation coefficients obtained were $R_c = 0.89$ and $R_s = 0.71$. The standard errors of estimate were $S_c = 0.75 \mu g/l$ and $S_s = 4.4$ mg/l. The values for the suspended matter are rather poor − but these are the best results for both the "sea-truth" parameters that we have been able to achieve so far. At this point, however, we would like to mention that we have not applied any corrections to the LANDSAT-2 MSS data. We do intend to study various corrections to these MSS data in the future. The kind of correlation given by the relation (6) for chlorophyll-a and
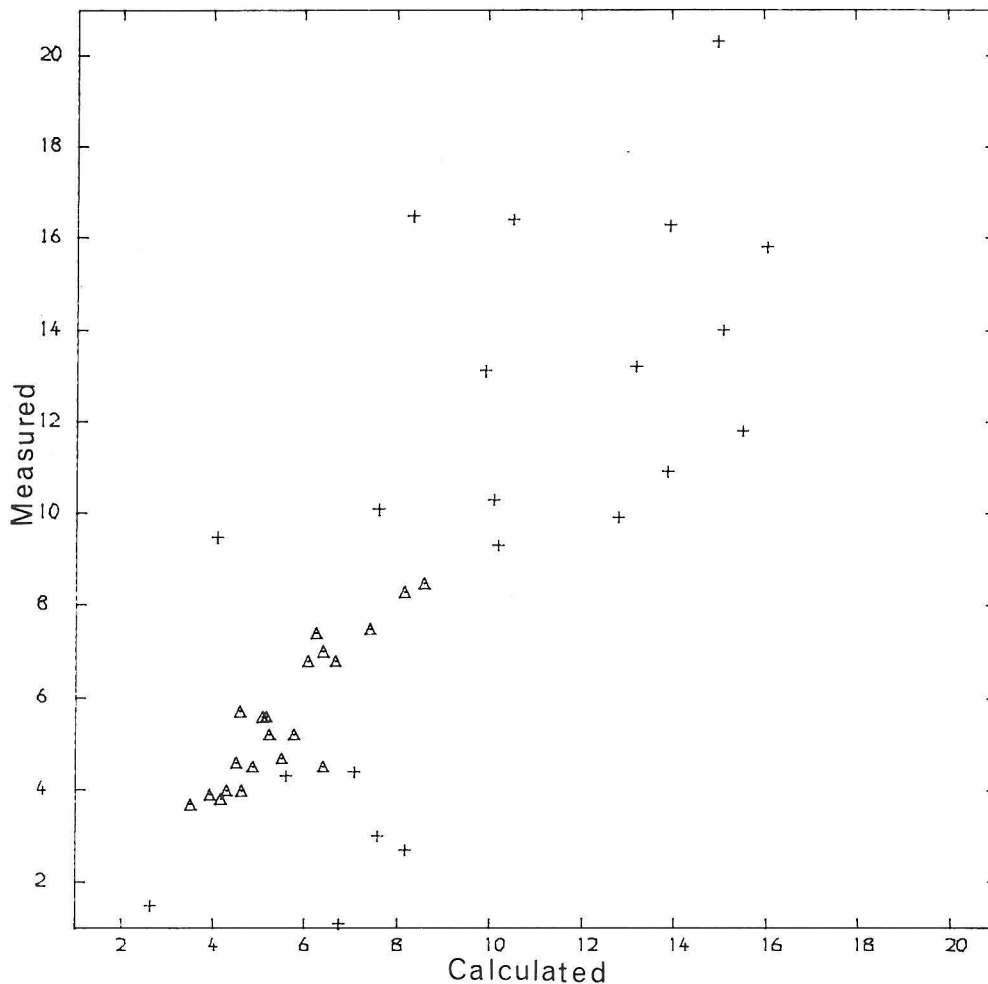
suspended matter is shown in figure 2.

Figure 2. The correlation given by equation (6) for chlorophyll-a (△)
         in µg/l and suspended matter (+) in mg/l. The measured values
         along track B are plotted against the calculated values.

