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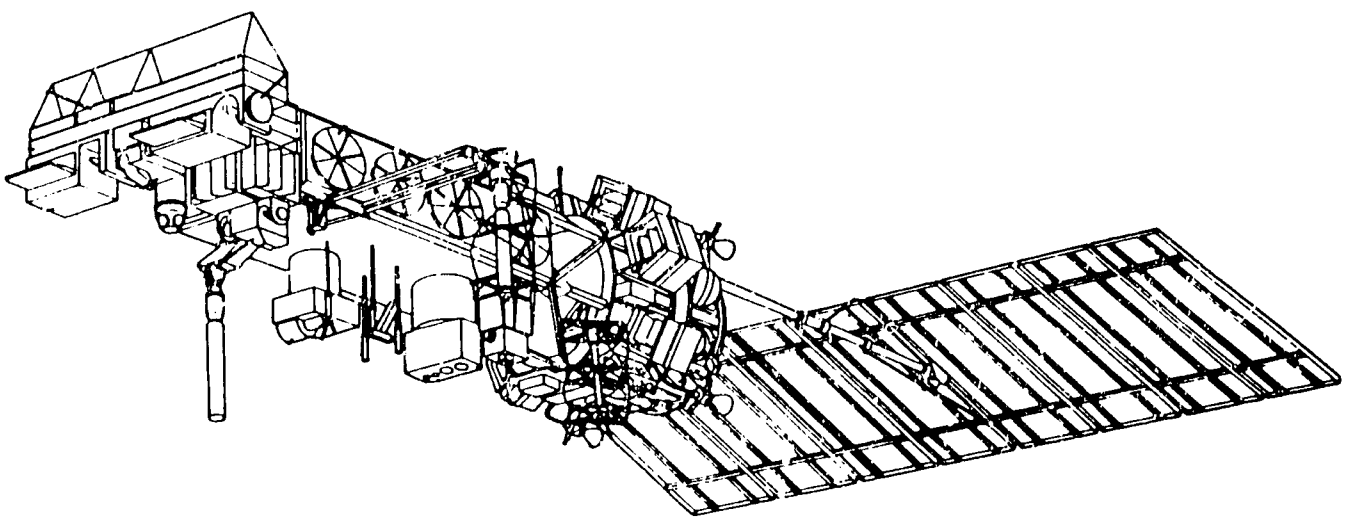
SATELLITE OCEANOGRAPHY - VOLUME 1: NOAA-N ADVANCED VERY HIGH RESOLUTION RADIOMETER DIGITAL DATA

WASHINGTON, DC
SEPTEMBER 1985



U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Environmental Satellite, Data, and Information Service

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SATELLITE OCEANOGRAPHY - VOLUME 1: NOAA-N ADVANCED VERY HIGH RESOLUTION RADIOMETER DIGITAL DATA

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SEPTEMBER 1985

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List of Acronyms

AISC - Assessment and Information Services Center
AVHRR - Advanced Very High Resolution Radiometer
C - Celsius
CZCS - Coastal Zone Color Scanner
HRPT - High Resolution Picture Transmission
GAC - Global Area Coverage
IFOV - Instantaneous Field of View
IP - Image Processor
LAC - Local Area Coverage
NESDIS - National Environmental Satellite, Data, and Information Service
NOAA - National Oceanic and Atmospheric Administration
MEAD - Marine Environmental Assessment Division
MSS - Multi-Spectral Scanner
RCDV - Raw Count Data Value
TM - Thematic Mapper

Abstract

The Marine Environmental Assessment Division (MEAD) of the National Oceanic and Atmospheric Administration (NOAA) is developing the capablity of utilizing satellite and aircraft remotely sensed data in their routine assessments of the coastal marine environment.

This training quide presents MEAD's initial work in this field of marine remote sensing utilizing the NOAA-n AVHRR data with emphasis on the East coast of the United States. Methods are described for filtering the data for the reduction of pixel-to-pixel variability, separating land/cloud features from water features (land/cloud masking), delineating sediment/chlorophyll (turbidity) plumes, deriving estimates of sea surface temperature (SST), displaying image representations of the SST field, and delineating ice within the Chesapeake Bay. The techniques discussed are applicable to other regions of the world and are being tested for the Exclusive Economic Zone (EEZ) of the Philippine Islands.

Acknowledgments

Thanks are expressed to Robert Dennis, Dr. Kurt Hess, Dr. David Johnson, Karl Pechmann, Dr. Isobel Sheifer Dr. Richard Stumpf, and Dr. Kenneth Turgeon for their patient review and comments of the initial drafts of this manual. Special thanks are expressed to Katherine Benkert for her assistance in the inital phases of this project and review comments. Publication of this manual would not have happen without the kind assistance of John Ellis and Pollie Jackson.

The upper panel of Figure # 3 is printed with the kind permission of William French, executive director, of the American Society of Photogrammetry from their publication Manual of Remote Sensing Second Edition, 1983.

1. Introduction

Oceanographers have historically been limited to sampling the oceans' physical, chemical, and biological properties at a few widely spaced locations (station data) and then inferring the vertical and horizontal distributions of these properties. Satellite oceanography allows the surface distributions of temperature, turbidity, chlorophyll, winds, waves, and the height of the sea surface above the geoid to be measured at varying spatial scales over large tracks of the ocean in real time. Satellite oceanography is continuing its rapid development and the proposed suite of new satellites will in the near future allow operational world ocean collections of all of these data fields.

The incorporation of this satellite data with station data is required for verification of the satellite derived fields as well as interpreting the station data within the mesoscale oceanic features delineated in the satellite data. These two different types of data sets compliment and extend the usefulness of each one.

The present remote sensing of the oceans extends from the visible wavelengths all the way to the microwave wavelength portion of the electromagnetic spectrum. Passive as well as active remote sensing systems have been developed and tested and many are now considered operational. Passive remote sensing consists of detecting the reflected sunlight or emitted microwave energy from the earth's surface while active systems consist of beaming microwave energy or lasers to the earth's surface and detecting that portion reflected back to the sensor(s).

Marine Environmental Assessment Division (MEAD) has developed the capability for utilizing satellite and aircraft remotely sensed data in assessments of the coastal marine environment. Emphasis is being placed on the near real time processing of the Advanced Very High Resolution Radiometer (AVHRR) data from the NOAA-n series of polar orbiting satellites and the development of climatological data sets from the LANDSAT Multi-Spectral Scanner (MSS) and Thematic Mapper (TM) sensors and the NIMBUS-7 Coastal Zone Color Scanner (CZCS) data.

The Division's remote sensing goal is the development of techniques for the detection and delineation of thermal, seston, and phytoplankton fronts. The seston and phytoplankton fronts can be used as indicators of relative water quality. Thermal fronts are also indicators of water quality and have potential application to commerical fishing activities.

This training quide presents MEAD's initial work in this field of marine remote sensing utilizing the NOAA-n AVHRR data with emphasis on the Mid-Atlantic Bight of the United States (Figure # 1). Methods are described for filtering the data for the reduction

of pixel to pixel variability, separating land/cloud features from water features (land/cloud masking), delineating sediment/chlorophyll (turbidity) plumes, deriving estimates of sea surface temperature (SST), displaying image representations of the SST field, and delineating ice within the Chesapeake Bay. The techniques discussed are applicable to other regions of the world and are being tested for the Exclusive Economic Zone (EEZ) of the Philippine Islands.

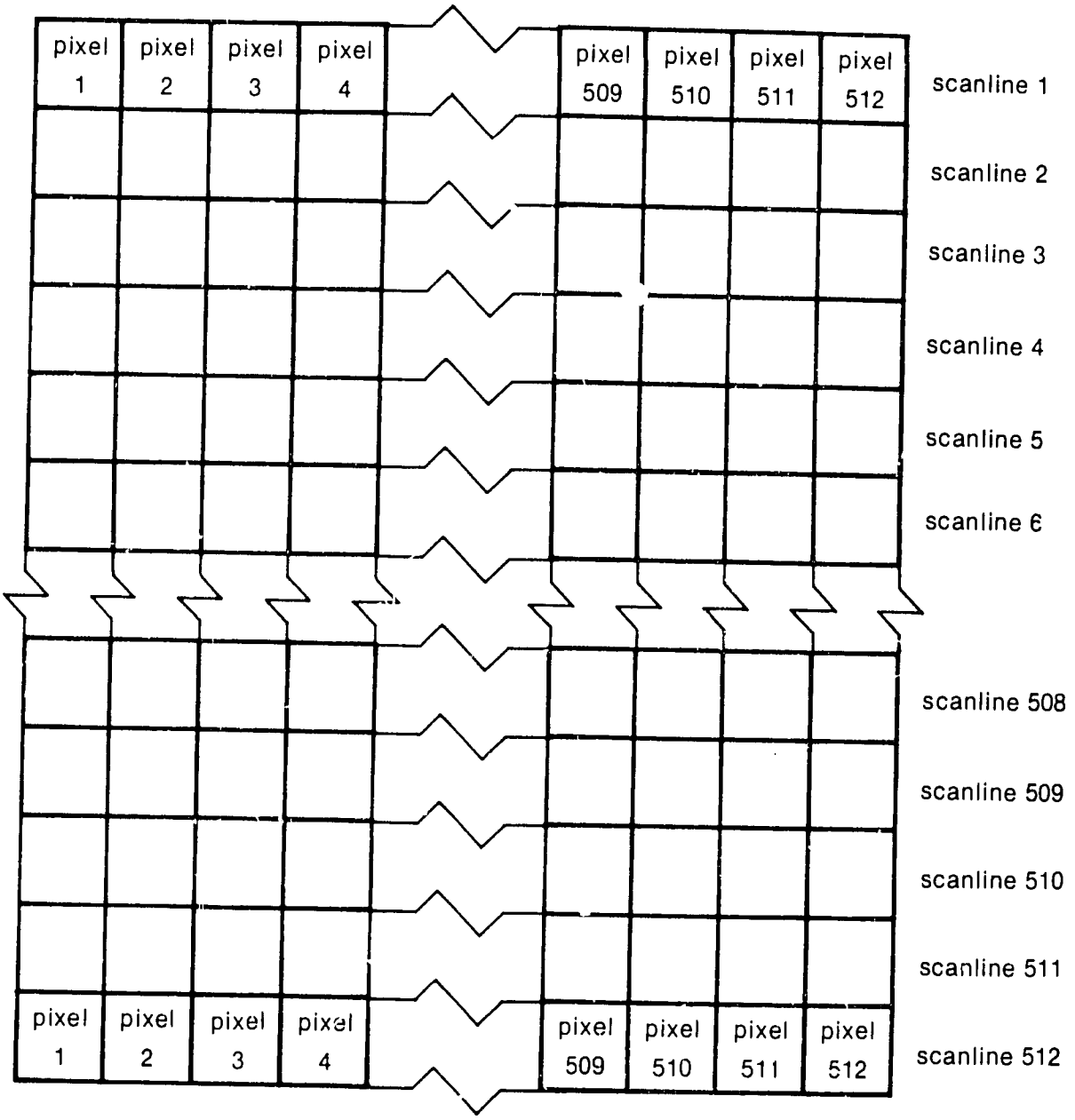
An image is a reconstruction of the digital data in picture form. An image can be produced which contains multiple scan lines and multiple pixels from the digital data for a single channel or a combination of channels (Figure # 2). The AVHRR digital data are stored as 2048 pixels (picture elements) per scan line, while for each pixel there are 5 digital values (one associated with each of the 5 sensor channels). The individual pixel digital data values are converted into either a series of gray tones or colors for display on the CRT (cathode ray tube) monitor. (This is analogous to taking the digital data and re-converting it to an analog signal.) The Log/E Image Processor (IP) contains 256 (8-bit display) different gray tones (0=black, 255=white) and/or approximately 64,000 different colors. It must be understood that a digitally produced image is a combination of the user's preconceived expectations and knowledge of the study area and the predetermined software procedures.

This training guide was written to familiarize beginner satellite remote sensor users with the NOAA-n series of polar orbiters. The theory of optical oceanography, satellite remote sensing, and digital image processing are only touched on briefly, but the application of satellite data to fundamental oceanographic problems is stressed. This manual was written with the thought that the reader would spend most of his effort looking at the imagery and accompanying text on a chapter by chapter basis. It is hoped that during the initial stages of generating imagery the reader would refer back to the appropriate chapter and develop a feeling for the expected outcome of performing the outlined digital image processing steps.

It is the intent of MEAD to continue to expand its remote sensing techniques and products utilizing the NOAA-n series of polar orbiting satellites. As new techniques are developed or interesting phenomena are observed in the imagery, then additional chapters will be written and included in this manual.

Figure # 1: A NOAA-7 AVHRR satellite image of the Mid-Atlantic Bight (located off the east coast) of the United States from April 12, 1982. Pertient land and water features are labelled to aid the user in locating features to be discussed in this manual.

Figure # 2: Schematic of a 512 pixels by 512 scanlines image. The word pixel is derived from the phrase picture element. A pixel is an individual data point which has a predetermined X and Y dimensions. Each scanline contains 512 individual pixels while the entire image contains 512 scanlines for a total of (512 X 512) 262,144 pixels.



2. Sensor Characteristics

Polar orbiting satellites of the NOAA-n series carry an instrument package called the Advanced Very High Resolution Radiometer (AVHRR). This is a four or five channel multi-spectral scanner (MSS). The number of spectral channels or bands is dependent on which satellite is being considered. The channels are located in the reflective and emitted thermal portions of the spectrum. The NOAA-7 satellite AVHRR spectral bands are as follows (Cornillon, 1982) (Figure # 3):

Channel #	Description	Band Width
Channel 1	visible band	.58 - .68 microns
Channel 2	near infrared (IR) band	.725 - 1.10 microns
Channel 3	thermal infrared band	3.55 - 3.92 microns
Channel 4	thermal band	10.5 - 11.3 microns
Channel 5	thermal band	11.5 - 12.5 microns

Channel 5 is not present in the NOAA-6 or NOAA-8 AVHRR instruments.

The AVHRR sensor records the energy detected in each of the spectral channels as 10-bit integer values (range of values 0 - 1023). This 10-bit data value is called the raw count data value (RCDV). The energy detected in channels 1 and 2 (the reflective visible and near IR channels) is a function of:

(1) the sunlight scattered by the atmosphere back to the sensor before reaching the earth's surface
(2) the reflective properties of the object on the earth's surface that the sunlight strikes
(3) the scattering by the atmosphere of the reflected sunlight while traversing the atmosphere to the satellite sensor.

For the thermal channels the energy detected by the satellite is a function of:

(1) the blackbody temperature of the object
(2) the emittance properties of the surface (water is assumed to have an emissivity of 1.0)
(3) the scattering and absorption of this emitted radiation as it traverses the atmosphere to the sensor.

