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APPLICATION OF NOAA SATELLITE DATA FOR CROP ASSESSMENT IN THAILAND

A Training Report on Satellite Assessment Methods

by

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PREFACE

The work described in this report represents the training activities of Mr. Somwang Martchaipoom, Mr. Supan Karnchanasutham, and Mr. Supak Wongporn of the Thailand Meteorological Department, Office of Agricultural Economics, and National Research Council, respectively during the period May 13 through June 21, 1985. The training program was designed to familiarize participants with data from the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA Polar-Orbiting Satellites and to provide insight on the application of this data to operational agroclimatic assessment techniques in Thailand. This report documents procedures used in training and includes findings and suggestions as reference for future work.

The enthusiasm, dedication and professionalism which Mr. Somwang Martchaipoom, Mr. Supan Karnchanasutham, and Mr. Supak Wongparn applied to this training effort was stimulating and presented a challenge to the many staff members with whom they worked. Their training was conducted by staff of the Climate Impact Assessment Division, Assessment and Information Services Center (AISC) in Washington, D.C. and Columbia, Missouri with assistance from staff of the Cooperative Institute of Applied Meteorology at the University of Missouri. AISC is part of the National Environmental Satellite, Data, and Information Service (NESDIS), NOAA. The training was partially supported by funds from the U.S. Agency for International Development, Office of Foreign Disaster Assistance.

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EXECUTIVE SUMMARY

This training program concentrated on the use of potential tools for assessing crop conditions in Thailand. Two potential tools were emphasized: (1) Meteorological satellite (NOAA-7, NOAA-9) AVHRR data to evaluate land use and crop condition using the Ambroziak Color Coordinate System and (2) Agroclimatic indices to detect large area anomolous conditions.

From the analysis conducted, it is concluded that:

(1) The vegetation index and color coordinate system from the AVHRR data of the meteorological satellites is a promising tool that can supplement hard copy images from these satellites. This satellite system provides large area daily coverage as opposed to the 16 to 18 day recurring coverage for Landsat. The data from AVHRR must be used in conjunction with other elements such as precipitation, sea surface temperature and land use maps. Efforts should be made to integrate satellite data into operational agricultural assessment in Thailand.

(2) Because of a lack of data, a time series was not made. Only three areas from October 23, and December 4, 1984 were selected: the Central, Northern and Northeastern parts of Thailand were chosen for the pilot study.

(3) Numerous potential applications for this data have been identified,. in particular, the Meteorology, Fisheries, Agriculture, and Irrigation Departments.

(4) There is a need to follow the AVHRR data on a daily basis, field check the interpretation results, and integrate the results in a cooperative way with the agroclimatic assessment team in Thailand.

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The training program was coordinated by Dr. Gary E. Johnson, Remote Sensing Scientist, NOAA. He conducted various lectures on vegetation assessment and remote sensing and shared his experience with the authors. His guidance and suggestions during the course of training are sincerely appreciated.

Mr. Russell Ambroziak, Chief of the Climate Impact Assessment Division, lectured on principles of color science and greatly facilitated understanding of the image interpretation process. Dr. Clarence Sakamoto, Chief of the Models Branch, lectured on the operational agroclimatic assessment program and the need for integration of satellite data into this process.

The authors also wish to thank staff members of AISC/NOAA, the Models Branch, and UMC for their valuable guidance and support. These staff members include:

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1. Introduction

The National Oceanic and Atmospheric Administration (NOAA), working with the U.S. Agency for International Development's Office of Foreign Disaster Assistance (USAID/OFDA), has designed and developed a drought early warning system for food crops in tropical regions. This system is based upon the detection of below normal rainfall during the growing season. Numerous sources of information are incorporated in the drought early warning assessment process. These include surface meteorological reports, satellite derived precipitation estimates, climatological records, crop calendar data, crop water requirements, news reports from impacted regions and countries, and, more recently, satellite agricultural assessments. It is NOAA's philosophy that no single source of data can be used as a "stand alone" tool for the assessment of drought early warning in the tropical regions under study. There is a need for agricultural assessment so that early planning and action can be initiated to stabilize agricultural commodity prices due to fluctuations in agricultural production and to cushion the consequences of acute food shortage due to drought, flood, pests and diseases.

The training program, of which this report is a portion, has been designed to acquaint scientific personnel from Thailand and Malaysia with the satellite agricultural assessments operationally conducted by the Models Branch of NOAA in Columbia, Missouri and Washington, D.C. The goal is to transfer the technology of satellite agricultural assessment to the countries involved. Satellite agricultural assessment is not a "stand alone" technique, but it is a valuable addition to the operational agroclimatic assessment processes ongoing in Thailand and Malaysia.

Remote sensing has long been viewed as a useful tool for providing valuable information concerning agriculture. Currently, Landsat imagery is frequently used for agricultural assessment. Scientists have only recently successfully extended the application of NOAA Polar Orbiting Satellite data to agriculture. The combination of visible and near infrared data from the NOAA Satellite has revealed valuable information regarding the growing condition of crops. The AVHRR data are used in two forms in the assessment procedure: color enhanced multispectral images and time series plots of the satellite vegetation index. NOAA organized this six-week training course to transfer the technology of these latest developments to Malaysia and Thailand.

This training emphasizes development of the AVHRR image enhancement technique and interpretation of the imagery. Training set examples developed during the training are included in this report. The training program was conducted in the Assessment and Information Services Centers' (AISC), Climatic Impact Assessment Division (CIAD) in Washington, D.C. and the CIAD Models Branch in Columbia, Missouri. Data for analysis were acquired from the NOAA-7 and NOAA-9 satellites at the Bangkok, Thailand receiving station. This High Resolution Picture Transmission (HRPT) data was provided to NOAA for analysis in both Washington, D.C. and Columbia, Missouri. The six week training program began in Washington, D.C. on May 13, 1985. The first week was conducted in Washington, the ensuing four and one-half weeks at the Models Branch in Columbia, Missouri. The training was completed in Washington on June 21, 1985.

2. NOAA Polar Orbiting Satellites

2.1. Characteristics

The NOAA polar orbiting satellites were primarily designed for meteorological prediction and warning, oceanographic and hydrologic services, and space environment monitoring and prediction. The program started in 1960 with launching of the experimental TIROS 1 satellite.

NOAA's goal is to maintain two operational spacecraft in orbit. Currently (June 1985) NOAA-8 is a descending (north to south) satellite, which passes the equator at 7:30 a.m. local sun time at nadir. NOAA-9, an ascending (south to north) satellite, passes the equator in the afternoon at about 2:30 p.m. local sun time at nadir. (See Figures 1, 2 and 3.)

One of the primary instrument systems on-board the NOAA polar orbiting satellites is the advanced very high resolution radiometer (AVHRR). The AVHRR has sensors sensitive in four spectral regions for NOAA-8 and five spectral regions for NOAA-9 (see below and Figure 4):

Channel 1, 0.58 -0.68 μm (visible) daytime cloud, snow and ice mapping.

Channel 2, 0.725-1.10 μm (near infrared) surface water delineation, vegetation/ agriculture assessments.

Channel 3, 3.55 -3.93 μm (infrared) nighttime cloud mapping, sea surface temperature measurements, land/water distinctions, hot spot detection (forest fire, volcanic activity).

Channel 4, 10.3 -11.3 μm (thermal infrared) day/night cloud mapping, sea and land surface temperature measurement, soil moisture, volcanic eruptions.

Channel 5, 11.5 -12.5 μm (thermal infrared) sea surface temperature measurements, soil moisture.

Polar Orbiting Satellites

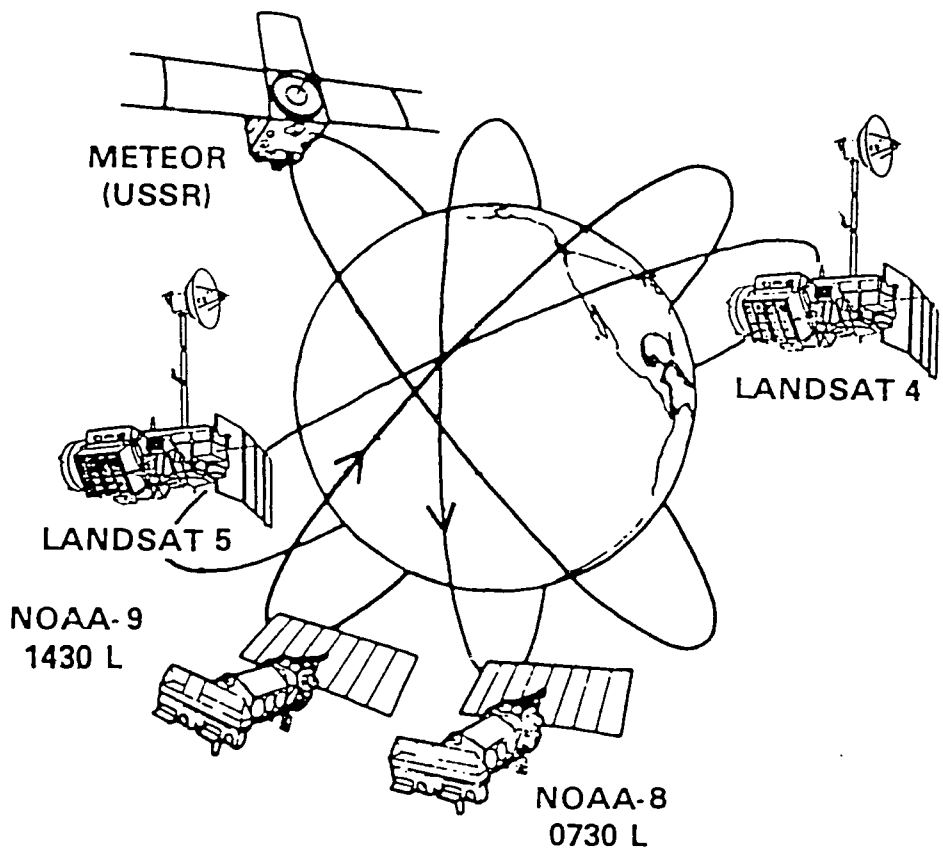


Figure 1

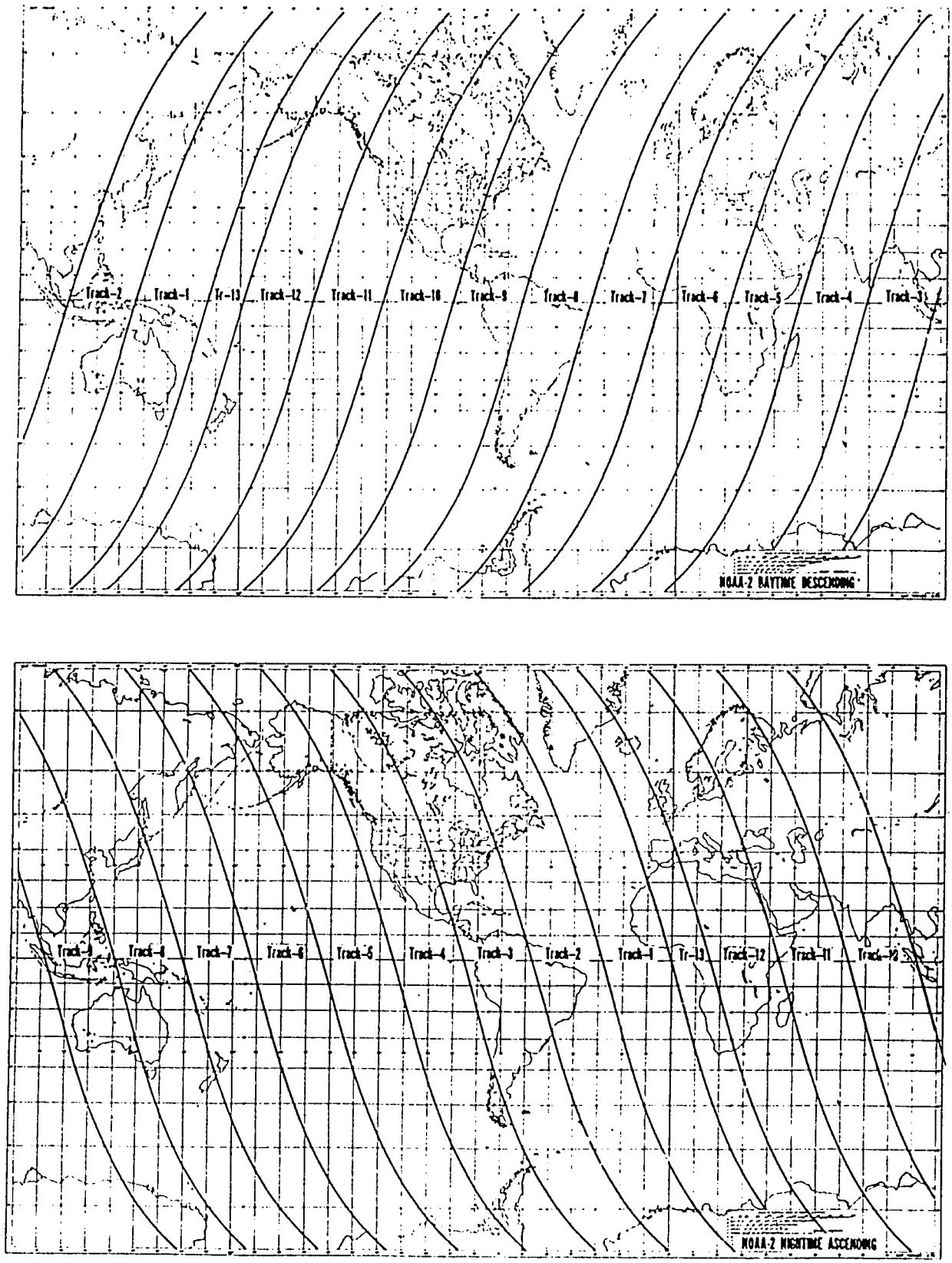

Track-2
Track-1
Tr-13
Track-12
Track-11
Track-10
Track-9
Track-8
Track-7
Track-6
Track-5
Track-4
Track-3
NOAA-2 DAYTIME DESCENDING
Track-9
Track-8
Track-7
Track-6
Track-5
Track-4
Track-3
Track-2
Track-1
Tr-13
Track-12
Track-11
Track-10
NOAA-2 NIGHTTIME ASCENDING

Figure 2

Structure of NOAA Polar Orbiting Satellites

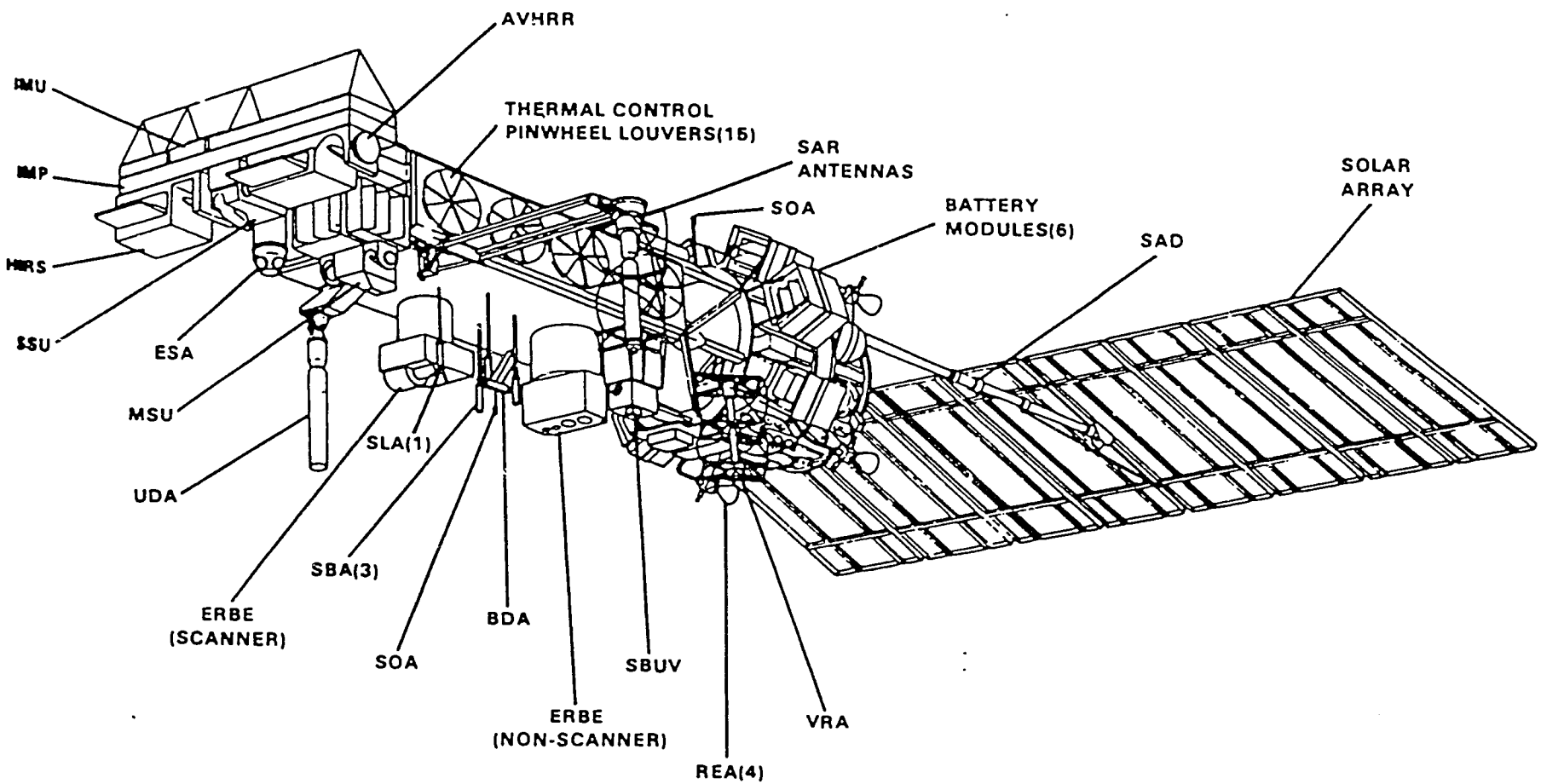
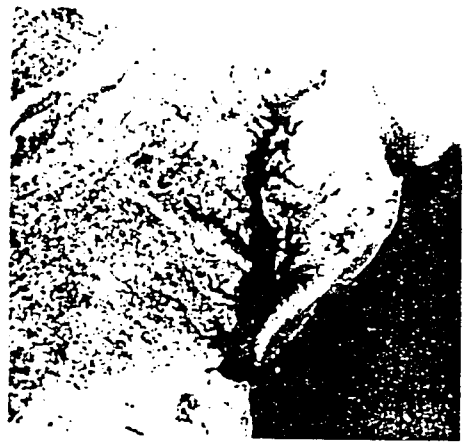


Figure 3

Channel 1 Visible

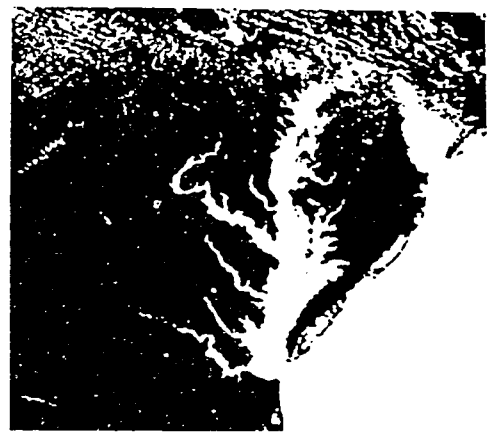
- Cloud Delineation
- Snow and Ice Monitoring
- Weather

Channel 2 Visible



- Location of Water Bodies
- Vegetation/Agriculture Assessments (In Combination With Channel 1)
- Range Surveys

Channel 3 IR



- Landmark Extraction
- Forest Fire Monitoring
- Volcanic Activity
- Sea Surface Temperature (Nighttime)

Channel 4 IR

- Sea Surface Temperature
- Weather
- Soil Moisture
- Volcanic Eruptions

Channel 5 IR

- Sea Surface Temperature
- Weather

Figure 4

2.2. Attributes

The spectral sensitivity of the AVHRR channel 1 is similar to the combined bands 5 and 6 of the Landsat Multispectral Scanner (MSS) and AVHRR channel 2 is similar to Landsat MSS Band 7. The spectral data of Landsat have been used extensively in vegetation studies. The advantages of the NOAA satellite data over the Landsat data for vegetation monitoring include: (1). it is near real-time (about one week after acquisition), (2), it is operational so that regular and continued coverage is assured, and (3), daily global coverage is provided.

3. AVHRR Instrument

The normal operating mode of the satellite calls for continuous direct transmission to earth of AVHRR data. These data, with an effective resolution of 1.1 km^2, are called High Resolution Picture Transmission (HRPT). Other AVHRR data are recorded on the satellite for later transmission. The recorded data is available in three modes, each with a different spatial resolution (see Figure 5):

1) Local Area Coverage (LAC): on-board recording of data from selected portions of each orbit of all spectral channels for central processing. The LAC pixel represents an area of 1.1 km^2.

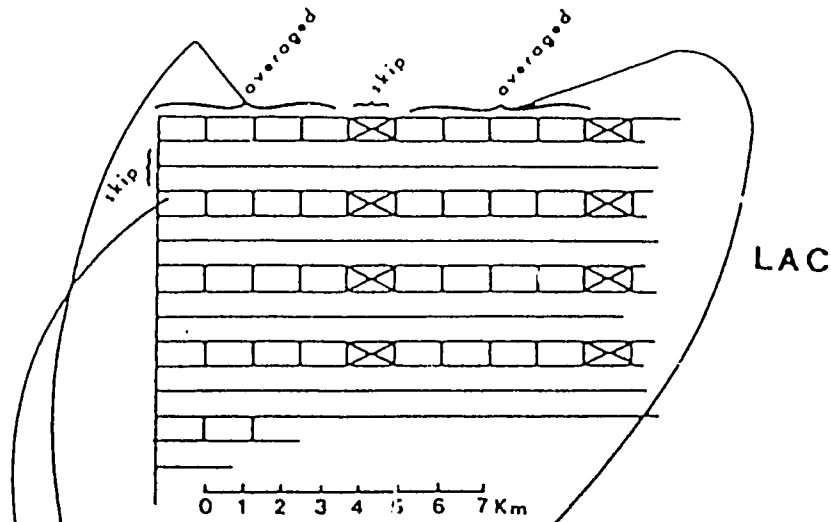
2) Global Area Coverage (GAC): global on-board recording of low resolution data from all spectral channels for readout by Command and Data Acquisition (CDA) stations. GAC data is generated from LAC data as follows. For every three scan lines of LAC data, the second and third scan lines are skipped. Scan lines to be processed are divided into groups of five pixels. The first four pixels of every group are averaged to make one GAC pixel, and the fifth pixel is dropped. One GAC pixel represents an area of about 16 km^2.

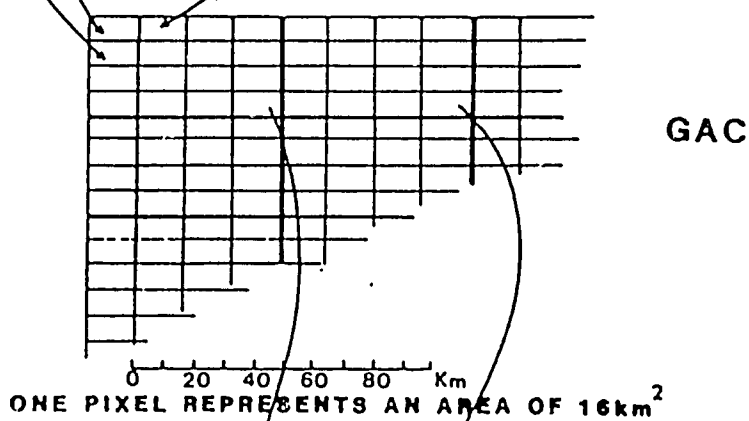
3) Polar Stereographic Data (PSG): generated from GAC data. The GAC pixels are mapped into a polar stereographic array, one for each hemisphere. Each GAC pixel is assigned to a specific PSG pixel. The PSG pixel is assigned the same spectral response as the last GAC pixel in a four by four grid on a given day. The sampled PSG pixel represents an area ranging from 225 km^2 at the equator to 900 km^2 at the poles. Since there are several passes each day and the scan lines overlap, a single day's PSG array consists of a mosaic of the daytime portion of 14 orbital passes.

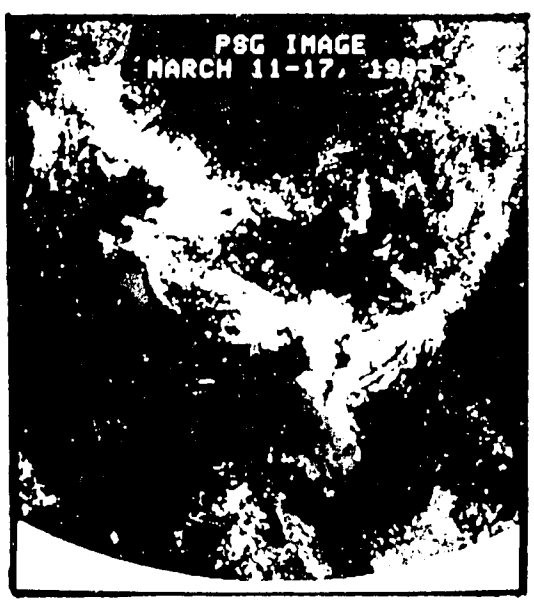
3.1. Data Format

In addition to the HRPT mode, about ten minutes of data may be selectively recorded on each of two recorders on-board the satellite for later playback. These recorded data are referred to as LAC (Local Area Coverage) data. LAC data may be recorded over any portion of the world as selected by NOAA/NESDIS and played back on the same orbit as recorded or during a subsequent orbit.

PSG DATA GENERATION







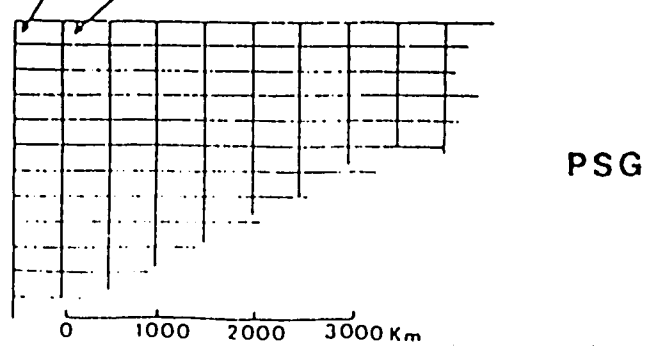


Figure 5

Full resolution data is processed on-board the satellite into GAC (Global Area Coverage) data which is recorded for transmission to CDA stations. GAC data contain only one out of three original AVHRR lines and the data volume and resolution are further reduced by averaging every four of five adjacent samples along the scan line.

The data set format for full data set copies (all channels) is different from the format for selective extract subsets (selected channels). Sections 3.1.1 and 3.2.2 contain formats for GAC full data set copies and GAC selective extract subsets, respectively. Sections 3.1.3 and 3.1.4 contain formats for LAC/HRPT full data copies and LAC/HRPT selective extract subsets, respectively.

3.1.1. Global Area Coverage (GAC) full data set copies

Each GAC data set contains an individual satellite recorder playback (or a portion of a playback if there is an interruption in the data due to noise, etc., in which case a single playback may be fragmented into a number of data sets). Data within each GAC data set are in chronological order with one logical record per scan. Two logical records are written per physical record. Each logical record contains 3,220 bytes written in binary in the following format:

Byte #	# Bytes	Content
1-2	2	Scan line number from 1 to 7
3-8	6	Time code (year, day, hour, minute, second)
9-12	4	Quality indicators
13-22	40	Calibration coefficients
53	1	Number of meaningful zenith angles and earth location points appended to scan
54-104	51	Solar zenith angles
105-308	204	Earth location
309-448	140	Telemetry (header)
449-3176	2728	GAC Video data
3177-3220	44	Spare

The time code includes the year, Julian day, and GMT time of day in milliseconds. The year is contained in the first seven bits of the first two bytes, the nine-bit day of year is right-justified in the first two bytes and the twenty-seven bit millisecond GMT time of day is right-justified in the last four bytes. All other bits are zero. The time code will always have the same format for all level 1 byte data sets and will not be repeated again.

