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CZCS Atlas of Water Optical Properties in the Alboran Sea

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Foreword

Applications of satellite remote sensing for monitoring the oceanographic environment are providing naval operations and planning an increased awareness of the dynamic spatial and temporal variability of ocean properties. The utility of visible remote sensing for quantitative bio-optical parameters provides global measurements where only limited ship measurements are presently available. Not only do remote sensing techniques provide increased savings for ships and manpower, they also provide a better understanding of the ocean environment.

This report demonstrates the technique of using the Coastal Zone Color Scanner satellite to be used to generate a water optical properties atlas. Potential remote sensing applications for naval operations and charting are shown, in addition to awareness of potential future ocean color satellite systems.

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Commanding Officer, NORDA

Executive summary

Optical water properties of the world oceans can be rapidly obtained from data from the Coastal Zone Color Scanner (CZCS) aboard Nimbus-7. Satellite processing techniques have been developed to eliminate the atmospheric contamination that contributes 90% of the total visible channel signal. The remaining signal, which constituted the ocean color, is directly related to the diffuse attenuation coefficient (*k*) at 490 nanometers for the upper surface waters. Calculation and geographic registration of *k* can be done for each of the 800-square-meter pixel resoluton of CZCS, and results show that the accuracy is within 25% of ship measurements.

Present ship measurements of water optical data are very limited. Ship optical instrumentation is difficult to deploy and calibrate, and does not provide synoptic coverage of the optical climate. Obtaining optical properties from visible satellites enables improved understanding of the temporal and spatial variability.

A series of CZCS images from the Alboran Sea have been processed for the diffuse attenuation coefficient. The monthly summary of *k* values demonstrates a technique for generating a *k* atlas using CZCS data. The Alboran Sea region illustrates a large majority of water masses: upwelling, strong fronts, river discharge, and clear central gyre. This spatial variability is coupled with the complex circulation resulting from the tidal pulsing of the inflowing Atlantic water at the Strait of Gibraltar. Results of the CZCS *k* atlas indicate that the water masses are changing more rapidly than expected. Also indicated is that ship measurements of optical properties in a region as complex as the Alboran Sea would be extremely difficult to interpret.

This report indicates the processing procedures used to calculate *k* from radiance data from the CZCS. Additionally, problems, assumptions, and recommendations for future processing are discussed.

Acknowledgments

This research was funded by the Defense Mapping Agency Hydrographic Topographic Center, Program Element 63701B/3201. Programming and technical assistance is acknowledged to members of the Remote Sensing Branch of NORDA, namely G. Stevenson and S. Peckinpaugh. Appreciation is also extended to the National Environmental Satellite Service for making the satellite available in a timely manner.

Contents

List of figures

CZCS atlas of water optical properties in the Alboran Sea

I. Introduction

Historically, the oceanographic data base of optical properties is severely limited by both the number of observations and the type of measurement. It has been shown that for large ocean and coastal regions the existing optical property data base is inadequate for determining the spatial and temporal variability (Arnone, 1983, 1984). This data base, which exists at the National Oceanographic Data Center (NODC), assimilates optics data as Secchi depth measurements and contains approximately 96,000 readings dating back to the early 1900s. Problems with the quality and the frequency of measurement have demonstrated that improved techniques for measuring and monitoring the optical properties were warranted.

The necessity for an improved data base for monitoring the ocean optical properties is based on the requirement for electro-optical systems to operate within the ocean environment. These systems, which operate based on the propagation of visible radiation through sea water, are critically influenced by the spectral optical characteristics. More specifically, development of laser and multispectral scanning remote sensing systems by the Defense Mapping Agency to determine bathymetry requires knowledge of the water optical properties in coastal areas to assess system performance. Since coastal waters have extremely high spatial and temporal variability, methods to improve on data collection and analyses are required.

Recently, ocean color imagery from the Coastal Zone Color Scanner (CZCS) aboard the Nimbus-7 satellite has been used to determine the optical property of the diffuse attenuation coefficient in the surface layer (first attenuation coefficient). The absolute water-leaving spectral radiance in two of CZCS channels has been empirically related to the attenuation coefficient. The application of CZCS imagery in providing the optical data base allows a unique capability in determining the spatial and temporal variability. The synoptic coverage of the 1500 nautical-mile swath of the satellite, coupled with the near daily coverage, permits absolute optical values to be computed for each of the 800-meter pixels within the scene. Satellite retrieval of oceanographic data is far more cost effective and is not limited by political boundaries.

The objective of this study is to demonstrate the application of CZCS data for generating an optical atlas for the Alboran Sea in the Western Mediterranean. All CZCS data were screened for cloud-free imagery to obtain at least two images of the optical properties per month. By compiling monthly imagery from 1978 to 1982, a statistical approach to accessing the variability of the optical properties should be illustrated by the imagery. This atlas will illustrate that visible satellite data can be successfully utilized to generate temporal atlases of ocean optical properties. The study will indicate the procedures used in generating the optical properties, as well as the problems and limitations of the technique. The oceanographic implications of the result will be discussed in relation to the processes. Furthermore, recomendations will be discussed for improving the methodology to address an operational system capable of handling large regional coverage.

II. Methods

A. Coastal Zone Color Scanner processing

The use of CZCS data to generate an optical atlas requires that a large amount of cloud-free data be available for a region and that it be collected thoughout a period of several years. Large amounts of CZCS data are presently archived at the National Environmental Satellite Data Information Service (NESDIS), with additional imagery arriving daily. These data sources are still limited for worldwide atlas development because of cloud-cover restraints. CZCS was launched in November 1978 and has been collecting world-wide data based primarily on user requests. Some key locations that border the U.S. routinely have data collected. The world coverage from CZCS is difficult to access, since many locations are not cloud-free; however, extensive world coverage provides data for a large percentage of the oceans. NESDIS has computer searches available for rapid assessment of CZCS data. Presently, CZCS has limited operation, since it has well surpassed its design life of two years. It now acquires about 30% of the original data rate. User requests are still permitted on a no-charge basis.

CZCS is a six-channel multispectral scanner in sun-synchronous orbit with a ground resolution of 800 m at nadir (Hovis et al., 1978). the narrow spectral channels are listed below:

Channel	Center (nm)	Bandwidth (nm)	Sensitive Parameter
1	443	20	chlorophyll
2	520	20	"yellow substance"
3	550	20	suspended sediments
4	670	20	atmospheric aerosols
5	750	100	land/water boundary
6	11500	1000	surface temperature

The selection of these spectral channels was based on the scattering and spectral absorption of the ocean water constituents. For example. in open ocean waters the phytoplankton pigment concentration of chlorophyll has strong absorption at 443 nanometers (Arnone, 1982). CZCS has a four-gain setting that permits the the scanner to measure subtle changes in the ocean color in three visible channels. (Channel 4, which is in the red portion of the spectrum, is not assumed to contribute to the ocean color and therefore represents atmospheric contamination only (Gordon and Clark, 1980)). CZCS has a repeat time such that coverage for three consecutive days is followed by two absent days. The scanner is also able to tilt 20° ahead of or behind the satellite's nadir track, which permits data collection to avoid seasonal sunglint areas and enhance ocean color quality.

The technique by which CZCS data can be utilized to generate an optics atlas is based on a relationship established by Austin and Petzold (1980). Figure 1 illustrates that the diffuse attenuation coefficient, (k) (at 490 nanometers), is related to the ratio of the upwelling/water-leaving radiance at two wavelengths. Water-leaving radiance is that flux measured just below the sea surface. This suggests that if it were possible to descend the satellite to just below the sea surface and measure the upwelling radiance at 443 and 550 nanometers, then the diffuse attenuation coefficient at 490 nanometers can be computed from their ratio. The problem arises with eliminating the influence of the atmosphere. This problem is compounded, since approximately 90% of the signal sensed by CZCS (channel 1 is greater) arises from the atmosphere. The remaining 10% of the signal, which is the water-leaving radiance, can be used to compute the diffuse attenuation coefficient.

The method by which the atmospheric contamination is removed was originated by Gordon (1978). Removing atmospheric contamination does not include cloud areas, since the sensor cannot see through them. The removal process applies to CZCS pixels, which "see" the sea surface. Single-scattering models of photon interaction with the atmosphere indicate that Rayleigh scattering and aerosol scattering can be used in summation to determine the atmospheric contribution. Rayleigh scattering can be computed based on the angular position of the ground position with respect to the solar and spacecraft position. Aerosol scattering is more difficult to determine, since it responds to the various types of aerosols (size distributions, compositions, spatial variabilities, etc.). However, if it is assumed that channel 4 (670 nanometers) is only a measure of the aerosol contribution, then by subtracting the water-leaving radiance, the three visible channels can be computed. The subtraction is not straightforward, however, since the aerosol contribution at 670 nanometers is different then at 443, 520, or 550 nanometers. The method used to address the spectral relationship between atmospheric aerosols is

$$\frac{La_\lambda}{La_{670}} = \left(\frac{670}{\lambda}\right)^{\eta},$$

where $La\lambda$ = aerosol contribution,
η = Angstrom coefficient.

Several approaches to applying this technique in estimating the Angstrom coefficient and performing the atmospheric correction have resulted in encouraging results (Gordon et al., 1983). The procedure used in processing the CZCS imagery for this atlas is documented by Arnone and La Violette (1984).

Following the subtraction of the atmospheric contribution for each pixel in the visible channels, the resulting water-leaving radiance is ratioed and a diffuse attenuation coefficient computed from the algorithm shown by Austin and Petzold (1980; Fig. 1). Good agreement with ship measurements will be shown in the following section.