The data present in the channel 1 and 2 imagery are generated by the reflection of sunlight off the land, clouds, and the leaves of the vegetative matter. The reflection and scattering of sunlight for channels 1 and 2 can be coarsely grouped as two and three dimension processes. The reflection of sunlight off land and the leaves of vegetative matter is a two dimensional process. For the oceans (clouds) the reflection of sunlight off the sea (cloud) surface and the penetration and scattering of sunlight within the water column (cloud) determines the raw count data values and thus

is a three dimensional process. Scattering by water particles and any other material (living, dead, or inorganic) suspended within the water column is recorded by the AVHRR instrument in channels 1 and 2. Thus, the three dimensional distribution of suspended material within the water column will determine the RCDV for water pixels. The depth within the water column from which sunlight is scattered back towards the sensor is dependent on the wavelength of light and the vertical distribution of scatterers.

Channel 1 (the visible channel) has a water penetration depth on the order of meters to ten's of meters. If the amount of scattering is large the amount of detected reflected sunlight is large, while the penetration depth is small. In open ocean waters the penetration depth is large due to the small number of scatterers. The scattering of sunlight from the sea floor in shallow areas must be considered and for clear oceanic waters near coral islands the return signal may be primarily due to reflection off the coral bottom due to the lack of suspended scatterers.

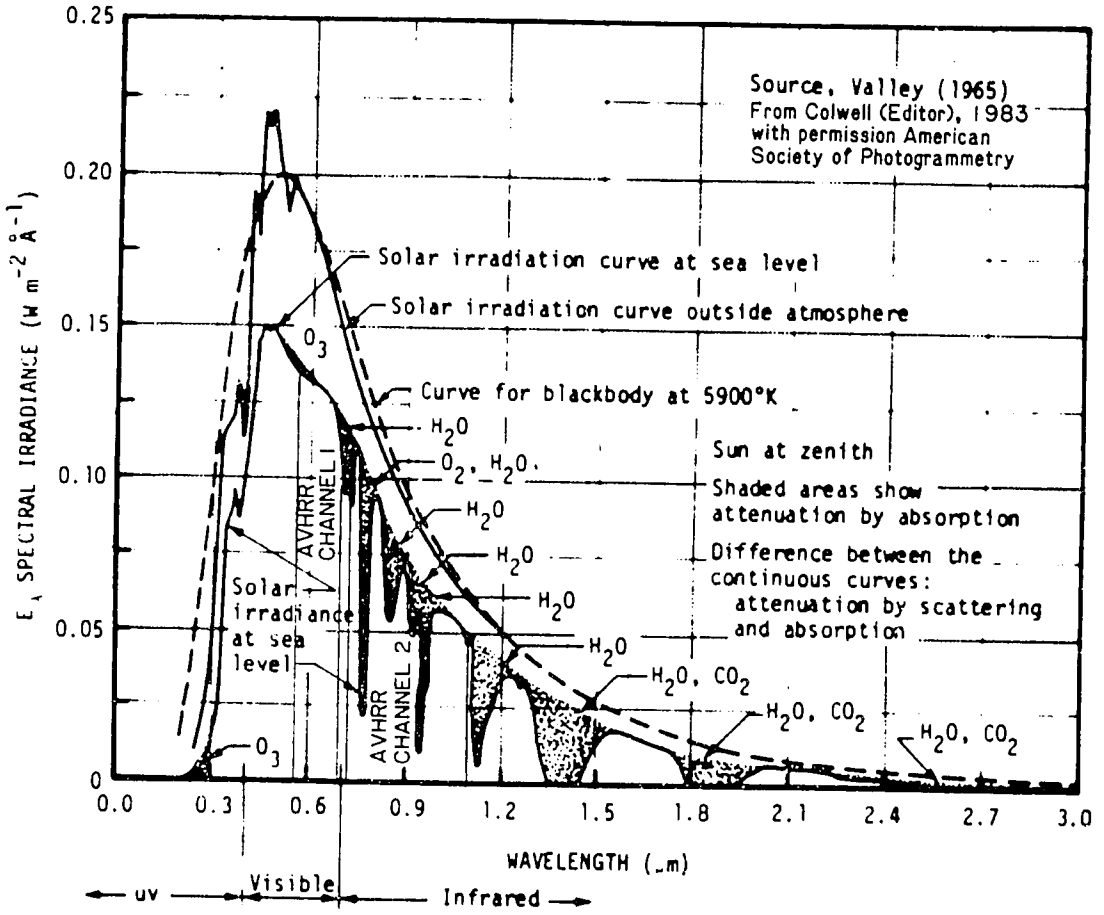
Channel 2 (the near-IR wavelength channel) has a smaller water penetration depth than the channel 1 visible channel. Water molecules absorb the near-IR energy of sunlight, reducing the amount of sunlight reflected back to the satellite. The absorption in the near-IR channel is such that the water RCDV for channel 2 are generally smaller than channel 1, i.e., channel 2 imagery is darker for water features than the same features in channel 1. (The reverse is true for healthy vegetative matter. Channel 2 RCDV are larger (brighter) than the channel 1 values i.e., channel 2 imagery is brighter for healthy vegetative matter than channel 1.) The amount of sunlight that is reflected back in this near-IR band depends upon the amount of scattering in the surface layers (decimeters to one or two meters) of the water column. A high return signal for channel 2 indicates highly turbid waters at the sea surface. Clear oceanic waters have a small channel 2 return signal due to the limited number of scatterers in the upper meters of the water column.

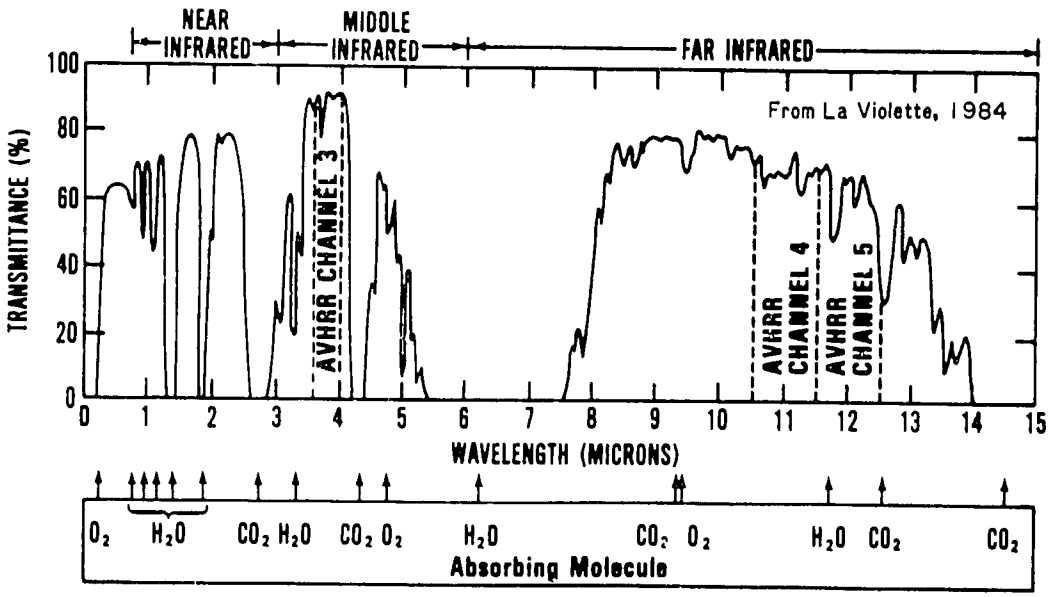
Data from two or three of the thermal channels can be combined through regression equations developed by the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) to generate estimates of the sea surface temperatures (McClain, 1981; Strong and McClain, 1984). These estimated temperatures are called Multi-Channel Sea Surface Temperatures (MCSST). Accuracy of approximately $\pm 1^{o}C$ is obtainable from the MCSST algorithms.

The Field Of View (FOV) of the AVHRR sensor is 110.8 degrees, i.e., it scans through an angle of $\pm$ 55.4 degrees from nadir (the point on the earth's surface directly below the satellite). The Instantaneous Field of View (IFOV) of all the sensor channels is approximately 1.4 milliradians, i.e., the sensor collects data over an incremental angle of 1.4 milliradians. At the nominal satellite altitude of 833 km. the nadir ground resolution is approximately

1.1 km. The analog signal from the sensors is digitized at a rate equilvalent to 0.95 milliradians which results in a nadir ground resolution pixel (picture element) size of approximately 0.8 km. The resulting scan line of data contains 2048 equal-angle pixels. For each pixel the digitized analog signal results in a digital 10-bit raw data count value for all channels which are recorded and stored on magnetic tape. The interested reader should obtain a copy of the NOAA Polar Orbiter Data (TIROS-n , NOOA-6, NOAA-7, NOAA-8, NOAA-9) Users Guide (Kidwell, 1985) which explains the characteristics of each polar orbiter satellite in detail and the formats of the magnetic tapes which store the data.

Figure # 3: Solar Spectrum and the AVHRR Channels. Upper panel from Colwell, 1983 printed with permission of American Society of Photogrammetry. Lower panel from La Violette, 1984.





3. AVHRR Data Forms and Characteristics

The AVHRR data is available in three basic forms:

(1) Local Area Coverage (LAC)
(2) High Resolution Picture Transmission (HRPT)
(3) Global Area Coverage (GAC)

LAC and HRPT data are both the full resolution AVHRR data, i.e., 2048 pixels per scan line. LAC data are recorded on board the satellite then transmitted to earth at a later time. HRPT data are the direct broadcast of the AVHRR data to receiving stations in real time. GAC data are the processed subset of the AVHRR data recorded on board the satellite and transmitted to ground at a later time, but are not the full resolution AVHRR data. The volume of the AVHRR high resolution data have to be reduced by averaging pixels and skipping scan lines so that a global view of the earth is available for analysis with only 1 or 2 ground recieving stations.

AVHRR data are available in a digital (tape) form which allows the user to manipulate individual pixel channel values for the production of images and in image (picture) form. NESDIS generates computer compatible tapes (CCT) of the AVHRR data designated the AVHRR LEVEL 1B data. This LEVEL 1B product is described in the publication NOAA Polar Orbiter Data (TIROS-n, NOAA-6, NOAA-7, NOAA-8, NOAA-9) Users Guide (Kidwell, 1985). For the production of imagery the full five, one, or two channel AVHRR LEVEL 1B tape products may be ordered from the Satellite Data Service Division (SDSD) of NESDIS (World Weather Building, Room 100, Washington, D.C., 20233; phone 301-763-8111).

The LEVEL 1B product is a digital tape which can contain one or more files of AVHRR data. The amount of AVHRR data contained on a tape is dependent on the user's area of interest on the earth's surface and the type of AVHRR data requested. Up to 18 degrees of latitude of AVHRR LAC or HRPT data can be stored on a single tape. These 18 degrees of data can be in one file or several files. For example, a tape contains 3 separate files of data. These 3 files could be of 3 different regions (whose sum total of latitude is less than or equal to 18 degrees) or it could be 3 files containing 6 degrees of latitude of the same geographic region but for 3 different dates. For the AVHRR GAC data more degrees of latitude or a greater number of different data sets for the same area of interest can be stored on an individual tape. Each file on the Level 1B tape contains the general data set header information associated with this data file as well as the earth location, solar zenith angles, sensor calibration data, RCDV for all sensor channels, etc. for each scan line. The sensor calibration data allows the user to generate the "albedo" values for channel 1 and 2 data as well as the blackbody temperature values for the thermal channels. The earth location data allows the user to generate

precise co-registered map projections of the input data for time series analysis, etc.

Due to the large field of view, pixel size symmetrically increases as one moves away from nadir (the assumption of a spherical earth is required for the symmetry). Thus, the pixels at large scan angles represent areas on the earth's surface which are larger than the 0.8 kilometer nadir pixel size. This results in geometric distortions of land, cloud, and ocean features at these large scan angles.

At large scan angles the reflected sunlight and the thermal energy recorded by the sensors have traversed a larger volume of the atmosphere than those near nadir pixels. This results in an increase in atmospheric contamination of these pixels. This contamination is difficult to completely remove by numerical model techniques and should be considered when interpreting pixel features at large scan angles.

A good rule of thumb is do not use the first 200-300 pixels and the last 200-300 pixels in each and every HRPT/LAC scan lines due to the increased atmospheric contamination and geometric distortions of the features observed. For GAC data the first and last 40-60 pixels should be excluded from analysis.

GAC data presents another type of geometric distortion. GAC data is HRPT/LAC data processed on board the satellite by repeatedly averaging 4 HRPT/LAC pixels and then skipping 1 pixel for a total of 409 GAC pixels per scan line. Two HRPT/LAC scan lines are then skipped before a new GAC scan line is generated. Thus, a GAC pixel can be thought of representing an area of 4.0 kilometers horizontally by 2.4 kilometers vertically. Since a GAC pixel is not square, severe distortions of land features, etc. are generated. This distortion must be kept in mind during the interpretation and analysis of GAC data.

IMAGE # 1: Unenhanced NOAA-7 HRPT/LAC AVHRR channel 2 image for April 23, 1982 with the center line of the Chesapeake Bay near nadir. Note, water is dark (black), clouds are bright (white), and land is intermediate (shades of gray). The coastlines, coastal wetlands, and islands are sharp and crisp and compare favorably to published maps of the Bay's major and minor features (within the resolution of the AVHRR data).

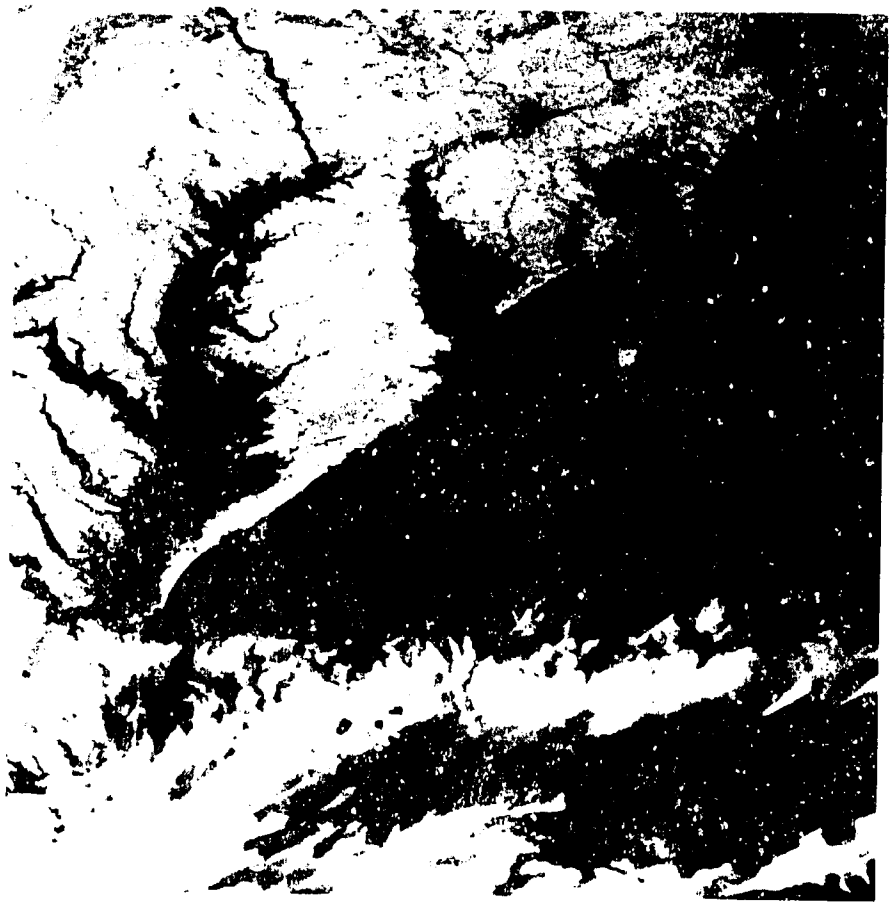


IMAGE # 2: This is a processed NOAA-7 HRPT/LAC AVHRR sea surface temperature (MCSST) image with the center line of the Chesapeake Bay far off nadir for April 12, 1982. Note, the geometric distortion of the coastlines and islands. Many of the minor features observed in the near nadir Image # 1 cannot be discerned. The comparison of this image to maps of the Bay is not as satisfactory as Image # 1.