The quality indicators are contained in four bytes. The first byte contains processing detected conditions and the last three bytes contain DACS quality indicators.

The calibration coefficients consist of slope and intercept values for each of the five channels. Each value is stored in four bytes.

A fixed number of zenith angles and earth location points are appended to each scan. However, only the first seven zenith angles and the first seven earth location points have meaningful values (n is defined in byte #53). The maximum number of points possible in a scan is fifty-one. There are 409 points in a GAC scan line. However, the solar zenith angles and earth location data (latitude, and longitude) are sampled every eight points starting at the fifth point (5, 13, 21, ..., 389, 397, 405). There are fifty-one possible solar zenith angles and earth location values for each scan line. Each zenith angle requires one byte and is scaled with seven integer bits and one fractional bit. The latitude and longitude values are each stored in two-byte fields in 128ths of a degree (East positive).

The telemetry data contain information which may be used to compute calibration coefficients when these are not included.

The GAC video data consist of five readings (one for each channel) for each of the 409 points in a scan. They are packed as three ten bit samples in four bytes, right-justified. The last four-byte group contains two ten bit samples with ten trailing zero bits. The first two bits of each four byte group are zero. The 2045 samples (409 points x 5 channels) are ordered scan point 1 (channel 1, 2, 3, 4 and 5), scan point 2 (channel 1, 2, 3, 4, and 5), etc. Note that for TIROS-N, NOAA-6, and NOAA-8 there is no sensor for the channel 5 position.

3.1.2. Global Area Coverage (GAC) selective extract subsets

The following section describes the data set format for GAC data sets which have been produced using channel selection. When channels are selected for GAC data, the format is identical to that described in section 3.1.1 except for the GAC video data. For the GAC video data, the selected channels (no more than two) are packed in consecutive half words (16 bits). The data values for each channel selected are contained in the ten least significant bits and the remaining six most significant bits are zero filled. If two channels are selected, the GAC video has the following format:

Point #	Byte #	Bit #	Content
1	449-450	1-6	Zero filled
		7-16	1st value, 1st selected channel
2	451-452	1-6	Zero filled
		7-16	1st value, 2nd selected channel
3	453-454	1-6	Zero filled
		7-16	2nd value, 1st selected channel
4	455-456	1-6	Zero filled
		7-16	2nd value, 2nd selected channel

GAC video format (continued)

•	•	•	•
•	•	•	•
•	•	•	•
409	2,083-2,084	1-6	Zero filled
		7-16	409th value, 2nd selected channel

The total record length for two channel selective GAC would be 4,168 bytes (2 x 2,084 since there are two scans/record) with no spare bytes trailing. Similarly, if one channel were selected the record would contain 820 bytes (409 points/scan +1 (to make a whole word) x 2 bytes/point) for the GAC video, which would make the entire record 2,536 bytes long (2 x 1,268).

3.1.3. Local Area Coverage/High Resolution Picture Transmission (LAC/HRPT) full data set copies

Each HRPT data set contains the HRPT data from one CDA contact. Each LAC data set contains an individual satellite recorder playback (10 minutes of recorded HRPT data). The data within each data set is in chronological order with one scan contained in two records. The two records are written in binary and contain 7,400 bytes in the following formats:

Record #	Byte #	# Bytes	Content
1	1-2	2	Scan line number
	3-8	6	Time code
	9-12	4	Quality indicator
	13-52	40	Calibration coefficients
	53	1	Number of meaningful zenith angles and earth location points appended to scan
	54-104	51	Solar zenith angles
	105-308	204	Earth location
	309-448	140	Telemetry (header)
	449-7,400	6952	LAC/HRPT video data
2	1-6,704	6704	LAC/HRPT video data
	6,705-7,400	696	Spare

The content and order of the LAC/HRPT records are identical to the GAC record described in section 3.1.1, with the exception of three fields. The three exceptions are the solar zenith angles, earth location, and LAC/HRPT video data. Also, note that the calibration coefficients are ordered channels 1, 2, 3, 4 and 5, the same as GAC data.

There are 2,048 points in a LAC/HRPT scan line. The solar zenith angle and earth location data (latitude and longitude) are sampled every 40 points starting at point 25 (25, 65, 105, ... 1,945, 1,985, 2,025). There are fifty-one possible zenith angles and an earth location value for each scan line. Each solar zenith angle requires one byte and is scaled with seven integer bits and one fractional bit. The latitude and longitude values will each be stored in two-byte fields in 128th of a degree (East positive).

The LAC/HRPT video data contains five values (one for each channel) for each of the 2,048 points in the scan (i.e., 2,048 points x 5 channels = 10,240 samples). Data are packed as three ten bit words in four bytes, right-justified. The last four-byte group contains one ten bit word with twenty trailing zero bits. The first two bits of each four-byte group are zero. The LAC/HRPT video data is ordered scan point 1 (channel 1, 2, 3, 4, and 5), scan point 2 (channel 1, 2, 3, 4, and 5), etc.

3.1.4. Local Area Coverage/High Resolution Picture Transmission (LAC/HRPT) selective extract subsets

When channels are selected for LAC/HRPT data, the format is identical to that described in section 3.1.3 except for the LAC/HRPT video data. For the LAC/HRPT video data, the selected channels (not more than two) are packed in consecutive halfwords (16 bits). The data

values for each channel selected are contained in the ten least significant bits and the remaining six most significant bits are zero filled. If one channel is selected, the LAC/HRPT video data have the following format:

Point #	Rec #	Byte #	Bit #	Content
1	1	449-450	1-6 7-16	Zero filled 1st value of selected channel
2	1	451-452	1-6 7-16	Zero filled 2nd value of selected channel
3	1	453-454	1-6 7-16	Zero filled 3rd value of selected channel
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
912	1	2,271-2,272	1-6 7-16	Zero filled 912th value of selected channel
913	2	2,271-2,272	1-6 7-16	Zero filled 913th value of selected channel
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
2,048	2	2,271-2,272	1-6 7-16	Zero filled 1048th value of selected channel

Note that all LAC/HRPT data set scans require two records regardless of the number of channels selected. For an example of two channel selection for LAC/HRPT data, use the GAC two-channel format in section 3.1.2 as a guide.

4. The Vegetation Index

4.1. Spectral Characteristics

The assessment of vegetation via multispectral remote sensing systems is based on the inherent reflectance characteristics of the vegetated surface itself and the differential reflectance detectable between the visible and the near, or reflective, infrared bands. Some typical reflectance curves for three categories of land cover are shown in Figure 6 in relation to the spectral bandwidth of multispectral sensors for three sensor systems.

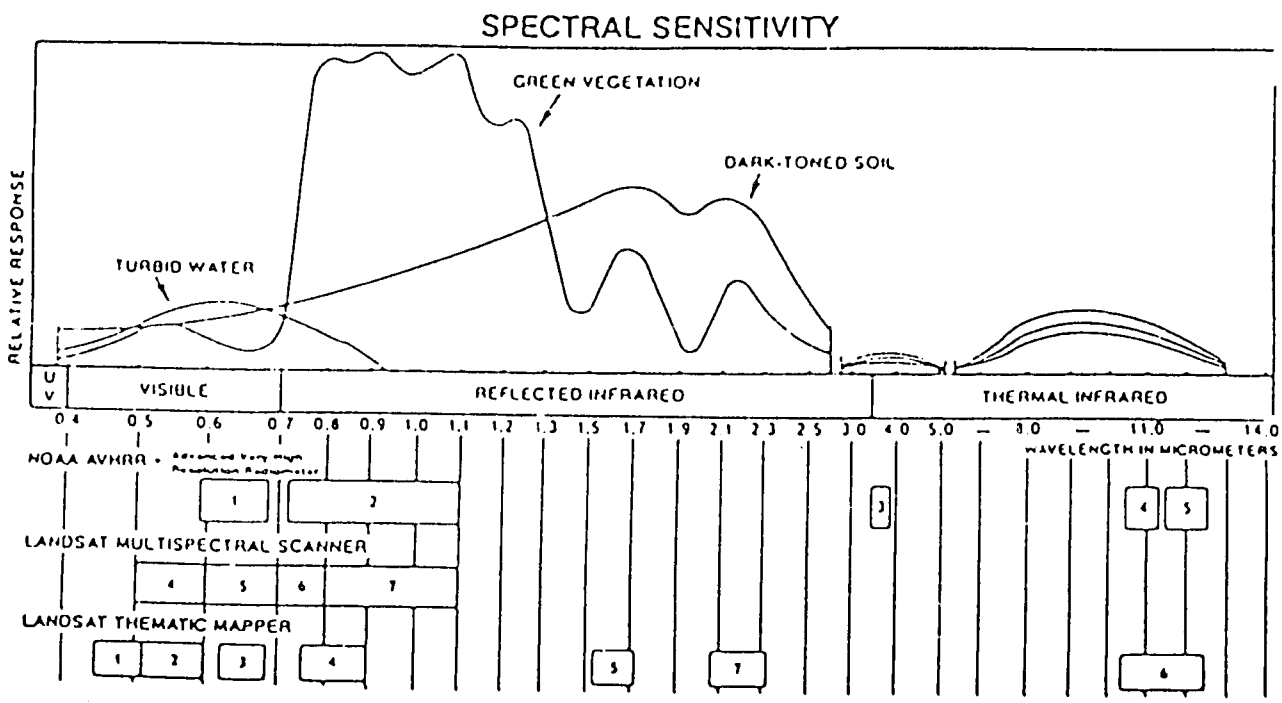


Figure 6. The spectral sensitivity of three typical land cover features as related to bands sensed by three multispectral systems.

The strong absorption of light by chlorophyll present in green leaves results in reflectance of less than 20% in the 0.5-0.7 m spectral interval corresponding to visible green and red. This reflectance increases sharply

to approximately 60% for green vegetation in the 0.7-1.3 μm spectral range of the reflected infrared (Hoffer and Johannsen, 1969). These multispectal reflectance characteristics have been used widely, especially with Landsat data, to classify land cover type, estimate crop acreage, and detect plant stress.

4.2. What is the vegetation index?

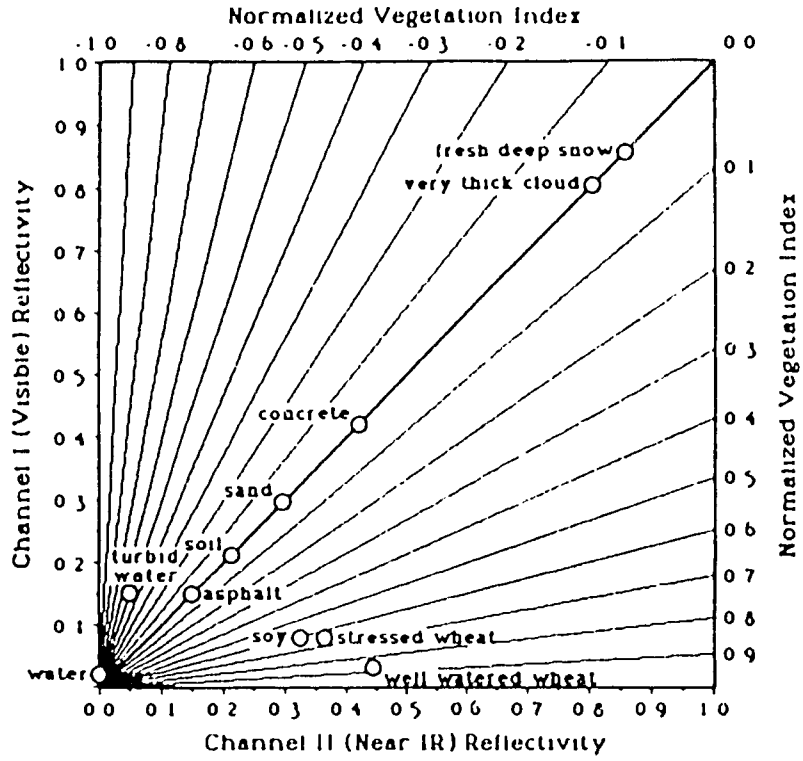
A vegetation index is a ratio or difference of the near IR and visible reflectances. Vegetation indices help to compensate for variations in the solar spectrum irradiance and partially correct for atmospheric effects and reflectance differences of objects due to changes in the scan angle of the sensor. Indices are also useful to effectively summarize data, considerably reducing the amount needed for assessment. Indices have been used to monitor insect breeding grounds, forest fire potential, desert encroachment, and agriculture (extent of cultivation, type of crop, and stage of development).

Generally speaking, a vegetation index is nothing more than a number which tells whether an object is vegetation or non-vegetation. The higher the index value, the "greener" the pixel is. "Greener" pixels are those with healthier and denser vegetation. Non-vegetative targets have low, possibly negative, index values.

4.3. Why satellites can monitor vegetation

The reason that data from any satellite can be used to monitor the earth's vegetation and distinguish it from other materials is shown by the following target plots in Figure 7.

Targets Plotted as a Function of
Vegetation Index* and
AVHRR Channels I and II Reflectivity



* The vegetation index displayed here is frequently referred to as the normalized vegetation index. It is defined by

$$(C_2 - C_1) / (C_2 + C_1)$$

where C_1 = channel I reflectivity
C_2 = channel II reflectivity

Figure 7

The target plots are calculated by combining the spectral reflectivity curves of the various targets with the spectral response curves of the AVHRR sensors for channels 1 and 2. These points represent the primary spectral information contained in both AVHRR and Landsat data for monitoring the health of surface vegetation.

Living vegetation is the only substance that has a positive index value. Plants cannot use the near IR radiation for photosynthesis. They must reject this radiation or it will cause additional heat stress. When the cells are turgid (tightly filled with fluid) small air spaces form between them, causing most of the near IR radiation to be reflected.

Clear water reflects only small amounts of visible radiation and absorbs much of near IR radiation. This makes water the only substance with negative index values. Particulates within the first millimeter of the water surface increase the near IR reflectance, but the visible reflectance will always be the greater.

The vegetation index is mapped by plotting individual AVHRR visible reflectance values on an X-Y cartesian grid vs. their corresponding near IR values. Clouds, bare soil, concrete, sand and water reflect nearly equal amounts of visible and near IR radiation so their plotted values fall near the diagonal of the graph. Vegetation reflects more in the near IR than in the visible, so these values fall in the lower right half of the grid. The greater the difference between near IR and visible reflectances, the more biomass is present and the greater the Leaf Area Index (Schneider, et al., 1981). The normalized vegetation index (NVI), a good indicator of vegetative turgidity (Tucker, et al., 1982), is expressed as:

$$NVI = \frac{\text{near IR reflectance} - \text{visible reflectance}}{\text{near IR reflectance} + \text{visible reflectance}}$$

4.4. Mixed Pixels

A mixed pixel contains more than one target. Because GAC pixels are large (4 x 4 km), they are frequently mixed. It is important to understand what happens to the image when there are mixed pixels. For a mixture of two different targets, the resultant pixel will lie on a line connecting the two target plots. In Figure 8, Point B represents a mixture of stressed wheat and concrete. The location of point B depends on the relative amount of each target in the pixel. Point B represents about 90% wheat and 10% concrete.

For three or more targets, the plot of the mixed pixel lies in a polygon formed by connecting points of the various targets. The actual position of the pixel in the polygon depends on how much there is of each target. Point A shows roughly equal amounts of sand, soil and soy.

Clouds are a bit more complicated because the brightness of a cloud partially depends on how much of a pixel it covers. It is unlikely that a cloud 1000 m in diameter would be 10,000 m thick. Thin clouds (light circle C and D) have much lower reflectances than thick clouds and are more likely to be the clouds which would cover a small portion of a pixel. Very bright, thick clouds will usually completely cover several pixels and only edge pixels will be mixed.

The result is that healthy green vegetation does not move coward bright thick clouds on the graph when part of the pixel is cloud covered.

The Effect of Mixed Pixels on the Plot of Targets

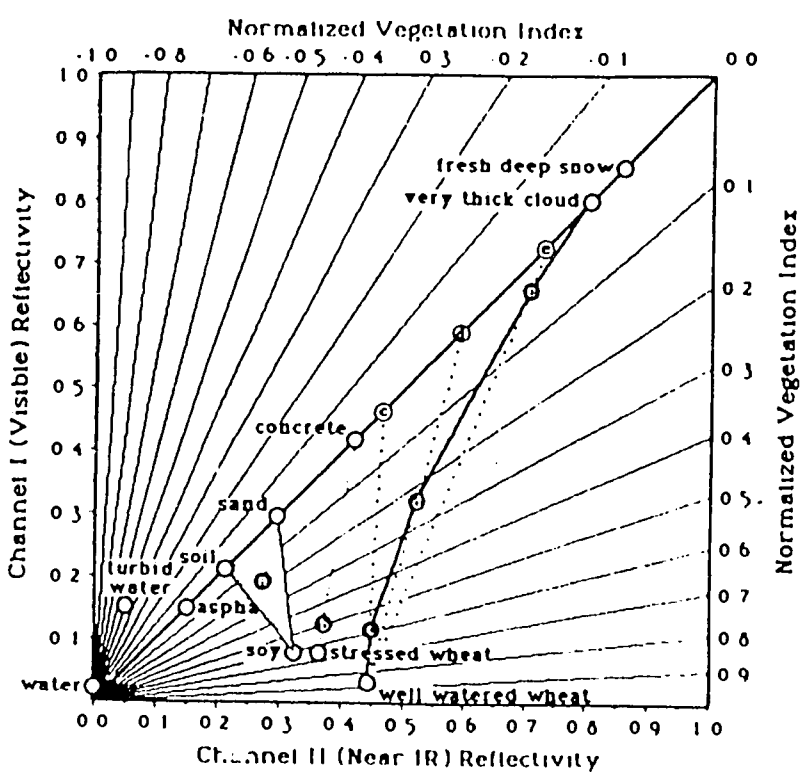


Figure 8

Rather, for small amounts of cloud in a pixel, the point moves straight up, as for example the point at dark circle C. As the cloud cover increases, the target moves along a curve that becomes tangent to the diagonal (dark circle points C, D, E and very thick cloud cover), rather than along a straight line as with other targets.

4.5. Time Series

Because of the high temporal resolution provided by the AVHRR, time series analysis of vegetative conditions on a local, regional and global scale has significant potential. To date, time series analysis which meets a rigorous statistical definition of the technique has not been done due to the lack of a continuous, complete and homogeneous data set (G. Hart, personal communication, 1984).

Time series plots of the weekly composite vegetation index allow easy comparison of year-to-year as well as within season changes. The index is derived as the average weekly value over predefined agroclimatic regions. Many changes in the vegetation index are the result of changes in the atmosphere, e.g. clouds, haze and precipitable water. It is critical that the assessor understand the nature and the impact of these effects before attributing any change in the index to the condition of vegetation on the ground. Two techniques have been used to help understand atmospheric effects on the time series data: filtering the time series data and producing 2 dimensional scatterplots of visible and near IR pixel values within defined areas.

4.6. An application

An example from Africa appears in Figure 9. The vegetation index time series plots are the main assessment tool. The 1983 and 1984 time

series comparison for southern Mali shows that throughout the growing season, satellite vegetation indices were lower in 1984 than in 1983. This indicates more unfavorable crop conditions and probable lower yields in 1984 compared to 1983. The AVHRR enhanced imagery showed southern Mali as yellow and pale green late in the 1983 growing season while it was mainly yellow and orange at the same time in 1984. This suggests worse crop conditions in 1984 with probably lower yields. Millet is the main crop growing in southern Mali and millet yield estimates (kilograms/hectare) for 1983 and 1984 were 449 and 367 respectively (FAO, 1984).

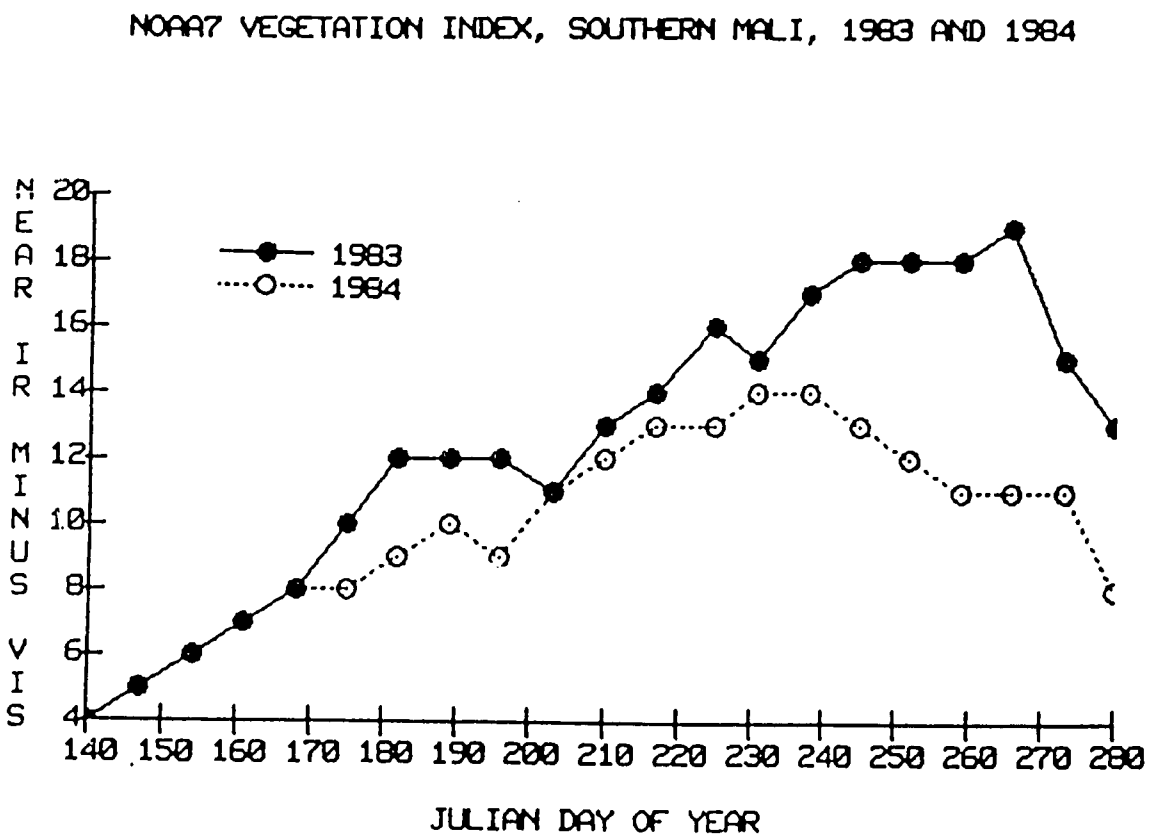


Figure 9

1983 and 1984 satellite vegetation index time series comparison for southern Mali. Visible and near IR reflectances are scaled 0 to 255 and their differences are plotted vs. time.

4.7. Problems in viewing vegetation

The assessment of vegetation from a polar orbiting satellite is not without problems. These include consistency in the distance from the sensor to the target, the variable presence of cloud cover, the relative frequency of repetitive observation, the inherent spatial resolution of the remote sensing system being utilized, and the interpretation of cause and effect relationships in the evaluation of the data.

4.7.1. Distance from Sensor to Target

Polar orbiting satellites, such as those mentioned in this section, operate at altitudes of 725 to 920 kilometers. The signal received by the detectors must pass through all of the Earth's atmosphere before being sensed. This distance may be increased significantly in off-nadir viewing, the case with the NOAA-AVHRR sensor. The $^{+}$ 56° field of view of the AVHRR instrument results in an atmospheric optical thickness which ranges from 1.0 at the nadir to 2.2 at the extremities of the field of view (Holben and Fraser, 1983). To reduce the problems associated with extreme look-angles, some researchers have chosen to consider only the central part of the swath. A significant impact of this action has been a reduction in the effective field of view utilized for some vegetative applications (Tucker et al., 1984; Miller and Moore, 1983; Townshend and Tucker, 1984).

4.7.2. Presence of Cloud Cover

The use of visible and reflective infrared portions of the spectrum for the analysis of surface features is dependent upon the absence of clouds from the scene. Clouds reflect light differently than vegetated surfaces and effectively block out the reflectance

values from beneath them and most of the information content in their shadow areas. Clouds smaller than the pixel resolution of the system being employed and faint cirrus clouds pose the greatest problems (Tucker et al., 1984).

4.7.3. Frequency of Observation

The relative frequency of observation of the area of interest becomes increasingly important as it relates to the phenological stage of the vegetation. In the case of the Landsat system, the repeat cycle is limited to 16 days with one satellite or 8 days using both Landsat 4 and 5. The NOAA polar orbiting satellite provides the opportunity for daily observation.

4.7.4. Spatial Resolution

Resolution of the remote sensing system, as expressed by the Instantaneous Field of View (IFOV), ranges from 80 m on the Landsat MSS (30 m on thematic mapper) to 1,100 m with the AVHRR. The signal received by the sensor detector is an integrated value from the entire IFOV area. Thus, the variability of cover type occurrence potentially increases as the IFOV becomes larger. Because it is the integration of all reflected energy over the IFOV which is being detected by the sensor, the contribution of background information, e.g., soil, must be considered in the context of evaluation of the signal.

4.7.5. Cause and Effect Relationships

The information provided by a remote sensing system consists of series of digital values from each portion of the spectrum being sensed. These signals vary in proportion to the presence or absence of vegetation, its density, the condition of the atmosphere being looked

through, the moisture content of the background soil, etc. These recorded values provide valuable data about the scene being sensed. These data do not in and of themselves, however, provide causal information regarding the condition being observed. Diminished reflectance values in the reflected infrared portion of the spectrum may tell the trained scientist that vegetation is under stress. The determination of the cause of this stress must be determined by other means, including direct field observations.

5. Color Consideration*

5.1. Color Models

A color model is a mathematical explanation of a color behavior context. Since color science is inexact, there are numerous models. Different models exist for input and mixing of colors, storage of color information, and output of colors to various media.

The range of natural colors that the eye perceives in nature is greater than the color range for photographic film dyes, which in turn is larger than the modern TV color gamut and the ranges for inks, dyes, and paint pigments. No artificial media approach the color acuity of human vision. Many of the existing compromises, such as TV, paint, and color photography, are nevertheless acceptable.

Since computer-generated pictures are first developed using color monitors and later translated into other forms, the color subsets of human vision that are relevant to a discussion of computer graphics are the ranges for television, film dyes, and print media. Conversion between color media is difficult and inexact, and although none of these color subsets approach reality, practical conversion between them is still desireable. As background, we will first discuss the basis for color monitor displays: the RGB (red-green-blue) color cube.

5.2. The RGB Color Cube

Intensities or voltages of the red, green and blue electron guns of a color monitor are independently controlled, hence it becomes natural to think of the RGB system in terms of a three-dimensional space, a color

* Material for this section is from Baldwin, Lee, "Color Considerations," BYTE, September 1984, page 227.

space. The three color axes, representing intensity levels of the independent primaries, may be thought of as having values from zero to one, or from zero to 100 percent. Figure 10 illustrates the arrangement of the RGB primaries, the CMY secondaries, plus black and white, on the RGB color cube.

All of the colors possible from the additive mixing of colored light from a color monitor can be represented somewhere in this color cube (It is not the case that the colors from a monitor fill this space completely; actual monitor colors form a subset of this space known as the color gamut). It is easy to see that people will have trouble achieving a particular color mixture by specifying percentages of three additive primaries.

Intuitive color interfaces must display a sampling of the available hue range on the monitor. The operator first points to a hue and

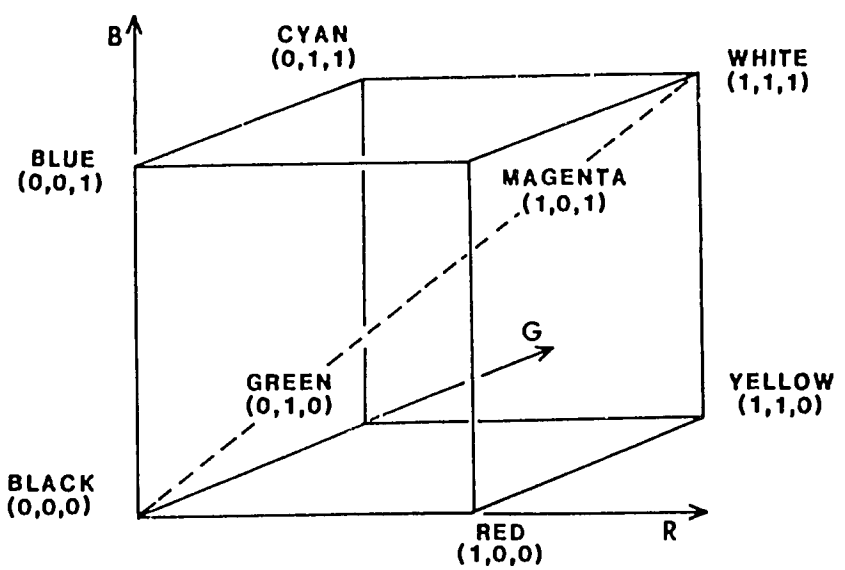


Figure 10. The RGB Color Cube, A Model that allows for Visualization and Mathematical Representation of Color Relationships. Points are Plotted as (R, G, B).

then adjusts the purity of the hue (its saturation, or tint) and its intensity or shade. Such a model is descriptive, as it uses concepts that are already in the language in a systematic way. This description fits the hue, saturation, and intensity color model, proposed by A.R. Smith at the New York Institute of Technology in the 1970's in a technical paper entitled "Color Gamut Transform Pairs."