B. Site selection

The selection of the ocean area in which an optics atlas could be generated was based on several criteria. The first was that adequate cloud-free CZCS coverage be available for the area. Second, the area should contain various optical types of waters, ranging from relatively open ocean to coastal. Third, the area should be restrictive in size (512 by 512 pixels) to limit the amount of processing. Finally, the areas should contain ship measurements coincident with the CZCS data to permit an evaluation of the atlas results. The area selected was the Alboran Sea.

The West Alboran Basin is the first Mediterranean basin east of the Strait of Gibraltar (Fig. 2). The general circulation of the Alboran Sea has been characterized as an inflow of Atlantic water through the strait that is confined to the upper 200 m. This water flows eastward along the Spanish coast for 100 km, then turns southward toward Cap Tres Forcas on the North African coast, where it splits into an east-west flow. This circulation creates a large anticyclonic gyre (Alboran Gyre) that occupies most of the West Alboran Basin. The coastal water along the southern Spanish coast is cold, highly saline, and nutrient-rich. The complex interaction with the inflowing Atlantic water is associated with the local meteorology, bathymetry, and tidal response at the inflow (Arnone and La Violette, 1984; La Violette, 1984; La Violette and Kerling, 1983). The large sea surface temperature variability (La Violette, 1984) indicates strong mixing or upwelling that should produce rapid changes in the amount of nutrients available for bio-optical activity. Additionally, the volume biological character of the waters are constantly changing in response to the advection or depletion of nutrients. Consequently, the optical properties that are directly related to the phytoplankton pigment concentration should show similar variability. Strong changes in the optical character are expected at the frontal positions.

C. Processing procedures

The CZCS data contained in the atlas were processed over an 18-month period. Initially, the CZCS archives were searched for cloud-free scenes of the Alboran Sea. All CZCS data collected from November 1978 through November 1982 were considered. A final selection of approximately 80 images was determined based on "quick look" photographs available through NESDIS. Computer compatible tapes (CCT), level 1, were received for processing on the Interactive Digital Satellite Image Processing System (IDSIPS) located in the NORDA's Remote Sensing Branch.

The entire scene (channel 4) for each CCT was initially entered into IDSIPS, and a subsection of the scene containing the Alboran Sea was determined. This subsection was typically one-quarter of the swath width of the entire two minute scene. The subsection scene containing three channels (1,3,4) was reentered into IDSIPS for 10 phases of processing.

PHASE 1. As the CCT subsection is read into IDSIPS, two functions are performed on the pixels as each line is entered. The first is that the data is calibrated into total absolute radiance received ($\mu W/cm^2$). Second, the Rayleigh contribution of the atmosphere is computed for each pixel, based on the angular position of the ground position with respect to the satellite and solar location. This calculation is performed for each channel based on the LOWTRAN IV model (Kneizys et al., 1980). The resulting image from this phase is a three channel (1,3,4) calibrated output in which the atmospheric Rayleigh radiance has been subtracted from the total radiance for each pixel.

PHASE 2. A second output that results from entering the CCT subsection into IDSIPS is the generation of a control points file. The geometric registration of subsection to a standard projection is necessary for developing an atlas, since it allows comparison from one scene to another. The control points file is necessary for the transform by which the subsection can be remapped into a Mercator projection. This file is generated from the 50 latitude and longitude points inbedded within each line of CZCS data. Geometric registration is critical, since CZCS imagery is highly distorted, especially toward the ends of the swath. Control points are obtained only from positions within the subsection area. For this atlas the upper left corner was selected as 37°48'N, 6°42'E. The subsection area extends 512 to the east and south of this point, with each pixel reprsenting 0.6 nautical miles. All CZCS imagery used in this atlas will be registered to this configuration.

PHASE 3. In certain instances the subsection containing the Alboran Sea was contained on two separate scenes. When this occurred, the scenes and control points had to be mosaicked into continuous format.

PHASE 4. To perform accurate geometric registration, the subsectioned image must be resampled across the swath such that each pixel represents an equal ground area. At nadir the ground and pixel resolution is 800 m, and as the pixel approaches the limits of the swath, the ground resolution increases in response to earth curvature and scanner angle. The procedure is then to linearize the scan line by resampling or increasing the number of pixels such that each is an equal area. Linearization was performed on the subsectioned image for all three channels in addition to modifications to the control points output file.

PHASE 5. The spatial remapping (warp) of the linearized subsection to a Mercator projection is applied by fitting a polynomial function to the control points to define the transformation. During this phase the error that the polynomial calculates for the control points is checked. This error establishes how closely the registered image conforms to the Mercator projection. Values are better then 2 pixels (1–2 nautical miles). This rubber map transform is resampled by nearest-neighbor reassignment. In generating this image, the output file now contains three channels, all registered to a Mercator projection with the configuration shown in Phase 2. This registration permits each pixel in the image to have a corresponding latitude and longitude.

PHASE 6. The atmospheric aerosol correction is performed using the three-channel (1,3,4) registered image.

The selection of the Angstrom coefficients is obtained by an interactive procedure (Arnone and La Violette, 1984), by first using channels 1 and 4, then channels 3 and 4. For each pixel in the registered image (512 by 512), the 670-nanometer value is weighted by the appropriate Angstrom coefficient and subtracted from the 443- or the 550-nanometer value. The procedure results in two images, one the water-leaving radiance at 443 nanometers and a second at 550 nanometers.

PHASE 7. The ratio of the 443- to the 550-nanometer image is computed for each of the registered pixels. This ratio, as discussed earlier, is directly related to the diffuse attenuation coefficient at 490 nanometers (Fig. 1). The resulting ratioed image represents a digital optical data base with addressable latitude-longitude gridding.

PHASE 8. The land in the ratio image is edited to zero values and inlays a land mask of the same area to which the image was registered. The land mask is generated by using the Central Intelligence Agency Data Base (1977) for land-water boundary. This program requires similar upper left latitude-longitude coordinates, pixel-to-degree ratio, and 512 by 512 pixel coverage that was used in Phase 2. By replacing the land with zeros, the data base enhances the display of the optical variability.

PHASE 9. To compensate for any problems caused by inaccuracies in the atmospheric correction or calibration procedures, the ratioed images are normalized to clear water values in the central Alboran Gyre. These waters are relatively phytoplankton poor, and the diffuse attenuation coefficient ranges from 0.04 to 0.05 m^{-1}. Since this central gyre water can be easily defined, the ratioed values were normalized to coincide with these values. This procedure did not dramatically influence the data base and provided more accurate optical values.

PHASE 10. The subtle changes in the optical values are enhanced by using a color table when displaying the ratioed values. The color table also enables the display to readily classify dominant water masses. The color table used in this atlas enhances the diffuse attenuation coefficient values for all water types ranging from clear to turbid. By selecting other color tables, the variability of specific water types can be better represented. At this stage the ratioed image is displayed on IDSIPS and the color table applied. Following the graphic overlay of a latitude-longitude grid, the display CRT is photographed. Note that the data base still resides in digital form on computer disc.

III. Results

In October 1982 an international experiment was conducted in the Alboran Sea (¿Donde Va?, 1984) in which the diffuse attenuation coefficient was measured from ship at several locations across the Alboran Front (Arnone, 1983; Arnone and La Violette, 1984). Figure 3 illustrates that good agreement was found with the CZCS calculated values of the diffuse attenuation coefficient. Additionally, it was shown that temporal changes in the diffuse attenuation coefficient (0.05 to 0.1 m^1) occur within 24 hours in the Alboran front region. These changes are known to be frequent and are presently being investigated as to possible sources of origin.

Figures 4-16 contain 21 CZCS images processed by the previously mentioned procedure and illustrate the monthly (January-December) optical data base for the Alboran Sea. As noted by the dates on the figures, cloud-free imagery was processed from 1978 through 1982. Although it was attempted to obtain at least two images per month, only one image was available for March, April, and November that was considered acceptable for inclusion in the data base. Many images contain some cloud cover, which limits the usefulness for obtaining the diffuse attenuation coefficient in these regions. For many months additional images were processed, although only the two best images have been included in this atlas.

Figure 4 illustrates significant spatial variability of the diffuse attenuation coefficient for January. As illustrated by comparison with the other monthly images, similar circulation features are characteristic of this region. The circular blue region with k values of 0.04 represents the Alboran gyre. The frontal boundary surrounding the gyre represents the Alboran front and is typically characterized by elevated k values (yellow to red) 0.08-0.15. This frontal boundary is well formed on 21 January 1982, whereas on 1 January 1981, it is not. In response to the upwelling that occurs along the southern Spanish coast (36°10'N, 5°W), the k values are quite high (0.08-0.2) and extend southward from the coast for 30 km. Bordering the Spanish coast, waters that have k values greater than 0.4 occasionally occur, as illustrated by the figures for the other months.

In the waters associated with the Strait of Gibraltar, significant optical variability is observed. These changes can be expected, since the hydrology is extremely complex as a result of the Atlantic inflow mixing with the Mediterranean outflow in response to tidal and meteorological forces. Note that along the west Spanish coast north of the Strait of Gibraltar (36°30'N, 6°15'W) the k values are 0.5 and greater. Waters along this coast are greatly influenced by the discharge of the Rio Guadalauivir located north of Cadiz. Turbid water is observed during all months.

Along the northern African coast, turbid plumes of coastal waters are observed to extend 35 km northward into the Alboran Sea on 1 January 1981. The coastal position of these offshore extensions can be observed to occur in other images in the atlas, which suggests that certain coastal areas are frequently influenced by the offshore circulation. These areas will exhibit greater spatial and temporal optical variability. The atlas therefore provides a method to determine which coastal areas have a high probability of variability.