IMAGE # 3: This is a GAC channel 2 image produced from the HRPT/LAC data used for Image # 1. Note the geometric distortions, but with a near nadir image there is still good information available even with the reduced resolution.

4. Image Filtering

In the production of images for analysis and interpretation, the reduction in data variability (noise) is an important step. As in any type of measurement, there is a certain amount of variability introduced in each measurement. In the case of remotely sensed data, sources of variability include:

(1) sensor (instrument) noise,
(2) the effects of the scattering and absorption of the intervening atmosphere,
(3) errors in transmission and recording of the data, and
(4) the limitations of the instantaneous field of view (IFOV)

IFOV is the areal coverage at nadir of a single pixel. For the AVHRR sensor the IFOV at nadir is an area of approximately 0.8 km. squared. One can expect non-uniformity (variability) of coverage within this 0.8 km. squared area. If the area of the Earth's surface was reduced then the natural variability within this area would also probably be reduced. The 10-bit raw count data value is some function of the reflectivity or the blackbody temperatures within this 0.8 km. squared area. It is not necessarily an average, the highest, or the lowest possible raw count data value for this area on the Earth's surface scanned by this sensor. Thus, if the amount of variability within the area on the Earth's surface being scanned and converted into digital values was reduced then the digital values would probably better represent the actual spectral characteristic of the Earth's surface and thus be smoother (less variable). (The operational function of the AVHRR sensor package is for worldwide daily coverage. This requires the large IFOV and large scan angles, thus requiring some operational filtering (smoothing) of the data.)

The functional relationship between the raw count data values for a pixel and the sensor recorded values is beyond the scope of this report. Interested readers can refer to the technical literature in digital image processing (Colwell, 1983; Holz, 1985).

To reduce the variability and to aid in the interpretation of an image, spatial filtering is recommended. MEAD recommends the median filtering technique illustrated in Figure # 4. The median filter operation will replace each pixel with the median (50% occurrence) value within the user specified kernel. A kernel is a window within which the median value is determined. For a 3 by 3 kernel, 3 pixels wide by 3 scan lines, the median value is determined and replaces the center pixel.

Images 4,5,6, and 7 illustrate the same scene in an unfiltered condition and with 3 X 3, 5 X 5, and 7 X 7 median filter windows. As the size of the filter window increases the details of the scene become less distinct but the boundaries of major features become conceptually simpler. The user must decide what is the optimum

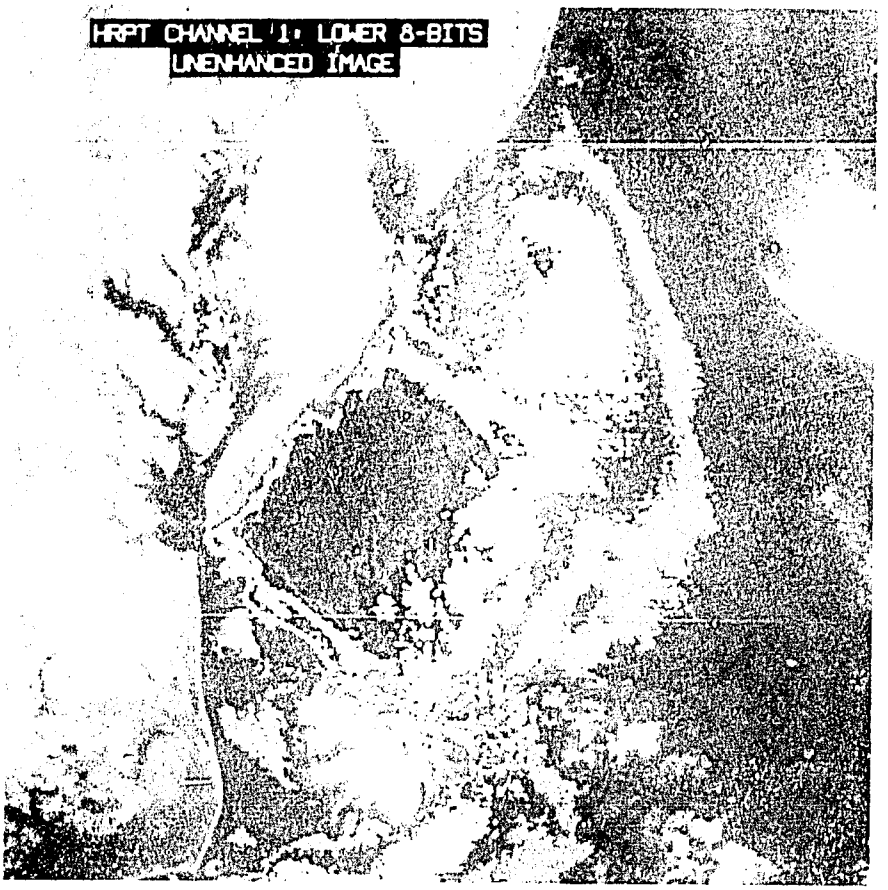
kernel size for the specific application.

Figure # 4: Schematic of the 3 by 3 kernel (window) used in the median filter operation. The i index is an increment in the horizontal (pixel) direction while the j index is an increment in the vertical (scan line) direction. These 9 display values are read, numerically sorted, and the median (50%) occurrence value determined. This median value then replaces the R i,j (center) display value. This operation is performed for all display pixel values.

$R_{i-1,j-1}$	$R_{i,j-1}$	$R_{i+1,j-1}$
$R_{i-1,j}$	$R_{i,j}$	$R_{i+1,j}$
$R_{i-1,j+1}$	$R_{i,j+1}$	$R_{i+1,j+1}$

IMAGE # 4: Unenhanced channel 1 (visible band) NOAA-7 image for April 12, 1982 of the Mid-Atlantic Bight of the United States displaying the least significant 8-bits of the raw count data values. Three different 8-bit raw count data values were color-contoured. Note the noisy edges of the contours and the apparent horizontal lines.

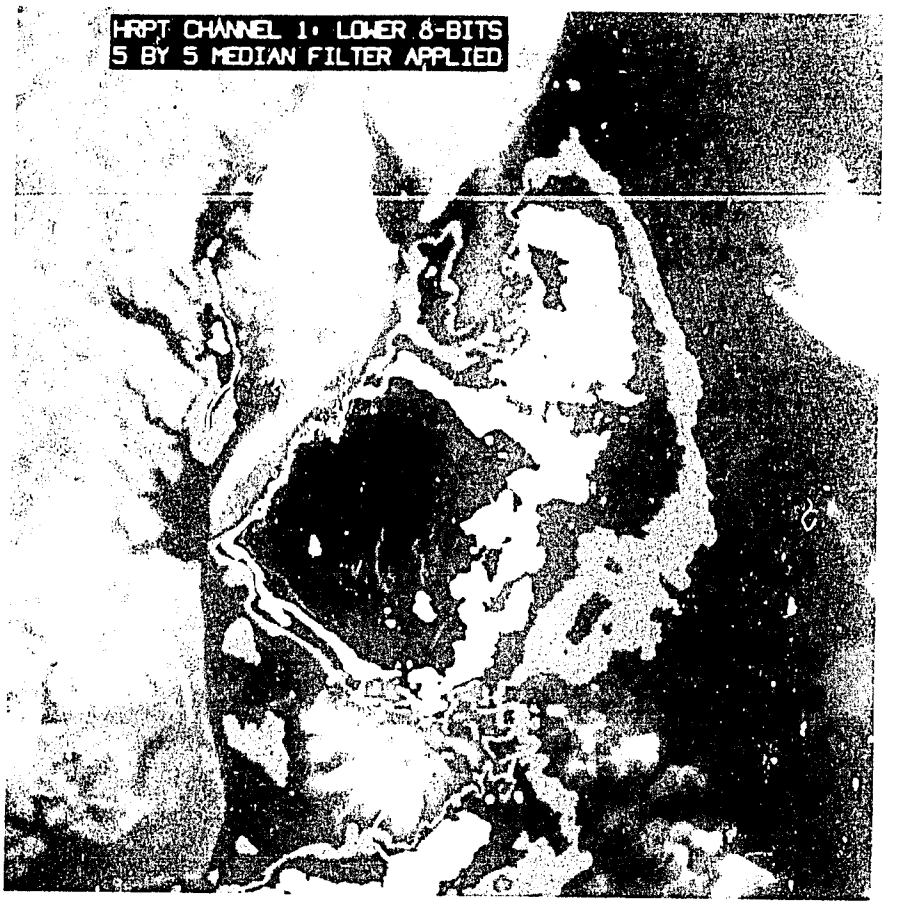
IMAGE # 5: The same data as Image # 4 after a 3 by 3 kernel median filtering operation was performed. Note contours are smoother (reduced variability) and the land features are still clear and crisp.


HRPT CHANNEL 1: LOWER 8-BITS
UNENHANCED IMAGE

HRPT CHANNEL 1: LOWER 8-BITS
3 BY 3 MEDIAN FILTER APPLIED

IMAGE # 6: A 5 by 5 median filtered image of Image # 4. The color contours are smoother than Image # 5 but note that the details of the land features are becoming blurred.

IMAGE # 7: A 7 by 7 median filtered image of the original data, Image # 4. The color contours are smoother still than Image # 6 but the land features are indistinct.


HRPT CHANNEL 1: LOWER 8-BITS
5 BY 5 MEDIAN FILTER APPLIED

HRPT CHANNEL 1: LOWER 8-BITS
7 BY 7 MEDIAN FILTER APPLIED

MEAD prefers the 3 by 3 kernel size for the median filter operation. It smooths the data sufficiently to make interpretation easier and at the same time does not cause the loss of large amounts of information. An additional advantage of the median filter is that sharp edges (land/water boundaries) are preserved by this spatial filtering operation.

5. Separation of Land, Clouds, and Water

Interpretation and analysis of satellite imagery for oceanographic features requires the enhancement (digital manipulation) of those pixels located in water. This is the result of the inherent low reflectivity (2% - 6%) of water in the visible and near-IR portion of the spectrum (AVHRR channels 1 and 2) i.e., raw count data values (RCDV)in the 50 to 100 range. (The human eye functions as a logarithmic detector. The detection of subtle changes in intensity of water features in the linear display of 0 to 255 RCDV is not possible and requires digital manipulation of the data to allow the user to visually detect the recorded changes.) In the enhancement of any image, flexibility is achieved by eliminating all pixels (information) not directly required in the analysis. Thus, the elimination of all or at least most of the land and cloud pixels prior to any image enhancement procedures allows more flexibility in the enhancement of the remaining pixels.

An image can be classified utilizing the channel 2 near-IR data into two groups of pixels:

(1) land and cloud pixels and
(2) water pixels.

This is possible because of the non-reflective (absorptive) nature of water in the near-IR portion of the spectrum, i.e., clear water pixels are dark (small RCDV) compared to land and cloud pixels which are bright (relatively larger RCDV). By setting all of the pixels of land and clouds to a single extreme value (say all black) we form a land/cloud mask which allows easy separation of water and land/cloud as two distinct areas. The water pixels can then be enhanced over the full range of display intensities or colors available without interference of land or cloud pixels.

If the water contains large amounts of suspended material (turbid waters), whether organic (phytoplankton) or inorganic (suspended material), then those water pixels will have larger RCDVs than less turbid, clearer, waters. Turbid water can have pixel values which can approach those values normally considered land pixels making the classification of an image into land/cloud and water pixels more difficult. This problem occurs infrequently and only in estuaries with large sediment loads. The user must decide what range of RCDV (maximum cutoff value) is to be considered water pixels. If highly turbid waters are located in the estuaries being analyzed then the user will have to decide among:

(1) excluding turbid areas by picking an upper limit value for water which eliminates pixels with RCDV in the range found in the turbid waters;
(2) including pixels of turbid waters with the same range of RCDV as land areas;
(3) including those turbid waters with the same range

of RCDV as land, and:

(a) manually editing out the land pixels; or
(b) excluding land areas based on a mask of a digitized base map of the boundaries of the water bodies; or
(c) using a geometrically correct land/cloud mask of the same area generated when the turbid waters were not present.

It is possible to logically combine or overlay a land/cloud/water classified channel 2 image with another image generated from the same AVHRR channel data into a single image. This allows the user to enhance any of the five AVHRR channel water pixels so that subtle water features present in an original image can be made more apparent.

This simple method is not foolproof. Some cloud-contaminated pixels may pass the classification process as water pixels. This type of classification error may occur from thin low or high clouds which allow enough reflected sunlight from the water to pass through the cloud for grouping with the sediment laden coastal water pixels.

The effects of sub-pixel cloud (clouds smaller than the 0.8 km. squared pixel size) contamination are not addressed by this procedure. When the land/cloud classified image contains many one- or two-pixel clouds for a given area of the image, the presence of sub-pixel clouds should be considered.

All the above contamination problems must be considered when interpreting satellite imagery. Constant referral to the original channel 1 and channel 2 imagery during the interpretation of the imagery is advisable.

IMAGE 8: An unenhanced NOAA-7 HRPT/LAC AVHRR channel 2, near-IR data, for the Mid-Atlantic Bight for April 12, 1982. The displayed data are a type 1C, (see section 7) the lower 8-bits of the possible 10-bits of data. Note, land and clouds are noticeably brighter than the water pixels. The water pixels in the upper Chesapeake Bay are not as dark as the waters on the shelf or elsewhere in the Bay. The western (leftmost) portion of the image contains extensive cloud contamination , i.e. the land and water features are still observed but are blurred and the water pixels are noticeably brighter than expected. Thus, the separation of land and cloud pixels from water pixels should be straightforward except in the northern Chesapeake Bay and along the western portion of the image. The rivers in the western portion of the image should be placed in the land/cloud group since any information about these rivers is contaminated by the overlaying clouds. The determination of the maximum limit of the RCDV accepted as water pixels should be determined by the RCDV present in the upper Chesapeake Bay. Take care that not many land pixels are included in this maximum limit. If land pixels are included, what generally occurs is that the shoreline pixels get grouped into the water pixels making rivers, lakes, and the Bay slightly wider.