5.3. The IHS Color Model

The intensity, hue and saturation (IHS) color model is derived from the RGB model and has descriptive advantages over RGB for color mixing in computer graphic systems.

The advantage of descriptive color models can be suggested by two examples: pink is described as red light mixed with white light, and gold is described as desaturated (grayed) yellow. In the RGB color system, how does one mix white light with other colors if there is no explicit control for the amount of white light? How does one add gray to a color in RGB? How would one find the gray to add?

In the RGB color cube of Figure 10, note the diagonal axis extending from black (r,g,b = 0,0,0) to white (r,g,b, = 1,1,1). If the color cube is viewed along this axis looking from white to black, the projected shape will appear as a hexagon with the principal colors (the primaries and secondaries) situated at its vertices (Figure 11).

The above shape is also the bottom of the hexcone shown in Figure 12. This solid is a deformation of the RGB color cube with more potential for taking human factors into account, that is, improving the user interface.

The IHS color model can represent all hues and colors possible to the RGB model. Hues are laid out around the edges of the hexcone,

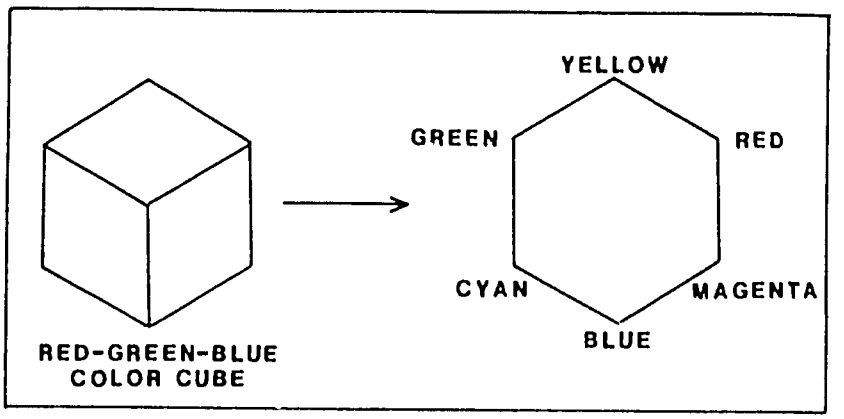


Figure 11. The RGB Color Cube, When Viewed along the Diagonal Black-White Axis appears as a Hexagon, with Primary Colors (Red, Green, and Blue) and Secondary Colors (Cyan, Magenta, and Yellow) Situated at the Vertices.

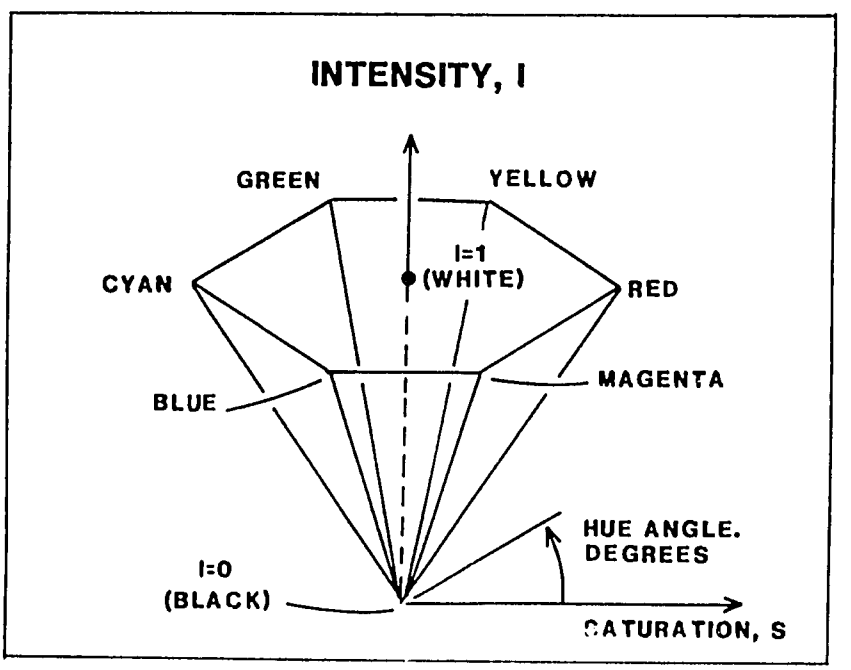


Figure 12. A Hexcone Representing the Intensity, Hue and Saturation (IHS) Color Model.

arbitrarily defined as starting from red at zero degrees, progressing counterclockwise toward yellow (hue angle=60 degrees), green (120 degrees), cyan, and so on. The intensity (I) of a color is the distance along the vertical axis from black (I=0) to white (I=1 or 100 percent). Saturation (S), the purity of a color as compared to its maximum purity at a given intensity, is the distance from the intensity axis radially toward the surface of the hexcone. Colors on the intensity axis itself (where S=0) are shades of gray. Pure hues are found at the edges of the hexcone where S=1 and I=1.

The IHS system is descriptive in the sense that its axes are named for perceptual quantities. IHS offers a more obvious way to explain colors such as pink, gold or light blue.

Selection of a pure hue, followed by adjustment of intensity and saturation, is intuitive. Tints and shades common to much artwork are produced by decreasing saturation (adding white) or decreasing intensity (adding black), respectively. Tints are located on the top plane of the hexcone with the pure hues; shades are found on the outside surfaces of the hexcone. Tones are everywhere within the hexcone's volume (see Figure 13).

IHS is superior to RGB for at least the user interface of a system requiring color input/output. Thinking of IHS as a distortion of RGB space suggests conversion algorithms. Linear transformations from RGB to IHS (and back) permit storage and display of pixel (picture element) values to be handled in the RGB system, while input and computation may be done using IHS. Such transformation algorithms are discussed below.

5.4. Color Space Transformation

Conversion between RGB and other color spaces is simplified by the fact that RGB is linear. Familiar linear algebra operations work in

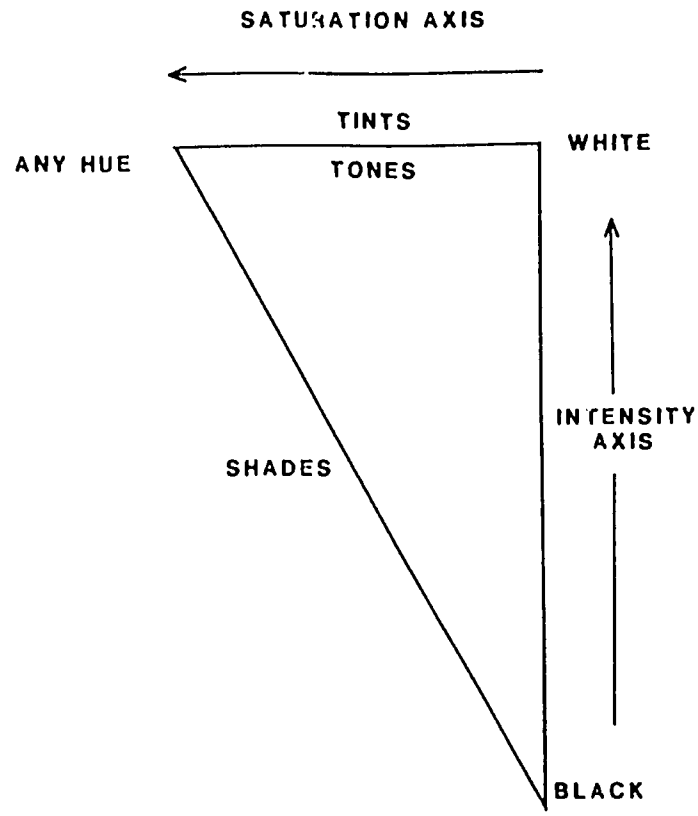


Figure 13. Cross section of the IHS hexcone showing tint, shade, and tone.

this space, which means that transformation algorithms between RGB and IHS are computationally inexpensive.

5.4.1. IHS-to-RGB Transform

For hue H from 0-360°, with Saturation S and Intensity I on the range of real numbers between 0 and 1:

$$h^1 = H/60$$
$$h^* = \text{greatest integer in } h^1$$

$$f = h^1 - h^* \text{ (the fractional part of } h^1)$$
$$p = (1 - S) \times I$$
$$q = (1 - S \times f) \times I$$

$$t = (1 - (S \times (1 - f))) \times I$$

then,

$$\begin{aligned} \text{if } H^* &= 0 \text{ then } (r, g, b) = (I, t, p) \\ &= 1 \qquad\qquad\quad = (q, I, p) \\ &= 2 \qquad\qquad\quad = (p, I, t) \\ &= 3 \qquad\qquad\quad = (p, q, I) \\ &= 4 \qquad\qquad\quad = (t, p, I) \\ &= 5 \qquad\qquad\quad = (I, p, q) \end{aligned}$$

5.4.2. RGB-to-IHS Transform

To transform RGB color information into IHS:

MAX = maximum of R, G, B
MIN = minimum of R, G, B

d = MAX - MIN
I = MAX . . . . . .*

If MAX is nonzero, set

S = d/MAX . . . . . .*

For MAX = 0, set S = 0 and H = undefined.

Otherwise:

r = (MAX-R)/d
q = (MAX-G)/d
b = (MAX-B)/d

if R = MAX, then set h = b - q
G = MAX, then set h = r - b + 2
B = MAX, then set h = q - r + 4

if h < 0, set H = 60 x h + 360. . . . . .*
h > 0, set H = 60 x h. . . . . .*

6. ACCS: Ambroziak Color Coordinate System*

6.1. Photo Interpretation

A successful coloring system simply uses what is known about physics to produce an image that facilitates assessment of vegetation while reducing confusion caused by atmospoheric conditions. This is not as difficult as it sounds, because there is a big difference between confusion and annoyance. Clouds, for example, have distinctive patterns which are easily identified as clouds in an image. The presence of clouds is an annoyance to a photo interpreter (PI), since they block the surface, but they do not confuse because they are clearly identifiable as clouds.

If the scene is correctly displayed to minimize confusion and maximize information, it is fairly easy to train people to use the satellite data to enhance their understanding of what is happening on the ground. This is a key point. If satellite data are used qualitatively, they must be combined with other data to produce quantitative answers. Other data include recent weather, climatology, cropping practices, and economics. These data are quantitative, but are usually coarse in spatial and temporal distribution. Satellite data can be used to interpolate these data, make gross value checks, and fill in data gaps.

*Material for this section is from Ambroziak, R.A. 1984. "A New Method of Incorporating Meteorological Satellite Data into Global Crop Monitoring", Proceedings of the Environmental Research Institute of Michigan Symposium, Paris, France.

6.2. False Color IR

There is already a system in use which fulfills the requirement of minimized confusion. The system has been used for aerial photography, Landsat, and NOAA AVHRR crop condition assessments with some success by trained PI's. This system is the false color IR (FCIR) color coordinate system which is based on the shifting of the blue, green, and red towards the IR to accommodate the near IR channel (Figure 14). Color film uses red, green and blue to reproduce all of the colors in a scene. The system works because these are the same as the receptors the eye uses to sense color. With the addition of the reflected IR light, one of the colors had to be dropped. Since Rayleigh scattering produces a blue haze on color photographs taken from high altitude, the blue light was the band dropped. In this system green becomes blue, red becomes green and near IR is depicted as red.

The FCIR system is extremely useful for identifying vegetation because of a convenient accident of color coordinate system alignment. The mind's natural color coordinate system is aligned with the most commonly used vegetative indexes. The result is an image that contains all the useful information contained in the original data displayed in a way that the mind can directly evaluate a biomass as changes in color. These color changes are not arbitrary. They are seen by the mind as changes on a single orthogonal axis; patterns of biomass can easily be detected.

All studies of Landsat and AVHRR that have attempted to produce a single number (index) to describe the health of vegetation have begun with the difference between, or the ratio of, the near IR channel and one of the visible channels. One of the most common indices is the difference divided

by the sum, which is called the "normalized" difference vegetative index. It is this index that is displayed as changes in saturation in the FCIR coordinate system (Figure 15).

This must be an accident because the FCIR system a RGB display, not an IHS display. The difference between these two coordinate systems is extremely important because although the eye receives RGB information the mind processes only IHS information. The net result is that patterns of RGB in an image are totally invisible to a PI while IHS patterns are easy to detect.

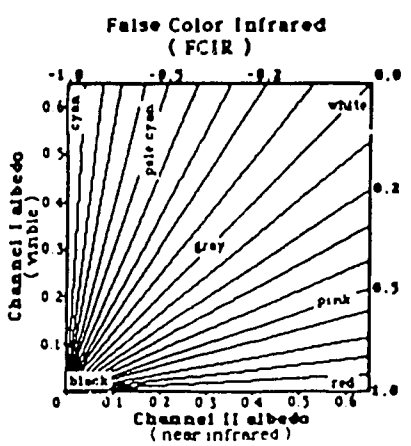


Figure 14

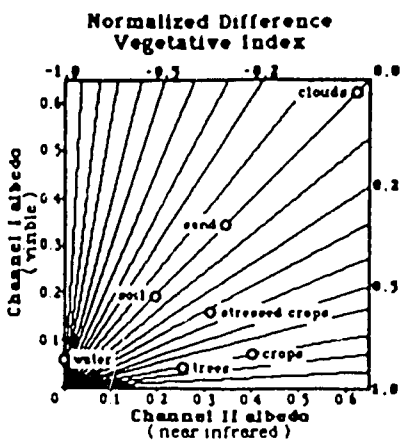


Figure 15

For crop monitoring an FCIR display is basically a two channel RGB display of one visible and the near IR channel. The earth's surface shows relatively little change between the visible channels but shows dramatic variation between any of the visible channels and the near IR. To produce the FCIR display the brightness of the red gun in the CRT is controlled by the value of the IR channel, and blue and green are equal (or nearly equal

in the case of three channel Landsat) and controlled by the visible channel. The result is a red and cyan (blue-green) display with natural brightness that is directly related to the "normalized" index values. Positive values (increasing biomass) are displayed as red, and negative values (water) are displayed as cyan. Where the two are equal the color is white or gray. Everything that is neither water nor vegetation lies along or very near this diagonal. The values of saturation computed from these colors are exactly equal to the index values. For example an index of 0.60 is displayed as a pink which is 60 percent saturated red.

Since changes in saturation of red are equal to changes in the vegetative index it is easy for a PI to make qualitative comparisons of the state of the vegetation on the ground -- the redder the better. This coordinate system has been in use for many years to discern features in the pattern of vegetative health. It is still the most useful, generally available method of analyzing imagery but it does have a serious flaw. The subtle changes in saturation may be sufficient to detect patterns, but they are too subtle to make any comparisons between points that are not adjacent. One reason is that the mind creates a false gradient when color change is too subtle to see easily. Another is that of the three axes of the IHS, saturation is the one with the worst resolution. Both intensity and hue are much easier to separate than saturation.

6.3. Arbitrary Index Coloring

The arbitrary index color system is at the opposite end of the coordinate system spectrum from the FCIR system. It solves the problem of comparing nonadjacent colors, but creates its own set of problems.

The arbitrary index color system uses few colors. They are chosen to be as different from each other as possible so that they can be uniquely identified (Figure 16). A narrow range of positive index values corresponds to each color except blue, which is assigned negative values to denote water. This coordinate system shows sharp, easily identified boundaries and serves as a quantitative contour map of positive index values. It is an ideal presentation of the index. If the effects of the atmosphere have been removed, it is the preferred method of displaying the index.

The arbitrary index color system, however, does not display all of the information contained in the original two-channel data, nor does it present a continuum that allows the relative comparisons which the mind makes so well. It may be great for display, but it is a poor analysis tool. Dark soil, light sand and clouds all have the same index value and will appear the same in the arbitrary index color system. If brightness is included, the data loss problem is solved, but the lack of a continuum remains.

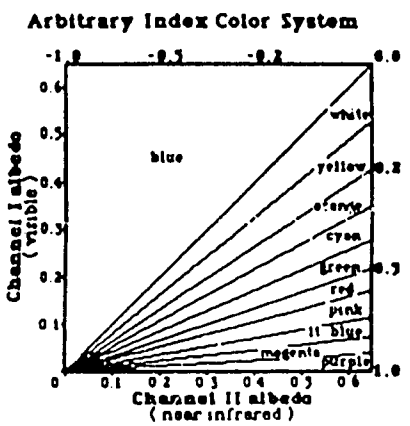


Figure 16

6.4. Fundamentals of Color Perception

AVHRR imagery is enhanced using a scheme recently developed by Ambroziak (the Ambroziak Color Coordinate System or ACCS) the combines the FCIR and arbitrary index color systems. This system simplifies the task of interpreting multispectral images by remapping the data into the intensity, hue and saturation (IHS) color space. More information can easily be gained from an image with the ACCS than with the traditional false color enhancements. This new system makes the scene look 'natural' with bright green lush vegetation, yellow stressed and sparse growth, brown and red bare soil, white clouds and black water.

To understand the ACCS we need to review some basic concepts of color perception. Color is the aspect of visual perception by which the spectral composition of electromagnetic radiation may be detected. Intensity (lightness) is the perception of an object as being very dim (black) or bright, e.g., a low intensity orange appears brown. Hue is the attribute of color perception denoted by blue, green, yellow, red, etc. Saturation denotes the presence or absence of color (or whiteness), e.g., as red becomes less saturated, it appears pink, then finally white. A color coordinate system is a rational method of ordering and specifying colors. Color coordinate systems fall into two groups: those based on the physical principles of color creation (additive and subtractive color mixures, e.g., the additive mixture of green and red results in yellow) or on principles of color perception (Wyszecki and Stiles, 1967).

The reason the ACCS is an improvement upon traditional multispectral image enhancement is that it is based on the system which humans use to perceive color. The human mind perceives visual input in terms of intensity, hue and saturation rather than the combinations of red.

green and blue (RGB) with which traditional imagery is presented. Over a wide range of conditions many colors can be matched completely by additive mixtures of three fixed primary colors. An RGB color system is based on this physical additive principle of color creation. Traditional false color imagery is created in this manner by mapping three parameters into the three primary colors. However, humans discriminate between colors and perceive them in terms of the attributes of intensity, hue and saturation. This can be seen intuitively by realizing how difficult it is to estimate what percentages of primary colors are needed to produce any given color while it is quite easy and natural to describe a color in terms of its intensity, hue and saturation.

Several other factors about color perception need to be mentioned. The eye-brain system is designed to gain information by interpreting the differences detected in visual input. Given various lighting conditions the eye cannot detect how much radiation it is receiving in a particular wavelength, only that two different inputs have differing intensity, hue and saturation characteristics (Ambroziak, 1984). In other words, the eye cannot interpret visual input quantitatively, only qualitatively. A blue house will appear blue no matter what the ambient lighting conditions. Even at sunset when most visible radiation received by the eye may be in the red wavelengths, the eye-brain system adjusts its relative perception to be able to 'see' a blue house. This is one reason that ACCS imagery is meant to be used only qualitatively, e.g., to compare vegetation conditions at different times, and not to make absolute statements about crop conditions.

6.5. AVHRR IHS Enhancement

The ACCS remaps multispectral AVHRR data into intuitively meaningful patterns in an IHS color perception system. An IHS color space has 3 independent parameters so as many as 3 independent sources of information can be presented. Three useful AVHRR derived parameters for monitoring vegetation and detecting atmospheric contamination are a normalized vegetation index, the maximum of the visible and near IR AVHRR reflectances, and a thermal IR temperature. These are mapped into an IHS color space so that the most useful parameters have the greatest visual resolution. The vegetation index is mapped into hue, the maximum of visible and near IR is mapped into intensity, and temperature is mapped into saturation. People can perceive intensity differences most easily, then hue, then saturation. More different hues, however, can be easily distinguished than intensities. Depending on how many classes of information are to be displayed, either hue or intensity would be the best representation for a particular parameter.

The mapping is done in the following manner. On an X-Y cartesian grid individual AVHRR visible reflectance values are plotted vs. their corresponding near IR values (Figure 17). On the graph, lines of equal NVI radiate from the origin and each class interval of NVI is assigned a different hue so that earth features are 'natural' looking (e.g., bare soil is red, stressed or sparse vegetation is yellow, lush vegetation is green). Figure 18 shows how the hues and saturations are mapped onto the X-Y reflectance plot.

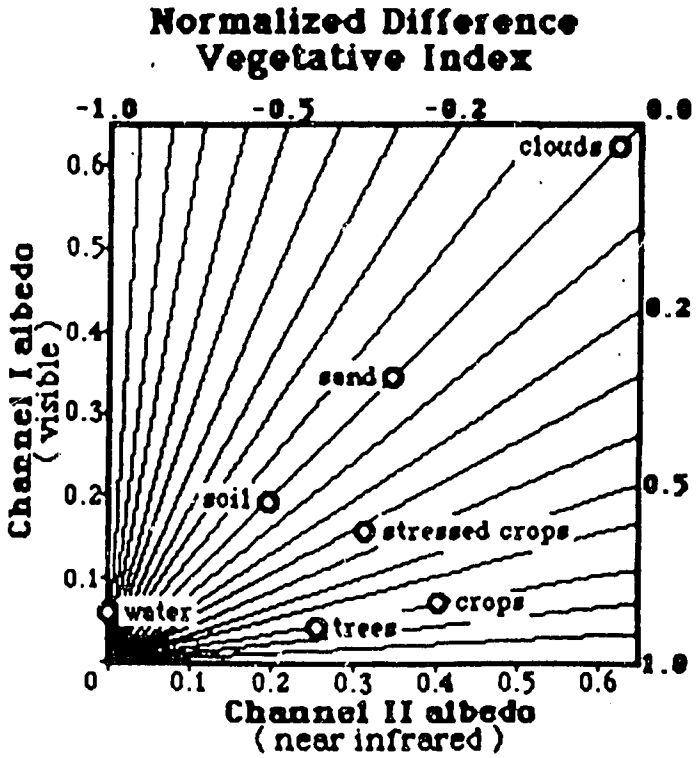


Figure 17. Targets plotted as a function of the visible reflectance (AVHRR channel 1) and normalized vegetation index ((ch 2 - ch1)/(ch 2 - ch 1)).

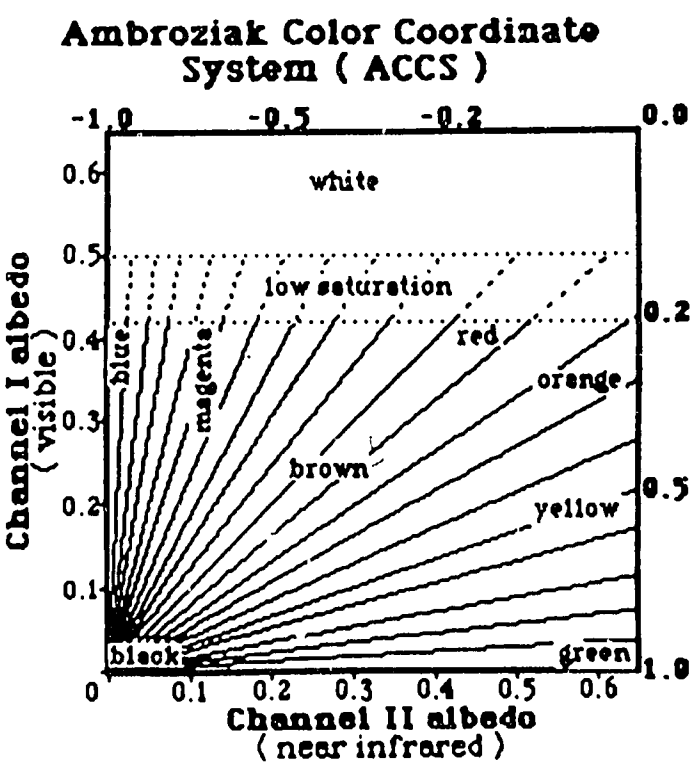


Figure 18. The mapping of hue and saturation onto the reflectance plot of Figure 17.

Saturation is used as a cloud filter. In PSG scenes, the thermal data are not available, so visible reflectances are used in cloud filtering. Pixels with higher visible reflectances are assigned lower saturations. As a result, bright visible pixels (clouds, sand) have a lot of white, while dark visible pixels (water, lush vegetation) have a deep, rich hue. In other AVHRR scenes, the 10.5-11.5 micron thermal band (channel 4) is used in a similar manner. Lower temperatures have a lower saturation while higher temperatures have a higher saturation. Cold clouds are white, higher elevations and warm clouds have a pale color, the warm lowlands have a deep, rich color. Thin cirrus clouds (which are very cold but do not completely block the long wave emission of the ground below them) produce a lower saturated version of the hue of the surface feature below them. This gives the impression of looking through a thin cloud at the ground below.

Intensity is used to make distinctions among pixels with the same NVI. The maximum of the visible and near IR reflectances is mapped into intensity so that the higher this maximum value, the brighter the image. If an NVI value of 0.0 is displayed as red, various features with an NVI of 0.0 will be shown with different intensities of red. Water (NVI near 0.0, very low visible and near IR reflectances) appears black, bare wet soil (NVI near 0.0 with somewhat greater reflectances than water) is a pale dark red, dry soil and sand (NVI near 0.0 with still greater reflectances) are a medium bright red and clouds (NVI near 0.0 with higher reflectances) appear as a bright red. Depending on how the saturation filter is set, some of the features with high visible reflectances will become white on the display. Forests generally are displayed with a lower intensity (darker shade) of green than cropland because of their reflectance characteristics.

A weekly compositing algorithm is applied to the daily PSG data to aid in removing clouds and large satellite look angles. In the composite data set, for each pixel location only the data for the day with the highest NVI is saved. This assures that the most cloud free pixel for the week is chosen. The only cloudy pixels in the composite are those which were cloudy every day.

No geometric or radiometric corrections are applied to the data, so the images must be interpreted subjectively. Clouds and areas far from nadir can easily be spotted and these regions ignored in the analysis. An ACCS image is useful in assessing crop conditions only when used in combination with other sources of information. The imagery is interpreted by comparing imagery for two different times and noting the changes. If a crop area looks worse this year than last year, it could be because the crops have been stressed or diseased, one crop in a multi-crop growing area was harvested, the crop growth rate is different, there is much standing water from excessive rains, there is atmospheric contamination, or for other reasons. The data can be interpreted successfully only if the analyst is familiar with local agricultural practices. Then, in many cases, a change in the data can be attributed correctly to a change in the condition of the vegetation.

PSG data are routinely used every week to assess continental sized areas. GAC, LAC, and HRPT scenes, as available, are used to analyze smaller sized regions. The ACCS enhancement can be changed interactively using a computer image processor to highlight areas where a greater visual resolution is needed.

6.6. Ambroziak Color Coordinate System

The first Ambroziak Color Coordinate System assigned green to an index value of 1, red to 0, and blue to -1 (Figure 19). The result is a

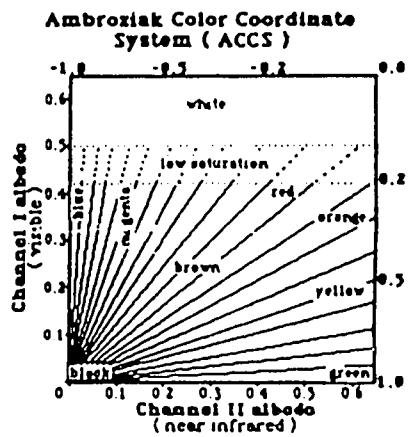


Figure 19

fairly natural looking scene with green vegetation, dark blue water, red and brown soils, and yellow stressed vegetation.