4. Chlorophyll-a and Suspended Matter Maps

     Having determined the various constants in equation (6),the LANDSAT-2
MSS data and the relation (6) have been taken as the basis for computing
concentrations of chlorophyll-a and suspended matter beyond the ship track.
The MSS data provide the intensities I_4, I_5, I_6 and I_7 for an arbitrary

pixel (L,P) of interest. The easting and northing co-ordinates of the
pixel are given by equation (2). The concentrations of chlorophyll-a and
suspended sediment within this pixel can then be computed using equation
(6). Thus, these quantities can be mapped as a function of E and N and
the results are presented in figures 3 and 4; figure 3 shows the chloro-
phyll-a map and figure 4 shows the suspended matter map. The calibration
of the grey scale used in each case is indicated by a wedge at the foot
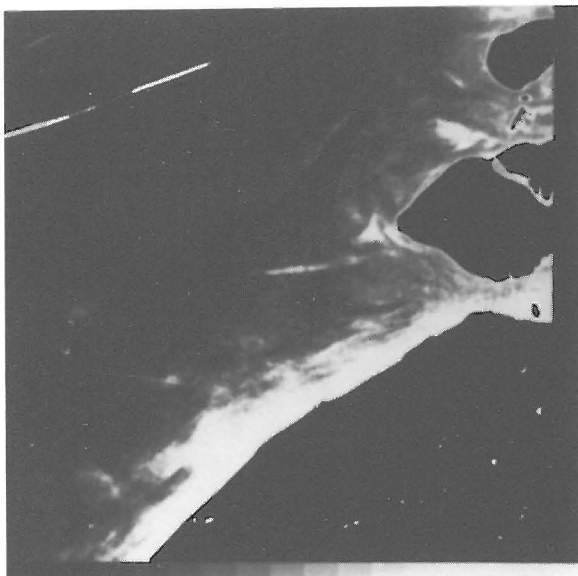of the map. In each case the land has been printed as solid black.

Figure 3.   Chlorophyll-a map in the extended region.   Each step in the
grey scale wedge corresponds to a step of 1 μg/l in concen-
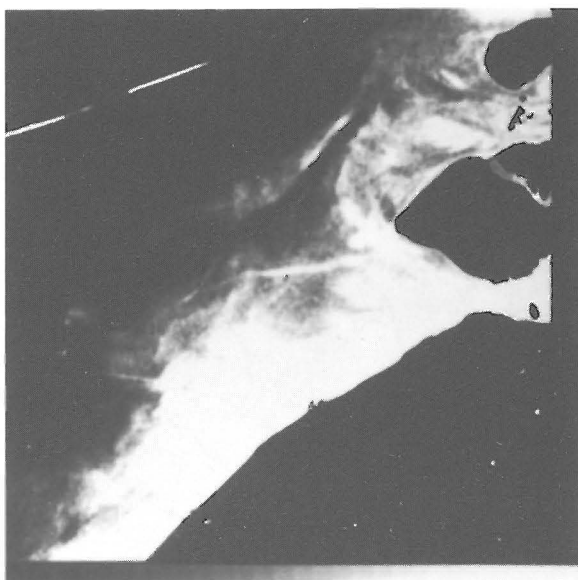tration, starting from 0 μg/l at the left-hand end of the wedge.

Figure 4.   Suspended matter map in the extended region. Each step in the
grey scale wedge corresponds to a step of 1 mg/l in concen-
tration, starting from 0 mg/l at the left-hand end of the wedge.