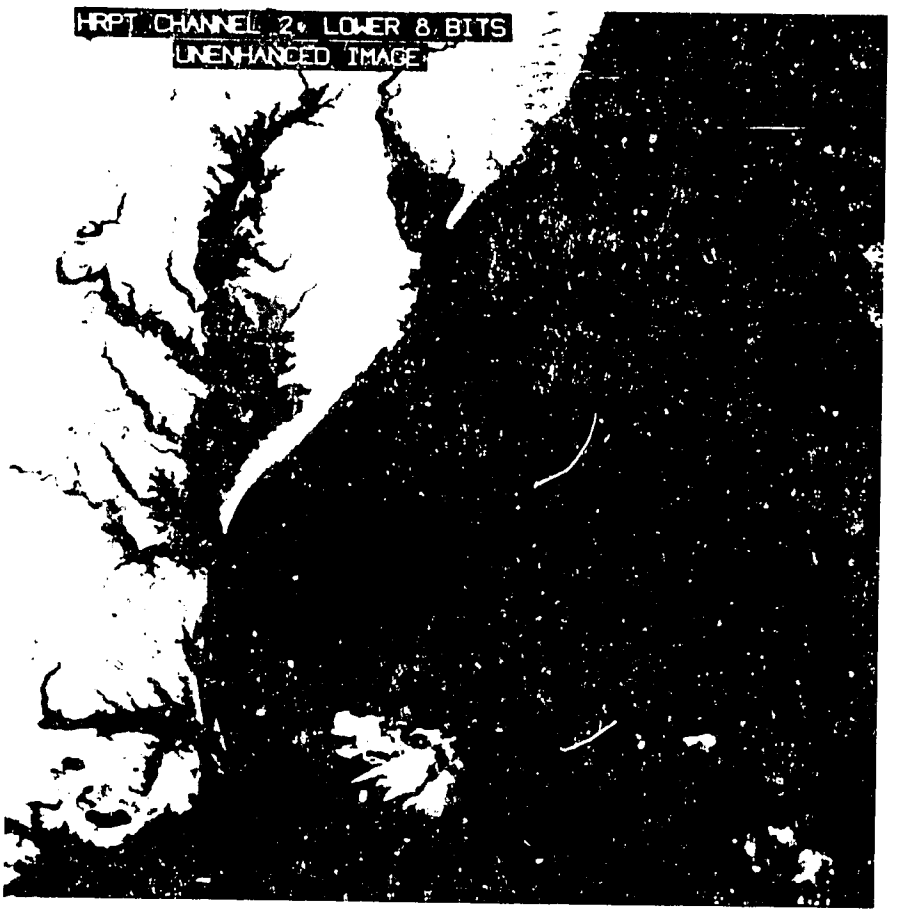


IMAGE 9: An unenhanced NOAA-7 HRPT/LAC AVHRR channel 2 percent reflectance image (see section 7) for the Mid-Atlantic Bight utilizing the same 10-bit input data as Image # 8. The percent reflectance data requires scaling for display since the input data has a range of 0 - 100 which if displayed as a linear function (display value 0=0% and 100=100%) does not generate a satisfactory display. Zero to 25% reflectance values are scaled to cover image display brightness values from 0 to 200; 26% to 80% are scaled between 201 and 255 brightness values; 81% to 100% reflectance values are set equal to a display value of 255. Scaling the percent reflectance data this way is, in fact, a type of image enhancement technique since the desired lower input values are stretched over a large range of output display values. In this particular image there were no display brightness values above 240. All land and water pixels were within the 0% to 25% fine scale percent reflectance range. Only cloud pixels had percent reflectance values above 25%. The same general features and relative brightness are observed in this image as in the least significant 8-bit image for the same input digital data. Thus, either the channel 2 percent reflectance or least significant 8-bit image could be used in the generation of the land/cloud mask.

IMAGE # 10: The land/cloud mask generated from Image # 8. Note, not all the water pixels were saved, i.e., the upper reaches of all the rivers present were not kept as water pixels but were classified as land. This elimination of these water pixels can result from (a) the RCDV for these waters being larger than the user determined maximum limit and/or (b) the median filter operation with a 3 by 3 kernel removed from those portions of the rivers which were too narrow to pass through this window size. The RCDV for the eliminated pixels can be the result of the waters being sediment laden, or sunlight reflected from the river bottom, or, for the leftmost (western) portion of the image, cloud contamination. The vertical band of clouds to the east of Delaware Bay shows a structure which generally occurs when there is high or low broken clouds. The area around these blacked out clouds should be interpreted with great care or not even considered in the analysis. Similiar features are seen in the lower right of the image and the leftmost portion of the large cloud that extends off the image on the righthand (east) side of the image. The salt marshes that extend along the east coast are delineated at this time due to the large surface area covered by water on this satellite overpass.

6. Enhancing an Image

Enhancing an image involves the digital manipulation of the display pixel data values in such a way that those areas of the image which are of interest are changed in a positive way that improves the interpretation and analysis of that image. There are infinitely many techniques for enhancing an image by the manipulation of the pixel data values. The user must beware of the real problem of working the same image or group of similiar images over and over again continually enhancing and displaying the image(s) without producing a final image product.

For the ocean areas the piece-wise linear stretching of pixel data appears to give the best results. Piece-wise linear stretching is a technique of sub-sampling the displayed pixel data values and expanding (stretching) the range of the displayed values for that sub-sample and contracting the display range of the remaining pixel data values. One can also take an image which does not use all possible 256 display intensity values and stretch the pixel data to fill that entire 256 display range.

Ocean and coastal RCDV for AVHRR channels 1 and 2 generally extend from 50 to 120. A value of 50 (relatively dark) is for clear oceanic waters and 120 (relatively bright) is for turbid coastal waters. The range of ocean pixel RCDV varies with geographic area and the time of the year, i.e., it is dependent on solar zenith and azimuth angles. But, oceanic and coastal water pixel display values generally extend over a range of 30 to 75 display values (Figure # 5). Thus, if the oceanic and coastal pixels can be redistributed in such a manner as to cover the full display range (0-255) then the delineation of features in the water becomes an easier task.

Another version of this enhancement technique is to gray scale contour desired water features, e.g., contour the sea surface temperature data into several different classes (See Image # 27). This involves determining the number of classes that will be gray scale contoured and then stretching the original display values into these new grouped display values. The number of classes should be limited to 10 or fewer classes. This results from the difficulty in seeing more than 10 - 12 different gray tones in any particular image. Thus, if there are more than 8 to 10 different classes in an image then the user should consider grouping several classes together, thus making fewer classes requiring display.

The three images for this section will show useful techniques of piece-wise linear stretching and the utilization of land/cloud mask images for the generation of imagery for oceanographic analysis.

Figure # 5: This is a graphical representation of the enhancement of a typical Mid-Atlantic Bight channel 1 or 2 image. The original display is linear with 0 RCDV displayed as 0 and RCDV of 255 displayed as 255. Water pixels are in the range of 50 to 100 for this presentation. RCDV of 0 to 49 are set to a display value of 0. RCDV of 50 is left at 50 while RCDV of 100 is set to 255. This results in a 4 times stretching of the data. All RCDV greater than 100 are in turn also set to 0. Thus, only the water pixels have been stretched and displayed while all land/cloud pixels have been removed.

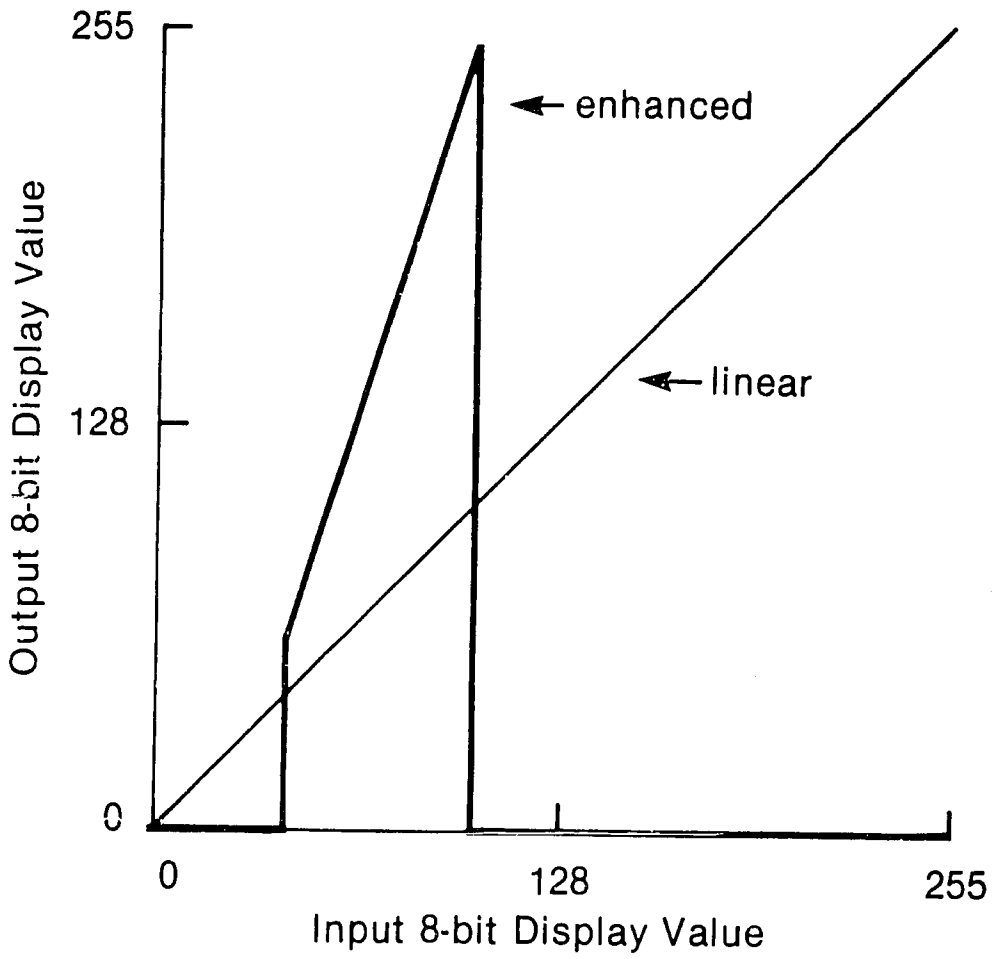


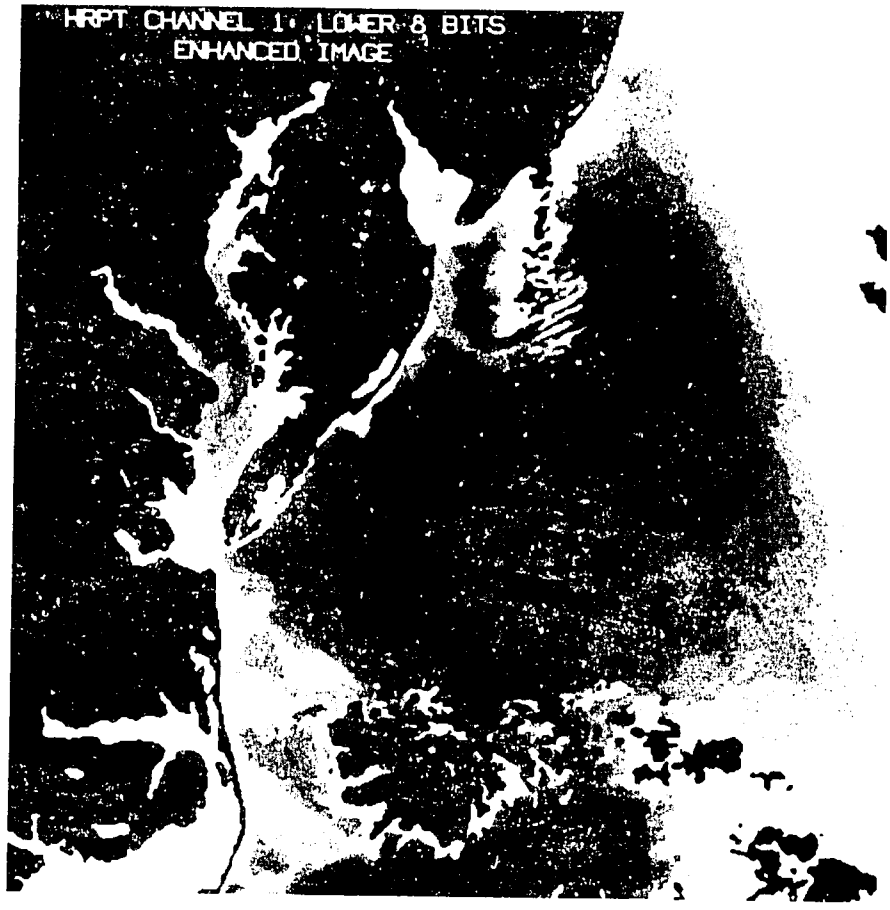
IMAGE # 11: An unenhanced, NOAA-7 HRPT/LAC AVHRR channel 1 Type 1c image (see section 7) for April 12, 1982. Note, high clouds are displayed as white pixels. The low clouds to the east of Delaware Bay and along the lefthand (western) portion of the image are in shades of gray. Highly turbid waters at the head of Chesapeake Bay and Albermarle and Pamlico Sounds are also in shades of gray. The majority of the water pixels are dark, shades of black, with little apparent variation. Water pixels in the upper righthand portion of the image are brighter than those water pixels more in the center of the image. The cause of this is under investigation but it is believed to be atmospheric contamination. No interpretation of the data in this area should be attempted without first correcting for the intervening effects of the atmosphere. The structure of the estuaries and coastline are easily seen as are the coastal wetlands and barrier islands.

IMAGE # 12: An enhanced version of Image # 11 channel 1 data. Water pixels in Image # 11 were determined to have display values ranging from 62 to 100, while land and cloud values were from 101 to 255. The water enhancement was performed to reassign display value 62 to 50 and display value 100 to 150 with the intervening display values linearly stretched between these lower and upper limits. Land and cloud display values of 101 to 255 were assigned to the 151 to 255 range of display values. Thus, the land/cloud pixel display range was compressed while the water pixel range was expanded by a factor of about 2.5. Note the thin clouds on the western portion of the image and those to the east of Delaware Bay are easily seen. The structure on land becomes less distinct. In fact the structure is still there but the eye cannot differentiate between the different bright (high intensity) pixels. Land/water distinction and in-water features at the mouth of the Chesapeake and Delaware Bays are more apparent. The in-water features may be sediment plumes. The structure of the waters in Albemarle and Pamlico Sounds are more apparent and very complex. The waters at the head of the Chesapeake Bay now appear as white pixels which may be interpreted as high sediment laden waters. Possible sediment plumes are also visible at Cape Hatteras and at the inlets to the barrier islands.