Clouds are bright red in this scheme which is annoying to the analyst. To remedy this problem, saturation is reduced to zero for the very high visible brightness values. Should a cloud filter become available, such as thermal detection, these data would be used to reduce saturation in a more efficient way. The presence of thin clouds or haze in a natural scene is discerned as a reduction in saturation. By making this change to the coordinate system the image takes on a more natural appearance.

This system proved to be extremely useful in monitoring the status of vegetation in the tropics during the northern hemisphere summer of 84. Test reports produced from only the images agreed closely with assessments

produced from all other data sources. Patterns of drought and plentiful rainfall were shown in finer detail than was possible with the station data alone.

Assessors determined that the ACCS is a significant improvement over the FCIR system, but that it lacked the comparison of distant points capability of the arbitrary index color system. A step toward this goal is achieved by cycling the hues at twice the rate of that used on the ACCS. The result is the ACCS2 which assigns green to an index value of 1, red to 0.5, blue to 0, cyan to -0.5, and green again to -1 (Figure 20). There is little or no chance for confusion between the greens because all values below -0.5 are very dark and appear black on the image.

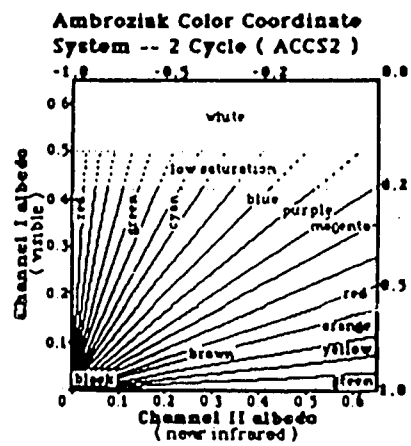


Figure 20

The ACCS2 is close to the arbitrary index color system in its color separation ability, yet it maintains all of the advantages of the FCIR system, making it an ideal tool for analysis. The ACCS2 images do not

have the natural appearance of the ACCS, but this is of no concern to the analyst using them. Comparisons of cumulative rainfall and the images shows close agreement between the index and point station values of rainfall. By using the two data sets, detailed maps of cumulative rainfall can be produced. Other uses for the system are being developed.

6.7. Other Uses

The ACCS's have no dependence on AVHRR data and have been demonstrated to be useful in viewing Landsat images. Aerial photography can be digitized through filters and also can be converted to one of the ACCS's. These higher resolution data can be combined with the lower spatial resolution AVHRR to produce a more valuable data set than either alone. The AVHRR data has high temporal resolution and provides a complete overview data set. The higher resolution data can provide detailed closeups of areas determined to be of interest from analyzing the AVHRR.

To analyze the world the 20 km resolution sampled AVHRR data is a reasonable size, but if a single country or small region is the subject of the analysis then the 1 km resolution Local Area Coverage (LAC) or High Resolution Picture Transmission (HRPT) data would serve as the basic data set. In this case Landsat and aerial photography would provide the closeup views of the region.

The basic data set provides a complete record of historic data from the date acquisition begins. This data set becomes not only a valuable and inexpensive research tool, but it increases the value and decreases the cost of the higher resolution imagery. The value of the higher resolution imagery is increased by putting it into a time and space context. The cost is reduced because less high resolution imagery is

needed, that which is obtained contains important information, and cloud contaminated scenes can be avoided.

7. Operation of Personal Computer Image Processor (PCIP package)

This section describes the use of software for image analysis on a personal computer. Prior to the development of this software, image processing could be done only on large, very expensive equipment. In contrast, this software is designed to run on a personal computer, costing a mere fraction of this total. Furthermore, extensive training is required in order to gain proficiency on the large image processor. The software programs contain simple commands and can be learned in a very short time. This allows the trainee to focus his efforts on mastering imagery analysis rather than computer procedures. A second manual is being prepared by AISC for training in basic color science and satellite imagery interpretation.

This section documents the software program and describes its use. Also included is a description of how the satellite data is processed and formatted for use on the personal computer image processor. This represents the first version of the software. As users gain experience, requests for changes are anticipated. Hence, the following documentation should be considered preliminary. Suggestions for improvements are encouraged.

7.1. Operational Procedure

This is a preliminary version of the personal computer image processor program. This version allows the user to display an image, zoom and pan. Once the image is read you cannot change the colors. You can exit the zoom and pan mode and read in another color table or create a new color table. Creating new color tables that can be stored on file is done through the headgen program. You can make a temporary table by exiting the zoom and pan mode and following the prompts. Setting up an image is easily

done by following the steps below. The example below indicates what the user actually types by using underlined print. Once the image is selected from the diskette, all the user has to do is select the size and location of the color legend. The program then is in the zoom and pan mode for analyzing the image.

1. Turn on computer and peripherals.
2. DOS operating disk in Unit A
3. Type Init (with graphics diskette in Unit A)
4. Put program Disk in Unit A (pcip)
5. Data Disk in Unit B
6. Following the prompt sign A > Type the following:

   pcip b: filename

   The filename indicates the date of the image; for example: H4339.30C. The pcip means personal computer image processor program. This step loads the program, computes and loads the color table, and loads the image into memory with image displayed.

7. The user is prompted to position the color triangle and must designate x & y coordinates from 0 to 512 (typically 0,0 works well as the color triangle is put in the upper left corner).

8. Select size of legend (1-4)---3 is very good for demonstrating the colors, but may cover part of the image, 1 is more practical when doing analysis.

9. Zoom and pan mode is now in place. Use page up and down for zoom, use arrows to pan - the image moves in the direction of the arrow.

10. To exit from zoom, hit the "escape key" (esc) or hit "control e" (Ctrl E).

11. If you depress these keys, the program asks if you want new color tables.

12. If yes, then type new header (e.g., b: THAI01.LUT). The image will then use this color table to display the image. Color tables are created in the next section.

7.2. Look Up Table (LUT)

Images can be made brighter or darker and certain object (clouds) highlighted by altering the look up table (LUT). This is accomplished by using the "HEADGEN" program which creates a LUT that is stored and can be

retrieved from disk file. This program allows the user to enter values for intensity, hue and saturation. There are 16 intensity levels, 18 hues, and 12 saturations. These values determine the color and brightness of the pixels in the image. In general, the changes in brightness of vegetation are made by adjusting intensity and changes in clouds are made by changing the saturation table. By altering the hue table one is in effect changing the vegetation index.

To create a LUT, you type:

b: headgen THAI01.LUT

where b: is the disk drive's name.

HEADGEN is the program.

THAI01.HED is the name of the header or LUT. Hence, if you were to retrieve this LUT, it would be named THAI01.LUT.

7.2.1. Intensity Table

Once the file is named, the program prompts the user to enter number of intensity. The screen would show "intensity 0 = " and the user might enter 0. The user will then enter values for itab 1 through itab 15 (16 values total). The standard intensity table comprises 16 values ranging from 0 (zero intensity) to 255 (maximum brightness) at equal intervals of 17. The values are as follows:

itab [ ] = 0
itab [1] = 17
itab [2] = 21*
itab [3] = 51
itab [4] = 68
itab [5] = 85
itab [6] = 102
itab [7] = 119
itab [8] = 136
itab [9] = 153
itab [10] = 170
itab [11] = 187
itab [12] = 204

```
itab [13] = 221
itab [14] = 238
itab [15] = 255
```

* 21 is used instead of 34.

These values range from 0 to 255 and produce a bright image. If one were to use multiples of ten from 0 to 150, the image would be considerably darker.

7.2.2. Hue Table

The hue table is created in a similar manner, but with values representing colors. The numbers are based on the color wheel with Blue = 0 or 252; Red = 84; and Green = 148. The remaining colors are combinations of these primary ones. The standard color table is as follows:

```
htab [0]  = 42
htab [1]  = 84
htab [2]  = 100
htab [3]  = 105
htab [4]  = 109
htab [5]  = 113
htab [6]  = 116
htab [7]  = 120
htab [8]  = 126
htab [9]  = 134
htab [10] = 152
htab [11] = 192
htab [12] = 212
htab [13] = 221
htab [14] = 226
htab [15] = 233
htab [16] = 242
htab [17] = 252
```

7.2.3. Saturation Table

The saturation table is used to manipulate cloud images. By lowering the saturation one sees more definition and the cloud becomes more 3-dimensional. However, one may not like to have grey clouds and

would prefer them to remain bright. An example of the latter case would be the following:

```
stab [0]  = 0
stab [1]  = 15
stab [2]  = 30
stab [3]  = 45
stab [4]  = 60
stab [5]  = 75
stab [6]  = 90
stab [7]  = 105
stab [8]  = 120
stab [9]  = 135
stab [10] = 150
stab [11] = 255
```

Finally, the program requests information about auxiliary colors. This will be used in the future, but the present version automatically adds black (zero intensity, zero hue and zero saturation) and you enter 0.

The program also asks the user to choose the number of records per file. An answer of 1 will permit the program to exit to DOS. In the future, the program will allow the user to add text annotation to the image.

Figure 21 is a block diagram showing how NOAA satellite data have been processed. The flow begins from the archive tape. Three of five available channels are used as input to the VAX 750 computer. These data are converted to vegetation index values, and stored on disk or made into floppy disks for subsequent analysis.

Satellite Data Processing and Storage

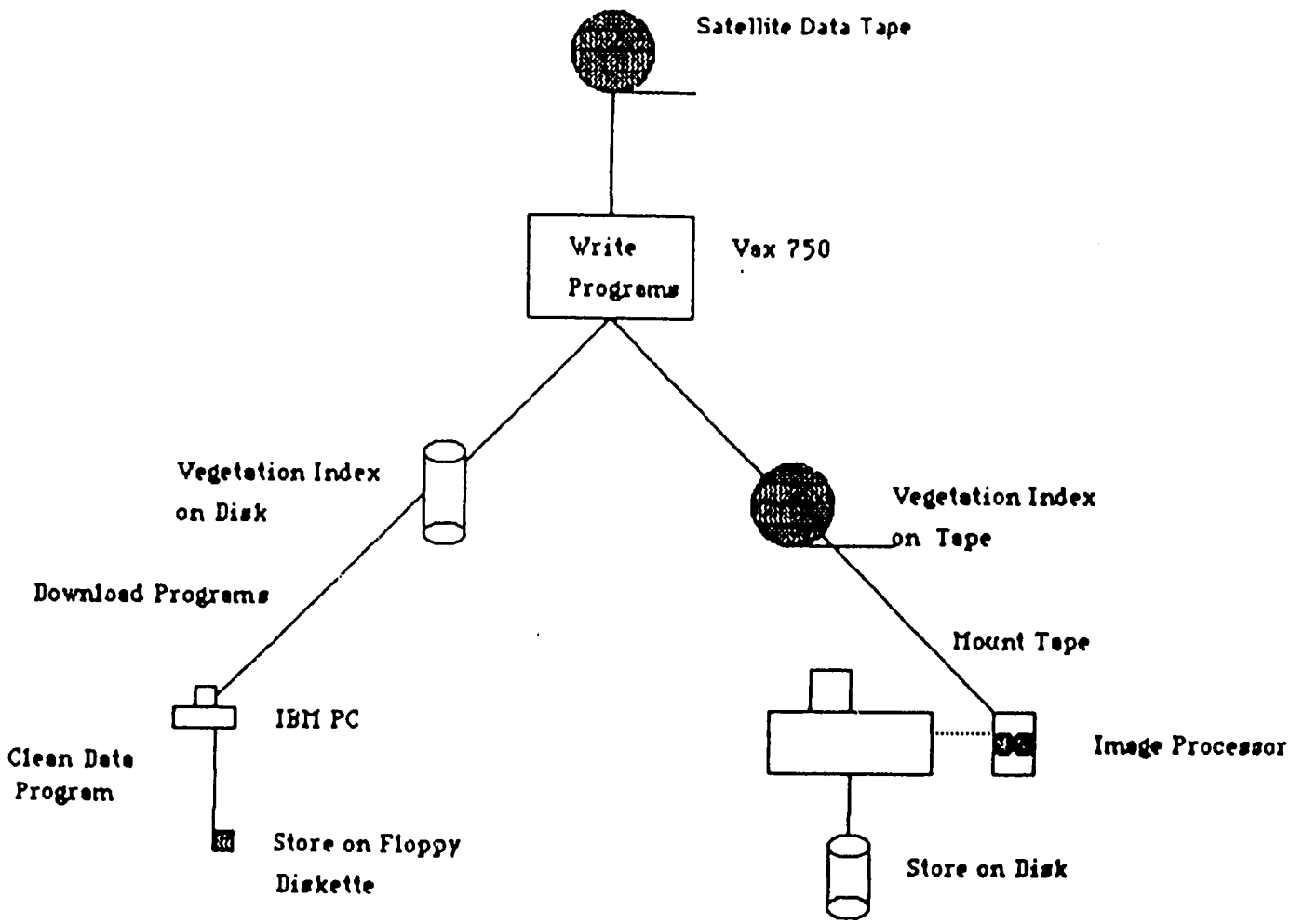


Figure 21

8. ACCS Color Enhancement

Before using the PCIP to manipulate or create a new color header or look up table for enhanced satellite data, it is very important to clearly understand the ACCS, its variable parameters and why they're used in such a way. Then you might ask yourself, what am I going to do with this data? What am I trying to focus on in detail? For example, are you interested in studying agricultural land like paddy field and its condition (emergence, maturity, harvest)? If so, your objective is to differentiate the paddy from other things (forest, orchard, urban, etc.) as much as possible. You may also want to try to enhance just the paddy data until you get the best result for use in condition analysis. Remember that normally each enhancement provides you with an optimum picture for only a few things at that data date. You never have everything for everyday at everyplace with one enhancement procedure.

8.1. ACCS IHS Color Model

Combination of the ACCS with the desired information is easier to understand when applied to a 3-dimensional IHS color model as shown in Figure 22. The intensity (I) of a color mapped to the maximum of the visible and near IR reflectance is a distance along the vertical axis from IMIN = 0 (black) to IMAX = 255 (white). Hue (H) are continuous, varying around the hexcone from HMIN = 0 (blue), 42 (Magenta), 84 (red), 126 (yellow), 148 (green), 210 (cyan), to HMAX 252 (blue) again, and define the vegetation index. The saturation (S) is used as a cloud filter, based on cloud temperature, and is the distance from the intensity axis radially toward the surface of the hexcone. Lowest cloud temperature is mapped to SMIN = 0 (white) and highest temperature to SMAX = 255 (pure or deep rich hue).

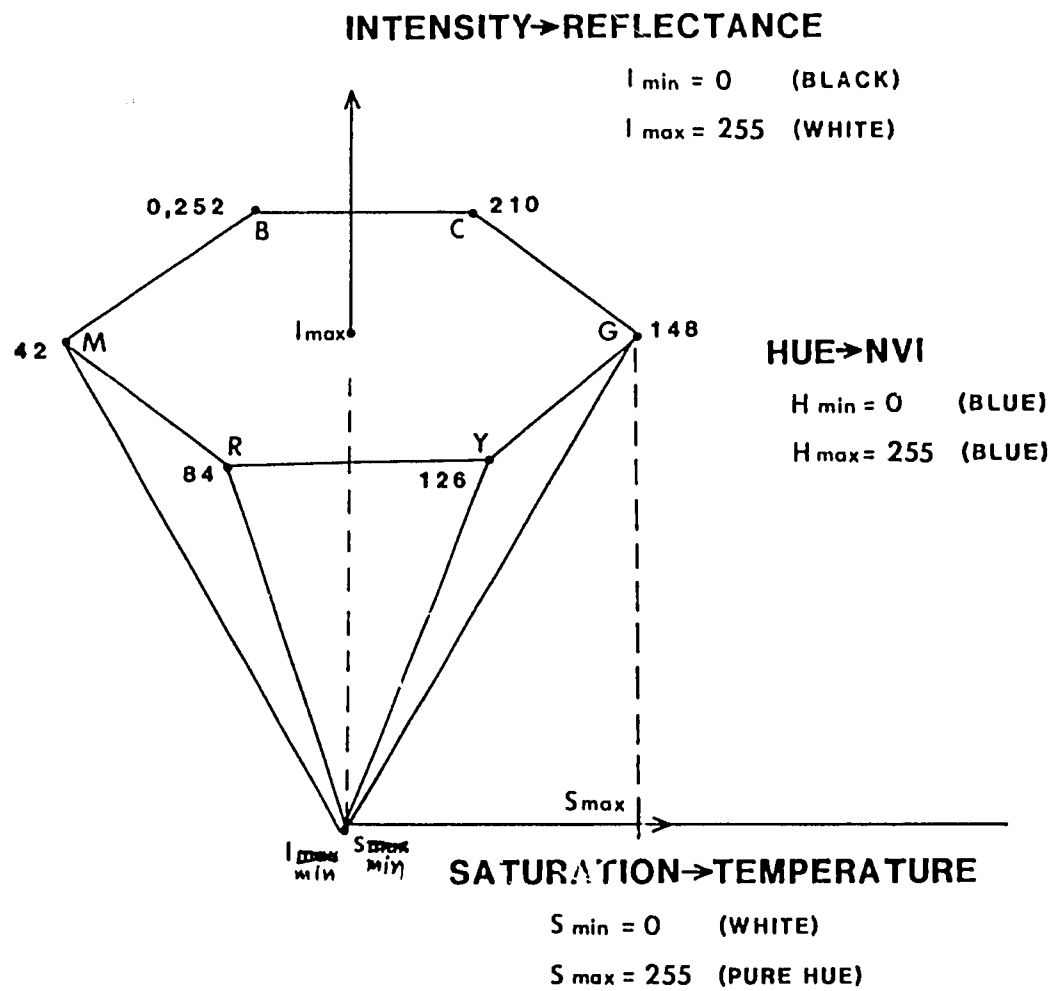
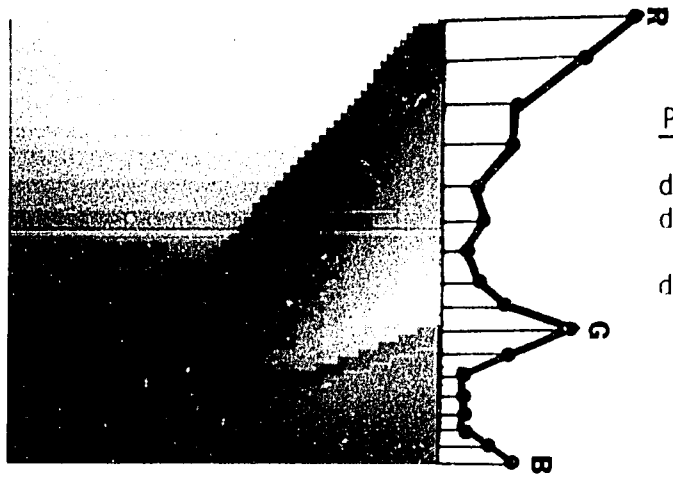


Figure 22. ACCS IHS Color Model

8.2. ACCS Characteristics

The current ACCS, which must operate on PCIP, generally uses two of many possible color coordinate systems, ACCS-2r and ACCS-2b. Generally, ACCS-2r is used for regions with sparse vegetation cover and ACCS-2b is used for dense vegetation cover (Ambroziak, et al). Some important characteristics of ACCS are:

1. ACCS was designed to reduce the non-linearity hue problem in human perception with respect to PCIP display system as shown in Figure 23. Therefore, it is very useful for general purpose interpretation and time series analysis.



Perceptual Hue Changes

dHp/dVI
dHp = Change in Perception hue
dVI = Change in vegetation index

Figure 23

2. Because the maximum hue resolution on ACCS is between the RED and GREEN portions, the red-green portion of the coordinate system is positioned over vegetation for the most precise analysis of crop conditions.

3. The most differentiation of change in perceptual hue with respect to change in the vegetation index, dHp/dVI, may be located between red to orange (red-yellow), green to yellow, and green to cyan. Strategic placement of the breakpoint color allows the photo-interpreter to work more easily.

8.3. Example of ACCS Color Enhancement for Thailand

8.3.1. Objective

The objective of this section is to establish a methodology and set standard procedures for use of PCIP and ACCS enhanced NOAA-NVI data, especially assessing crops in Thailand at Level III. In this training course, we have selected a sample area in central Thailand and concentrated mostly on paddy field conditions because these have potential for the greatest impact on the national economic system.

8.3.2. Methodology

The method used to achieve the desired results is as follows:

8.3.2.1. Display NOAA-NVI image for central Thailand recorded on December 4, 1984 (H4339.30C) by PCIP, adjust scale and position of image until satisfied.

8.3.2.2. Overlay 10 x 10 inch Area Counter Transparency Sheet, as shown in Figure 24, on color monitor screen and adjust for proper position over study area.

8.3.2.3. Changing ACCS-HUE table from htab [0] through htab [17], step by step, to find the color which gives the best contrast. Estimate an area for each vegetation index from Area Counter Transparency Sheet. This area is a qualitative value used only as a proportional area of each VI when compared to the others. However, because the Area Counter Transparency Sheet is 100 square inches, it might be easier to express the index in terms of qualitative or relative percentage area to avoid confusion later. Results are shown in Table 1.

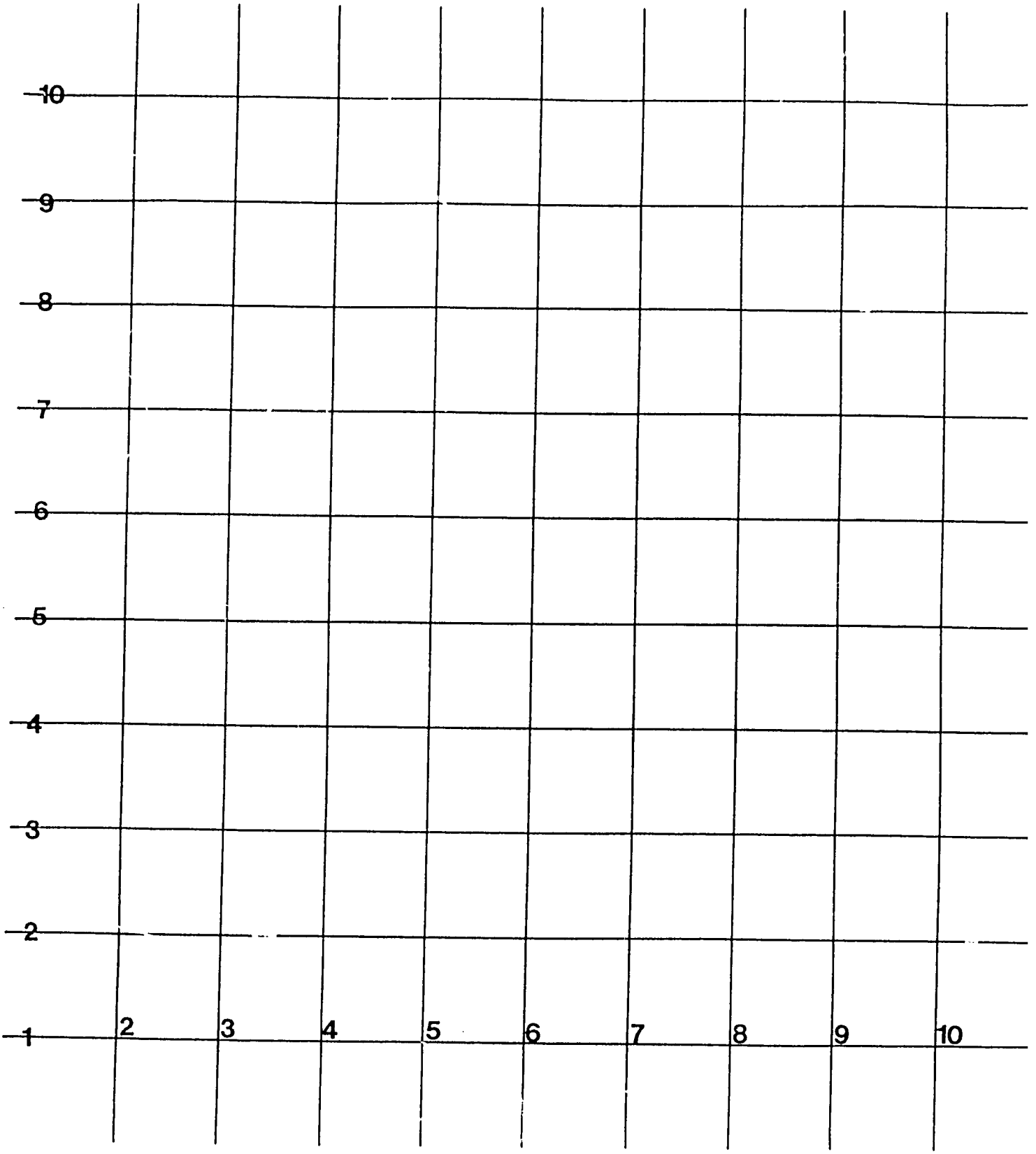


Figure 24. Area Counter Transparency Sheet, 10 x 10 inches.
(Not actual size.)

Htab No.	Color Change	Percentage Area	Class Index (not an interpretation)
0	42 to 126	0.5	Mud and Water
1	84 to 42	0.5	Water
2	100 to 42	0.3	Water
3	105 to 42	1.5	Water
4	109 to 84	2.5	Residential (Bangkok) + Urban
5	113 to 84	3.5	Residential (Bangkok) + Bare soil + Lowland
6	116 to 84	6	Baresoil + Urban
7	120 to 84	15	Harvest, Paddy
8	126 to 84	13	Harvest, Paddy
9	134 to 84	18	Mature, Paddy
10	152 to 84	18	Mature, Paddy
11	192 to 84	7	Orchard, Sugarcane
12	212 to 84	4	Orchard, Forest
13	221 to 84	2	Forest
14	226 to 84	0.2	Dense Forest
15	233 to 84	0	--
16	242 to 84	0	--
17	252 to 84	0	--
	TOTAL	92	
	Cloud Percentage Area	6	
	Counting Error	2	
	GRAND TOTAL	100	

Table 1. Relative Percentage of Class by Area for Central Thailand Image H4339.30C (12/4/84).

8.3.2.4. From Table 1, we can plot a histogram of relative percentage areas vs. ACCS-HUE step (htab no.) as shown in Figure 25.

8.3.2.5. By combining Table 1 with Figure 25, we obtain the following information about VI distribution:

(a) At htab or step number 0,1,2 and 3, all areas were grouped and set to the same color, in this case Red (84), to represent all of the water area.

(b) Htab or step numbers 13 and 14, all forest with only a few pixels, were grouped htab or step numbers 15, 16 and 17, which do not have any pixels in this step, and set to Blue (252).