Figures 5-16 illustrate somewhat similar results to the general features as for January, except that the spatial variability can be significantly different. The clouds have been identified in most of the images. At this time it is difficult to speculate on the causes of both the spatial and temporal variability. Present research is directed at understanding the processes that produce the variability observed. In general this region appears to display a high variability in response to the complex circulation patterns associated with the region. The temporal changes appear to occur on a much shorter time scale than monthly. For example, the changes in the spatial variability of *k* are observed in Figure 13 for October 6-13, 1982. The position of the Alboran front changes, and the *k* values at this position change from 0.04 to 0.15 within 6 days. Comparisons of the monthly *k* values do not appear to indicate any type of seasonal trend, but are dominated by the spatial variability resulting from the circulation. This atlas represents an extremely dynamic region atypical of most ocean regions.

IV. Problems

Using the CZCS data for atlas development presents several problems.

- Lack of seasonal data coverage
- Accuracy of computing absolute *k* values
  - decay of onboard sensors and resulting calibration
  - assumption of channel 4 (670 nanometers) having zero water-leaving radiance
  - assumption of uniform aerosol "type"
- Computer processing time
- CZCS has exceeded life expectancy and replacement satellite not expected until mid 1990s

The lack of world-wide seasonal coverage is mostly the result of cloud contamination. About 80% of the CZCS data is expected to be cloud covered. This problem requires repeated coverage of certain regions, especially those for which limited quality is available. Requests for coverage to increase data availability are currently accepted. Although CZCS is not an operational system and should not be expected to provide operational coverage, a large data inventory is available from which initial world coastal optical properties can be established.

The atmospheric removal techniques have several limitations that ultimately result in the accuracy from which the attenuation coefficient can be computed. The radiometric decay of the sensors from prelaunch calibration is an initial problem. Various investigators have shown encouraging results on modeling the decay coefficients (Gordon, 1983, Sun, 1983). The assumption that there is zero water-leaving radiance at 670 nanometers is not valid in very turbid coastal water with high suspended sediment concentration. At *k* values starting at approximately 0.7, a small underestimate of the value is expected. As the *k* value increases, the CZCS value will be further underestimated. Improvements to this method by estimating the water-leaving radiance at 670 nanometers (Smith and Wilson, 1980) are presently under investigation. The selection of the Angstrom coefficient is based on the characteristics of the aerosol. Although the optimum coefficient is selected for the entire region, fine spatial variations in the aerosol type are not accounted for (Arnone and La Violette, 1984). Improvements are presently being researched.

The time required to process the 512 by 512 pixel CZCS data to the format of this atlas is approximately eight hours. The processing procedures implemented have not been streamlined for operational processing. Improvements to both software and hardware are required if larger format atlases are to be constructed.

Present estimates are for CZCS to fail within 1986. CZCS has well outlasted its design life by five years. Presently, the Ocean Color Scanner (OCS) is being tested as the replacement. An OCS system is being considered on a NOAA polar orbiter and the Navy Remote Ocean Sensing System (N-ROSS) II in the mid 1990s.

V. Recommendations

This atlas illustrates that extremely strong spatial and temporal variability occurs in optical properties. This variability should be tested in other ocean regions to determine if the Western Mediterranean region is atypical. Additionally, long-term ground measurements would greatly aid in interpreting the validity of measurements from CZCS, which suggests that long term (yearly) optical moorings should be placed in coastal and shelf waters. Comparing these data with CZCS calculations should prove highly beneficial to determine how the 800 pixel resolution of CZCS relates to small scale variability.

Research should also address how the diffuse attenuation coefficient values computed from CZCS are related to the total coefficient of the water column. Since the signal that the satellite receives represents the first attenuation length of the water mass (Gordon and McCluney, 1975), any changes that occur below this depth will not be included in the CZCS calculation. Since the majority of the optical signal is generated in the euphotic zone, little optical changes are expected to occur below the first attenuation length in open ocean waters. In coastal and frontal waters, however, where stratification of water mass types is strong, the character below the first attenuation length may be significantly changing. Research is required to better understand these processes and to validate interpretation of the CZCS calculations.

Continued research is required in the area of atmospheric correction. Coastal regions that contain high sediment concentrations (river discharge) present problems to the existing CZCS processing algorithms. Recent progress has amplified this problem and encouraging results are apparent.

The utility for CZCS-type sensors is only beginning to be demonstrated, especially in ocean optical monitoring. Unfortunately, this experimental satellite is outdated and no similar new visible satellite is planned for the near-term launch. CZCS has provided the experimental platform to demonstrate ocean color monitoring. Results from this sensor have provided the framework for an improved operational sensor. Multispectral sensor technology has improved significantly in the past decade, and many of the problems that were shown to exist with CZCS will be eliminated with the launch of a new satellite. It is strongly recommended that the follow-up visible satellite to CZCS be considered for launch in the near future.

This CZCS atlas has demonstrated the present capabilities of existing algorithms for assessing ocean optical variability. Although the atlas exists in both digital and pictorial format, the compilation of a world-wide data base has not been adequately defined. The present data base exists as a series of eighty 512 by 512 files, each of the same location but each of a different time. These data can be stored on either a 200-megabyte disc or a nine-track computer tape. For a world-wide digital data base to be constructed, the methodology of the data base has yet to be addressed. Data reduction techniques for average monthly/yearly and statistical relationships for areas has not been considered. This development should be based on the user needs. Once these have been established, then a follow-up digital base can begin to be constructed.

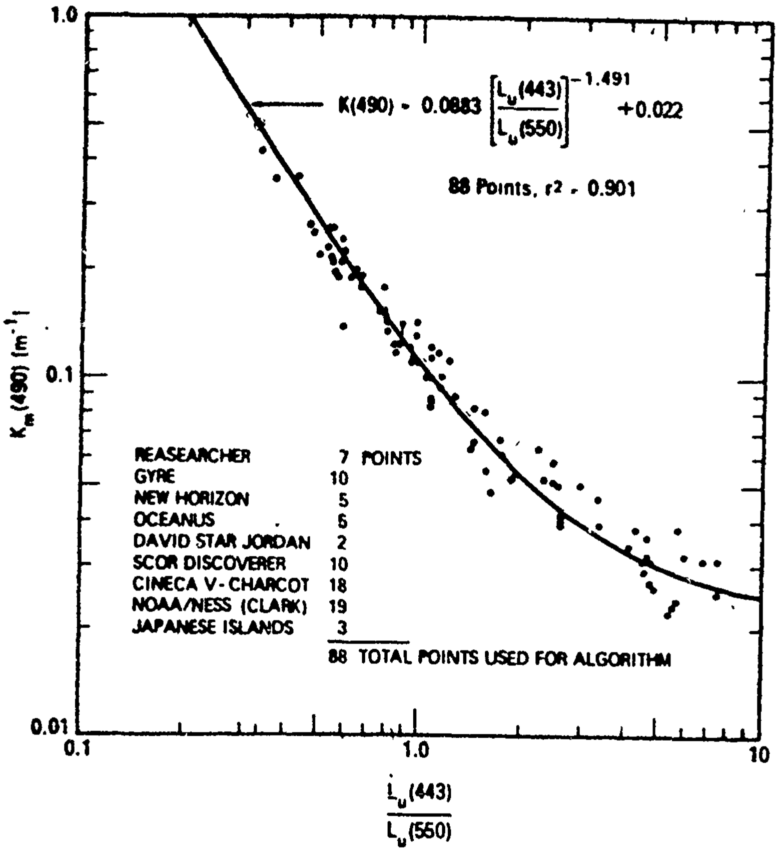

Figure 1. Relationship of the upwelling ratio of 443/550 to the diffuse attenuation coefficient

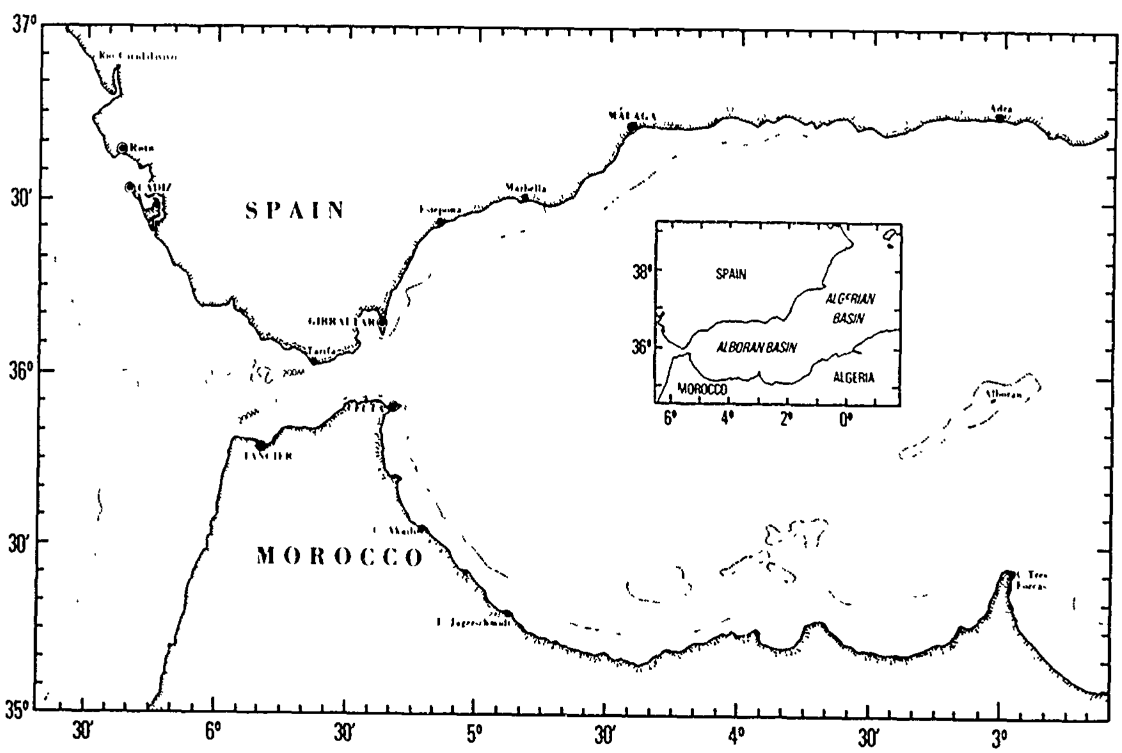

Figure 2. Alboran sea map.