5. Comparison with OCS Results

To facilitate comparison between the results of our analysis of the
LANDSAT-2 MSS data and the analysis of the OCS data we present, in
figures 5 (a) and 6 (a), extracts from the maps given in figures 3 and 4
for the area covered by the OCS data, i.e. in the vicinity of ship track
B. The data in figure 5(a) and 6 (a) are presented as contours, and are
compared with contours produced from the Joint Research Centre's analysis
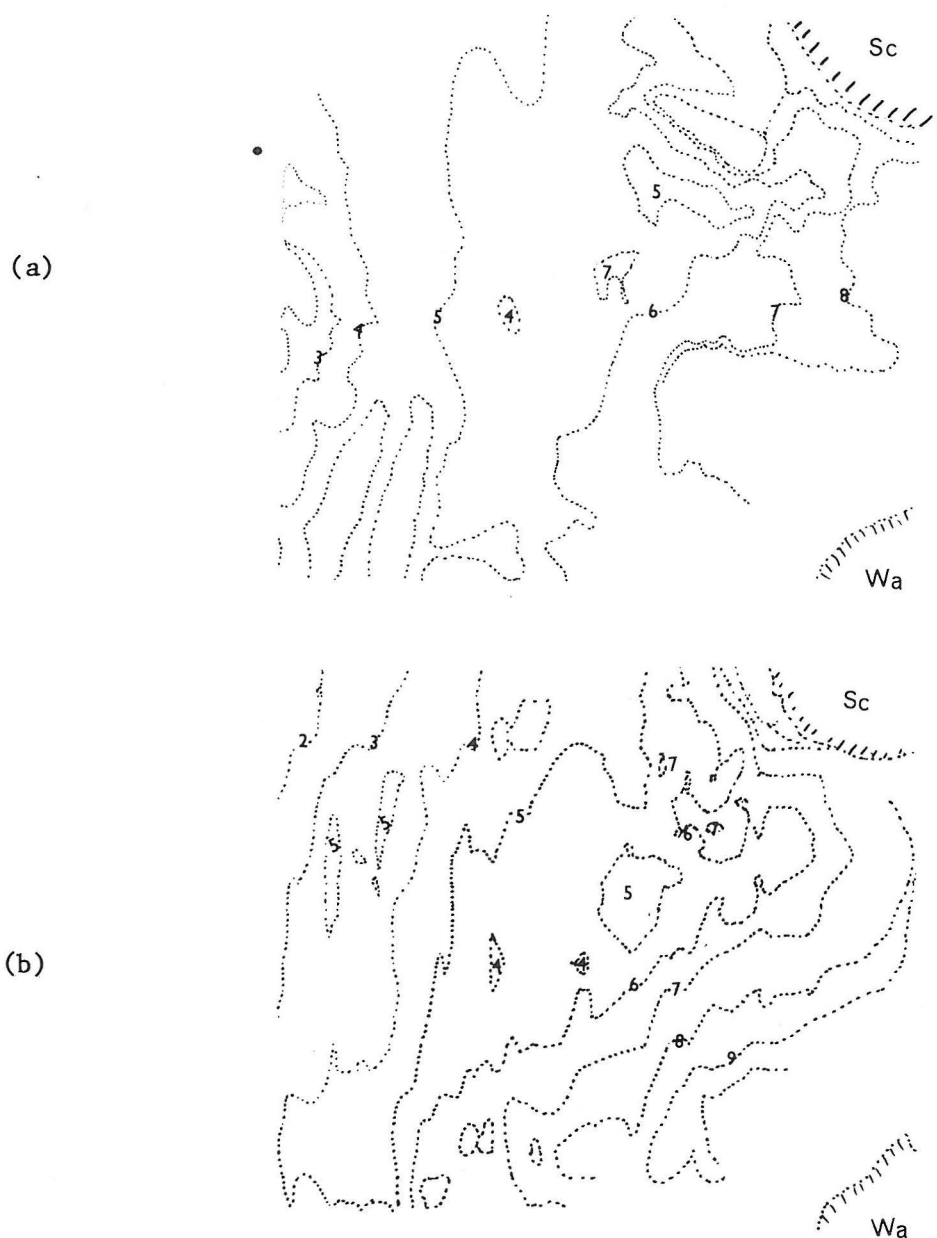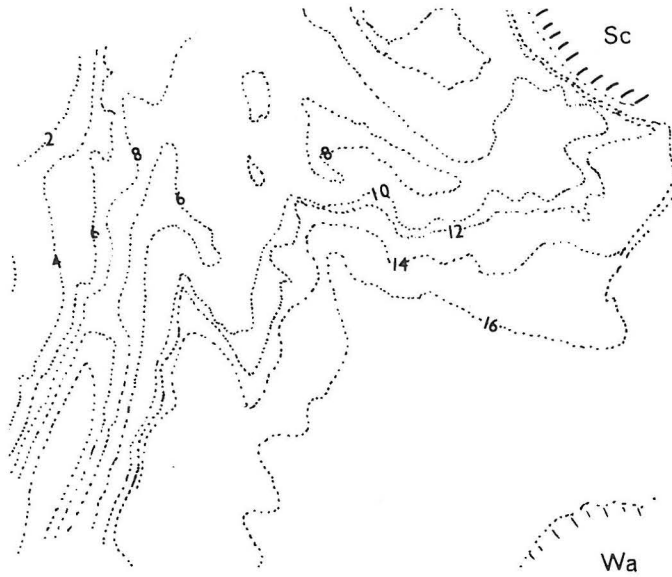of the OCS data, in figures 5 (b) and 6 (b).