HRPT CHANNEL 1, LOWER 5 BITS

HRPT CHANNEL 1, LOWER 5 BITS
ENHANCED IMAGE

IMAGE # 13: An enhanced version of Image # 11 but with the use of a land/cloud mask. The land/cloud mask allowed the user to stretch the water pixel display values for all coastal and ocean areas of the image over a large range of display values. Display value 63 was reassigned to 10 and display value 100 was assigned to 255. Thus, the water pixel range of values was expanded from spanning approximately 40 display values to 245, an 8 times stretching of the data. Note that the same surface water features are delineated in this image as in Image # 12. But, due to the stretching of the data, these ocean and coastal features are more easily seen.



7. Techniques for Displaying the 10-Bit Advanced Very High Resolution Radiometer Data on a 8-Bit Image Processor

The AVHRR raw count data values (RCDV) recorded on the digital tape product Level 1B of NESDIS are 10-bit integer values. Data values can be integers ranging from 0 to 1023. Thus, to use the entire range of the AVHRR RCDV in producing imagery, a minimum of a 10-bit display image processor is required. Most image processors and the AISC LOG/E Interpretation Systems Incorporated Image Processor (IP) in particular have a 8-bit (0 - 255 integer values) display capability. The conversion of the 10-bit raw data count values into 8-bit display values is a required step in the production of any images.

There are two basic techniques available for this conversion:

(1) Truncate the 10-bit data to 8-bits by (Figure # 6)
  (a) saving the rightmost (least significant) 8-bits,
  (b) saving the leftmost (most significant) 8-bits, or
  (c) saving the rightmost (least significant) 8-bits but if either of the two most significant bits are 1's, i.e., raw data count value greater than 255, then the entire 8-bit value is set to 255.
(2) Scale the 10-bit value to 8-bits by
  (a) converting the 10-bit channels 1 and 2 data into percent reflectance and scale the results for a 8-bit display processor,
  (b) converting the 10-bit thermal channel data into blackbody brightness temperatures and scale the results for a 8-bit display processor, or
  (c) converting the 10-bit thermal channel data into estimates of the sea surface temperature by the Multi-Channel Sea Surface Temperature (MCSST) algorithms and scale the results for a 8-bit display processor.

Technique 1a for channels 1 and 2 will cause highly reflective surfaces like high altitude clouds to be displayed as small data values, i.e. shades of black, making the separation of cloud from water features difficult. Technique 1b truncates the least significant 2-bits which for the marine environment contain a large amount of the information content in channels 1 and 2. (Channel 1 and 2 raw count data values for the marine environment are not larger than 255.) Technique 1c is similiar to 1a but all highly reflective surfaces are displayed as white (display value of 255). Thus, clouds are in shades of gray to white and there is good separation between marine and land/cloud features. Technique 1c presents the information available for channel 1 and 2 for the marine environment in a easily interpreted display.

Technique 2a requires the individual channel's calibration data available on the Level 1B tape to convert the RCDV to percent reflectance values. The algorithms are linear and described in the NOAA Polar Orbiter Data (TIROS-n, NOAA-6, NOAA-7, NOAA-8, NOAA-9) User Guide (Kidwell, 1985). The percent reflectance values (0% to 100%) then are scaled for display as 8-bit values (see Image # 9). Technique 2a should be as useful as the technique 1c especially when a comparison of images for different day and even years is to be performed. But, the solar zenith and azimuth are not taken into account by the present equations.

For the thermal channels techniques 1a, 1b, and 2c give the best results. Technique 2c requires the thermal channel's individual calibration data available on the Level 1B tape to convert the RCDV to blackbody temperatures (technique 2b). These blackbody temperatures are then used as input to satellite and time (day or night time) algorithms for the calculation of sea surface temperature (SST) values.

The MCSST algorithms attempt to correct the calculated blackbody temperatures for the absorption and scattering effects of the intervening atmosphere. Thus, estimated absolute temperatures are assigned to the sea surface pixels with this technique while relative temperatures are assigned by technique 2b. These MCSST equations are for water only, not for land. Those pixels located on land are not to have their display values interpreted in terms of estimated temperatures. The MCSST equations are a general set for use over the entire world. If a more detailed geographically limited set of equations are developed using in situ water temperatures and AVHRR thermal data, then the satellite estimates generated by these area limited equations will improve.

The generation of MCSST imagery (technique 2c) removes some of the detail of the thermal gradients. This detail can be more clearly discerned in the channel 4 data but the MCSST imagery allows the user to associate estimated sea surface temperatures to within 1°C with parcels of water. Thus, a channel 4 image complements MCSST imagery during the image interpretation and analysis.

Figure # 6: This diagram shows those bits utilized in displaying AVHRR 10-bit data on an 8-bit image processor.

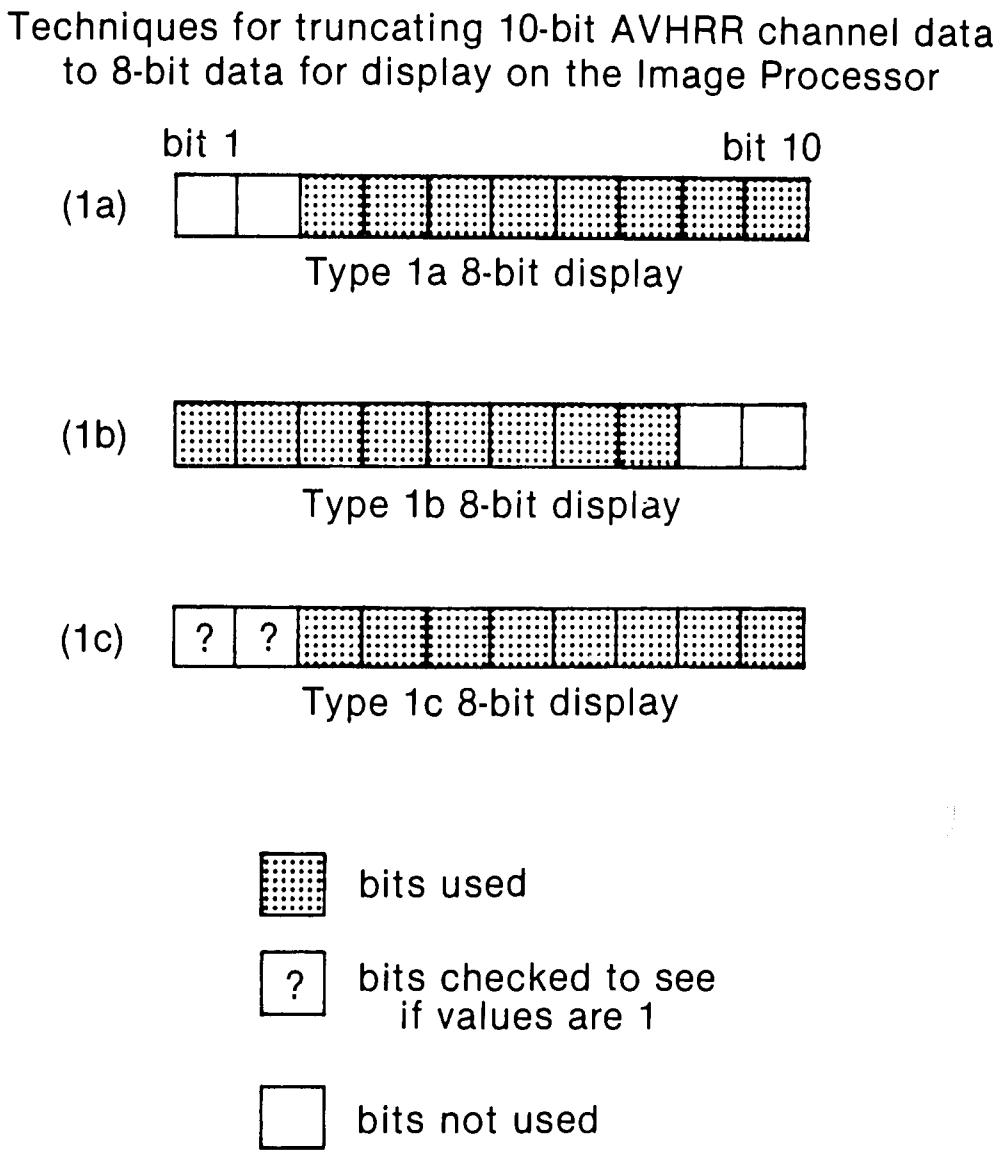


IMAGE # 14: An unenhanced Type la image generated from NOAA-7 HRPT/LAC AVHRR channel 1 data for April 12, 1982. The least significant 8-bits of data are used in generating this image. Due to this fact very highly reflective surfaces (some cloud tops) appear not as bright (white) features but in shades of black and gray. The low clouds to the east of Delaware Bay and along the lefthand, western, portion of the image are in shades of gray. What has occurred is that the RCDV was greater than 255. For example, if the RCDV was 256 then the displayed pixel value would be 0, while RCDV 325 would be displayed as a brightness value of 69. The water features appear the same as in Image # 16 but the classification of water pixels is now more difficult because some cloud tops have pixel display values within the water pixel display range. Note, the highly turbid waters at the head of Chesapeake Bay and Albermarle and Pamlico Sounds are also in shades of gray. The vast majority of the water pixels are dark, shades of black, with little apparent variation. The structure of the estuaries and coastline are easily seen as are the coastal wetlands and barrier islands.

IMAGE # 15: This unenhanced image was generated using the same input RCDV as Image # 14 but the most significant 8-bits of data have been displayed. This is a type 1b image display. Note, the entire image is darker, i.e., the displayed data has a reduced dynamic range compared to Image # 14. The readily apparent structure in this image is reduced compared to Image # 14 not only for water but also for land features.

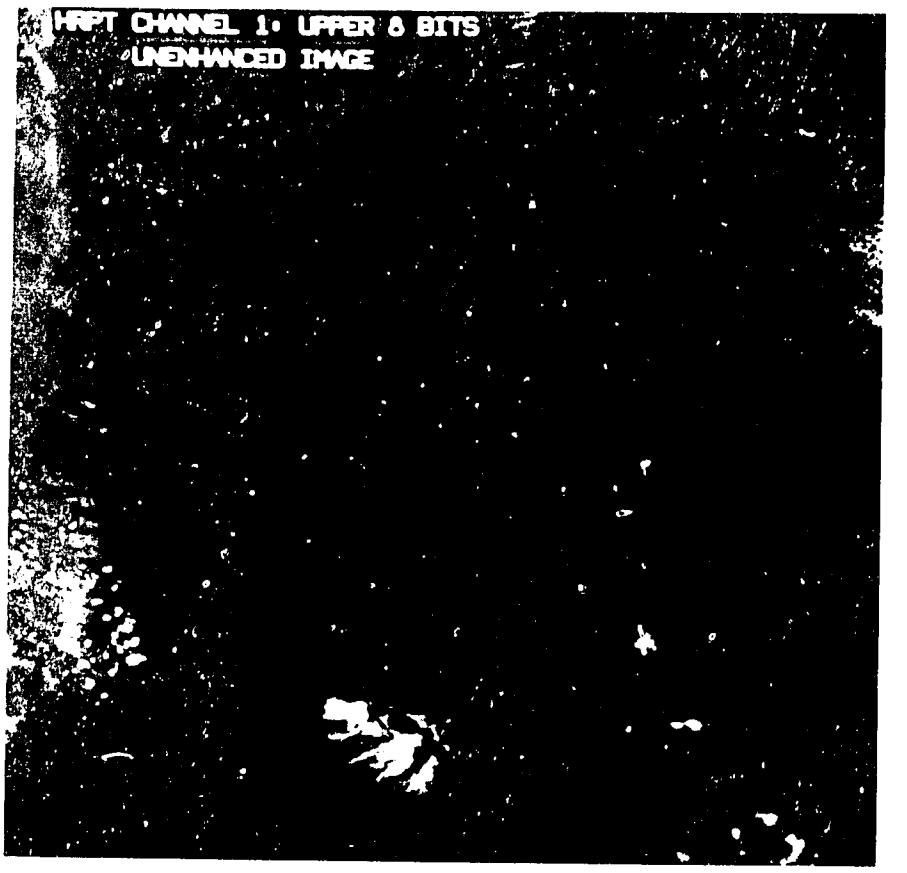


IMAGE # 16: An unenhanced HRPT/LAC AVHRR Type 1c display of the same channel 1 data as Images # 14 and 15. Note, the same water features are observed in this image compared to Image # 14 since the same 8-bits of water data are being displayed. But, the major difference is that highly reflective surfaces such as cloud tops are displayed as bright (white) features while in Image # 14 they were black or shades of gray. Thus, the separation of land/cloud features from water features is easier to perform with this type of display than with techniques 1a and 1b.

IMAGE 17: The same input 10-bit raw count data of Image # 14 has been converted into percent reflectance data and displayed as this image. Note, this image is similiar to Image # 16. This is due to the scaling of the percent reflectance values, where display value 0 equals 0% reflectance and 200 equals 25% reflectance and display value of 255 equals an 80% reflectance. All water and land pixels in this image are within the 3 to 25% reflectance range while there were no clouds that were more than 75% reflective. Since water pixels are generally in the range of 2% to 6% reflective their display values are between 16 and 48. When a close examination of the percent reflectance scaling for 8-bit display and the equations that convert the RCDV to percent reflectance is made, it is found that 1 display value equals approximately 1.5 RCDV. That is why this image is very similiar to the Type 1c Image # 16. High clouds are whiter than the thin cloud areas of the image. This is due to the more reflective surface of the high clouds resulting in larger percent reflectance values.