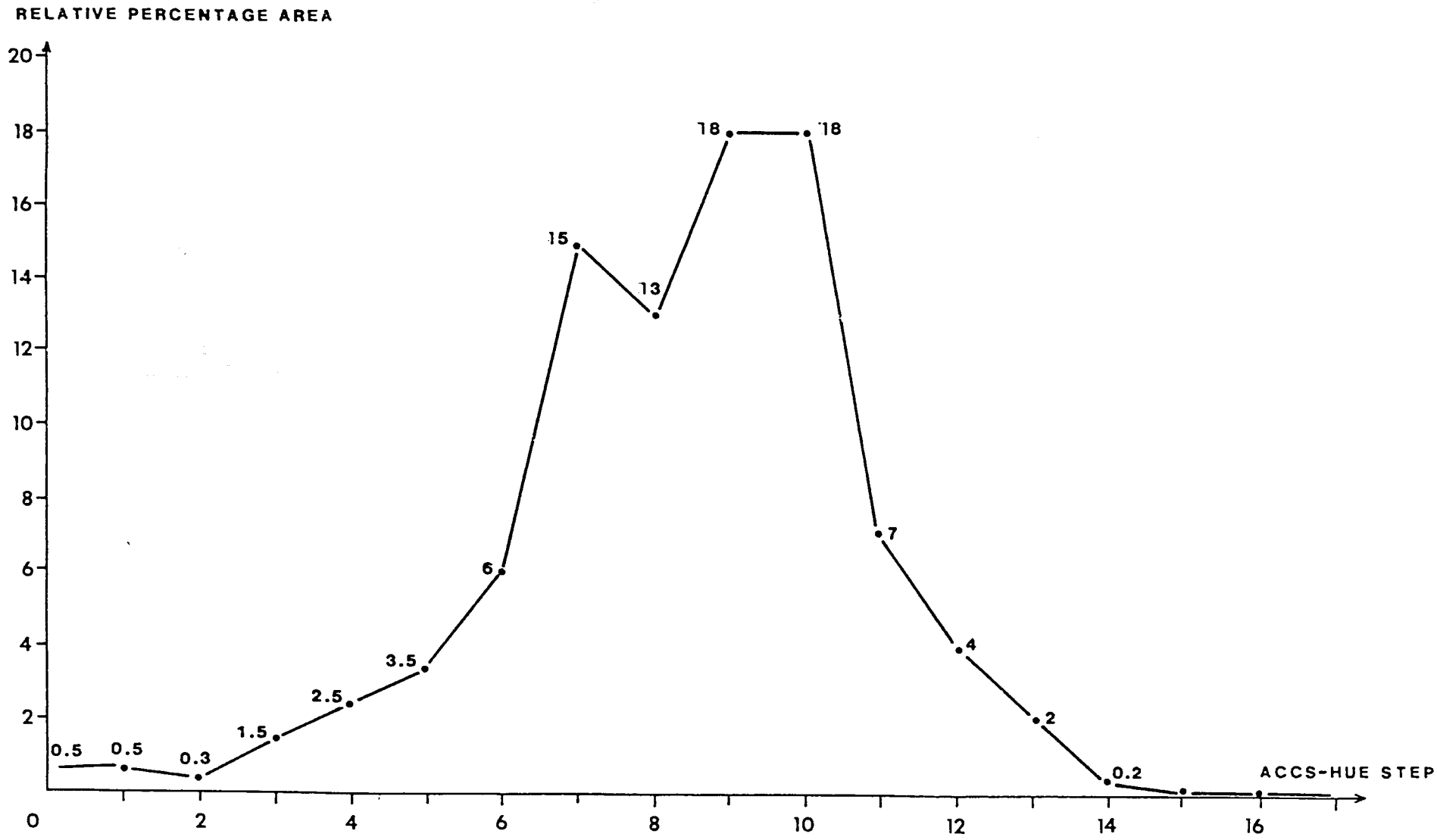


FIGURE 25: RELATIVE PERCENTAGE AREA HISTOGRAM.

(c) Because htab or step numbers 10 and 11 were a transition area between paddy field and orchard (crop to tree), it was advantageous to differentiate between these two kinds of vegetation as clearly as possible.

(d) From ACCS characteristics item 3, step number 10 (paddy field) was set to Green (152) and step number 11 (orchard) to Cyan (212), for the sharpest separation of color at the transition area.

(e) The ACCS-HUE ENHANCEMENT TABLE was built as shown in Table 2. First, the Red and Blue regions were set to the corresponding htab or step number. Second, Green and Cyan were set to the transition area. Third, the left htab or step was joined from R to G and C to B with a linear function. At this time linear function were used because of the time limitations in the training course but a systematic algorithm can be applied later. However, a linear scale between R to G automatically increases human perception in this region and between C to B perception will decrease a little bit compared with the ACCS-HUE parameter in Figure 26. In the future if any user has their own idea, some non-linear function or piecewise linear function may be used instead of a simple linear one depending on the application.

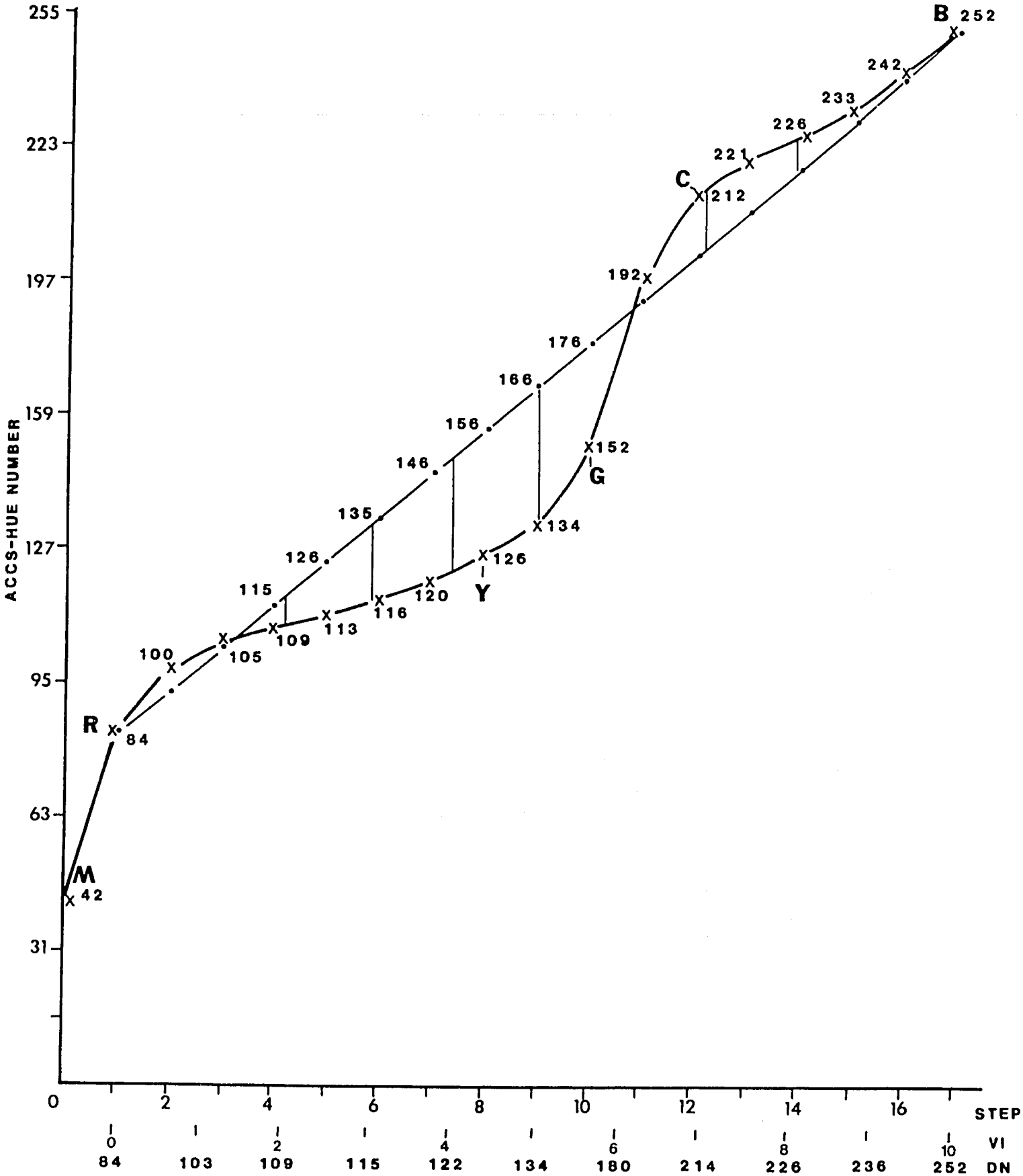


FIG 26: ACCS-HUE PARAMETER

Htab or Step no.	Hue Change From	Hue Change To	Explanation
0	42	42	nothing changes
1	84	84	
2	100	84	Refer to 8.3.2.5. a
3	105	84	
4	109	94	
5	113	104	
6	116	114	Refer to 8.3.2.5. e
7	120	124	(152 - 84)/7 = 10 (approx.)
8	126	134	
9	134	144	
10	152	152	Refer to 8.3.2.5. c & d
11	192	212	
12	212	232	Refer to 8.3.2.5. e; (252-212)/2=20
13	221	252	
14	226	252	
15	233	252	Refer to 8.3.2.5. b
16	242	252	
17	252	252	

Table 2: ACCS-HUE ENHANCEMENT TABLE for Central Thailand image 12/4/84, Diskette no. H4339C.30C.

Some examples of ACCS and ACCS-ENHANCED images of central Thailand on December 4, 1984 (H4339C.30C) are illustrated in Figures 27-30.

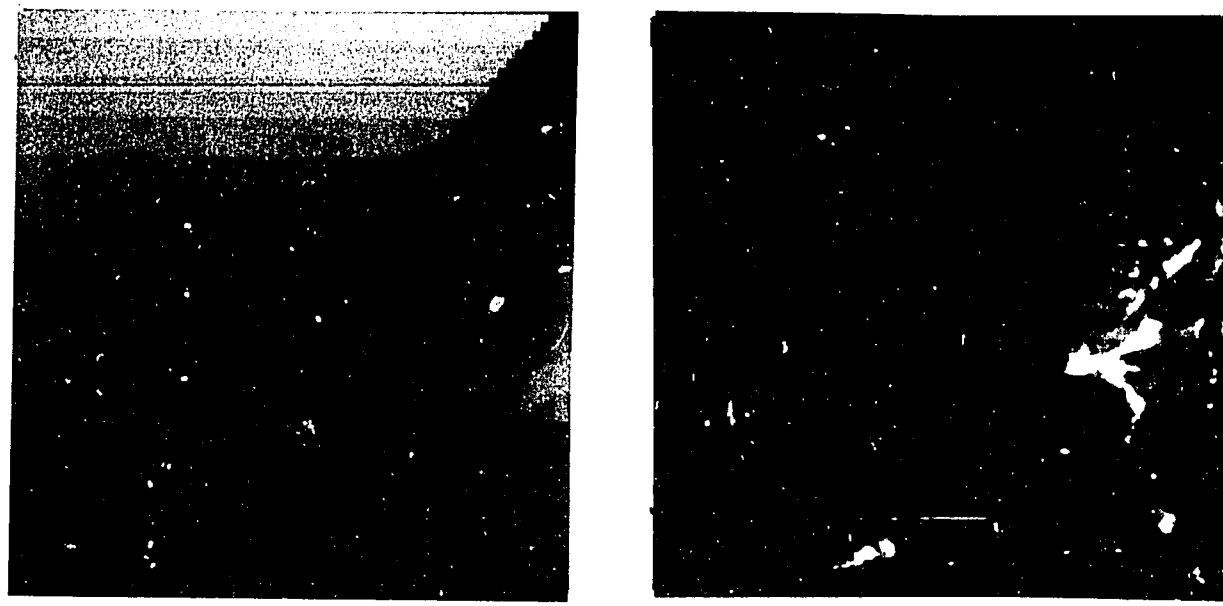


Figure 27. ACCS of central Thailand, image recorded on December 4, 1984.

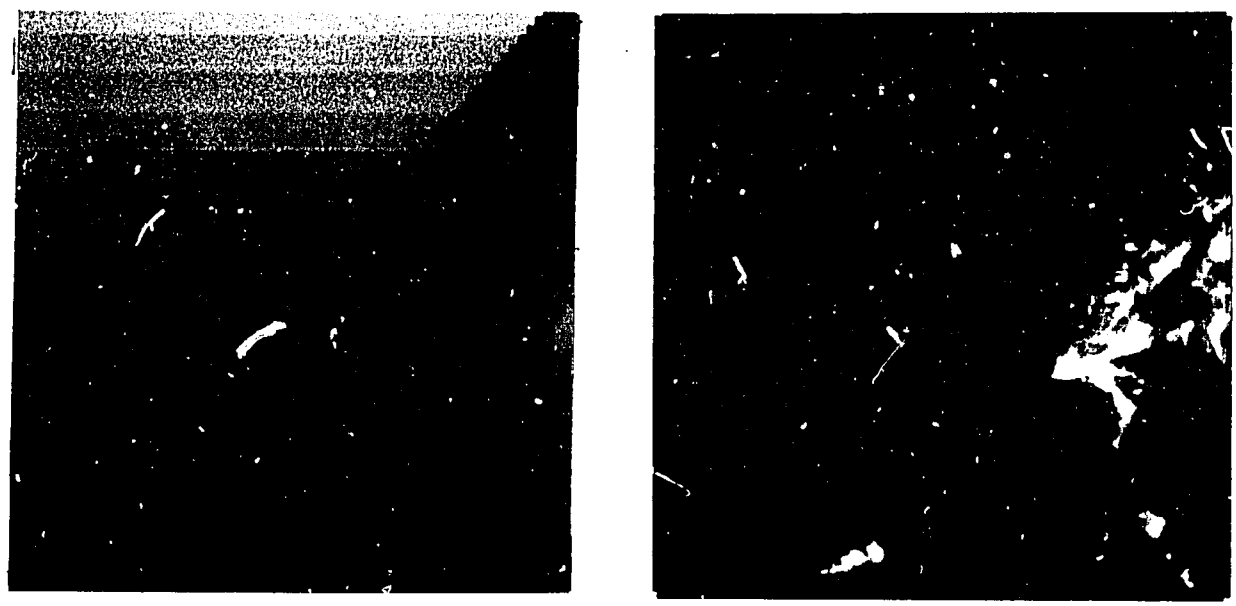


Figure 28. ACCS-ENHANCEMENT of central Thailand, image recorded on December 4, 1984.

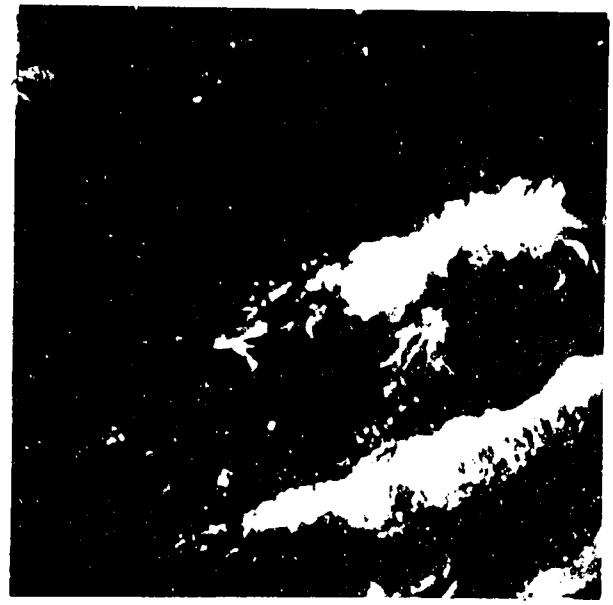


Figure 29: ACCS of central and northeast Thailand, image recorded on December 4, 1984.

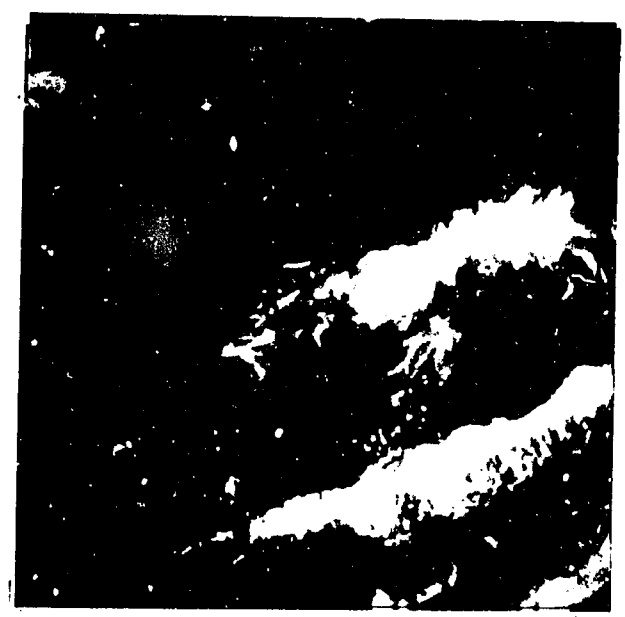


Figure 30: ACCS-ENHANCEMENT of central and northeast Thailand, image recorded on December 4, 1984.

9. Training Set Examples

Figure 31 provides a generalized flowchart of the steps taken in agro-climatic assessment. The text which follows outlines specific steps taken in this training program.

9.1. Data Selection and Production

An archive of photographs of Channel 2 images from the HRPT tapes collected in Thailand enables the user to select a study area which is as close to nadir and as cloud-free as possible. The Assessment and Information Services Center (AISC), Climatic Impact Assessment Division (CIAD) in Washington, D.C. transfers the processed image to an IBM floppy diskette and then forwards the data to the CIAD Models Branch in Columbia, Missouri. Here the study area is displayed with the Personal Computer Image Processor (PCIP) software (see Section 7) using the Ambroziak Color Coordinate System (ACCS) (see Section 8). Hard copes may be obtained by photographing the image directly from the color monitor. Later, a mosaic of photos may be made to provide larger area coverage.

9.2. Visual Interpretation

Direct visual interpretation is based on established photo interpretation factors such as size, shape, tone and color. Decisions in interpretation and classification are aided by use of crop calendars, land use maps, rainfall data and other ancillary materials. The classification system used to interpret the imagery recognizes three levels of complexity. The details of this system are outlined in Table 3.

Two areas were selected for study. The first covers most of northern Thailand (see Figure 32). A Level I analysis was performed. The final classified image and its legend are shown in Figures 33-34. The second area extends over central Thailand (see Figure 35). A Level I

AGRO-CLIMATIC ASSESSMENT FLOWCHART

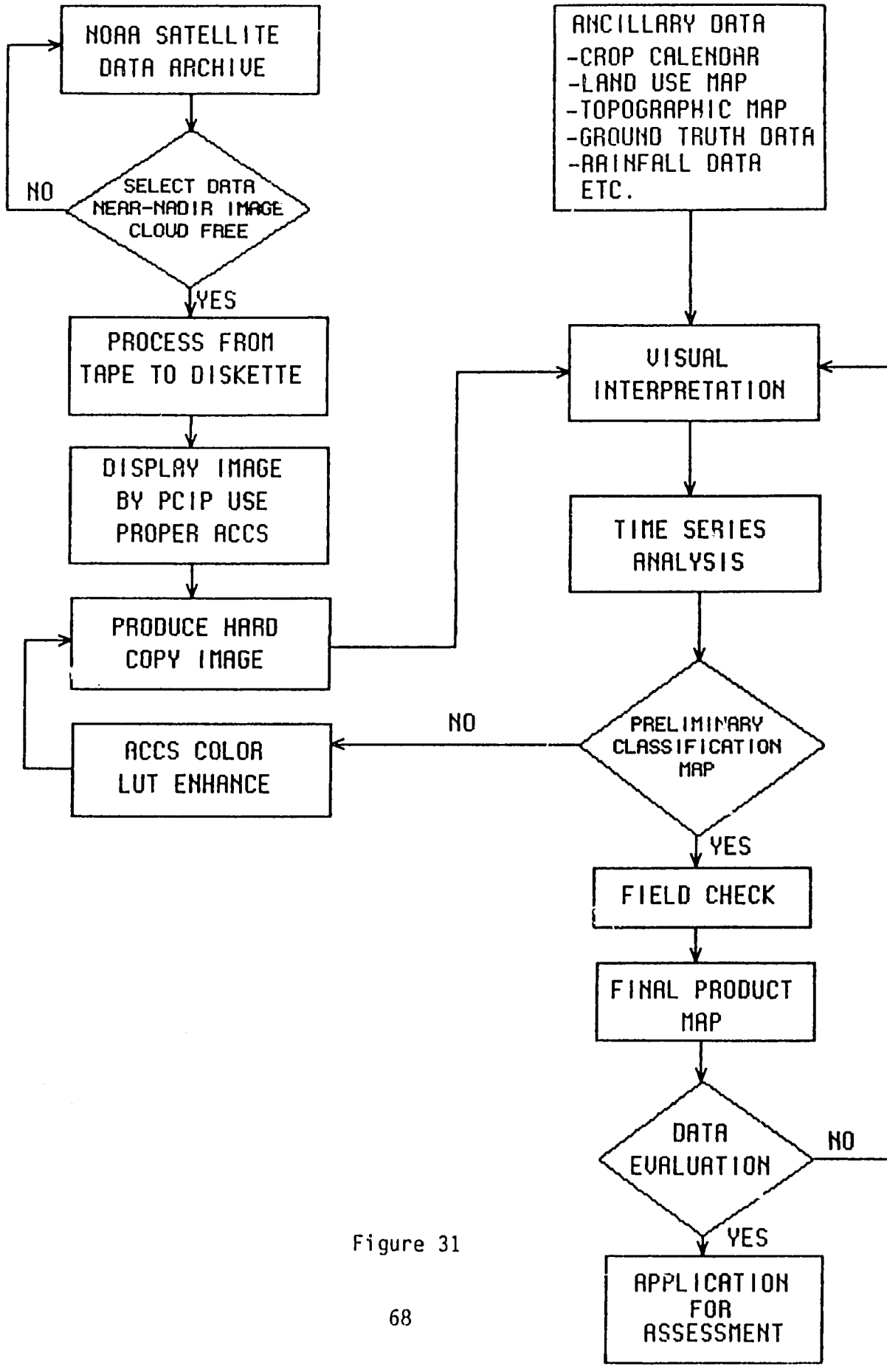


Figure 31

Land Use and Land Cover Classification System for Use with NOAA Imagery, Thailand

LEVEL I	LEVEL II	LEVEL III
1. Agricultural land	1.1 Paddy fields 1.2 Field crops 1.3 Orchards 1.4 Other agricultural land	1.1.1 Upland rice 1.1.2 Lowland rice 1.1.3 Floating rice 1.2.1 Corn 1.2.2 Sugarcane 1.2.3 Cassava 1.3.1 Horticulture 1.3.2 Rubber 1.4.1 After harvested land 1.4.2 Other
2. Forest land	2.1 Dense forest 2.2 Sparse forest 2.3 Mangrove forest 2.4 Mixed forest	
3. Water	3.1. River 3.2 Reservoir 3.3 Bay and Estuaries 3.4 Oceans	
4. Cloud	4.1 Cloud 4.2 Cloud shadow 4.3 Haze	
5. Other	5.1 Urban	

Table 3

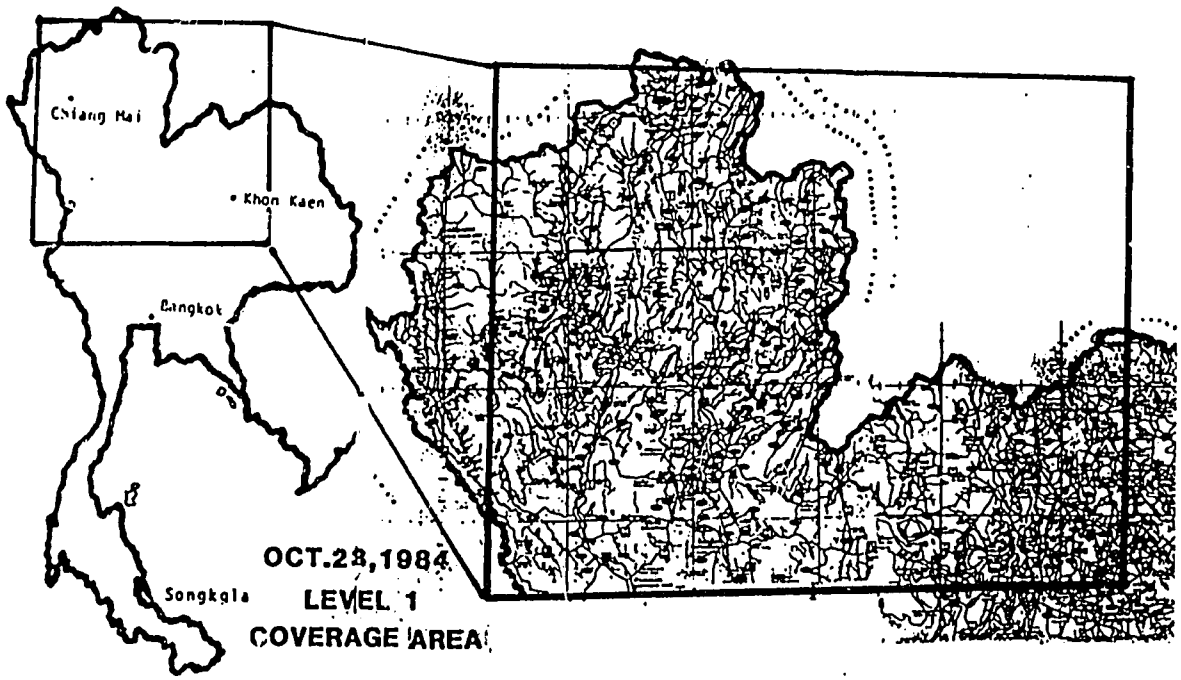


Figure 32

Color	Land Cover
yellow brown	lowland rice
dark brown	reservoir
green	sugarcane
dark blue	dense forest
black	reservoir

Figure 33: Legend to Accompany Figure 34.

NORTHERN AND UPPER PORTION OF NORTHEASTERN THAILAND
OCT. 23, 1984
(LEVEL I)

FIGURE 34

analysis was performed to provide a generalized view of the region (see Figures 36-37). Investigators then targeted a subregion within the area for Level II analysis (see Figures 38-40). Finally two smaller areas were selected for a more comprehensive Level III analysis (see Figures 41-43).

9.3. Time Series Analysis

Time series analysis is an effective way to monitor change in vegetative conditions. Two images of the same central Thailand area were selected to provide an illustration of this principle. The first, recorded October 23, 1984, is shown in Figure 44. The second, recorded December 4, 1984, is shown in Figure 43. The region covers part of the Bangkok metropolis and the Samutpakarn, Nonthaburi and Pathumthani provinces.

Changes are evident in at least three land cover types: horticulture, agriculture and urban. In areas of horticulture, note that the green and dark green colors in the earlier image have changed to dark green and blue. This would indicate an increase in the amount of vegetation or biomass, perhaps due to the influence of rainfall prior to December 4 (refer to rainfall data in the Appendix). Increased vegetation caused Channel 1 values to decrease and Channel 2 values to increase. Lower Channel 1 values are due to increased absorption and decreased reflectance of visible light. Increased Channel 2 values occur because of increased reflectance of near infrared radiation.

Most of the agricultural land in this area is comprised of paddy fields. Here the green and light green of the earlier image have paled to light green and yellow. This would indicated a decrease in biomass. Crop calendars help the interpreter. In the October image, the rice was in the flowering stage when leaf area index is at a maximum. As rice matures and

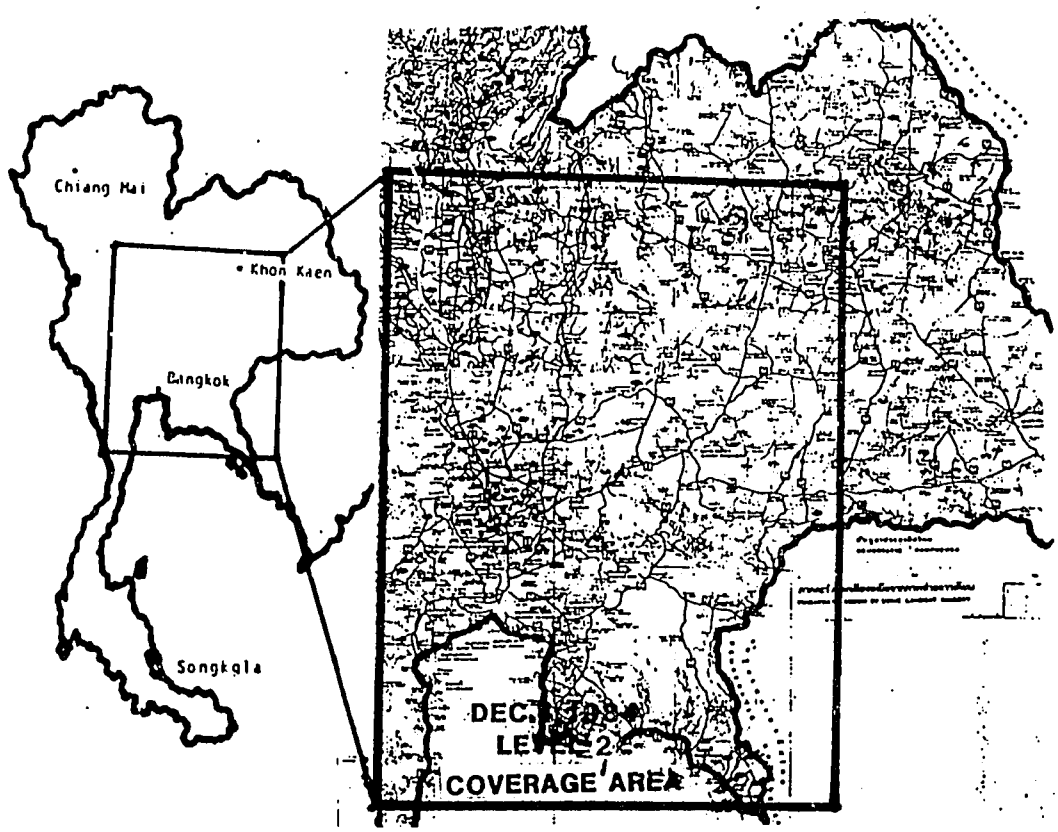


Figure 35

Color	Land Cover
brown	agricultural land
light green dark green blue	forest
black	water
white	cloud

Figure 36: Legend to Accompany Figure 37.