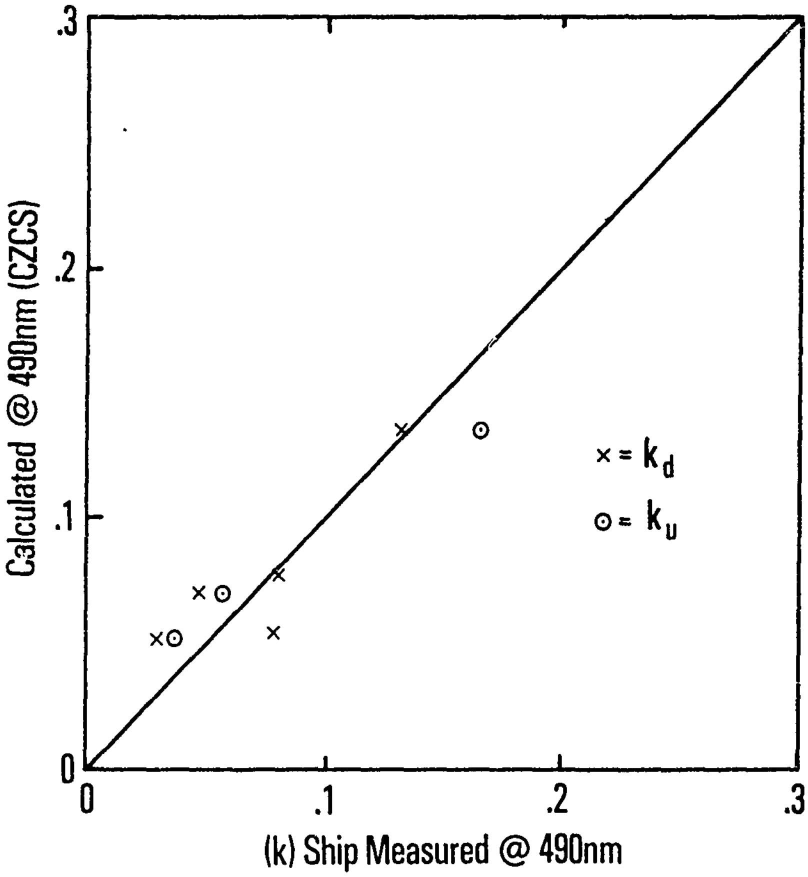

Figure 3. Comparison of k.