IMAGE # 18: This is the thermal channel 4 scaled blackbody temperature image for the same HRPT/LAC AVHRR data and orbit as Image # 14. The blackbody temperatures are only relative, not absolute temperatures. The absorption and scattering of the intervening atmosphere have not been removed from the calculated temperatures. Cold temperatures are white (display value 255) while hot temperatures are black (0 display value). Cloud tops are cold and are displayed in white and bright gray tones. The waters near the coast (shelf waters) and those in the estuaries and bays also have cool to cold temperatures. The warm Gulf Stream is observed offshore as a black band of waters. Intermediate in temperature, the slope waters are in gray tones separating the cool-cold shelf waters from the warm Gulf Stream water. Several warm core clockwise rotating eddies are observed in the slope water region and intense mixing is observed within the slope waters and between the slope and shelf waters. (See Image # 26)

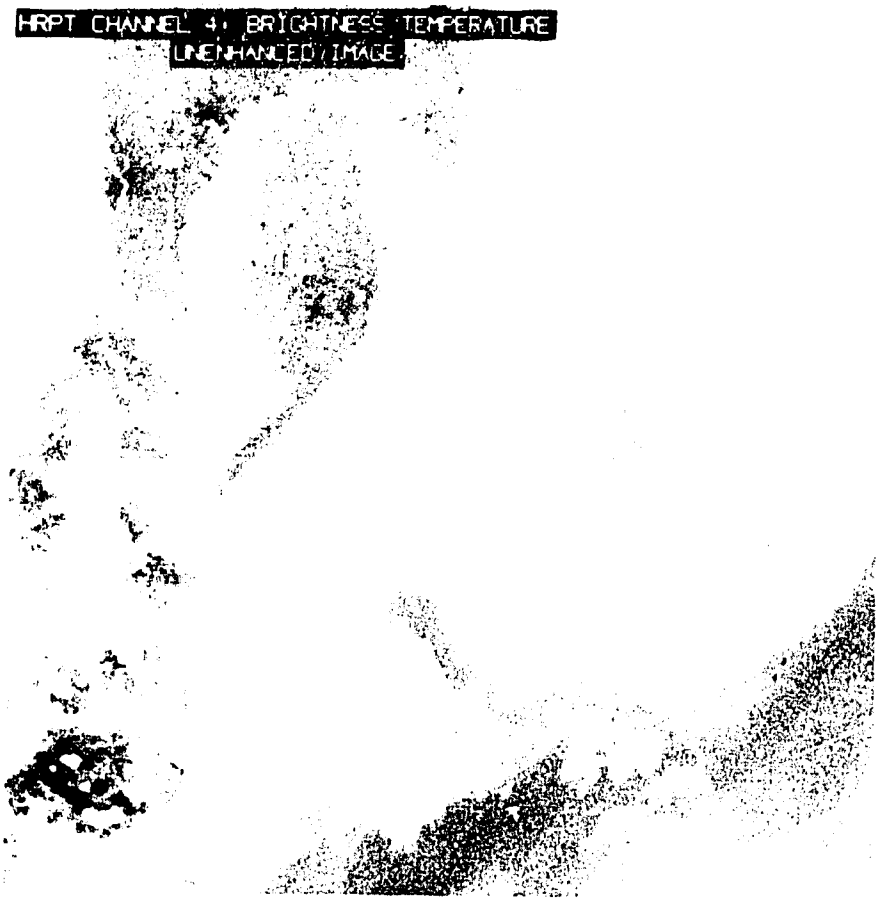


IMAGE # 19: This is a Multi-Channel Sea Surface Temperature (MCSST) unenhanced image of the thermal data for the same HRPT/LAC AVHRR date and orbit as the channel 1 images presented in this section. Note, warmer water temperatures are in shades of black and grays while colder waters are shades of white. Black 0 brightness value is 45°Celsius (C) while white is -19°C, brightness value of 255. Clouds generally are colder than water, thus clouds are in shades of white. The same water features observed in the scaled blackbody temperature image (Image # 18) are also observed in this image. The main difference between Images # 18 and 19 is that estimated absolute temperatures within 1° C are assigned to pixels in Image # 19.

8. General Techniques for Water Feature Delineation

The data present in the channel 1 and 2 imagery are generated by the reflection of sunlight off the land, clouds, and the leaves of the vegetative matter. The reflection and scattering of sunlight for channels 1 and 2 can be coarsely grouped as two and three dimension processes. The reflection of sunlight off land and the leaves of vegetative matter is a two dimensional process. For the oceans (clouds) the reflection of sunlight off the sea (cloud) surface and the penetration and scattering of sunlight within the water column (cloud) is a three dimensional process and determines the raw count data values. Scattering by water particles and any other material (living, dead, or inorganic) suspended within the water column is recorded by the AVHRR instrument in channels 1 and 2. Thus, the three dimensional distribution of suspended material within the water column will determine the RCDV for water pixels. The depth within the water column from which sunlight is scattered back towards the sensor is dependent on the wavelength of light and the vertical distribution of scatterers.

Channel 1 (the visible channel) has a water penetration depth on the order of meters to ten's of meters. If the amount of scattering is large the amount of detected reflected sunlight is large, while the penetration depth is small. In open ocean waters the penetration depth is large due to the small number of scatterers. The scattering of sunlight from the sea floor in shallow areas must be considered and for clear oceanic waters near coral islands the return signal may be primarily due to reflection off the coral bottom due to the lack of suspended scatterers.

Channel 2 (the near-IR wavelength channel) has a smaller water penetration depth than the channel 1 visible channel. Water molecules absorb the near-IR energy of sunlight, reducing the amount of sunlight reflected back to the satellite. The absorption in the near-IR channel is such that the water RCDV for channel 2 are generally smaller than channel 1, i.e., channel 2 imagery is darker for water features than the same features in channel 1. (The reverse is true for vegetative matter. Channel 2 RCDV are larger (brighter) than the channel 1 values, i.e., channel 2 imagery is brighter for vegetative matter than channel 1.) The amount of sunlight that is reflected back in this near-IR band depends upon the amount of scattering in the surface layers (decimeters to one or two meters) of the water column. A high return signal for channel 2 indicates highly turbid waters at the sea surface. Clear oceanic waters have a small channel 2 return signal due to the limited number of scatterers in the upper meters of the water column.

The separation of the scattering particles into the two broad classes of inorganic and organic is difficult to perform and it is still a question whether it can be done with AVHRR data. In coastal regions both inorganic and organic scatterers are

important. In a estuary or on the continental shelf one type might dominate at one time while at a different time the other dominates. Interpretation and analysis of coastal scattering features is a complex and subjective procedure. For the deep ocean the problem is simplified due to the lack of large quantities of inorganic particles, thus the types of scatterers are limited to phytoplankton (organic particles) only.

The thermal channels (3 to 5) measure the emitted blackbody temperature of the sea surface, cloud tops, or land/vegetation surfaces. For the sea surface only the upper few microns (0.001 meters) are responsible for the energy detected by the satellite. Wave action (foam production, etc.), and salinity affect the emissivity and the emitted energy of the sea surface. Thus, the skin temperature measurement inferred from the thermal channels is difficult to compare to sea surface temperature (SST) measured in situ, generally between 1 and 5 meters below the surface.

What is important about the thermal imagery (we will discuss the Channel 4 imagery in this section) are the gradients that can be observed. Absolute temperatures cannot be assigned to the pixel values but the gradients are important and measurable. These gradients tell the user the location of and mixing patterns between the cool and warm waters. The location of upwelled (cool) waters has direct application to fisheries due to increased nutrients in the upper water column for phytoplankton production. The absence of upwelling when it is expected is also important and can be observed using the thermal channel data.

Three sets of two images will be discussed. Each set consists of an unenhanced AVHRR image and an enhanced version utilizing a land/cloud mask, median filtering, and piece-wise linear stretching of the data presented in the unenhanced image (Chapters 4, 5, and 6). Data from AVHRR channels 1,2, and 4 will be presented. Channel 4 will be used as representing all the AVHRR thermal channel data. But, note that Channel 3 has had a noise problem prior to September 1982 and periodically since then on the NOAA-6 and NOAA-7 satellites.

IMAGE # 20: This image is an unenhanced HRPT/LAC AVHRR channel 1 Type 1c image (least significant 8-bits of data utilized) for April 12, 1982.

IMAGE # 21: This is an final enhanced version of Image # 20 utilizing a land/cloud mask, piece-wise linear stretching of the water pixels, and a 3 by 3 kernel median filter. The same surface water features are seen in this image as in Image # 20, but stretching the data values allows easier identification of ocean and coastal water features. Structures at the mouth of the Chesapeake and Delaware Bays, now apparent, may be sediment plumes. Probable sediment plumes are also visible at Cape Hatteras and the inlets on the barrier islands along the entire East coast. The waters at the head of the Chesapeake Bay have had their pixel values adjusted so that they appear white, signifying highly turbid waters. The brighter water pixels in the upper righthand portion of the image now seem to extend along the entire eastern side of the image. This brightening of the water pixels is assumed to be the result of atmospheric contamination of the RCDV for channel 1. No further interpretation of features seen in this area should be attempted.

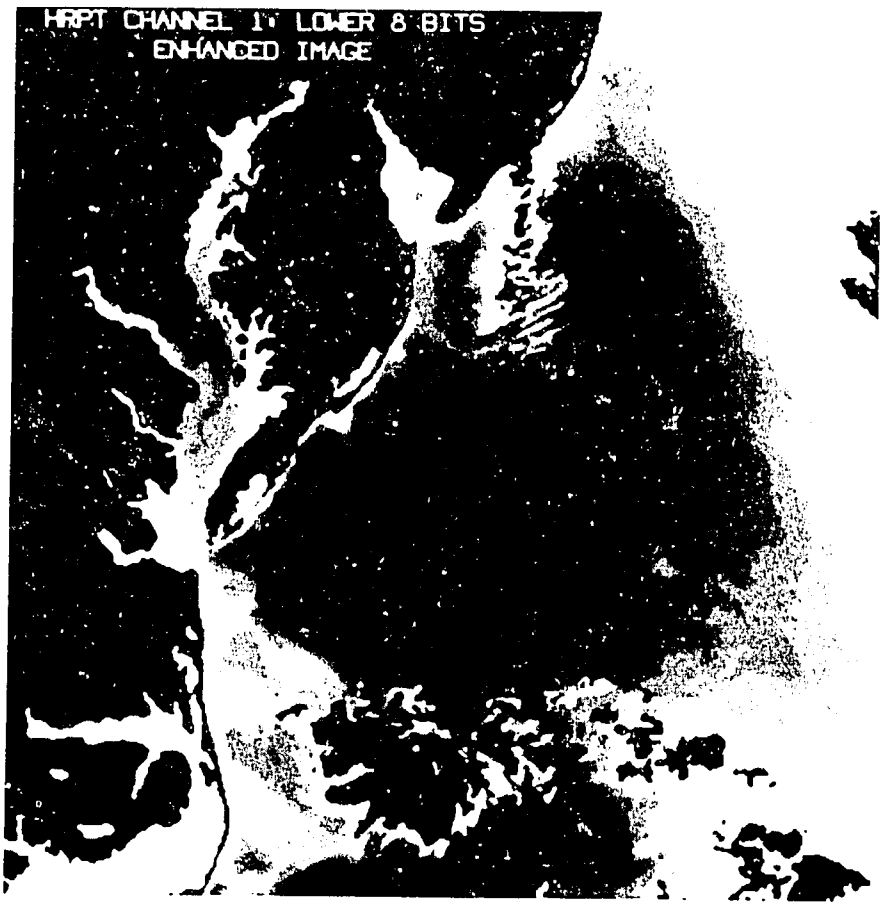
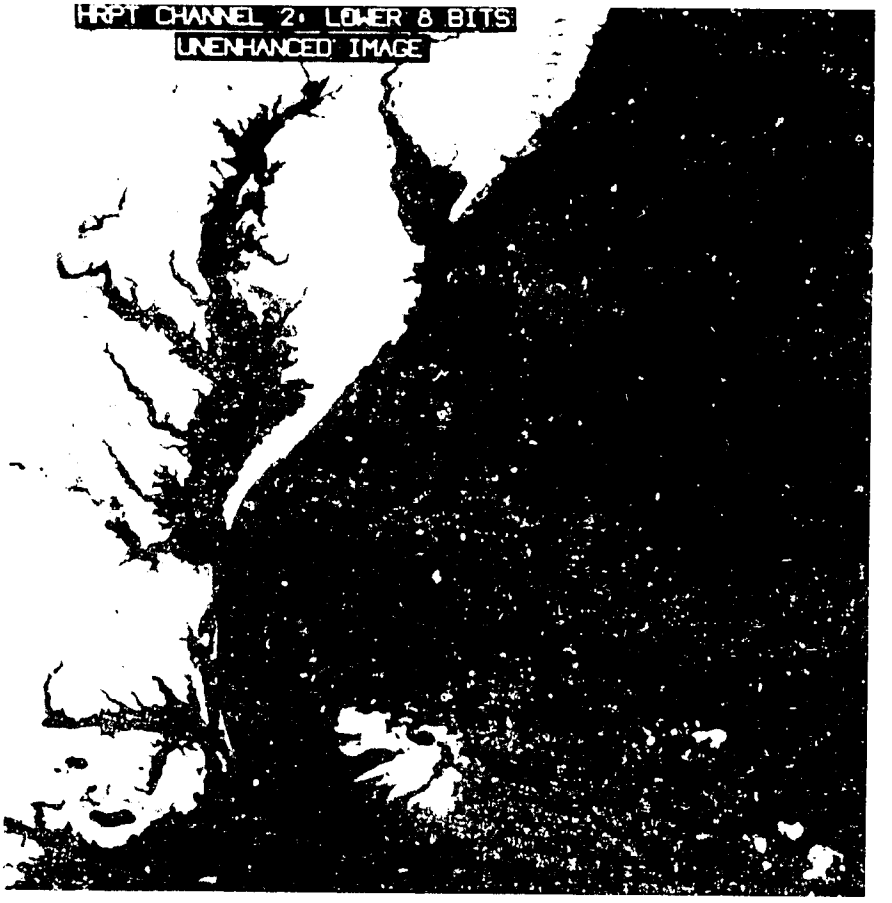

HRPT CHANNEL 1: LOWER 8 BITS
ENHANCED IMAGE

IMAGE # 22: This is an unenhanced HRPT/LAC AVHRR channel 2 near-IR Type 1c image for the Mid-Atlantic Bight for April 12, 1982.

IMAGE # 23: This is an enhanced version of Image 22 utilizing a land/cloud mask, piece-wise linear stretching of the display data, and a 3 by 3 kernel median filter. The same sort of atmospheric contamination of the eastern portion of the image is present in this channel 2 image as in the channel 1 (Image # 21). Thus any attempt to interpret features present in those areas should be done with caution. Relatively large sediment plumes are more apparent in the upper Chesapeake Bay, around the fringes of Delaware Bay especially on the northeastern (New Jersey) shoreline area, and in the North Carolina sounds. The presence of these brighter plumes in the near-IR data in the same general areas as plumes in the channel 1 visible channel imagery (Image # 21) aids in the determination of the location of those turbid waters which can be considered to contain more suspended materials than other bright areas noted in the channel 1 imagery. (Since the near-IR wavelengths of sunlight are strongly absorbed in water, any relatively large return signal from water requires many scatterers in the upper layers of the water column. Thus, if there are bright features observed in both channel 1 and 2 those brighter features in the channel 2 imagery possibly contain more scatterers than those not-so-bright features in the channel 2 imagery.) Turbidity fronts at the mouth of the bays (different gray scale water masses) delineating the exchange of waters between the bays and the shelf are easily seen in this image as well as the channel 1 imagery (Image # 21). The sediment plumes observed in the channel 1 imagery (Image # 21) at the inlets on the barrier islands are not seen in this image. This is probably due to the reduced number of scatterers in these plumes compared to those at the head of the Chesapeake Bay and around the edges the Delaware Bay and the North Carolina sounds. Thus, these waters are not as turbid as those plumes which are observed in both the channel 1 and 2 imagery. Many of the same features are observed in this image as in the channel 1 image (Image # 21, but a close comparison does show distinct differences which need to be investigated before explanations can be made.