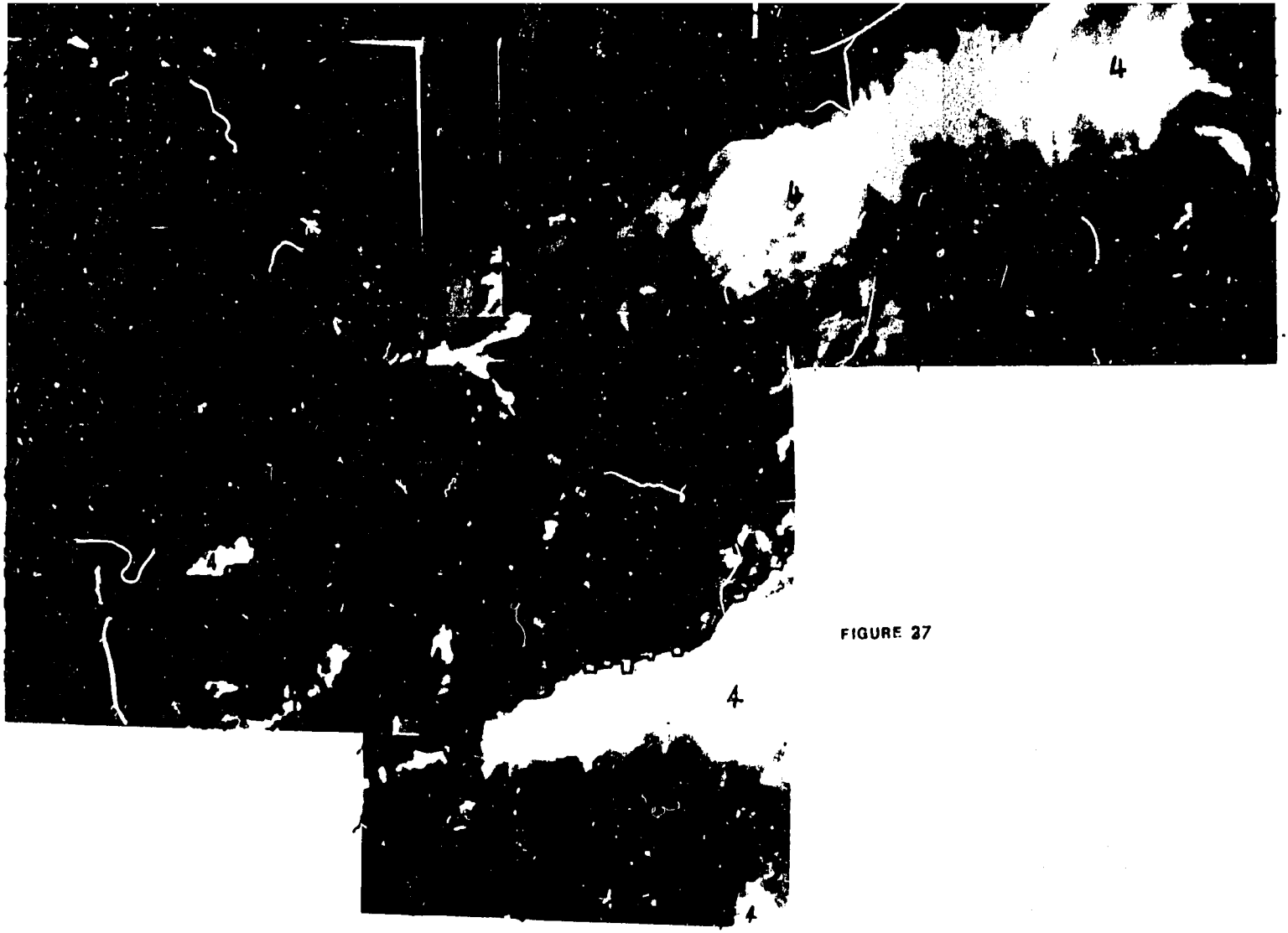
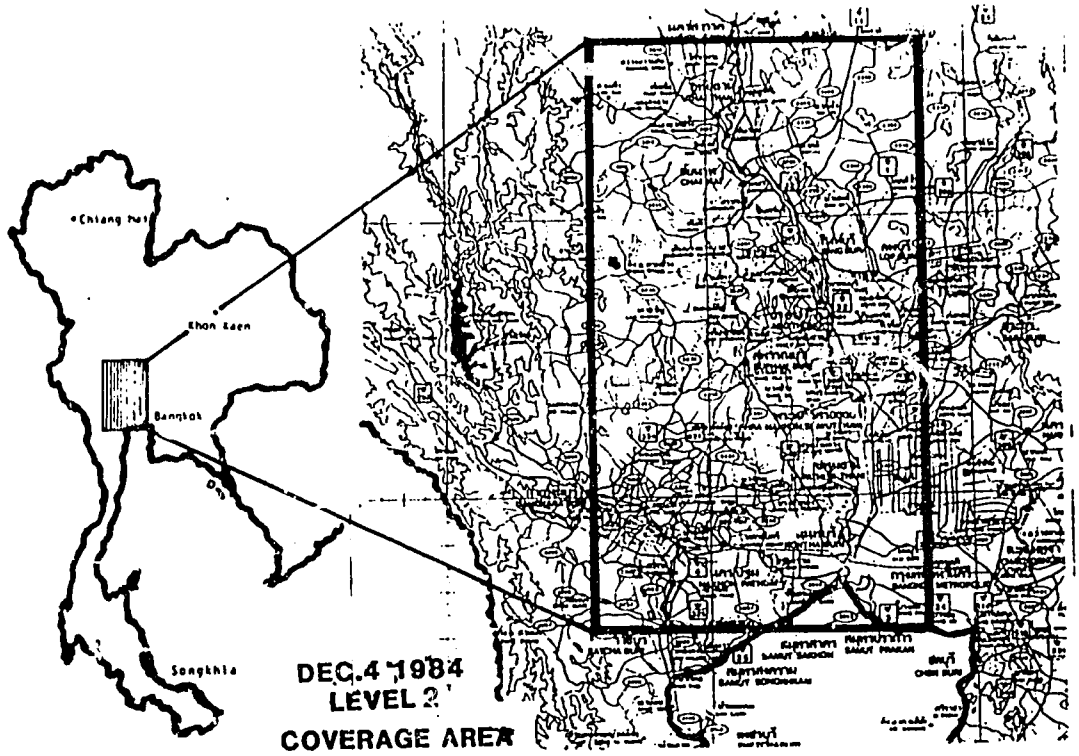
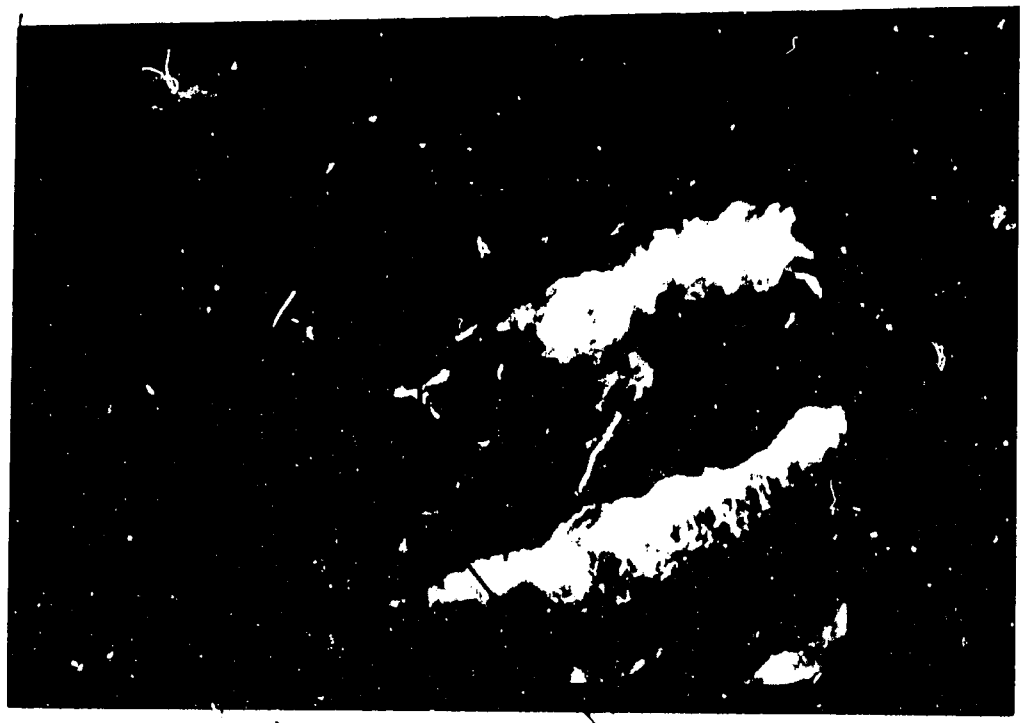


FIGURE 27



Color	Land Cover
yellow light brown brown	paddy fields, rivers
dark brown	paddy fields, mangrove forests, estuaries and urban areas
green	paddy fields
light blue	sparse forest
blue	dense forest
dark blue	field crops
biack	reservoir, ocean

Figure 39: Legend to Accompany Figure 40.



CENTRAL PART OF THAILAND
DEC. 4, 1984
(LEVEL II)

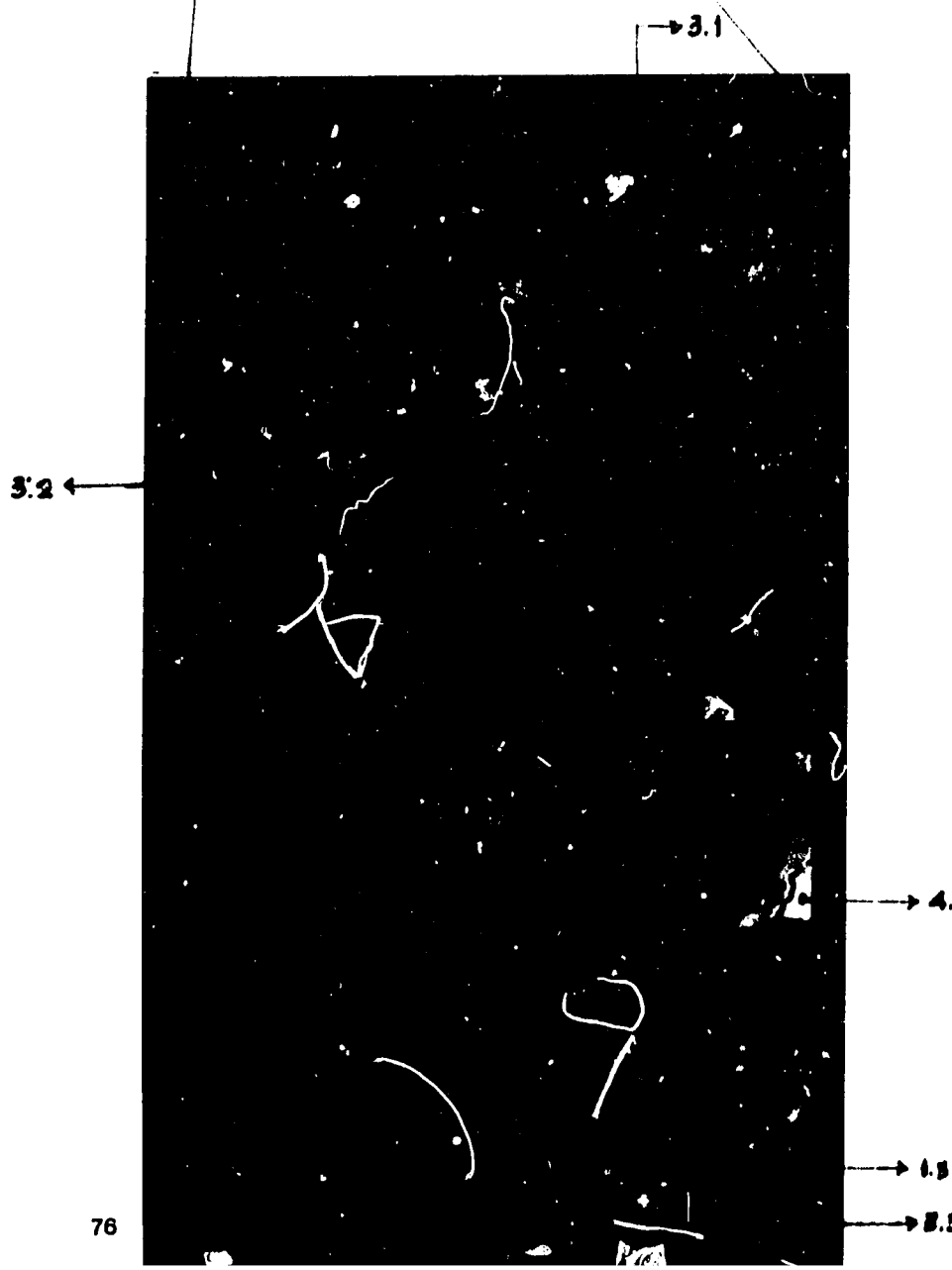


FIGURE 4D

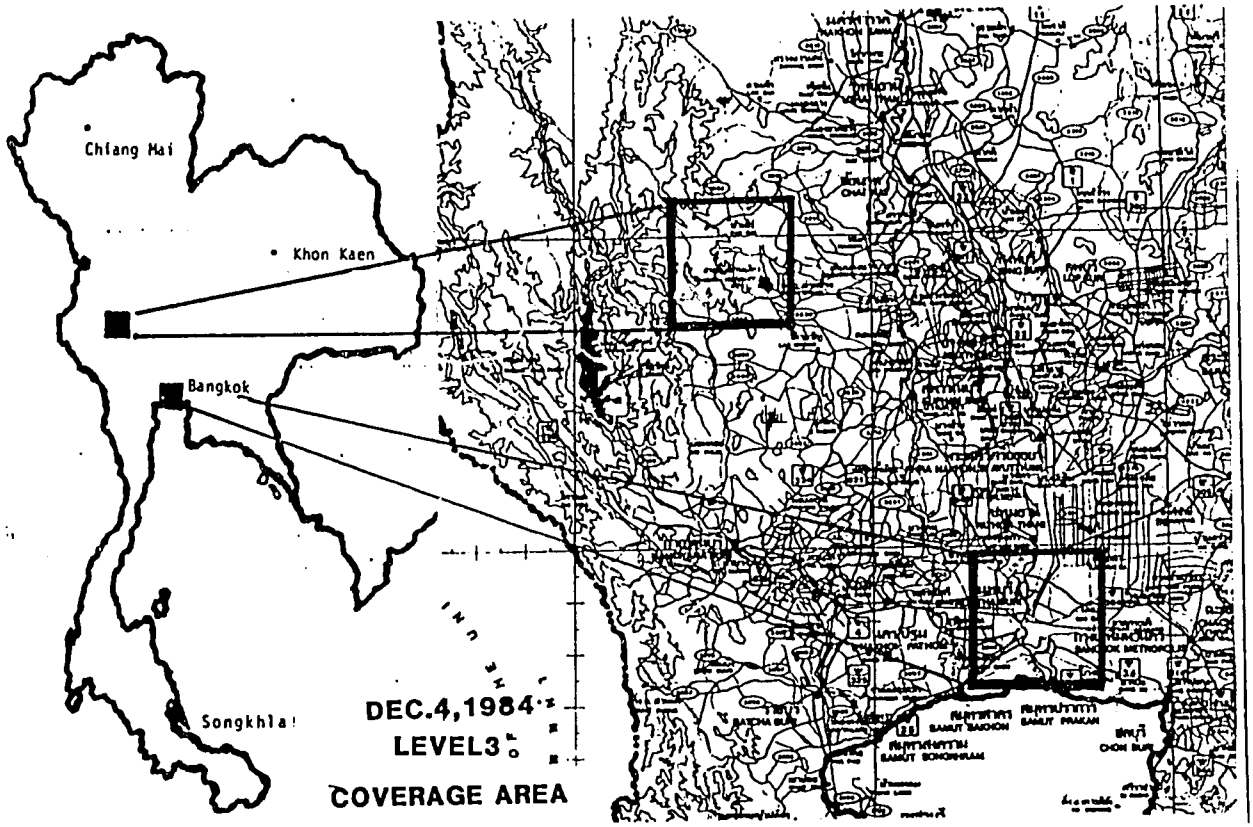

Chiang Mai
Khon Kaen
Bangkok
Songkhla
DEC.4,1984
LEVEL3
COVERAGE AREA

Figure 41

Color	Land Cover
yellow	river
light brown	lowland rice, harvested land, river
brown	floating rice, lowland rice, river, urban
dark brown	mangrove forest, estuaries, bays, urban
light green	lowland rice
green	lowland rice, river
dark green light blue blue	horticulture
violet	other
black	ocean

Figure 42: Legend to Accompany Figure 43.

CENTRAL AND UPPER CENTRAL PART OF THAILAND

DEC. 4, 1984

(LEVEL III)

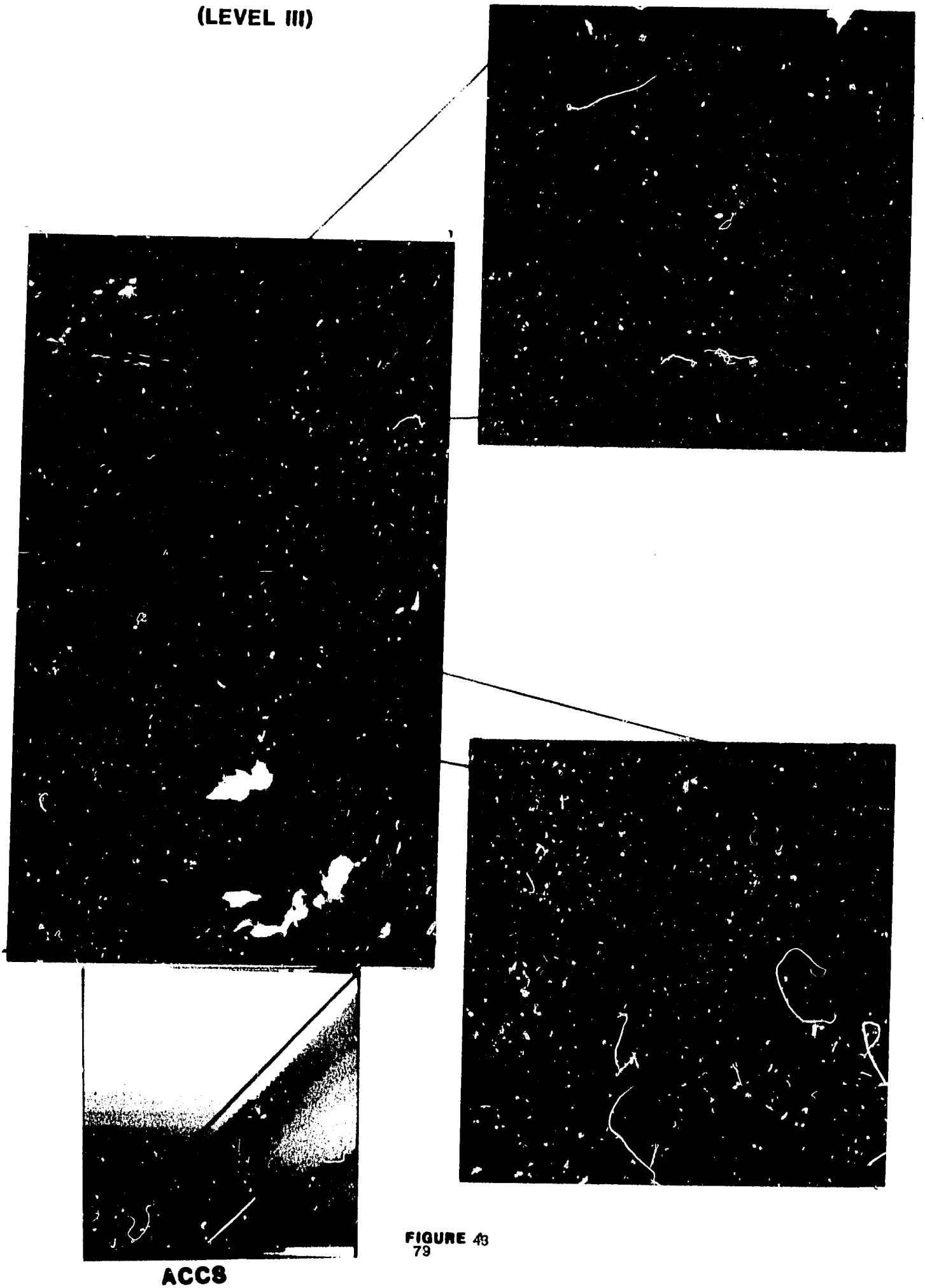


FIGURE 43

ACCS

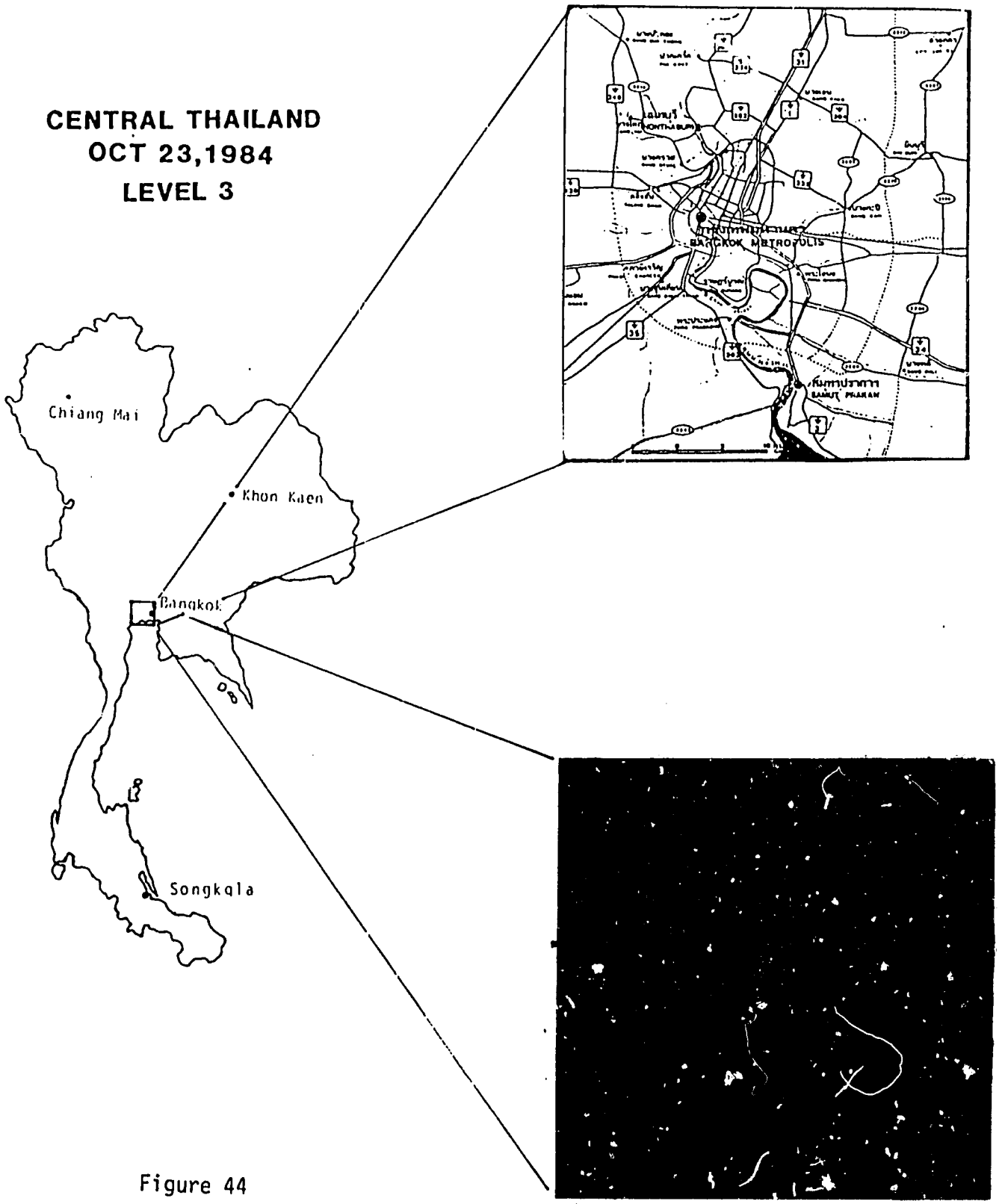
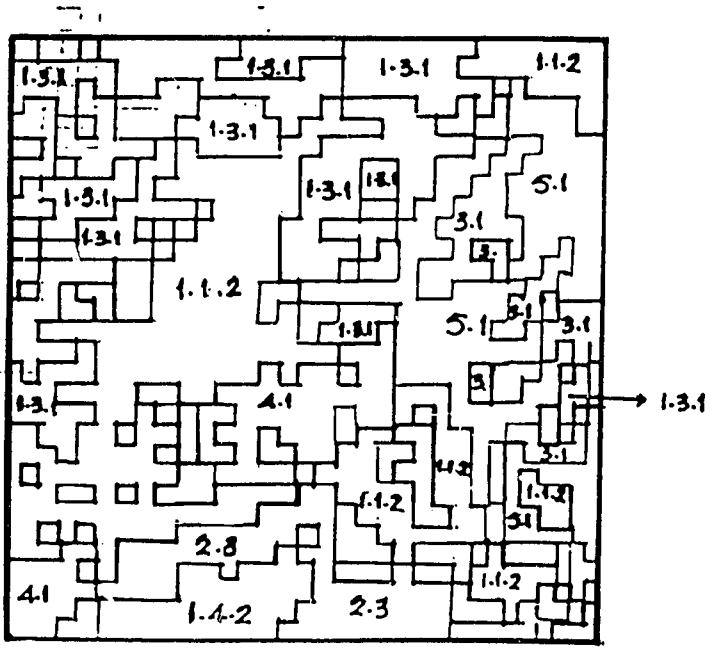

CENTRAL THAILAND
OCT 23,1984
LEVEL 3
Chiang Mai
Khon Kaen
Bangkok
Songkala
BANGKOK METROPOLIS

Figure 44


1.3.1
1.1.2
5.1
3.1
4.1
2.8
2.3
1.4.2

becomes ready for harvest, channel 2 values diminish, resulting in a lower vegetation index.

In the Bangkok urban area, brown shades are lighter in the later image and violet shades completely disappear. The earlier image reflects much wetter conditions due to both high tide and the southwest monsoon. By December, the area has become markedly drier.

9.4. Field Verification

Image interpretation must be checked by field verification. Because field checking is necessary for the correction of any misinterpretation, all of the data collected from field checks are used in correcting the preliminary classification map to improve map accuracy as follows:

1) Information is transferred from the preliminary classification map to 1:50,000 topographic maps of Thailand.

2) A random sampling method is used to determine field sample plots. It is recommended that there should be a minimum of five 1X1 kilometer plots per class.

Imagery in this report will be field checked upon return to Thailand.

10. Conclusions and Recommendations

10.1. Conclusions

This program focused on applications of NOAA satellite data for crop assessment in Thailand because of its drought vulnerability. The applications of NOAA satellite data for crop assessment developed during this program should be tested and evaluated before operational assessments are provided to users. Test assessments based on real-time NOAA satellite data can be provided to interested users in government. Assessments can be evaluated and verified according to user comments and reliable field reports. The usefulness of the crop indices and NOAA satellite data can then be determined.

The major goal of this training program is to help decision makers in the Center for Agricultural Statistics, Office of Agricultural Economics, Ministry of Agriculture and Cooperatives. The agroclimatic staff at the Meteorological Department is supplied data from the NOAA satellite in support of the crop assessment team as well.

The data is considered to have advantages for analysis in the areas of meteorology, fisheries, irrigation, agricultural assessment and land cover inventory.

Meteorology: It is believed that cloud classification, airmass analysis, rainfall estimation from convective clouds, and possibly land surface temperature can be derived from use of the AVHRR products.