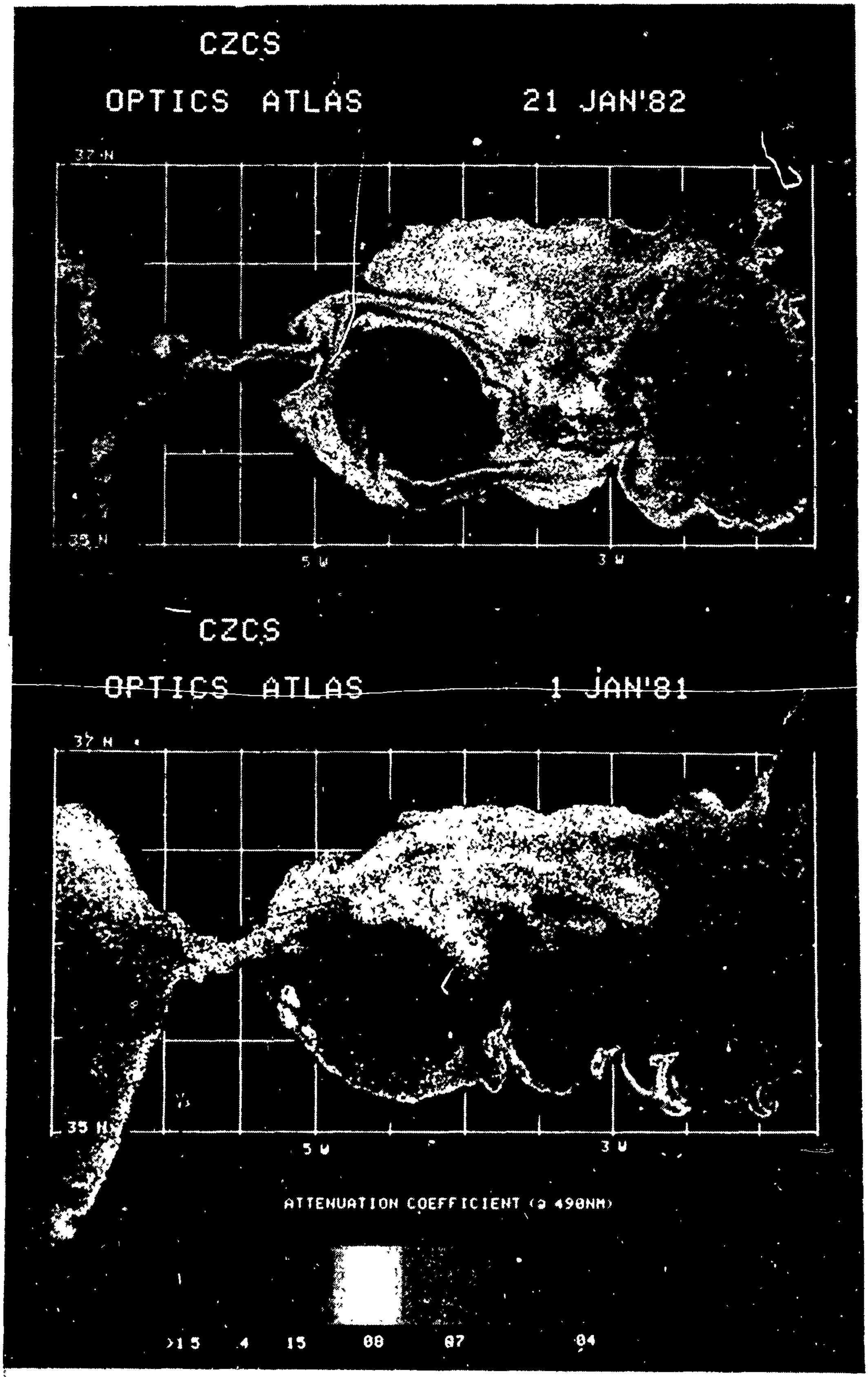

Figure 4. January image

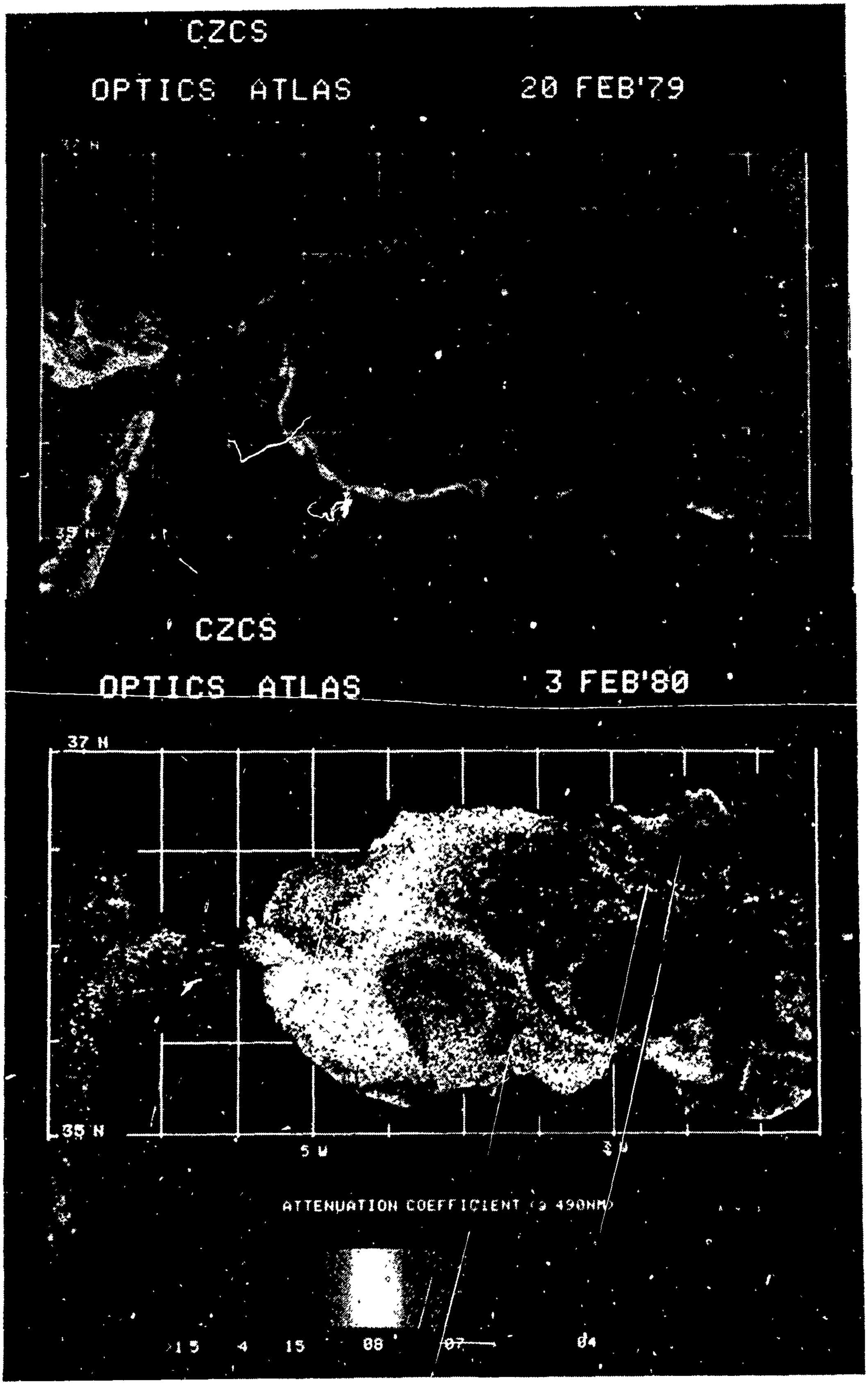

Figure 5. February image

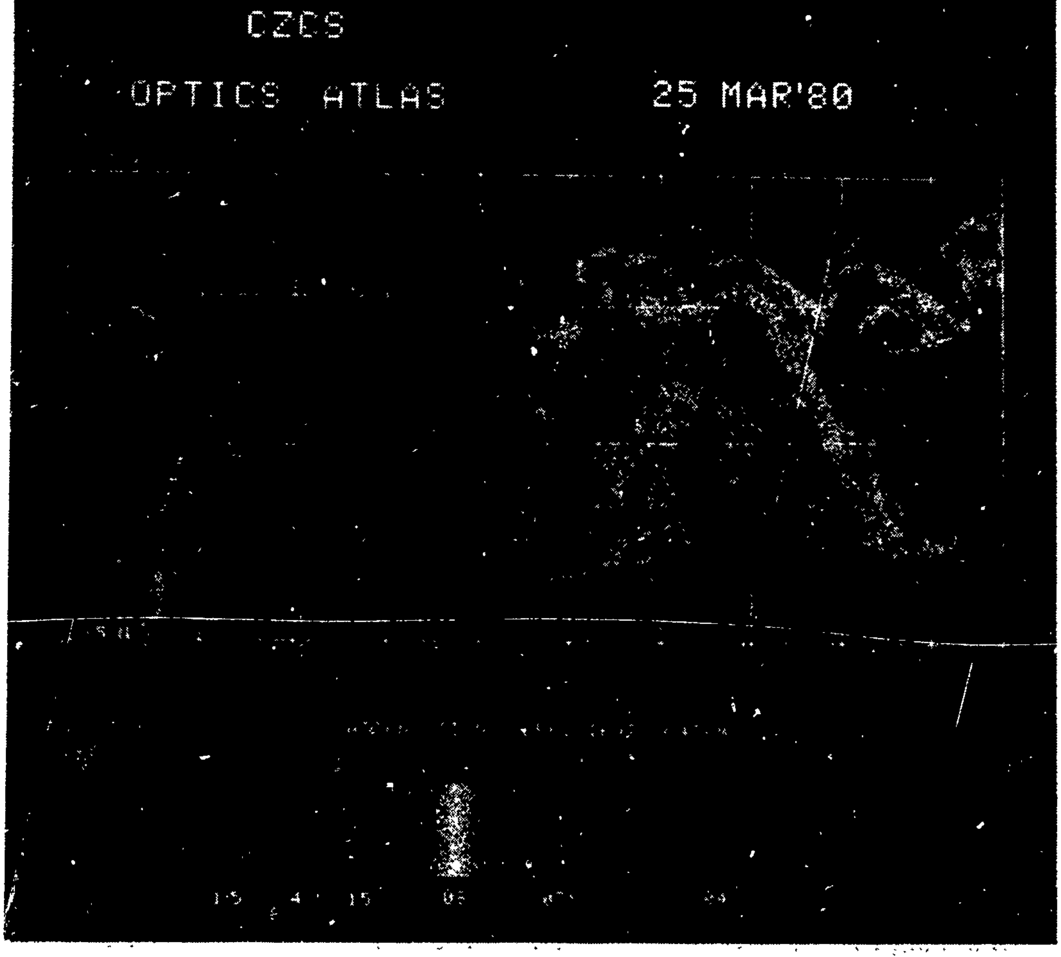

Figure 6. March image.

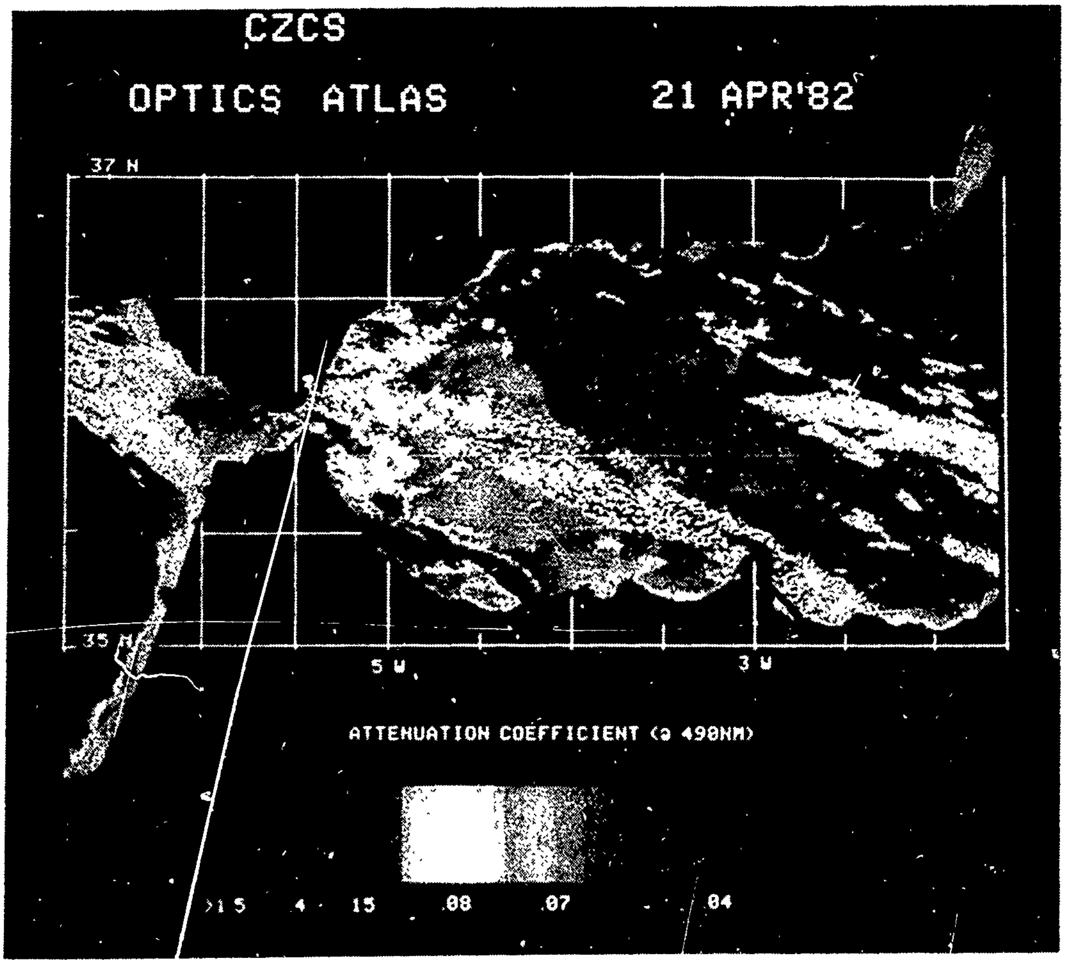

Figure 7 April image.