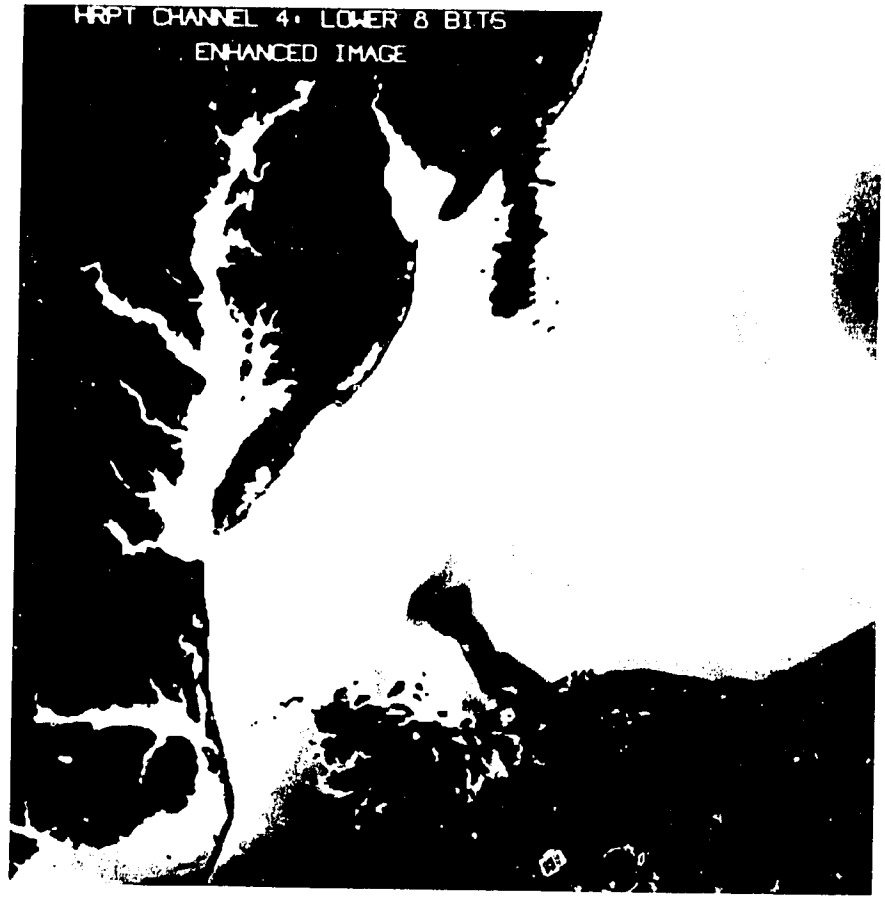

HRPT CHANNEL 2, LOWER 8 BITS
UNENHANCED IMAGE

HRPT CHANNEL 2, LOWER 8 BITS
ENHANCED IMAGE

IMAGE # 24: This is an unenhanced image of the channel 4, 10.5 - 11.3 micron band, AVHRR HRPT/LAC data collected concurrently with the previous channel 1 and 2 imagery presented in Images # 21-23. Only the least significant 8-bits (Type 1a) of the 10-bits of data were used in producing this image.

IMAGE # 25: This is an enhanced version of Image # 24. Note that all the same basic features are observed as in Image # 24, but with the enhancement of the pixel values, differentiation between the temperature fields were not greatly improved. This resulted because the displayed water pixel values of Image # 24 extended over almost the entire 0 - 255 (possible) range of display values. Thus, when the land/cloud mask was overlayed on Image # 24 the piece-wise stretching of the water data had minimal impact on the observed thermal field. This is an example where the color enhancement of an image, or limiting the enhancement to specific water features or geographic areas, would probably result in an image with more visual contrast making the interpretation and analysis of the imagery easier.

HRPT CHANNEL 4: LOWER 8 BITS


HRPT CHANNEL 4: LOWER 8 BITS
ENHANCED IMAGE

9. Multi-Channel Sea Surface Temperature (MCSST) Fields

The calcuation of sea surface temperature (SST) fields from remotely sensed data in the emitted thermal bands has been routinely performed from aircraft and satellites. The thermal bands (channels 3, 4, and 5) of the NOAA-n polar orbiting satellites are used by NESDIS to generate a variety of SST products, none on a pixel by pixel basis.

The MCSST algorithms are satellite, time of day (day or night time), and the channels selected specific (McClain, 1981; Strong and McClain 1984). The algorithms were developed by regressing observed in situ SST values with the nearest AVHRR thermal channel data. Thus, the atmospheric effects of absorption and scattering are accounted for by these equations. The basic steps involved in the MCSST procedures are to first calculate the pixels' blackbody temperatures in the desired thermal channels and then use these values as input to the required (desired) algorithm. The expected accuracy of MEAD MCSST procedures is approximately $\pm 1^{o}C$.

MEAD applies the MCSST algorithms to AVHRR LAC/HRPT and GAC Level 1B tapes pixel by pixel to produce images of the SST field which has been designated MCSST imagery. These high-resolution limited-area products are designed to complement those products already available from NESDIS.

In the interpretation of MCSST imagery a 8-bit display of the RCDV of the channel 4 data can be extremely useful. The MCSST algorithms produce a smoother (filtered) image which means some of the thermal features which can be observed in the channel 4 imagery are not neccesarily observed in the MCSST imagery. Thus, both types of imagery complement one another and should be available during the analysis and interpretation phase of any SST project.

An objective rating of the thermal gradients can be made by noting the number of different contour intervals over a given distance (number of pixels in either the horizontal or vertical direction). The more contour intervals crossed in a given distance then would be rated as a more intense gradient than one with fewer contours crossed for the same distance.

IMAGE # 26: Unenhanced Multi-Channel Sea Surface Temperture (MCSST) image of HRPT/LAC AVHRR data for April 12, 1982. Warmer water temperatures are in shades of black and grays while colder waters are shades of white. A black 0 brightness value is assigned 45°C while white is -19° C, brightness value of 255. Clouds generally are colder than water so they appear in shades of white. The Gulf Stream is located as the warm (darker) area in the lower portion of the image. Two anti-cyclonic warm core eddies as well as a cyclonic eddy are observed to the north of the Gulf Stream. The Chesapeake and Delaware Bays and shelf water appear as cold compared to the Gulf Stream. Slope waters are intermediate temperature waters separating the shelf waters and the Gulf Stream. Colder (brighter pixels) waters are entering the image from the north and warming as they travel southward along the coast. Shelf and slope waters appear to be constricted by land at Cape Hatteras and the Gulf Stream. The gradients in the slope waters stand out better in this unenhanced image than those on the shelf or the Gulf Stream.

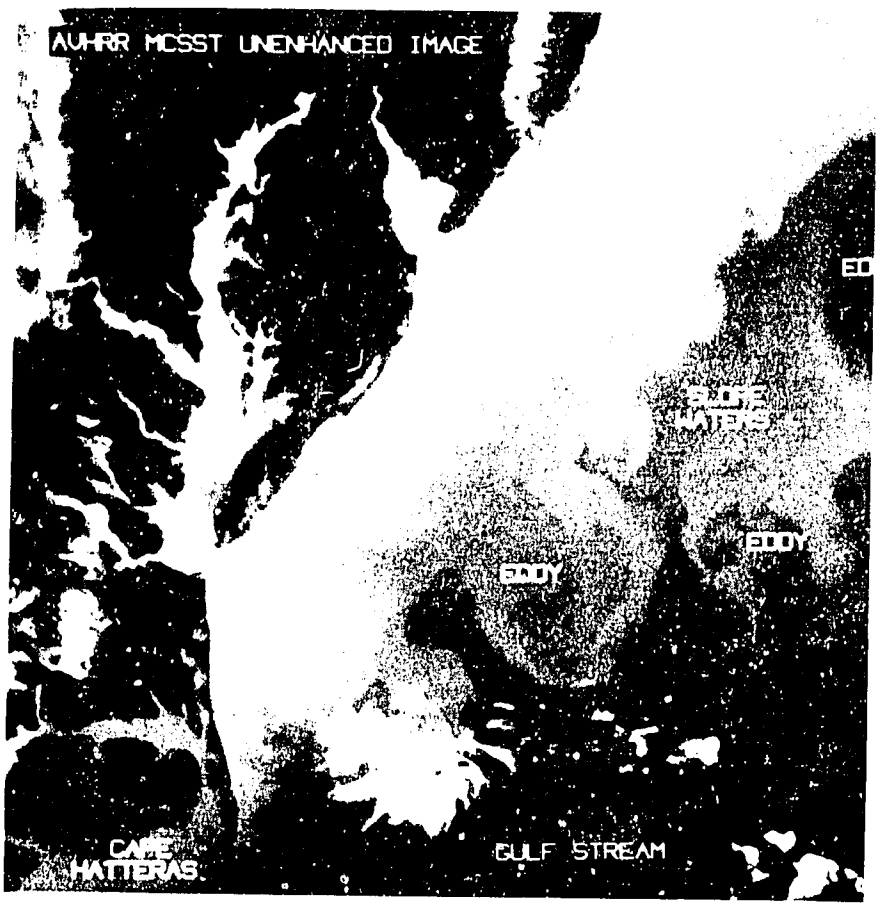
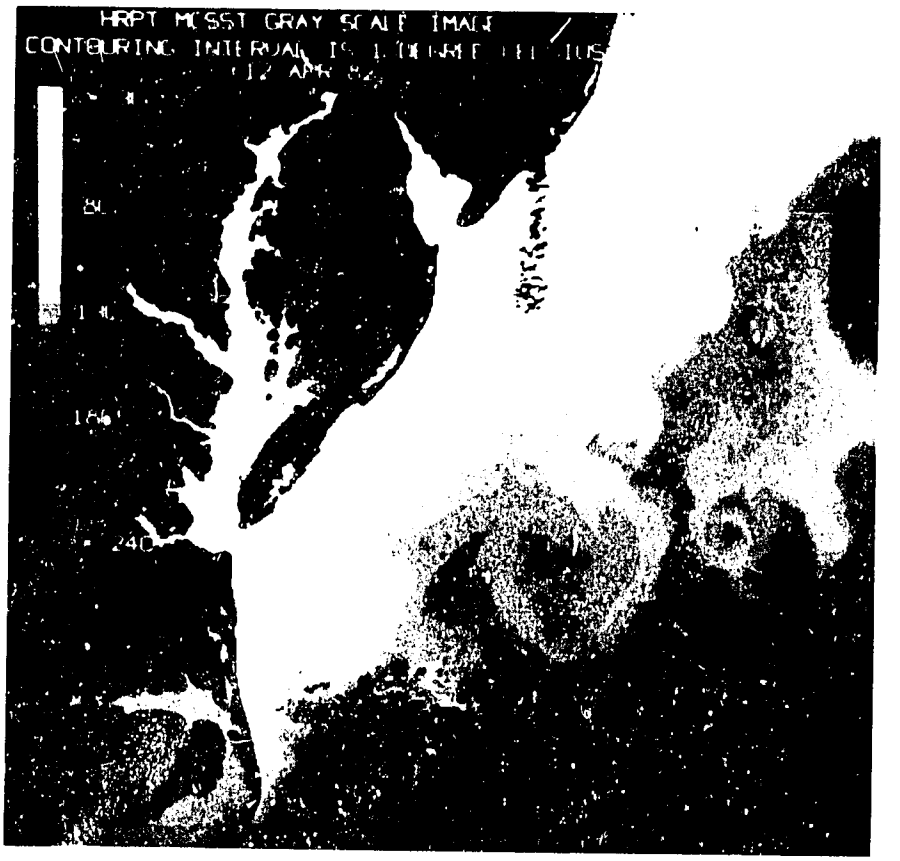


IMAGE # 27: Enhanced gray scale, 1° C contour interval, version of Image # 26. The structure of the temperature field is more easily delineated than in the unenhanced image especially on the outer shelf and within the estuaries. The large number of contour intervals, 21 in this image, makes the gray scale separation of the contour intervals difficult to interpret. To increase the ease in interpreting this image the user should either concentrate on subsets of the image by chosing distinct water masses (e.g., the estuaries, shelf, slope, or Gulf Stream) or utilize color to increase the separation of the different classes. If there are more than 8 to 10 different classes in an image then the user should consider grouping several classes together, thus making fewer classes requiring display. The thermal gradients are easily seen where shelf and slope waters mix (shelf/slope front), within the Gulf Stream proper, within the Chesapeake Bay and the North Carolina sounds, and to the north of Cape Hatteras where the shelf waters are mixed into the slope waters within a very restricted area. The exchange of waters between the Chesapeake Bay and the shelf can be observed as distinctive thermal fronts. A smoke plume near the mouth of Chesapeake Bay can also be observed as a cold narrow cloud. When a land/cloud mask is overlayed onto this image, those cloud pixels not classified as clouds become easily discerned by their whiter (colder) appearance compared to water and land.

IMAGE # 28: This is a color contoured version of the gray scale Image # 27. Note the easy differentiation between the water temperatures. The thermal gradients stand out and attract the attention of the interpreter. The intense mixing of the shelf, slope, and Gulf Stream waters to the north of Cape Hatteras is easily seen in the colors of blue through yellow to the red of the Gulf Stream. The complex structures within the bays and sounds are easier to see and aid the interpretation of the physical processes controlling the temperatures.


HRPT MCSST GRAY SCALE IMAGE
CONTOURING INTERVAL IS 1 DEGREE CELSIUS
12 APR 82
8C
12C
18C
24C

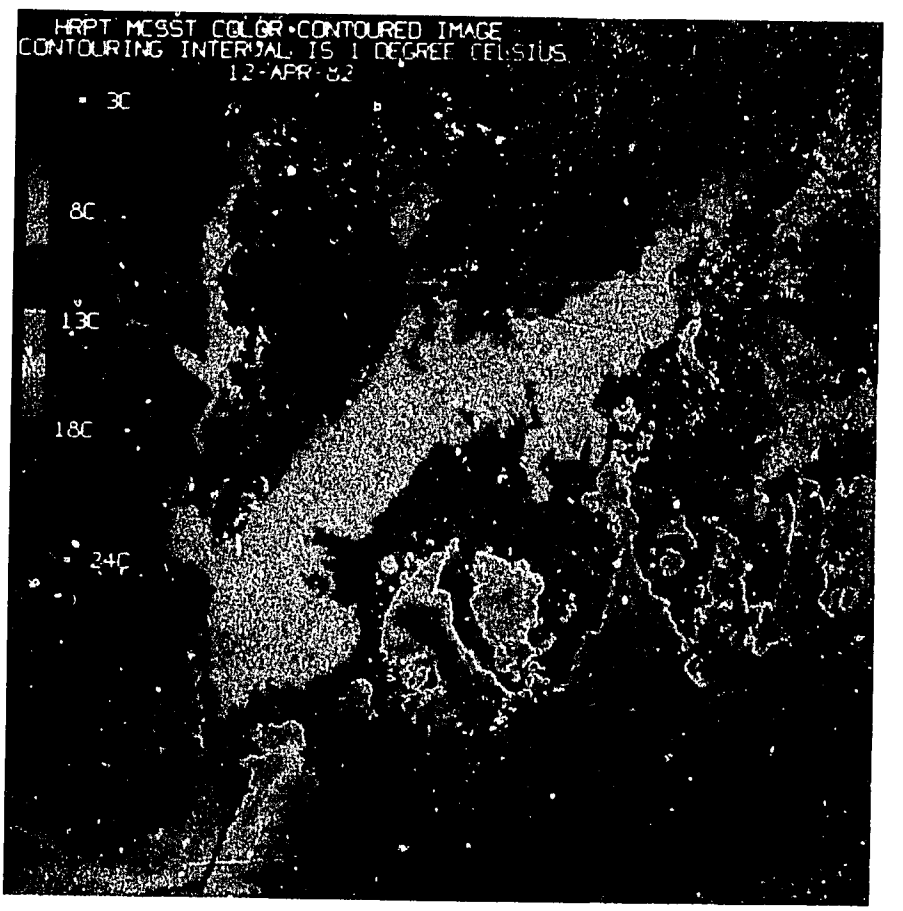

HRPT MCSST COLOR-CONTOURED IMAGE
CONTOURING INTERVAL IS 1 DEGREE CELSIUS
12-APR-82
3C
8C
13C
18C
24C

Figure # 7: This is a base map of the Philippine Islands to aid in locating water temperature features discussed in Image # 29.