Fisheries: Currently black and white imagery from the AVHRR sensor is used for analysis for fisheries. This project has not progressed very far due to a lack of information and data. Hopefully, the data will be of further use in fisheries analysis.

Irrigation: The damage of floods has been a major impact on the economy of Thailand. It is felt that a time series analysis from AVHRR

data may help in the assessment of damage to agricultural and possibly in flood forecasting. The Mekong River Committee, which is concerned with Thailand, Laos, Kampuchia and Vietnam could benefit from AVHRR data, as frequently the monsoon causes flooding in rice fields along the river.

Agricultural Assessment: The AVHRR data and ACCS can be useful in assessing the condition and trend of agricultural crops. To do this most effectively, data with minimal clouds is required and more experience in relating image tones to crop conditions must be completed. Further, the imagery derived in this training may be a useful input to the development of an area frame sampling methodology for Thailand.

Land Cover Imagery: The resolution and frequent coverage of Thailand by the AVHRR sensor permit the inventory of land cover of a coarse resolution possible on a more frequent basis.

NOAA satellite imagery is felt to be an efficient tool for study. This data source should be viewed as complimentary to higher resolution Landsat data for analyses requiring more detail. NOAA satellite imagery is cost effective and can be analyzed on a microcomputer. Further, this technology can easily be transferred to Thailand and interpretation of the ACCS images for crop assessment can be done faster and most cost effectively than with conventional images.

10.2. Recommendations

While this training has been effective, it is felt that the PCIP software would have more utility if histograms of channel 1, channel 2, and the normalized vegetations index for user selected areas could be displayed. It would also be helpful to be able to annotate the screen with

text before photographs are taken. There is also a need for the development of cloud removal techniques through compositing of LAC or HRPT data.

To proceed further with the analysis of NOAA satellite data requires access to hardware and software to be able to display and analyze the imagery. It is also necessary to field check the data upon return to Thailand. To most effectively integrate the satellite assessment into the operational agroclimatic assessment processes, the following organizational structure is suggested:

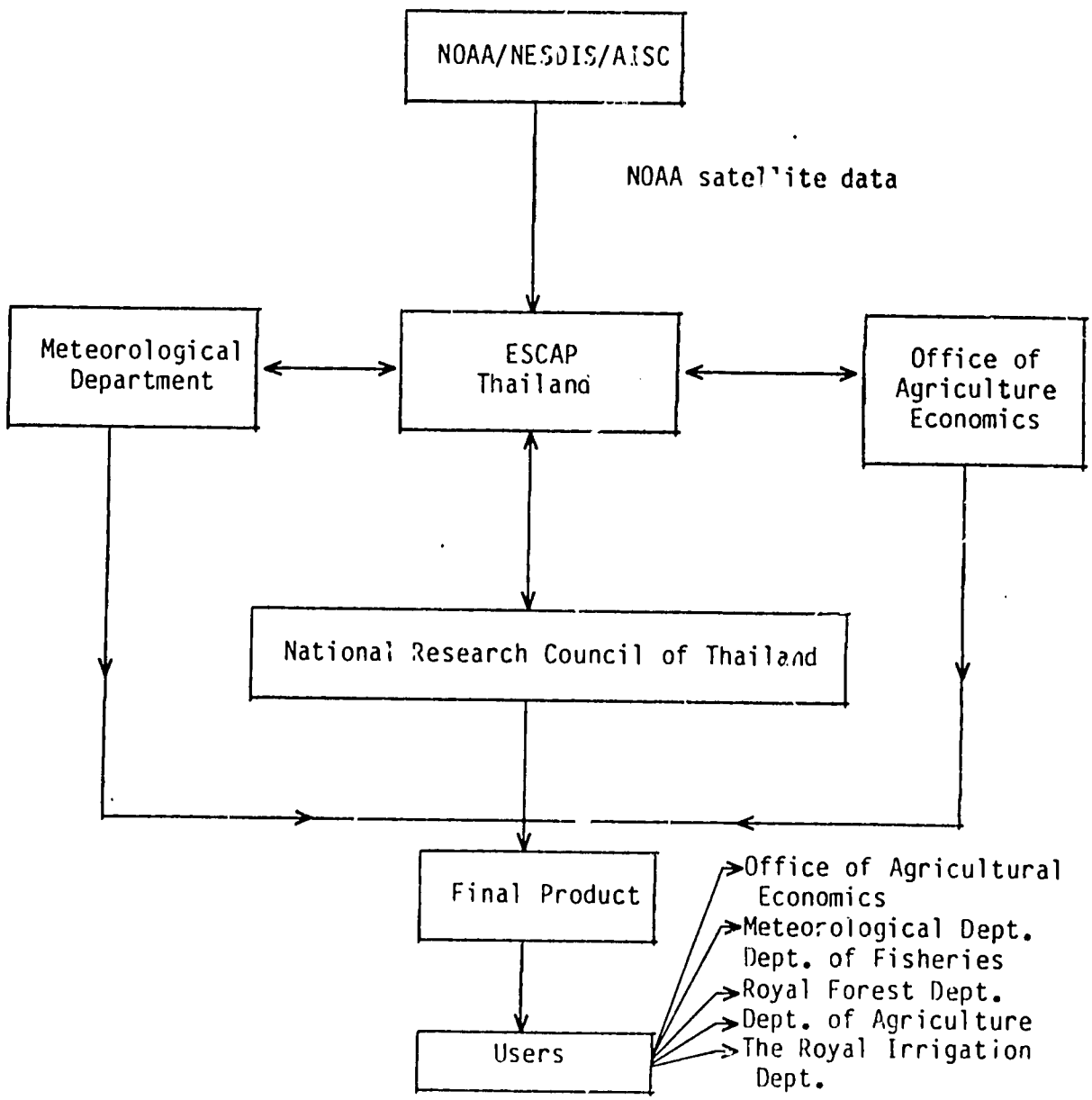


Figure 45: Proposed Organizational Structure for Integration of Satellite Data into Agroclimatic Assessment

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12. Glossary

ABSORPTANCE: A measure of the ability of a surface to absorb incident energy, often at specific wavelengths.

ABSORPTION: The process by which radiant energy is absorbed and converted into other forms of energy.

ACCS: Ambroziak Color Coordinate System. A method of display based on intensity, hue and saturation which is helpful for interpretation of an image.

ACCS-2b: A form of the ACCS which cycles the hues at twice the rate of that used in the ACCS. The 2b represents two sides of the color triangle between index values of zero and one, with blue on the diagonal or zero index value (45° angle of the color triangle).

ACCS-2r: Same as the ACCS-2b, except that the 2r represents two sides of the color triangle between index values of zero and one, with red on the diagonal or zero index value (45° angle of the color triangle).

ARBITRARY INDEX COLOR SYSTEM (AICS): A color system which uses a few colors to maximize perceptual resolution. This system does not contain all of the image information generally desired.

ASCENDING NODE (AN): The point at the equator at which the satellite in its orbital motion crosses from the southern to the northern hemisphere. Terrestrial Ascending Node (TAN) is given in degrees longitude. Celestrial Ascending Node (CAN) is given on right ascension hours, minutes, etc.

ATMOSPHERIC ATTENUATION: The reduction of radiation intensity due to absorption and/or scattering of energy by the atmosphere; usually wavelength dependent; may affect both solar radiation traveling to the earth and reflected/emitted radiation traveling to the sensor from the earth's surface.

ATMOSPHERIC WINDOWS: Those wavelength ranges where radiation can pass through the atmosphere with relatively little attenuation; in the optical portion of the spectrum, approximately 0.3 to 2.5, 3.0 to 4.0, 4.2 to 5.0, and 7.0 to 15.0 μm.

ATTITUDE (SATELLITE): The position of the axis of a satellite with respect to (a) its orbital plane, (b) the earth's surface, or (c) any fixed set of coordinates.

AVHRR: Advanced Very High Resolution Radiometer; part of the payload on board the NOAAn satellites.

AZIMUTH (α): A horizontal direction expressed in degrees measured clockwise from an adopted reference direction, usually true north.

BACKGROUND: The area on an image or the terrain that surrounds the area of interest or target.

BAND: A wavelength interval in the electromagnetic spectrum.

BLACKBODY: An ideal absorber and ideal radiator which absorbs all the radiant energy incident upon it and emits radiation at all wavelengths.

BRIGHTNESS: The attribute of visual perception in accordance with which an area appears to emit more or less light.

CCT: Computer Compatible Tape, the magnetic tape upon which the digital data for the satellite images are recorded, suitable for analysis on a general purpose computer.

CELL: An area on the ground from which EMR is emitted or reflected.

CLASSIFICATION: The process of assigning individual pixels of a multispectral image to categories, generally on the basis of spectral-reflectance characteristics.

CLUSTERING: The analysis of a set of measurement vectors to detect their inherent tendency to form clusters in multidimensional measurement space.

COLOR: That property of an object which is dependent on the wavelength of light it reflects, or emits.

COLOR COMPOSITE IMAGE: A color image prepared by projecting individual black and white multispectral images in color.

COVERAGE: The ground area represented on aerial photographs, photomosaics, or maps.

DATA: Numerical or quantitative notations.

DATA-ACQUISITION SYSTEM: The collection of devices and media which measures physical variables and records them prior to input to the data-processing system.

DATA COMPRESSION: Any technique that condenses the available data so as to make data storage or transmission more efficient with minimal loss of information.

DECLINATION (δ): The angular distance of an object north (+) or south (-) from the celestial equator measured along the hour circle passing through the object.

DENSITY: In an optical image a point-by-point measure of the degree of blackness; often used in a more general sense to refer to relative intensities in remote sensing data.

DESCENDING NODE (DN): The southbound equator crossing of the satellite; given in degrees longitude, date, and time for any given orbit or pass.

DISTORTION: On an image this refers to changes in shape and position of objects with respect to their true shape and position.

ELECTROMAGNETIC RADIATION (EMR): Energy propagated in the form of an advancing interaction between electric and magnetic fields (EMR).

ELECTROMAGNETIC SPECTRUM: The ordered array of known electromagnetic radiations.

EMISSION: The process by which a body emits electromagnetic radiation, usually as a consequence of its kinetic temperatures.

FALSE COLOR IR SYSTEM: A color coordinate system in which the colors are shifted towards the longer wavelengths. In this system, blue is generally dropped, green is assigned a blue color, red becomes green, and near IR is represented as red.

FAR INFRARED: A term for longer wavelengths of the infrared region, from 7.0 μm to 15.0 μm.

FEATURE: In pattern recognition, one of the measurements of a pattern or a mathematical transformation of such measurements; in remote sensing, often the reflectance measurement in one channel of the sensor. The number of features associated with a pattern defines its dimensionality.

FORMAT: Size and scale of an image.

GAC: Global Area Coverage, an image format of the AVHRR data of the NOAA satellite; each pixel represents an area of about 16 km^2.

GEOMETRIC TRANSFORMATIONS: Adjustments made in the image data to change its geometric character, usually to improve its geometric consistency or cartographic utility.

GMI: Gray-McCrary index, a vegetation index constructed from the NOAA-AVHRR data, calculated as follows: $GMI = Ch_2 - Ch_1 + 100$.

GROUND RECEIVING STATION: A facility that records image data transmitted by a satellite.

HUE: The attribute of a color that differentiates it from gray of the same brillance and allows it to be classed as blue, green, red or intermediate shades of these colors.

IMAGE: The representation of a scene as recorded by a remote sensing system. Although image is a general term it is commonly restricted to representations acquired by non-photographic methods.

IMAGERY: The product of image forming instruments (analogous to photography).

INFRARED (IR): Pertaining to energy in the 0.7 - 100 μm wavelength region of the electromagnetic spectrum. For remote sensing, the infrared wavelengths are often subdivided into near infrared (0.7 - 1.3 μm), middle infrared (1.3 - 3.0 μm) and far infrared (7.0 - 15.0 μm). Far infrared is sometimes referred to as thermal or emissive infrared.

INSTANTANEOUS FIELD OF VIEW: A term specifically denoting the narrow field of view designed into scanning radiometer systems.

INTENSITY: Apparent brightness of light.

IRRADIANCE: The measure of radiant flux per unit area falling on the surface of a body.

LAC: Local Area Coverage, an image format of the AVHRR data of the NOAA satellite. (One pixel represents an area of about 1.2 km^2.)

LAI: Leaf Area Index; can be defined by the averaged leaf area per ground area occupied by a crop.

LOOK ANGLE: Direction of the look or direction in which the sensor is pointing when transmitting or receiving from a particular cell.

MICROMETER: (μm) a unit of length equal to 10^{-6} of a meter or 10^{-3} millimeter.

MIXED PIXEL: A pixel containing more than one target.

MSS: Multispectral Scanner.

MULTISPECTRAL SCANNER: A line-scanning sensor which uses an oscillating or rotating mirror, a wavelength-selective dispersive mechanism, and an array of detectors to measure simultaneously the energy available in several wavelength bands, often in several spectral regions. The movement of the platform usually provides for the along-track progression of the scanner.

NADIR: The point on the ground vertically beneath the perspective center of a remote sensing system.

NEAR INFRARED: Part of the electromagnetic spectrum that includes wavelengths from 0.7 to 1.3 micrometers.

NESDIS: National Environmental Satellite, Data, and Information Service.

NOAA: National Oceanic and Atmospheric Administration.

NODE: The points at the equator at which the satellite in its orbital motion crosses the equator. The line connecting the ascending and the descending nodes is called the line of nodes.

NOISE: Random or repetitive events that obscure or interfere with the desired information.

ORBIT: The path of a satellite around a body under the influence of gravity.

PATTERN RECOGNITION: The automated process through which unidentified patterns can be classified into a limited number of discrete classes through comparison with other class-defining patterns or characteristics.

PAYLOAD: Equipment a satellite carries necessary for the operation of the vehicle during its flight.

PERCEPTUAL RESOLUTION: The perceived resolution of a color coordinate system by the mind.

PIXEL: Picture Element is the area on the ground represent represented by each digital value.

PSG: Polar Stereographic projection; a cartograhic projection of the sphere in which the point of sight is at the center and the plane of projection passes through one of the polar circles.

RADIANCE: Radiant flux (watts)

RADIATION: The propagation of energy in the form of electromagnetic waves.

RADIOMETRIC CORRECTION: All those operations intended to correct known faults in the image due to sun angle differences, differences in instrument calibration, and differences in atmospheric conditions.

REAL TIME: To make images available for interpretation simultaneously with their acquisition.

REFLECTANCE: The ratio of radiant energy reflected by a body to that incident upon it.

REGISTRATION: The process of geometrically aligning two or more sets of image data such that resolution cells for a single ground area can be digitally or visually superimposed. Data being registered may be of the same type, from very different kinds of sensors, or collected at different times.

REMOTE SENSING: The collection of information or electromagnetic radiation from an object without being in physical contact with the object.

RESOLUTION: The ability of an entire remote sensor system to render a sharply defined image (lines per mm).

SATELLITE: An object in orbit around a celestial body.

SATURATION: The degree to which hue is undiluted by white light.

SCALE: Ratio of the distance on an image to the equivalent distance on the ground.

SCAN LINE: The narrow strip on the ground that sweeps across the flight direction of the detector in a scanner system.

SENSOR: Any device which gathers energy (EMR) or other data and presents it in a form suitable for obtaining information about the environment.

SPECTRAL BAND: An interval in the EMR spectrum defined by two wavelengths, frequencies or wave numbers.

SPECTRAL RESPONSE: The response of a material as a function of wavelength to incident electromagnetic energy, particularly in terms of the measurable energy reflected from and emitted by the material.

SPECTRAL SIGNATURE: The spectral characterization of an object or class of objects on the earth's surface. Often used in a way which naively oversimplifies the complexity of the spectral representation problem in a natural scene.

SPECTROMETER: An optical instrument used to measure the apparent electromagnetic radiation emanating from a target in one or more fixed wavelength bands or sequentially through a range of wavelengths.

SUN-SYNCHRONOUS ORBIT: Nominally a retrograde, quasi-polar orbit such that the satellite crosses the equator on the ascending node always at the same local (solar) time.

SWATH WIDTH: The overall plane angle or linear ground distance covered by a multispectral scanner in the across-track direction (transverse to the direction of travel of the sensor platform).

SYNCHRONOUS SATELLITE: A satellite in a west-to-east orbit of the earth at an altitude of 22,300 statute miles. At this altitude it circles the axis of the earth once in 24 hours. Thus its speed in orbit is synchronous with the earth's rotation.

TARGET: The portion of the earth's surface which produces by reflection or emission the radiation measured by the remote sensing system.

TERRESTRIAL: The term used to designate a line or a point on the earth's surface.

TRACK: The actual path of an aircraft above the surface of the earth.

VEGETATION INDEX: Mathematical combination of the different bands that have been found to be sensitive indicators of the presence of green vegetation.

VISIBLE RADIATION: Energy at the wavelength from 0.4 to 0.7 μm, that is detectable by the eye.

ZENITH: The point in the celestial sphere that is exactly overhead as opposed to Nadir.

13. Appendices

1. Equipment and Cost
2. Crop Calendar
3. Land Uses of Thailand in 1983.
4. Legend
5. Agro-Economic Zone
6. Land Utilization by Agro-Economic Zone and Province, Year 1982.
7. Monthly and Annual Rainfall of Thailand 1984.

EQUIPMENT AND COST

Satellite Agroclimatic Assessment

Models Branch, Columbia, MO U.S.A.

IBM PC XT Micro Computer with 256K RAM	$3,000.00
1 360K Floppy Disk Drive	
1 10M Hard Disk	

OR

IBM PC Micro Computer with 256K RAM	$2,000.00
2 360K Floppy Disk Drive	
Color Graphics Board	$250.00
Monochrome Monitor	$200.00
Number Nine Graphics Board	$2,000.00
Hitachi High Res. RGB Monitor HM-2719	$3,000.00
Total cost with/XT	$8,450.00
Total cost with/PC	$7,450.00

CROP CALENDAR

Area/Country	Region/Station	Crop	Season	J	F	M	A	M	J	J	A	S	O	N	D
Thailand	Central	Maize	Main					///	//		000	00			
		Rice	Broadcast	000				///	///	//					000
			Main	000				///	-+++	//—	—				000
			Secondary	///	-+++	—		000	000						
	East	Maize	Main					///	//		000	00			
		Rice	Broadcast	000				///	///	//					000
			Main	000				///	-+++	-++-	—				000
	Khorat, Plateau	Maize	Main					///	//		000	00			
		Rice	Main				//	-+++	-++-	—				000	00
	Northeast	Rice	Main				//	-+++	-++-	—				000	00
	Northern Hills	Rice	Main				//	-+++	-++-	—				000	00
	Northern Plains	Maize	Main					///	/		000	00			
		Rice	Main				//	-+++	-++-	—				000	00
	Southcentral	Rice	Main	000	00				///	-+++	—				00
	Southeast	Rice	Main		000	00				//	-+++	-++-	—		
	Southwest	Rice	Main	00				//	-+++	-++-	—				000
	West	Maize	Main					///	//		000	00			
		Rice	Broadcast	000				///	///	//					000
			Main	000				///	/-++	-++-	—				000

/ plant
- transplant
0 harvest

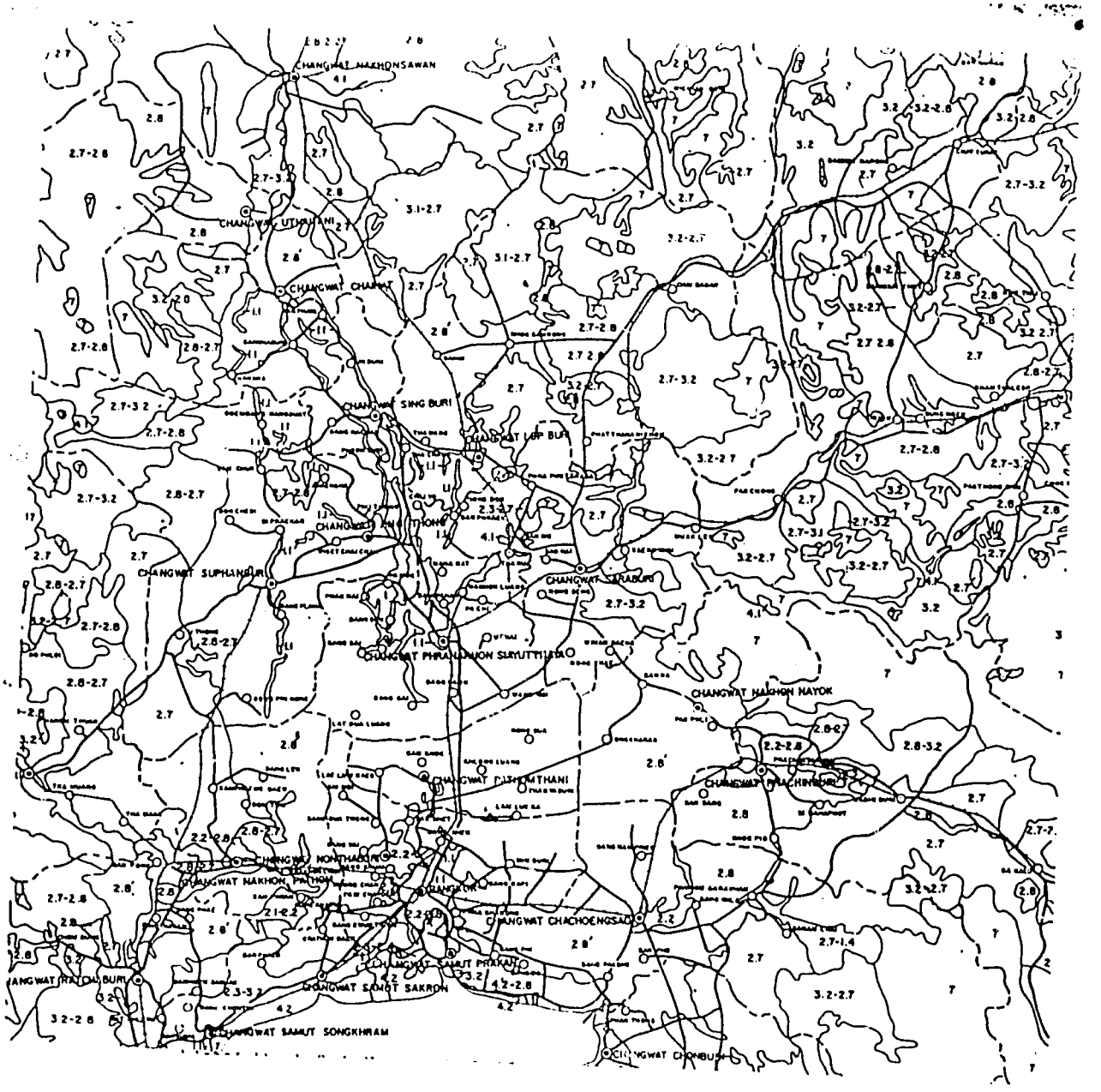
LAND USES OF THAILAND IN 1983

Interpreted from Landsat Imageries

Scale 1:1,000,000

Land Development Department

Ministry of Agriculture and Cooperatives



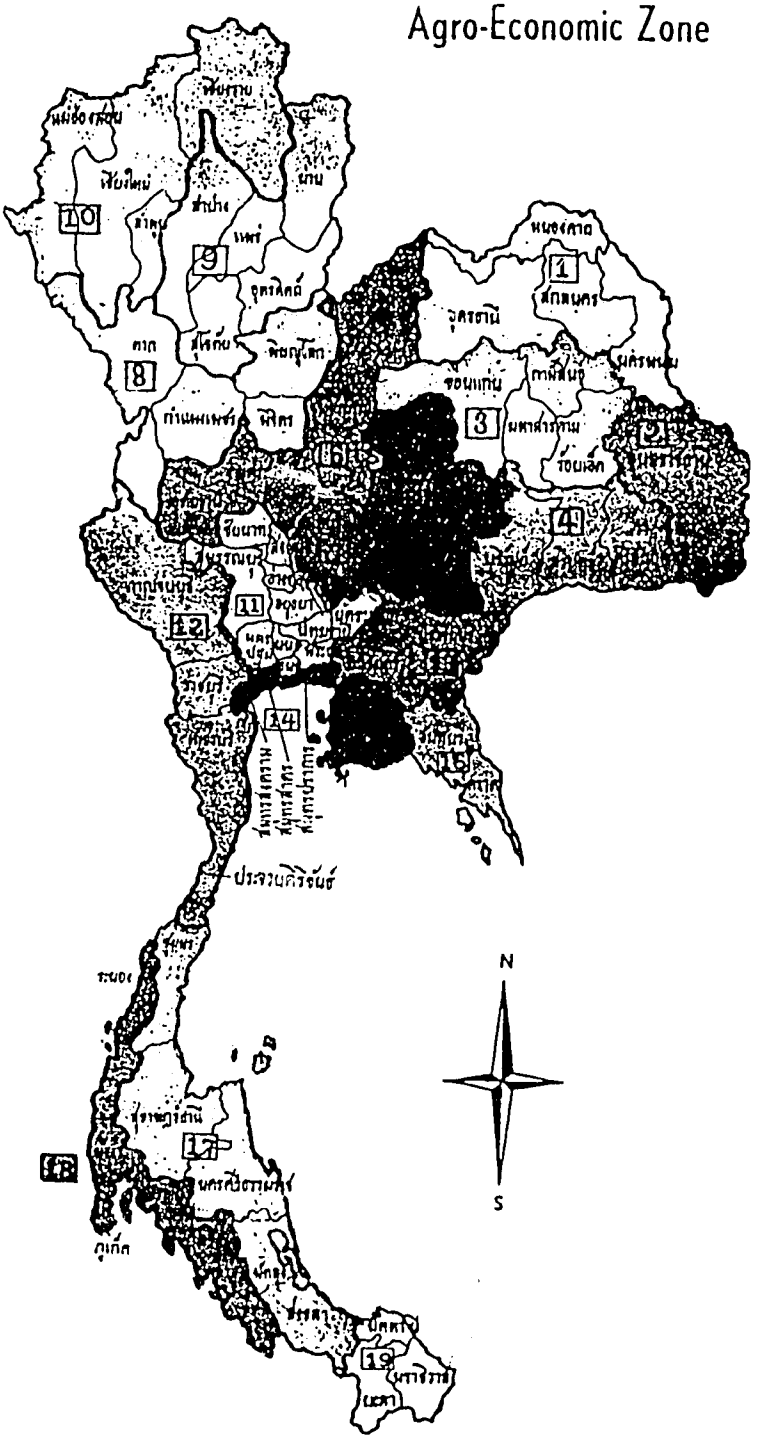
LEGEND

- Road, hard surface, two or more lanes wide
- Railroads
- River, stream.
- Primary administrative division boundary (Changwat)
- Changwat, Amphoe offices
- Mapping boundary
- International boundary.