Figure 5.   Chlorophyll-a concentration contours in the vicinity of ship
            track B (a) from LANDSAT data and (b) from OCS data. The units
            are μg/l. The coastline is hatched and Sc denotes Schouwen and
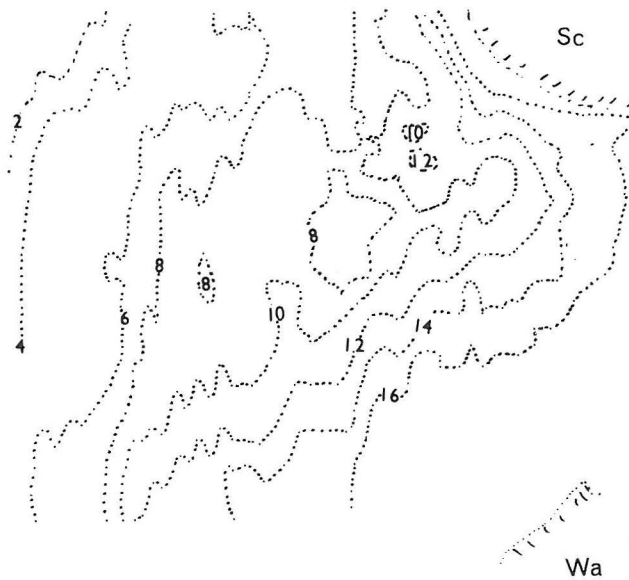   Wa denotes Walcheren.

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(a)

(b)

Figure 6. Suspended sediment concentration in the vicinity of ship track B
(a) from LANDSAT data and (b) from OCS data. The units are mg/l.
The coastline is hatched and Sc denotes Schouwen and Wa denotes
Walcheren.

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From figures 5 and 6 it can be seen that qualitatively, and even semi-quantitatively, there is a quite significant measure of agreement between the maps produced from the LANDSAT and OCS data. This is very gratifying, especially in view of the fact that we have not, so far, made various corrections to the LANDSAT data. It would have been naive to have expected any better agreement between the two sets of results at this stage. We are encouraged, therefore, to conclude that meaningful interpretations of multispectral scanning data can be given provided simultaneous "sea-truth" data are available for calibration purposes.

6. Conclusion

The comparison with the OCS results shows that our results, which are based on LANDSAT data, follow the general trend depicted in the OCS analysis maps. One should bear in mind, however, that one should not hope for a perfect correlation at this early stage. First, as noted earlier, we have yet to apply various corrections to the MSS data. Secondly, the ocean currents play important roles during the time difference between which the two sets of data (the "sea-truth" data and the MSS data) were obtained.

We should, perhaps, re-emphasise that although the algorithm used for the chlorophyll-a was satisfactory the same algorithm could account for only 51% of the suspended matter. We plan to study further the problem of finding a better algorithm, at least for the suspended matter.

7. Acknowledgements

References.

1. B.M. Sørensen, 1977, EURASEP Project, OCS Experiment, 1977, Report No.1 Joint Research Centre, Ispra.
2. P.J.F. Geerders, B.M. Sørensen and B. Lundgren, 1978, EURASEP Project OCS Experiment 1977, Report No. 2. Joint Research Centre, Ispra.
3. J. McManus, 1978, Water Quality Measurements in the North Sea, EURASEP OCS Experiment 1977, Cruise Report No. 4, Tay Estuary Research Centre, Dundee.
4. B. Sturm, B. Lundgren, G. Maracci and W. Mehl, 1978, Some Results from the EURASEP OCS Experiment in 1977, Pre-print of a paper presented at IURCM Colloquium on Passive Radiometry of the Ocean, Sidney, Canada.
5. B.M. Sørensen, 1979, The North Sea Ocean Colour Scanner Experiment 1977, Final Report, Joint Research Centre, Ispra.
6. F. Becker et al, 1978, Mathematical and Physical Principles of Remote Sensing, Notes on the Lecture Delivered at the Summer School of Space Physics, Strasbourg, Centre Nationale d'Etudes Spatiales, Toulouse.
7. P. van Wie and M. Stein, 1977, A LANDSAT Digital Image Rectification System, IEEE Trans. Geosci. Electr., GE-15, 130-7.
8. W.R. McCluney, 1976, Remote Measurement of Water Color, Remote Sens. Environ., 5, 3 - 33.