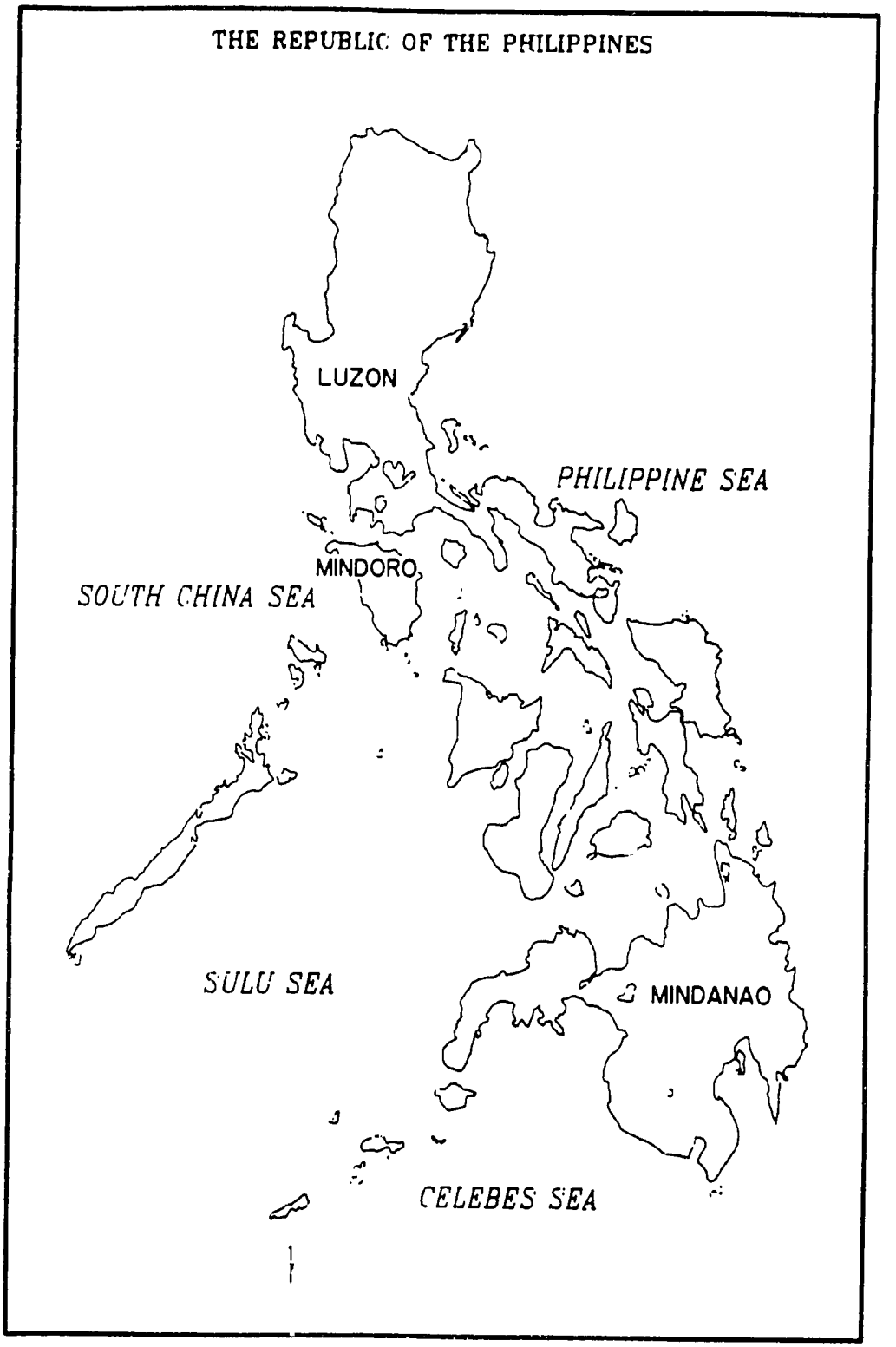
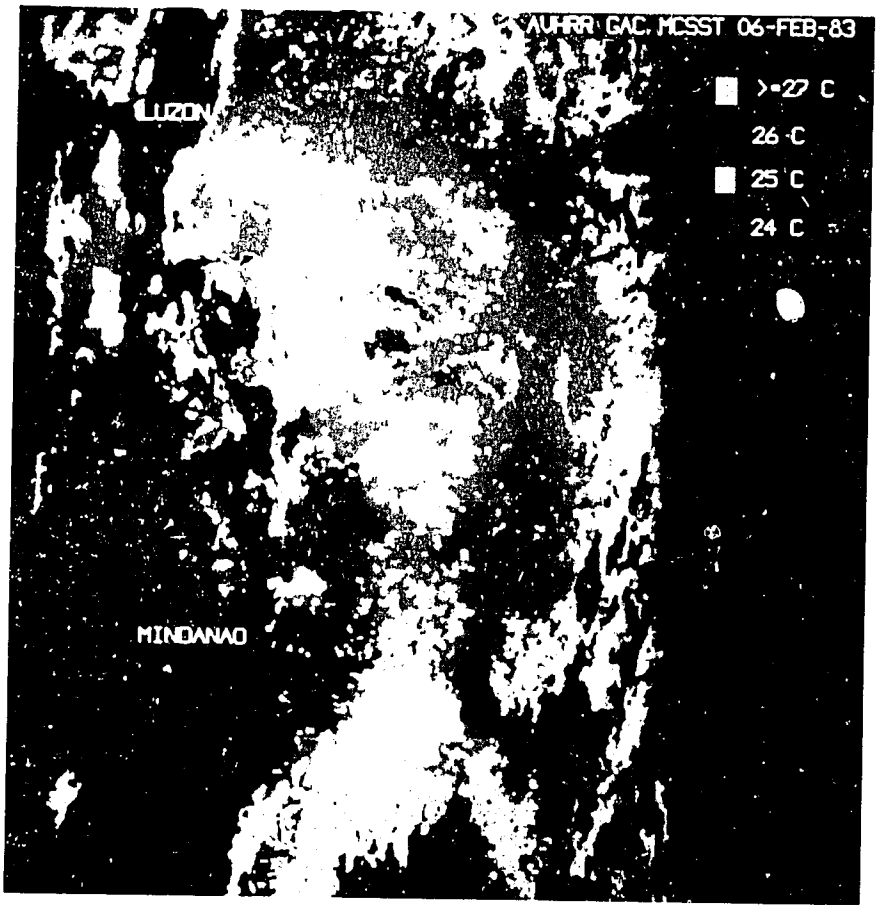


IMAGE # 29: This is a color contoured MCSST image of AVHRR GAC data for the Philippine Islands for February 6, 1983. Note, since this is AVHRR GAC data there is extensive geometric distortion (vertical stretching) of the land masses as well as the cloud and temperature fields. (See Figure # 7). The first and last 40 to 60 pixels of this image should not be used in any analysis and interpretation. The majority of the first 40 to 60 pixels in this image were classified as land or clouds by the land/cloud mask procedures. The last 40 to 60 pixels and some of the colored pixels on the left side of the image are classified as relatively cold 23°C and colder water pixels for this image. These relatively cold pixels result from the large scan angles of the AVHRR thermal channels being contaminated by the large volume of intervening atmosphere. Thus, the temperature values associated with these pixels are not to be assumed correct and thus not used in any analysis. Two pools of 25°C waters can be observed embedded in the large 26°C water mass to the east (right) of the island of Luzon (the northernmost land mass in this image). Several pools of 27°C and warmer waters are noted to the east and west of the island of Luzon. A large pool of 27°C and warmer and 26°C waters are noted to the west of the island of Mindoro (just south of Luzon). This pool of warmer water and the one to the west of Luzon are in the area of sun glint. The AVHRR data for this image were collected at local afternoon which will place the sun in the western portion of the image. If one examines the channel 2 image which went into the generation of the land/cloud mask this western portion of the image was brighter than the eastern portion. If the waters in these warmer pools are calm then solar heating will raise the surface temperatures above those waters which are roughened by wind and wave action. What is causing these waters to be calm and then result in increased solar heating is not known but is being investigated. Pixels not classified as clouds have formed halos around several linear cloud formations to the east of Luzon. These misclassified pixels are cold and appear in the dark blue colors.


AVHRR GAC MCSST 06-FEB-83
>=27 C
26 C
25 C
24 C
LUZON
MINDANAO

10. Ice Delineation

The delineation of ice within estuaries using the HRPT/LAC AVHRR data can be performed using the visible channel 1 data. The imagery of the least significant 8-bits or the percent reflectance of channel 1 will delineate snow and ice cover due to their higher raw count data values (RCDV) compared to water or bare land due to the highly reflective surface of the snow and ice.

Overlaying a winter snow and ice image of channel 1 with a land mask for the same area allows the delineation of ice within an estuary. Water areas free of ice will appear dark, i.e., they have small RCDV, as is normally observed for water, while areas of snow and ice cover will be bright.

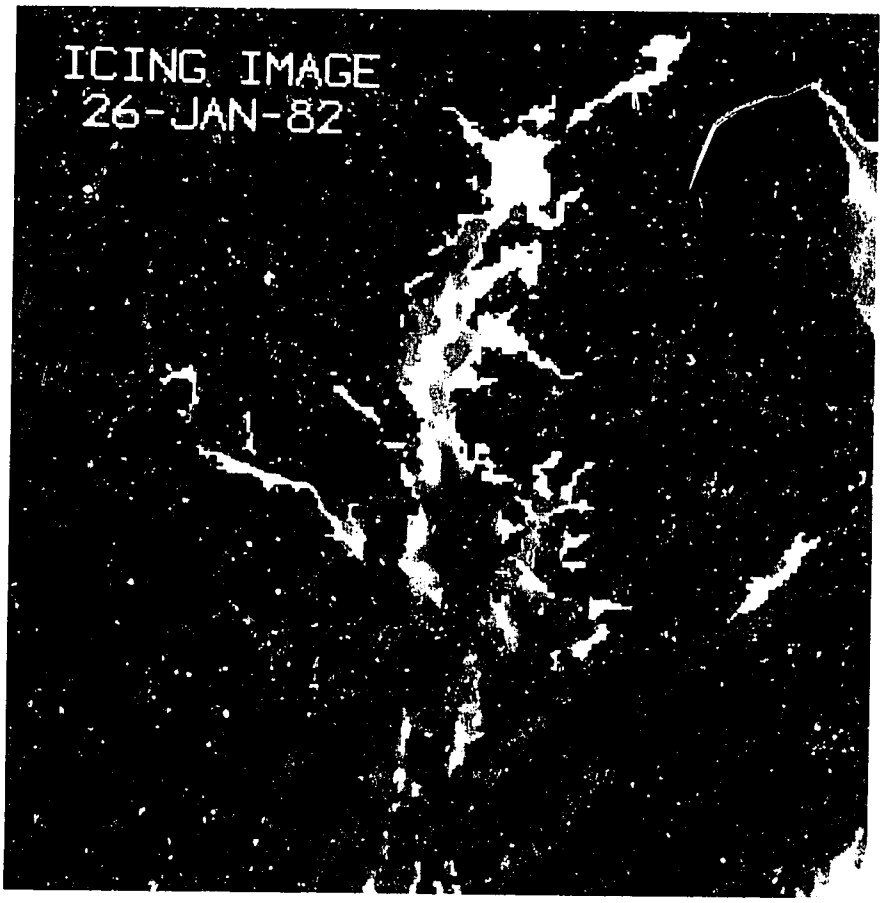
IMAGE # 30: An unenhanced HRPT channel 1 least significant 8-bits image of the Mid-Atlantic Bight for January 26, 1982. The separation of snow and ice cover on water and that on land is difficult or cannot be made without prior knowledge the geography of the area so as to assign pixels which are located on land and those over water.

IMAGE # 31: Enhanced version of Image # 30, overlayed with a land mask generated from an April 1982 image. Six ground control points (GCP) were used to geometrically correct the April image to overlay the January image. Ice in the estuaries and coastal waterways is apparent as very bright areas. The hazy white/gray areas in the water may be areas of broken ice or slush.

HRPT CHANNEL 1, LOWER 8 BITS
26 JAN 82

ICING IMAGE
26 JAN 82

IMAGE # 32: Twofold enlargement of Image # 31 of the Chesapeake Bay. This enlargement of the image allows for easier interpretation of the features in the imagery. The circular hole in the ice near the head of the Bay appears to be several pixels (1 pixel = 0.8 km. square) in size. The location and checking of RCDV of a dark band across the head of the Bay confirms that this is an opening in the ice and is appearently clear water.



11. False Color AVHRR Images

Color Infrared (IR) film is a useful tool in assessing the condition of vegetation and performing land use classification. The charateristics of the color IR film are such that the red film pigment is sensitive to the near-IR portion of the spectrum, the green is sensitive to the red, and the blue is sensitive to the green portion of the spectrum. This type of imagery is extensively used in determining the health of and vegetation types in forests, crop lands, and marshes (salt or fresh water).

A similiar type of color IR product can be generated using the AVHRR channel 1 and 2 digital data where:

Channel 1 0.58 - 0.68 microns is assigned to the blue and green
Channel 2 0.725 - 1.1 microns is assigned to the red

This imagery is useful for examining the drainage basins and coastal wetlands, which are the nursery grounds for many species of fish and crustaceans.

Image 33: An HRPT/LAC AVHRR false color image of the Mid-Atlantic Bight for April 12, 1982. Forested areas are dark red and the remainder of the land is in shades of red representing less dense vegetation. High clouds are white (bright). Water is dark (black). The thin clouds covering the lefthand, western, portion of the image make the water light blue in color and the vegetation a whiter (less saturated) shade of red. Work by the United States Geological Survey at the EROS Data Center is continuing on the generation of false color IR images from the AVHRR sensor which better represents the LANDSAT MSS false color IR images than that presented here.

12. References

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