Description	Area		Percentage
	Rai	Km²	
1. Urban land	1,444,810	2,311.696	0.45
1.1 Residential	1,050,804	1,681.286	0.33
1.2 Airfield	32,422	51.875	0.01
1.3 Institutional	49,923	79.877	0.01
1.4 Industrial, mines	311,661	498.658	0.10
2. Agricultural land	147,002,887	235,204.619	45.84
2.1 Horticultural	88,061	140.897	0.03
2.2 Orchards and Perennial trees	2,682,263	4,291.621	0.84
2.3 Coconut	2,178,113	3,484.981	0.68
2.4 Rubber	9,340,537	14,944.859	2.91
2.5 Oil palm	245,030	392.048	0.08
2.6 Sugar palm	162,490	259.984	0.05
2.7 Field crops	48,462,508	77,540.013	15.11
2.8 Paddy	71,076,708	113,722.733	22.16
2.8 Irrigated paddy	12,644,385	20,231.016	3.94
2.9 Lotus	122,792	196.467	0.04
3. Pasture and range land	33,091,803	52,946.884	10.32
3.1 Pasture	1,089,339	1,742.942	0.34
3.2 Idle land	32,002,464	51,203.942	9.98
4. Water	2,879,965	4,607.944	0.90
4.1 Reservoirs	2,431,074	3,889.718	0.76
4.2 Fish and shrimp ponds	448,891	718.226	0.14
5. Miscellaneous land	1,626,462	2,602.334	0.51
6. Barren land, rock outcrop	126,975	203.160	0.03
7. Others	134,523,985	215,238.377	41.95
Total	320,696,887	513,115.019	100

Remarks; Two units associating in proportion 70 ≈ 30 %

Three units associating in proportion 50 ≈ 30 ≈ 20 %


Agro-Economic Zone
N
S

LAND UTILIZATION BY AGRO-ECONOMIC ZONE AND PROVINCE, YEAR 1982

Source: Agricultural Statistics of Thailand Crop Year 1983/84
Center for Agricultural Statistics
Office of Agricultural Economics
Ministry of Agriculture and Co-operatives

Unit : rai

Agro-Economic Zone and Province	เนื้อที่ทั้งหมด Total land	เนื้อที่ป่าไม้ Forest land	เนื้อที่ถือครองทางการเกษตร Farm holding land								เนื้อที่ไม่จำแนก Unclassified
			ที่อยู่อาศัย Housing area	ที่นา Paddy land	ที่ไร่ Under field crops	ที่ไม้ผลและไม้ยืนต้น Under fruit tree & tree crops	ที่ผักและไม้ดอก Under vegetable & flowers	ที่ทุ่งหญ้าเลี้ยงสัตว์ Grass land	ที่ว่างเปล่า Idle land	ที่อื่น ๆ Other land	
Whole Kingdom	320,696,883	97,934,375	2,579,037	73,222,199	29,284,920	11,873,182	341,584	766,312	3,881,080	1,638,479	99,125,715
Zone 1	33,627,338	6,847,500	248,005	8,238,214	3,524,234	182,787	26,807	87,342	780,133	174,750	13,518,066
Nakhon Phanom	3,445,418	537,500	36,111	885,788	110,583	20,287	5,012	9,874	95,621	18,022	1,725,620
Sakon Nakhon	6,003,602	1,116,875	51,115	1,911,079	289,473	41,572	2,565	20,476	291,423	20,470	2,258,555
Mong Khai	4,582,675	537,500	37,078	1,376,377	585,493	23,102	9,384	10,684	197,083	24,464	1,781,510
Udon Thani	9,743,368	1,597,500	75,960	3,186,254	1,204,165	52,849	6,086	31,065	150,152	71,660	3,367,677
Loei	7,140,382	2,350,000	35,539	493,486	1,267,130	15,905	1,897	2,597	2,311	31,320	2,940,197
Nukdahan	2,712,393	708,125	12,202	385,230	67,390	29,073	1,863	12,646	43,543	7,814	1,344,507
Zone 2	14,417,346	2,963,750	97,212	5,180,507	706,191	80,061	14,879	52,726	810,486	90,857	4,420,677
Yasothon	2,601,040	343,750	24,700	1,163,953	209,051	26,546	5,588	1,805	104,206	20,208	700,633
Ubon Ratchathani	11,816,306	2,620,000	72,512	4,016,554	497,140	53,515	9,291	50,921	706,280	70,045	3,720,044
Zone 3	19,639,918	1,663,750	255,905	8,827,302	2,143,619	110,016	13,802	104,513	213,215	94,169	6,213,627
Kalasin	4,341,716	627,500	56,300	1,469,165	480,271	16,532	2,626	7,054	83,198	14,170	1,584,900
Khon Kaen	6,803,144	740,000	70,174	2,719,339	1,037,197	31,206	5,878	20,855	46,529	56,273	2,576,293
Maha Sarakham	3,307,302	98,750	45,056	1,791,309	416,894	26,508	3,126	49,856	30,339	9,706	835,758
Roi Et	5,187,156	197,500	84,375	2,847,489	209,257	35,770	2,172	26,748	53,149	14,020	1,716,676
Zone 4	17,053,698	1,368,125	164,592	8,666,340	988,474	104,814	13,977	6,483	162,526	98,362	5,480,005
Buri Ram	6,451,178	473,750	63,273	3,096,952	394,662	29,461	3,801	2,907	85,020	47,527	2,253,610
Si Sa Ket	5,524,985	628,125	41,515	2,698,776	400,408	44,034	8,427	1,506	46,785	23,241	1,630,166
Surin	5,077,535	266,250	59,804	2,870,612	191,204	31,319	1,749	2,070	30,721	27,599	1,596,207
Zone 5	20,795,157	3,445,000	175,796	5,345,681	4,055,568	132,926	20,772	185,623	4[illegible],647	259,574	6,754,570
Chaiyaphum	7,986,429	1,547,500	54,146	1,666,765	987,772	42,929	2,069	26,778	147,015	143,790	3,363,664
Nakhon Ratchasima	12,808,728	1,897,500	121,650	3,676,915	3,067,796	89,997	18,703	158,845	2[illegible],632	115,784	3,393,905
Zone 6	18,122,712	4,791,875	145,578	5,053,600	3,425,393	167,931	20,371	34,401	159,460	59,727	4,200,354
Nakhon Sawan	5,998,548	2,648,125	69,955	2,754,214	1,142,671	55,057	8,706	11,201	6,125	33,255	1,267,239
Phetchabun	7,917,760	2,351,875	53,101	1,563,628	1,071,456	65,199	10,2[illegible]	6,120	76,953	17,294	1,901,886
Uthai Thani	4,206,404	1,791,875	22,522	735,758	411,266	47,677	1,[illegible]	21,080	74,432	9,178	1,091,229
Zone 7	6,110,150	243,125	72,819	1,924,686	2,230,9[illegible]	72,440	1,485	7[illegible],153	[illegible],859	15,519	1,460,745
Lop Buri	3,874,846	181,875	37,765	1,187,163	1,567,598	32,[illegible]	308	22,64[illegible]	7,627	9,273	827,990
Saraburi	2,235,304	61,250	35,074	737,523	663,321	40,236	1,177	55,490	2,232	6,246	632,755
Zone 8	25,225,629	11,616,250	148,850	5,157,209	2,460,574	216,897	6,330	15,760	120,339	38,633	5,394,767
Kamphaeng Phet	5,379,681	1,735,625	37,108	1,289,851	1,182,980	68,376	929	4,029	81,647	4,538	974,542
Tak	10,254,156	7,961,250	16,[illegible]	240,092	276,818	21,887	1,104	3,705	5,796	1,279	1,725,827
Phichit	2,831,883	-	43,167	2,018,994	291,457	42,652	870	-	5,695	10,494	418,526
Phitsanulok	6,759,909	1,969,375	52,157	1,608,272	70[illegible]313	83,982	3,419	8,016	27,201	22,322	2,275,822

Land Utilization (cont.)

Agro-Economic Zone and Province	เนื้อที่ทั้งหมด Total land	เนื้อที่ป่าไม้ Forest land	เนื้อที่ถือครองทางการเกษตร Farm holding land								เนื้อที่ไม่จำแนก Unclassified
			ที่อยู่อาศัย Housing area	ที่นา Paddy land	ที่ไร่ Under field crops	ที่ไม้ผลและไม้ยืนต้น Under fruit tree & tree crops	ที่สวนผักและไม้ดอก Under vegetable & flowers	ที่ทุ่งหญ้าเลี้ยงสัตว์ Grass land	ที่การว่างเปล่า Idle land	ที่อื่น ๆ Other land	
Zone 9	28,112,073	15,152,500	142,224	2,965,096	1,732,232	216,245	7,940	6,641	122,100	44,177	7,722,918
Nan	7,170,045	3,509,375	18,738	260,110	313,361	31,716	498	-	24,078	6,947	3,005,222
Phrae	4,006,624	1,716,250	18,463	297,805	189,626	24,715	768	2,105	30,211	5,104	1,801,577
Lampang	7,833,726	5,903,125	39,359	567,183	264,142	29,838	2,792	1,513	38,778	12,230	974,566
Sukhothai	4,122,558	1,838,125	44,293	1,237,974	542,901	86,503	2,686	2,113	21,266	11,636	335,061
Uttaradit	4,899,120	2,185,625	21,371	602,024	422,002	43,473	1,196	910	7,767	8,260	1,606,492
Zone 10	34,567,267	23,236,875	174,929	3,528,333	812,594	261,071	41,741	2,196	256,486	28,303	6,224,539
Chiang Mai	12,564,911	10,438,750	57,844	876,473	208,889	128,753	25,296	1,748	50,663	5,487	773,008
Chiang Rai	7,298,981	3,024,375	61,197	1,548,910	395,321	67,428	10,870	-	163,097	11,323	2,016,460
Mae Hong Son	7,925,787	6,023,750	5,785	107,688	28,297	8,221	1,148	-	7,215	765	1,742,918
Lamphun	2,816,176	1,701,250	20,830	296,512	30,805	37,756	3,205	648	18,366	389	706,415
Payao	3,959,412	2,048,750	29,273	698,750	149,282	18,913	1,222	-	17,145	10,339	985,738
Zone 11	12,611,843	741,875	223,481	7,271,832	1,185,101	360,202	70,093	2,454	41,867	38,258	2,676,680
Chai Nat	1,543,591	6,250	21,755	903,115	137,219	32,485	302	1,017	1,085	700	439,663
Nakhon Nayok	1,326,250	313,750	20,424	769,758	7,057	31,958	530	-	1,299	7,358	174,116
Nakhon Pathom	1,325,204	-	35,343	502,435	299,505	61,478	23,679	-	2,860	2,354	427,550
Nonthaburi	388,939	-	6,069	149,916	-	45,412	1,816	-	1,228	1,391	183,107
Pathum Thani	953,660	-	14,157	700,576	1,874	44,075	11,958	-	4,600	9,674	166,746
Ayutthaya	1,597,900	-	26,095	1,307,076	8,446	24,766	2,874	-	1,282	2,165	225,196
Sing Buri	514,049	-	9,040	415,973	6,015	14,296	642	-	356	612	67,115
Suphan Buri	3,348,755	421,875	60,889	1,685,344	723,051	55,047	8,586	1,208	23,945	12,379	356,431
Ang Thong	605,232	-	17,706	490,564	420	15,872	1,157	229	-	740	78,544
Bangkok Metropolis	978,263	-	12,003	347,075	1,514	34,813	18,549	-	5,212	865	558,212
Zone 12	23,295,230	10,881,250	141,957	1,958,659	2,032,190	549,569	46,815	61,785	117,791	64,406	7,440,908
Kanchanaburi	12,176,968	7,760,625	47,768	472,246	1,093,211	57,376	6,692	5,467	18,639	20,764	2,694,180
Prachuap Khiri Khan	3,979,762	899,375	25,467	75,135	411,720	337,293	13,920	14,189	41,114	9,584	2,151,965
Phetchaburi	3,890,711	1,560,625	27,928	573,974	181,006	89,984	5,557	25,319	51,923	18,656	1,355,737
Ratchaburi	3,247,789	660,625	40,694	837,104	346,253	64,916	20,646	16,810	6,113	15,402	1,239,026
Zone 13	10,817,813	2,667,500	84,292	2,830,476	1,272,375	238,704	6,310	28,059	68,081	100,263	3,520,523
Chachoengsao	3,344,375	846,250	37,987	1,009,474	423,472	127,025	3,914	2,378	24,883	51,315	817,628
Prachin Buri	7,473,438	1,821,250	46,305	1,821,402	848,903	111,679	2,346	25,711	43,999	48,948	2,702,895
Zone 14	1,433,217	20,000	21,020	380,587	8,213	188,067	14,078	-	414	33,995	766,843
Samut Prakan	627,558	-	9,151	231,105	-	54,262	2,935	-	189	25,933	303,983
Samut Sakhon	545,217	-	7,043	140,718	3,613	67,254	10,843	-	78	5,821	309,847
Samut Songkhram	260,442	20,000	4,826	8,764	4,600	66,551	300	-	147	2,241	153,013
Zone 15	4,946,875	312,500	58,993	554,861	2,199,536	339,245	3,769	12,272	9,553	70,007	1,386,139
Chon Buri	2,726,875	161,875	31,047	374,679	1,289,764	128,742	2,582	2,540	3,808	59,377	672,461
Rayong	2,220,000	150,625	27,946	180,182	909,772	210,503	1,187	9,732	5,745	10,630	713,678

Land Utilization (cont.)

Agro-Economic Zone and Province	เนื้อที่ทั้งหมด Total land	เนื้อที่ป่าไม้ Forest land	เนื้อที่ถือครองทางการเกษตร Farm holding land								
			ที่อยู่อาศัย Housing area	ที่นา Paddy land	ที่ไร่ Under field crops	ที่ไม้ผลและไม้ยืนต้น Under fruit tree & tree crops	ที่สวนผักและไม้ดอก Under vegetable & flowers	ที่ทุ่งหญ้าเลี้ยงสัตว์ Grass land	ที่รกร้างว่างเปล่า Idle land	ที่อื่น ๆ Other land	เนื้อที่ไม่จำแนก Unclassified
Zone 16	5,723,125	1,706,250	29,452	345,314	370,878	579,952	3,911	13,460	201,311	147,027	2,319,570
Chanthaburi	3,961,250	1,210,000	20,645	215,329	286,751	384,110	2,750	2,502	160,668	123,611	1,554,984
Trat	1,761,875	496,250	8,807	130,085	90,127	195,842	1,161	10,958	40,643	23,416	764,586
Zone 17	24,788,339	5,486,250	246,220	3,550,545	85,240	4,610,233	22,466	38,720	251,605	201,482	10,295,578
Chumphon	3,755,630	947,500	21,638	188,291	20,327	632,582	2,200	2,932	81,034	42,338	1,816,788
Nakhon Si Thammarat	6,214,064	1,008,125	86,110	1,538,478	18,265	1,514,232	4,910	9,433	93,791	70,926	1,869,794
Phatthalung	2,140,296	333,125	44,565	657,692	8,560	398,738	855	5,566	13,430	16,695	662,070
Songkhla	4,621,181	611,250	52,924	756,209	8,488	1,004,925	2,598	9,992	27,175	10,294	2,137,326
Surat Thani	8,057,168	2,586,250	40,983	409,875	29,600	1,059,756	11,903	10,797	37,175	61,229	3,809,600
Zone 18	12,573,113	3,381,250	71,108	812,373	38,504	2,012,014	4,836	5,720	78,303	68,998	6,100,007
Krabi	2,947,820	307,500	17,731	195,713	13,574	462,753	1,381	407	18,194	22,473	1,903,094
Trang	3,073,449	675,000	26,746	377,536	4,264	805,526	1,933	2,656	26,622	16,790	1,136,376
Phanghga	2,606,809	936,875	9,997	45,933	6,556	363,909	576	801	17,579	8,798	1,235,785
Phuket	339,396	28,750	3,216	13,442	395	106,720	631	-	2,306	4,970	178,966
Ranong	2,061,278	965,000	3,640	23,431	4,614	73,544	-	1,074	3,864	9,947	976,144
Satun	1,549,361	488,125	9,778	156,318	9,101	199,562	315	762	9,738	6,020	669,642
Zone 19	6,835,540	1,408,750	76,684	630,184	7,085	1,449,606	1,202	25,774	62,084	9,972	3,164,199
Narathiwat	2,797,144	556,250	32,988	242,699	4,335	598,956	598	3,221	42,836	5,042	1,310,219
Pattani	1,212,722	45,625	31,332	300,665	2,010	280,389	418	6,459	8,012	1,884	535,928
Yala	2,825,674	806,875	12,364	86,820	740	570,261	186	16,094	11,236	3,046	1,318,052

MONTHLY AND ANNUAL RAINFALL OF THAILAND 1984

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1. Chiang Rai	0.0	17.1 2	3.3 1	59.9 12	148.6 19	118.2 17	270.1 23	431.0 25	316.6 14	187.1 14	24.5 3	T	1576.4 136
2. Mae Hong Son	0.0	9.5 3	0.0	196.7 9	128.3 14	288.8 27	250.4 23	292.7 27	143.2 17	97.3 16	0.5 2	0.0	1407.4 140
3. Phayao	0.0	24.9 3	1.4 1	98.1 8	111.6 16	62.3 16	91.8 18	229.1 22	181.4 17	84.7 12	0.1 1	0.0	885.3 114
4. Chiang Mai	0.0	7.8 2	0.0	35.9 7	77.0 14	138.4 17	100.4 16	163.4 19	143.0 15	127.2 15	0.7 2	0.0	783.8 107
5. Nan	0.0	77.0 6	4.5 3	178.6 11	164.6 22	168.0 19	163.4 17	296.8 28	214.0 13	66.0 9	0.0	0.0	1352.9 125
6. Lamphun	T	12.5 4	0.0	53.2 4	146.1 14	68.1 12	125.5 15	87.9 17	177.8 15	159.0 13	1.2 2	0.0	831.3 96
7. Lampang	0.2 1	8.8 3	0.5 1	89.3 4	125.5 14	106.2 15	91.4 21	191.9 23	148.9 13	92.1 15	19.1 1	0.0	873.9 109
8. Phrae	T	13.9 3	0.0	114.4 6	201.0 14	152.7 18	131.7 14	144.6 15	264.8 19	152.8 14	T	0.0	1180.9 103
9. Mae Sariang	0.0	49.0 3	0.0	75.5 7	107.0 11	266.1 21	184.2 24	208.6 25	233.0 18	103.6 14	0.0	T	1227.1 133
10. Uttaradit	0.0	9.2 2	0.0	46.8 5	197.3 12	230.4 19	184.8 14	180.6 25	236.0 15	151.4 17	T	0.0	1236.5 112
11. Phitsanulok	T	21.7 2	0.0	43.2 7	116.4 15	106.8 19	60.9 14	71.7 12	337.7 17	248.7 16	2.6 2	0.0	886.6 107
12. Tak	0.1 1	72.5 3	0.0	33.8 4	53.0 19	182.7 19	130.8 13	57.9 15	241.7 17	182.1 13	17.8 2	0.0	972.4 97
13. Phitsanulok	0.0	24.4 3	7.5 1	16.6 4	131.0 14	163.5 17	111.2 16	229.3 25	237.6 17	87.9 15	1.4 2	0.0	1011.4 115
14. Mae Sot	0.0	49.5 7	T	71.4 8	74.1 11	513.3 28	195.9 26	335.0 29	143.6 19	113.2 17	0.4 1	0.0	1496.4 146
15. Kamphaeng Phet	T	22.3 4	29.9 4	87.5 6	127.4 18	192.8 27	97.8 20	72.3 22	327.7 17	159.0 20	11.4 4	0.0	1128.1 142
16. Phetchabun	0.0	3.4 4	4.9 2	23.5 9	106.4 15	330.4 21	110.3 14	191.3 22	167.1 17	86.8 17	8.0 3	0.0	1032.1 124
17. Nong Khai	0.3 1	4.3 4	53.3 2	87.4 6	207.8 18	189.6 19	329.2 23	458.9 21	254.0 14	182.0 16	14.3 4	0.0	1781.1 148
18. Loei	0.0	89.5 4	5.2 3	135.1 10	141.2 16	125.5 15	125.7 23	113.6 17	329.6 13	112.9 15	33.5 2	0.0	1211.8 118
19. Nakhon Phanom	2.0 1	0.0	16.0 2	315.4 15	193.0 16	264.0 25	479.9 23	778.2 29	179.1 12	95.0 11	61.3 6	0.0	2383.9 143
20. Udon Thani	0.1 1	5.6 3	32.4 4	100.3 10	123.5 19	142.3 18	254.5 20	216.9 22	167.3 15	83.2 15	13.0 2	0.0	1139.1 129
21. Sakon Nakhon	T	0.7 1	9.3 6	126.6 15	121.5 22	190.6 23	364.0 23	438.2 25	273.1 16	87.8 12	31.5 5	0.0	1639.3 147
22. Mukdahan	0.7 1	0.0	35.0 3	126.8 12	202.8 16	288.7 18	290.4 19	387.6 28	212.9 18	138.3 12	64.8 7	0.0	1680.3 134
23. Khon Kaen	0.2 1	4.9 1	10.2 2	58.3 10	159.7 15	214.4 17	279.0 15	311.4 16	208.6 17	96.4 13	3.6 4	0.0	1246.7 114
24. Roi Et	4.7 1	0.0	29.3 3	151.6 12	269.3 15	138.8 16	69.1 16	247.1 21	224.9 22	248.3 13	11.7 8	0.0	1394.8 127
25. Chaiyaphum	0.3 1	39.7 3	60.2 4	63.4 10	77.2 10	135.1 12	48.3 7	109.7 12	232.8 17	126.8 15	3.4 2	0.0	896.9 92
26. Khon Ratchathani	0.0	5.0	102.6 4	184.0 8	235.4 16	204.6 20	187.3 13	568.3 24	330.6 [illegible]	343.4 [illegible]	30.8 7	0.0	2147.[illegible] 134
27. Nakhon Ratchasima	T	11.2 3	11.5 6	55.1 7	244.3 15	80.1 13	112.0 11	169.2 13	167.0 19	143.7 11	22.6 3	T	1015.7 101
28. Surin	16.6 1	8.2 2	9.3 4	63.6 9	120.4 16	165.9 17	139.0 19	175.6 21	246.6 19	140.0 13	5.6 6	0.0	1190.8 127
29. Nakhon Savan	T	22.0 3	4.4 2	48.1 7	106.0 10	94.7 14	232.8 17	119.7 17	191.0 20	58.8 15	8.5 4	0.0	886.0 109
30. Lop Buri	0.2 1	58.7 5	35.3 4	121.2 7	56.5 10	96.3 12	259.4 13	144.0 21	177.6 14	123.6 10	51.3 3	0.0	1124.3 100

T = unmeasurable of rainfall.

0.2 = The amount of rainfall in milimeter.

1 = The amount of rainy day in that month.

Monthly and Annual Rainfall of Thailand 1984 (cont.)

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
31. Suphanburi	0.0	42.9 1	7.1 3	4.9 2	76.4 14	30.6 9	177.3 15	55.5 13	371.8 17	133.9 11	0.1 1	0.1 1	779.6 88
32. Kanchanaburi	3.2 2	8.8 1	29.5 5	49.3 5	118.5 12	125.8 15	126.3 12	16.9 6	248.6 16	204.5 16	26.7 2	T	
33. Don Muang	2.1 1	46.9 2	119.4 4	149.0 8	24.9 11	100.6 12	103.4 13	156.4 14	208.9 16	111.8 14	2.0 1	T	1019.4 86
34. Bangkok Metropolis	0.6 1	12.9 1	53.9 3	52.9 5	184.0 12	130.9 21	239.8 20	93.2 20	331 20	292.8 16	25.8 4	T	1398.0 128
35. Prachin Buri	58.2 1	66.3 5	103.2 7	85.7 12	212.2 17	162.9 20	246.0 19	354.9 26	213.5 22	256.6 14	3.1 4	0.0	1762.6 147
36. Aranyaprathet	3.2 1	3.5 2	18.7 5	57.0 8	222.1 16	183.0 20	101.4 15	375.6 26	254.4 18	129.9 13	9.1 10	T	1357.9 132
37. Chon Buri	T	4.3 5	41.7 3	65.3 8	105.7 12	354.1 18	183.6 12	117.6 16	260.3 22	88.0 15	40.2 9	T	1260.8 122
38. Ko Sichang	T	9.0 2	38.2 3	34.2 3	166.0 10	163.7 12	198.5 10	39.9 11	144.1 20	141.3 15	126.3 8	0.0	1111.2 94
39. Pattaya	T	19.9 3	60.6 4	10.2 3	49.3 9	92.6 13	76.8 12	34.6 7	248.7 18	117.1 14	105.6 10	0.1 1	
40. Sattahip (U-Tapao wx.)	22.0 1	21.0 2	56.8 3	37.3 4	36.4 6	152.8 12	108.1 12	29.7 7	179.3 16	138.5 14	67.3 8	0.1 1	838.7 86
41. Rayong	2.0 1	25.5 4	10.4 3	14.1 5	161.2 15	148.1 15	110.8 8	48.2 9	195.1 19	122.7 13	26.3 4	0.0	865.2 96
42. Chanthaburi	15.9 2	9.9 2	32.2 5	256.4 13	574.5 22	630.7 27	249.9 20	536.2 24	434.8 24	199.9 14	55.8 4	18.0	2954.2 156
43. Khlong Yai	60.9 6	24.3 7	70.4 6	394.2 16	423.9 22	1264.2 27	513.8 19	909.3 28	512.4 21	299.7 16	130.7 6	40.8 5	4584.6 181
44. Phetchaburi	5.2 2	18.6 4	45.5 2	4.7 3	33.5 8	99.8 16	95.8 11	52.7 11	117.1 14	182.0 14	49.4 6	1.9 1	706.4 90
45. Hua Hin	6.4 2	16.2 2	5.4 2	12.1 4	31.4 11	126.6 20	128.6 17	71.5 15	87.8 14	126.7 16	7.1 8	0.0	619.8 111
46. Prachuap Khiri Khan	8.4 3	64.0 6	38.7 4	32.7 4	61.5 10	137.0 23	70.9 12	73.1 21	103.0 19	80.5 12	11.7 2	13.8 2	695.3 118
47. Chumphon	22.0 7	103.2 11	25.7 5	49.9 10	79.6 18	307.1 28	80.3 18	310.2 26	181.4 17	240.7 18	198.9 10	92.2 11	1691.2 179
48. Ko Samui	146.7 20	56.1 8	83.6 7	106.1 10	163.7 17	55.4 15	140.8 20	59.2 12	105.5 16	182.0 19	289.7 14	184.2 17	1580.0 175
49. Surat Thani	47.4 12	21.3 5	0.6 2	33.6 8	94.5 20	127.3 17	69.4 17	115.8 15	212.1 19	155.2 17	346.4 8	256.8 15	1480.4 155
50. Nakhon Si Thammarat	192.9 18	96.7 14	29.1 7	94.3 7	208.8 23	113.0 17	225.4 23	36.6 13	168.3 20	291.5 19	904.4 21	436.9 21	2798.0 203
51. Songkhla	68.9 19	75.7 7	69.3 8	158.2 9	90.5 12	87.2 15	106.7 14	40.7 5	211.4 14	219.6 19	352.4 20	810.4 20	2291.0 162
52. Pattani	68.4 11	106.0 13	48.3 7	71.7 7	205.6 16	87.0 13	191.7 12	51.6 7	70.8 15	176.5 17	205.5 17	460.5 21	1723.6 156
53. Narathiwat	142.9 21	93.8 16	173.6 13	129.2 12	155.8 15	128.5 14	180.8 12	139.3 12	128.5 16	197.3 18	341.7 26	870.2 25	2681.6 200
54. Hat Yai	96.4 15	35.3 10	49.6 11	183.7 13	117.8 12	95.7 18	145.6 18	69.2 10	211.9 19	176.3 18	97.3 16	373.7 14	1652.5 176
55. Ranong	21.6 7	6.6 6	133.8 9	441.7 12	391.4 23	882.7 27	424.3 29	880.3 27	420.3 26	253.7 20	22.1 6	92.2 8	3850.7 194
56. Takua Pa	49.5 9	69.4 10	116.0 11	367.6 18	561.2 23	632.8 27	503.8 23	192.8 22	456.0 20	289.9 20	164.9 16	85.7 13	3488.8 213
57. Phuket	34.0 7	1.4 2	67.7 5	382.8 17	203.2 21	469.7 25	411.4 25	86.5 13	331.5 20	281.5 23	68.6 6	230.0 18	2560.3 182
58. Phuket Airport	66.0 13	47.6 5	61.4 7	239.0 16	148.2 25	360.2 25	855.2 25	81.2 17	381.7 21	171.2 17	146.3 11	130.5 15	2078.5 195
59. Trang	70.4 11	2.8 4	45.8 7	274.4 17	182.0 20	305.1 25	176.7 21	34.8 14	274.5 18	259.1 16	119.3 10	182.4 12	2126.7 182
60. Satun	20.5 4	38.6 4	130.9 9	228.9 15	116.4 17	233.2 20	227.3 21	105.9 15	252.1 15	137.3 21	65.2 15	110.9 15	1667.2 171
61. Ko Lanta	29.8 7	3.5 3	68.8 2	296.3 13	216.4 22	366.9 25	504.0 24	36.2 10	220.0 17	473.6 18	52.1 9	131.7 16	2399.3 165
62. Surat Thani Airport	81.5 10	27.8 7	6.4 2	83.1 8	123.4 17	125.3 22	142.7 16	133.0 16	183.5 18	179.1 18	184.1 9	241.1 13	1511.0 156
63. Nong Nguhao	*		*39.0 2	48.9 4	123.4 11	239.2 14	100.9 16	113.1 16	178.5 16	158.5 13	1.0 3	0.0	1002.5 95
64.													

* = This rainfall station is just operated.