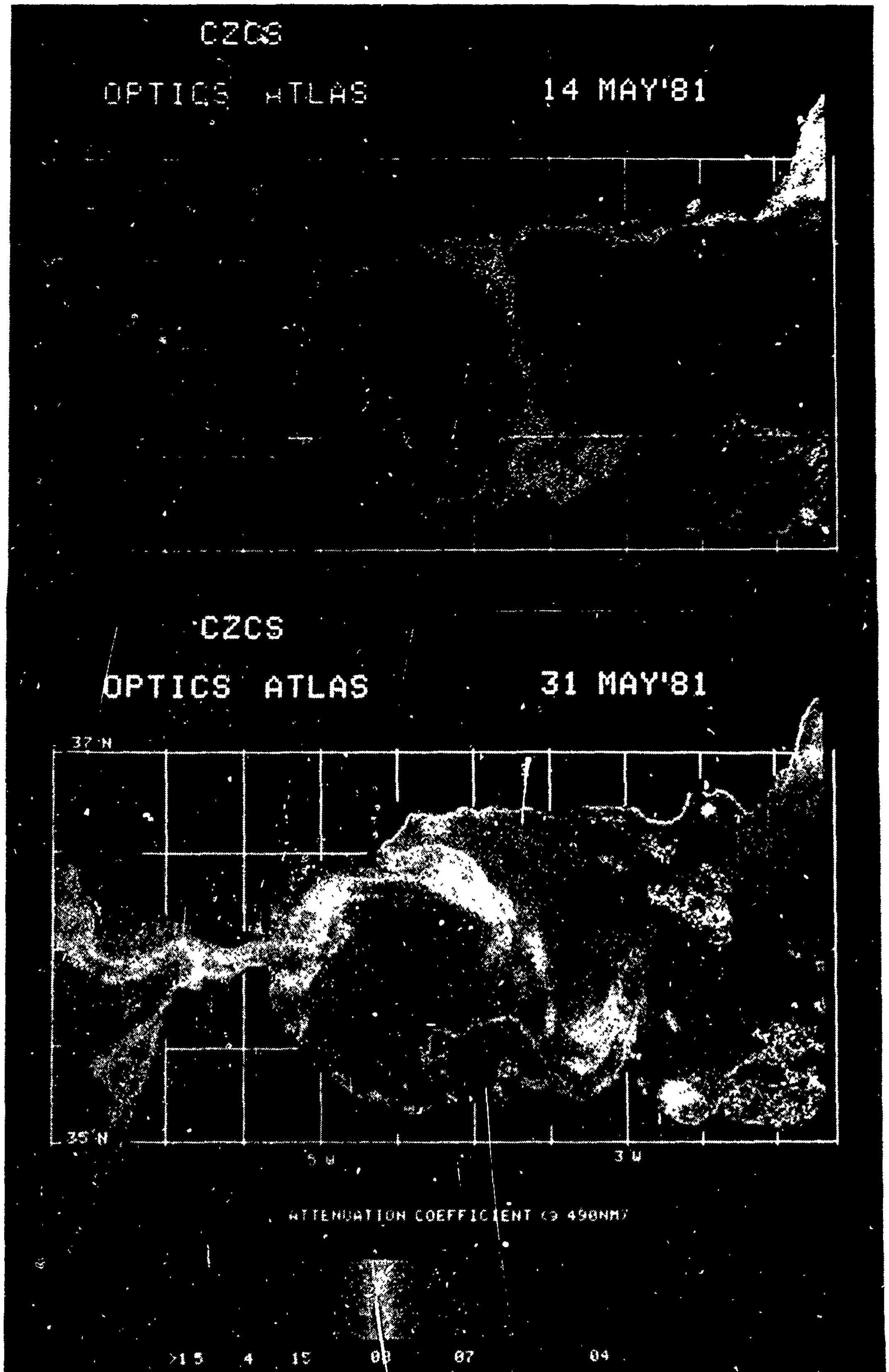

Figure 8. May image.

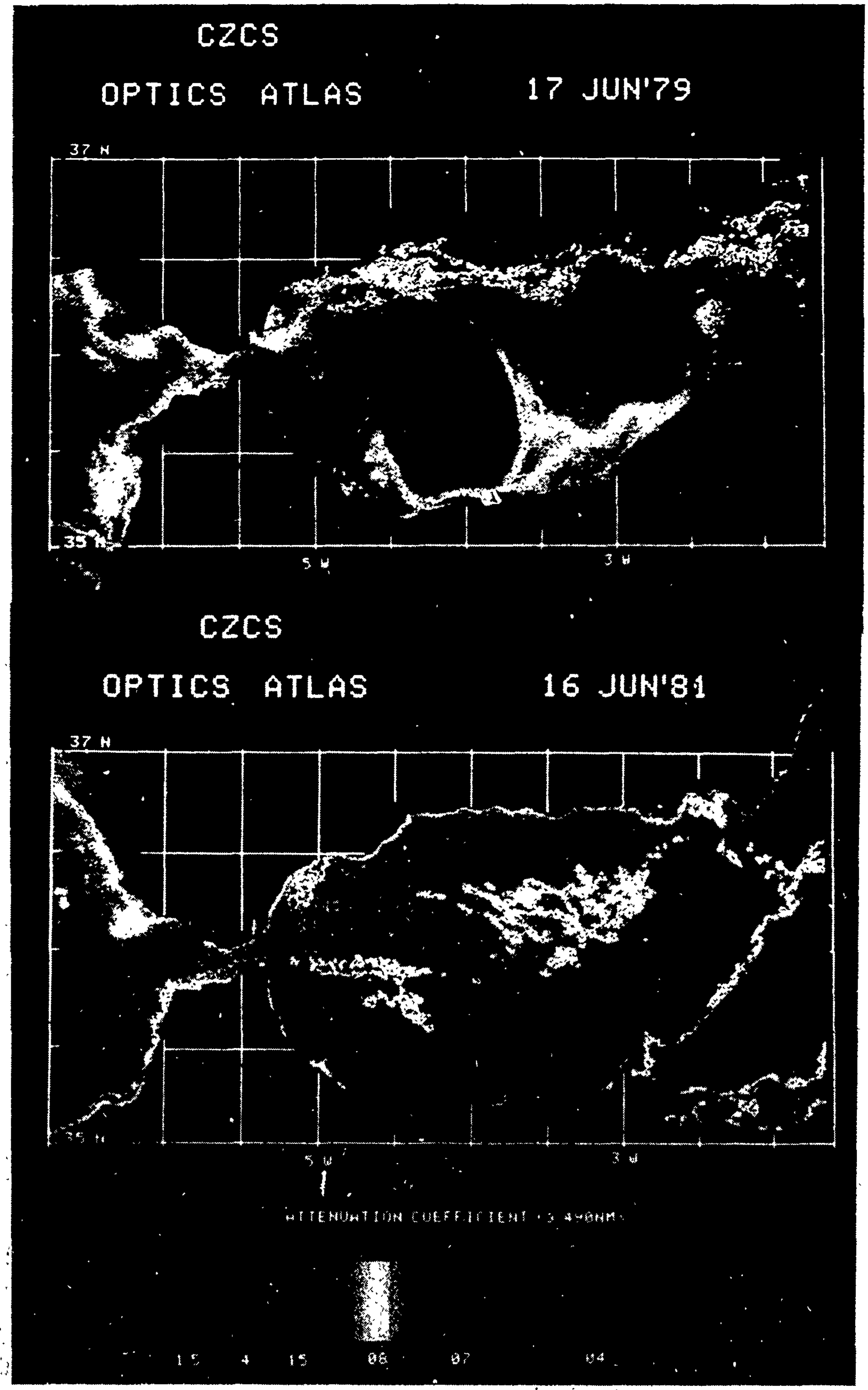

Figure 9. June image.

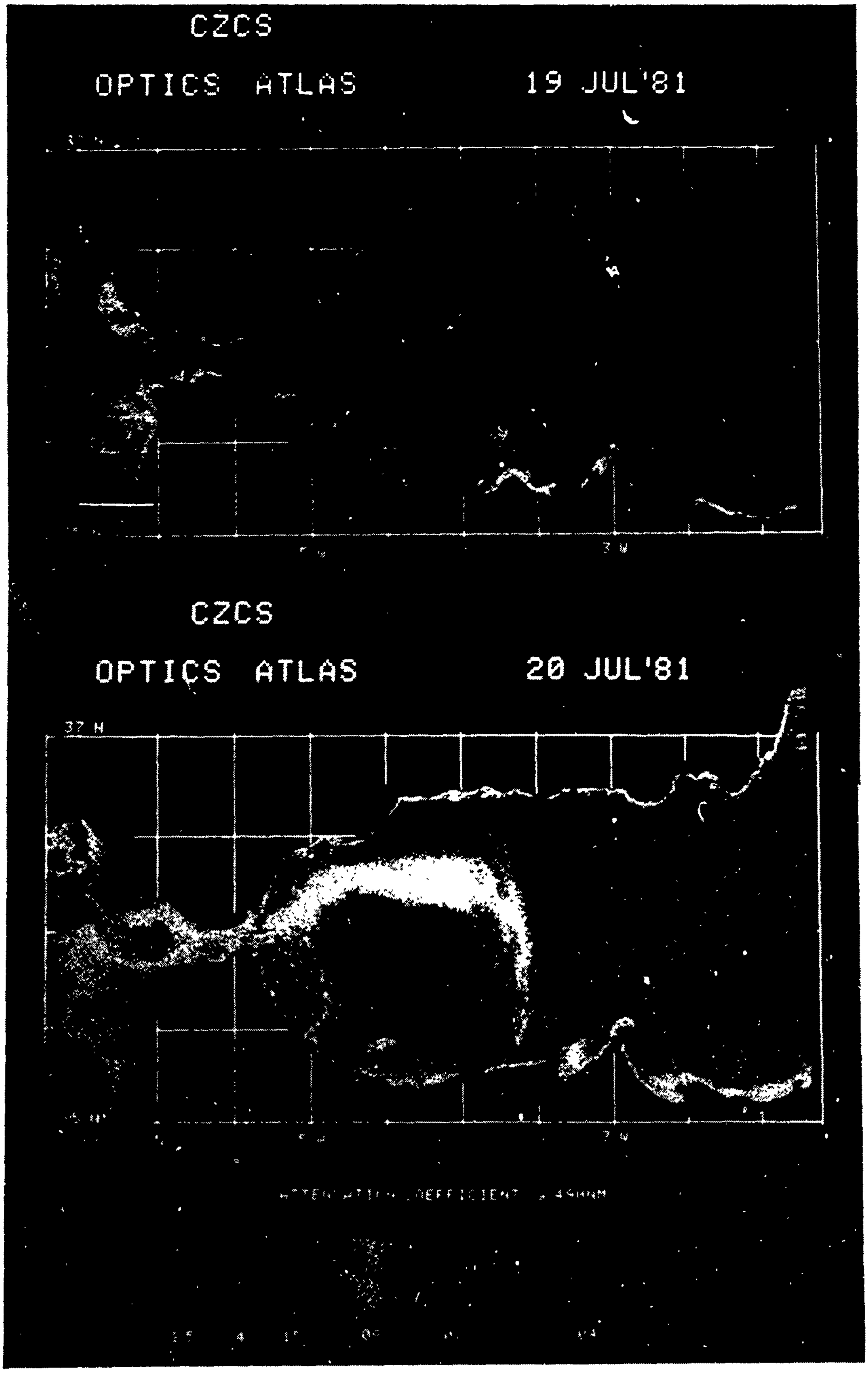

Figure 10. July image.

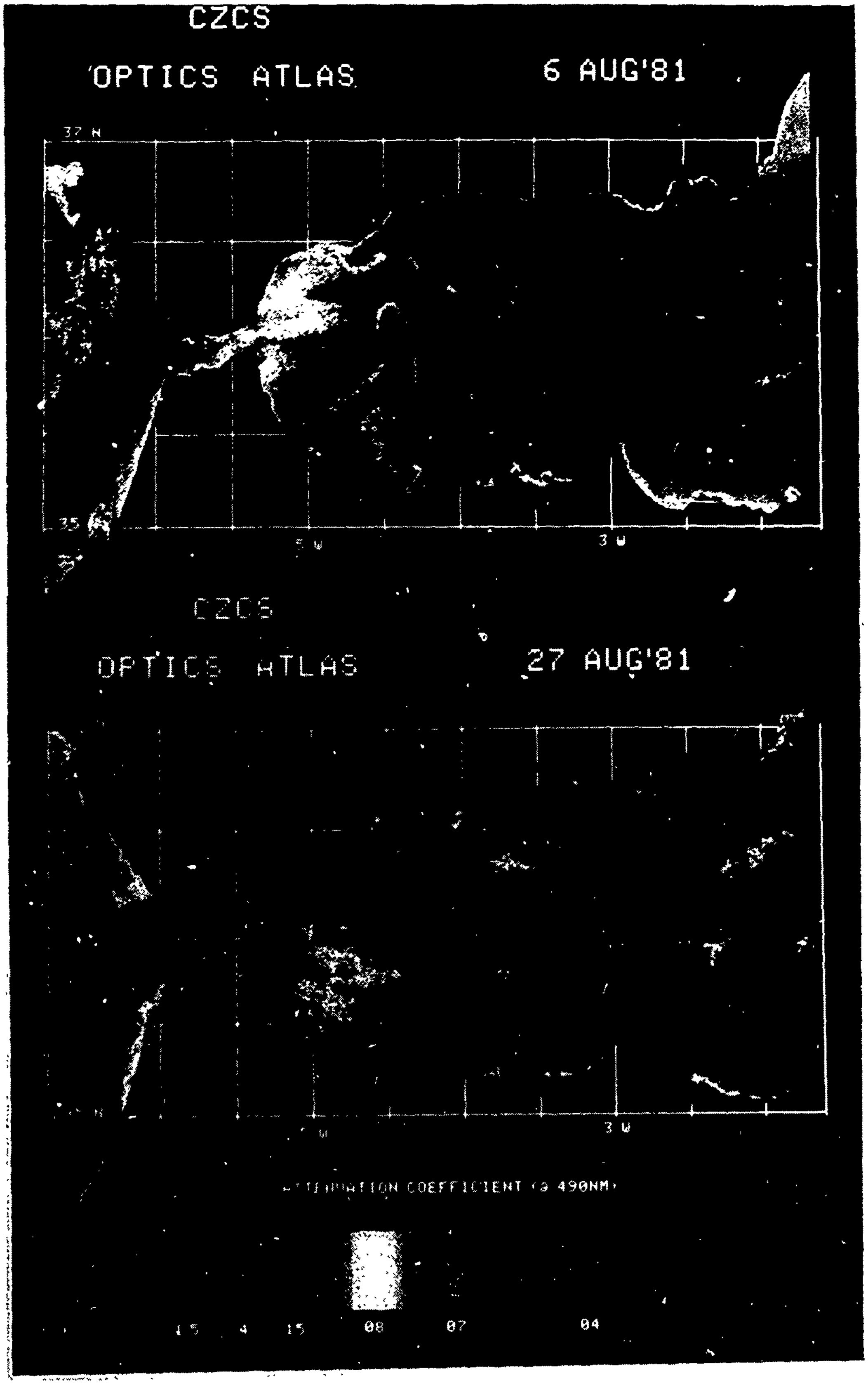

Figure 11. August image.

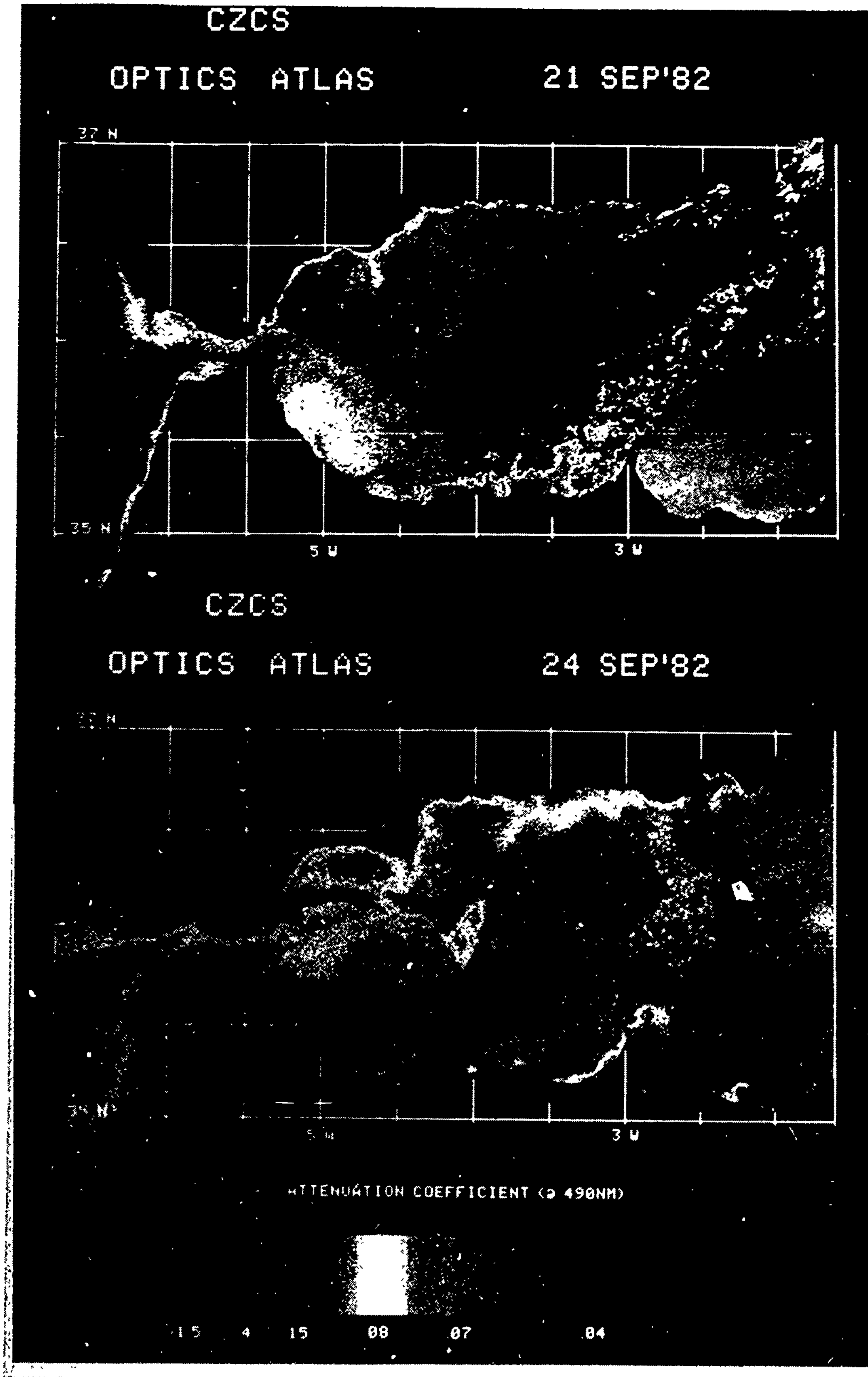

Figure 12. September image.

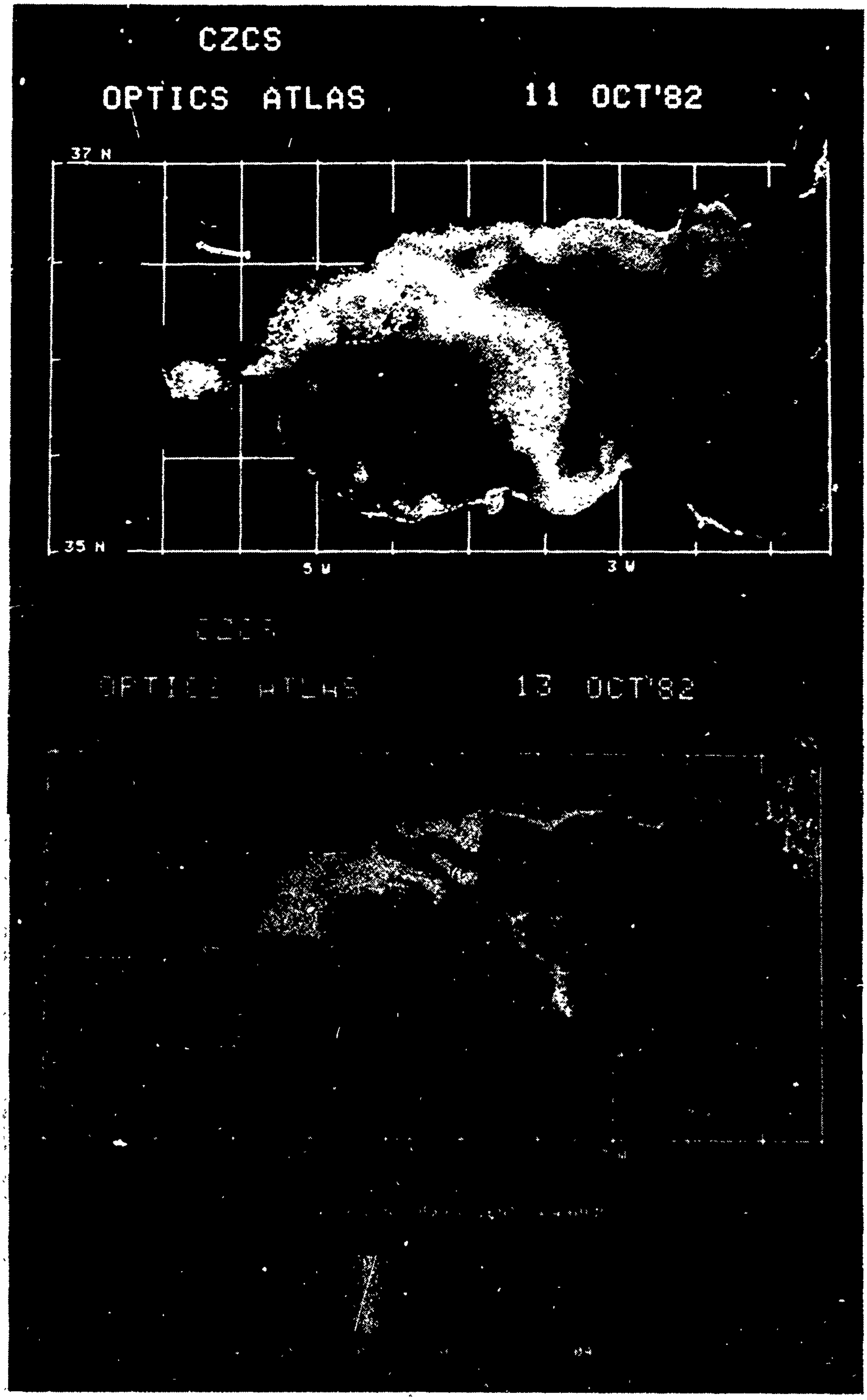

Figure 13. October image.

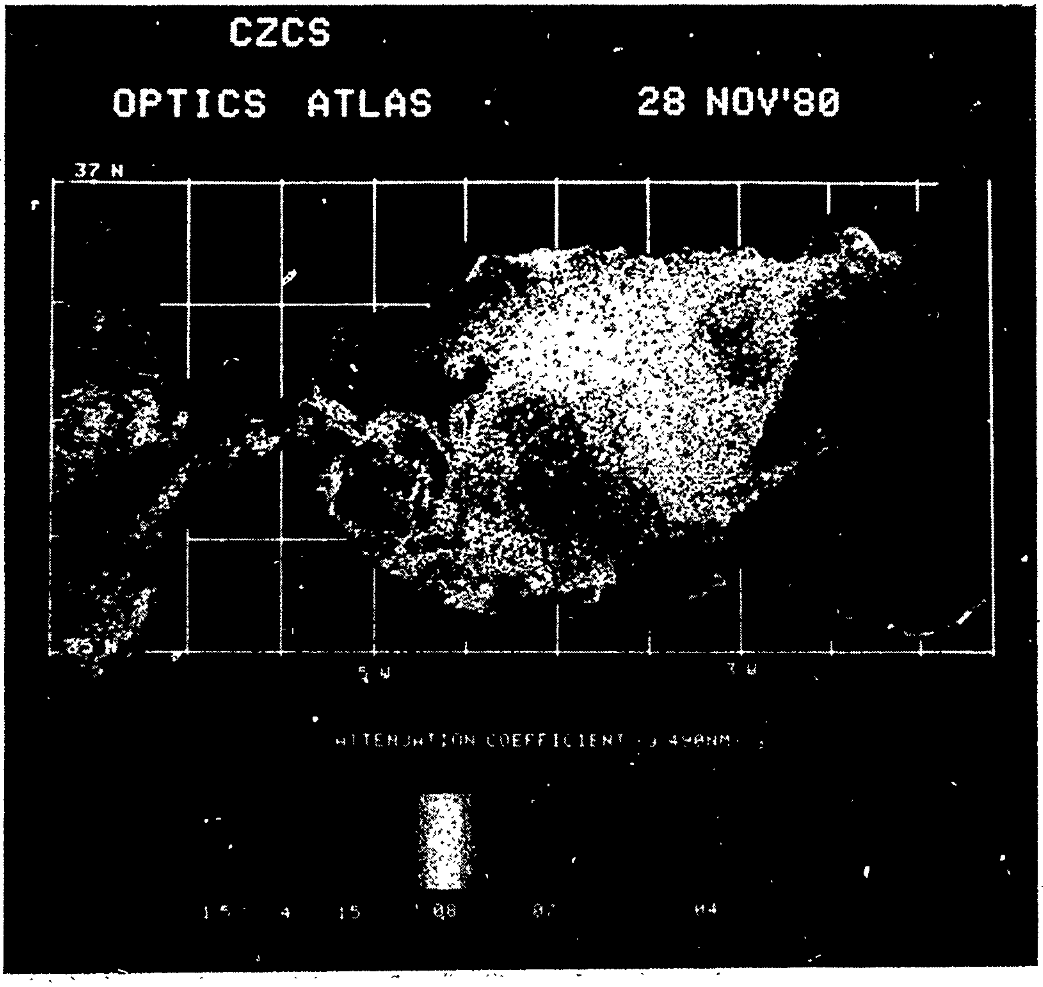

Figure 14. November image.

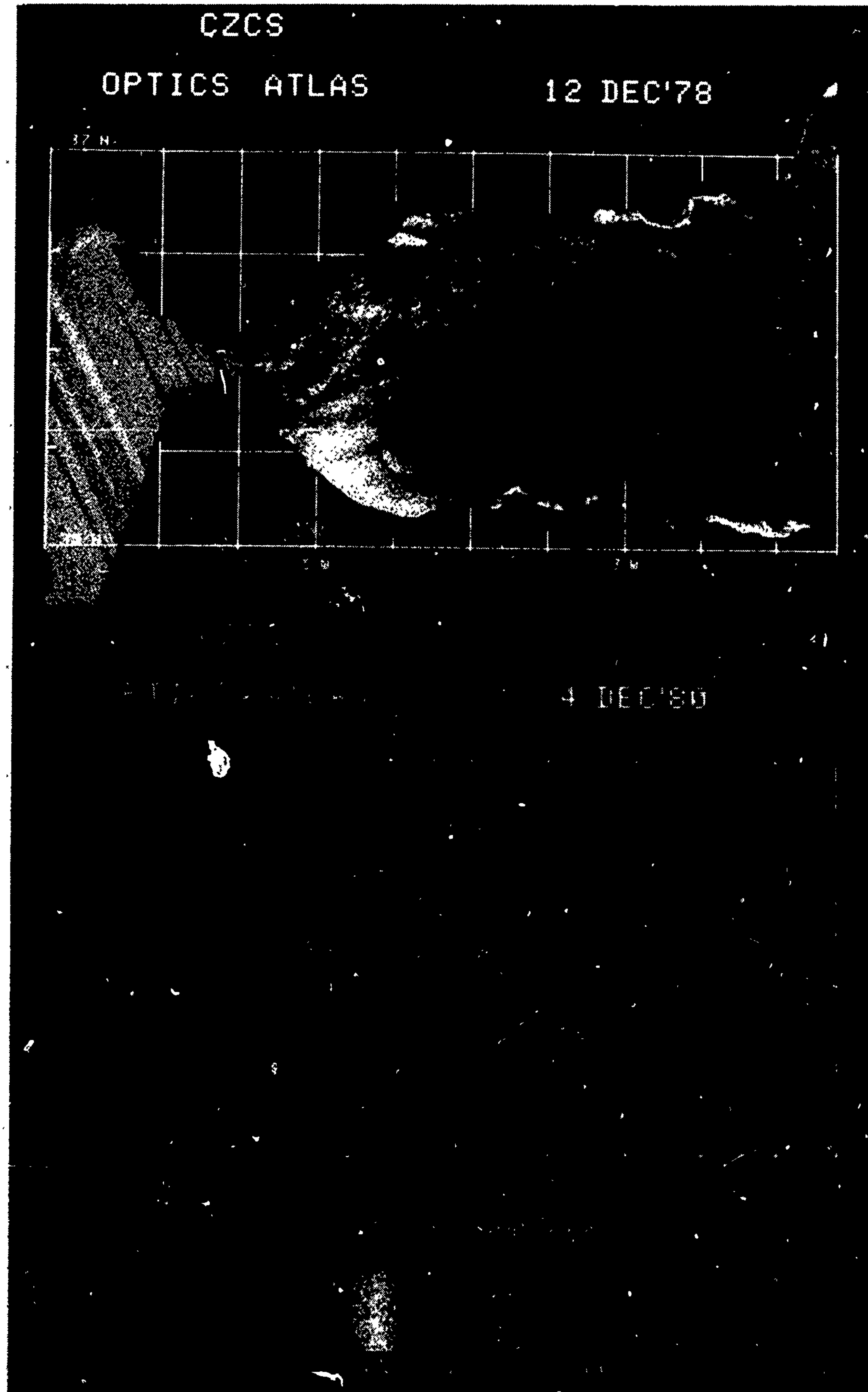

Figure 15. December image.

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Optical water properties of the world oceans can be rapidly obtained from data from the Coastal Zone Color Scanner (CZCS) aboard Nimbus-7. Satellite processing techniques have been developed to eliminate the atmospheric contamination that contributes 90% of the total visible channel signal. The remaining signal, which constituted the ocean color, is directly related to the diffuse attenuation coefficient (k) at 490 nanometers for the upper surface waters. Calculation and geographic registration of k can be done for each of the 800-square-meter pixel resolution of CZCS, and results show that the accuracy is within 25% of ship mesurements.

This report indicates the processing procedures used to calculate k from radiance data from the CZCS. Additionally, problems, assumptions, and recommendations for future processing are discussed.

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