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THE NOAA/AVHRR: A NEW SATELLITE SENSOR FOR MONITORING CROP GROWTH

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I. ABSTRACT

Visible and near-infrared data from the Advanced Very High Resolution Radiometer onboard NOAA-6 and NOAA-7 are assessed for their usefulness in vegetation and crop monitoring. This paper surveys the programs being carried out by several United States and international agencies with the help of these AVHRR data. Areas of current and anticipated research and development are set forth.

II. INTRODUCTION

On July 23, 1972, the National Aeronautics and Space Administration (NASA) launched the Earth Resources Technology Satellite, later renamed Landsat-1. Two follow-on satellites in the series, Landsats-2 and -3 were launched in January 1975 and March 1978, respectively. Each of these satellites contains a Multispectral Scanner Subsystem (MSS) which provides 80-meter resolution coverage in four different spectral channels. Visible (MSS band 5) and near infrared (MSS band 7) channels have been used extensively in studies of crop growth and terrain classification (Short et al., 1976).[11]

In October 1978, the National Oceanic and Atmospheric Administration/National Earth Satellite Service (NOAA/NESS) launched TIROS-N, the first operational four-channel polar orbiting satellite. Previous NOAA polar orbiting satellites (the ITOS series) had contained sensors that imaged only in the visible and thermal infrared regions of the spectrum. The Advanced Very High Resolution Radiometer (AVHRR) onboard TIROS-N provided data in the four spectral intervals of: 0.55-0.9μm, 0.725-1.1μm, 3.55-3.93μm, and 10.5-11.5μm. Because the overlap in the first two channels hindered effective multispectral studies, the first channel was narrowed to the purely visible region, i.e., 0.58-0.68μm, effective with the launch of NOAA-6 in June 1979. Figure 1 shows spectral response curves for MSS bands 5 and 7 and NOAA-6 AVHRR Channel 1 and 2. Although the curves are quite similar, note that the AVHRR Channel 2 responds to energy from a larger portion of the spectrum than MSS band 7. Whereas the MSS band 7 response begins at about 0.8μm, almost 30 percent of the AVHRR Channel 2 response lies in the 0.7μm to 0.8μm region. The purpose of this report is to assess the comparative usefulness of NOAA AVHRR Channels 1 and 2 in the monitoring of vegetative parameters that have been previously studied exclusively from Landsat MSS data.

III. SATELLITE, SENSOR, AND DATA

The NOAA-6 satellite operates at an altitude of 850 km with a local equatorial crossing time of 0730 and 1930. It has an orbital period of 102 minutes which produces 14.1 orbits per day. Its four-channel AVHRR has an instantaneous field of view (IFOV) of 1.4 milliradians which yields a resolution of 1.1 km. NOAA-6 scans the Earth spanning an angle of ± 56 degrees from nadir. The NOAA-7 satellite launched in June 1981 is similar to NOAA-6 in every aspect except for its local overpass times (0230 and 1430) and the addition of a fifth AVHRR channel (11.5 to 12.5μm).

A network of three NOAA/NESS ground stations (in Alaska, California, and Virginia) are utilized in tracking and monitoring the NOAA polar orbiters. Data over North America can be read out in real-time at any of the three stations; data recorded over other parts of the world can only be transmitted to the Alaskan (Gilmore Creek) and Virginian (Wallops Island) stations. The digitized data are retransmitted via a communications satellite to NESS headquarters in Suitland, Maryland for a permanent storage on a Terra Bit Memory (TBM) system. The data can then be copied onto nine-track computer compatible tapes (CCT's) for further study and analysis. Tapes for each orbit contain up to 11 minutes of data covering an earth swath of 4500 km (along the orbital track) x 2700 km (horizon-to-horizon). Each recorded satellite pass consists of about 4000 scan lines; each scan line is comprised in turn of 2048 picture elements (pixels). These data pixels are represented on the tapes as 10-bit digital counts with values ranging from 0 to 1023. Calibration coefficients, solar zenith angles and earth location data are included with each scan line. Detailed information on NOAA-6 and the AVHRR can be found in Hussey (1977)[5], Kidwell (1979)[6], and Schwalb (1979)[10]. The data can be ordered from the NOAA/Satellite Data Services Division, World Weather Building, Room 100, Washington, D.C. 20233

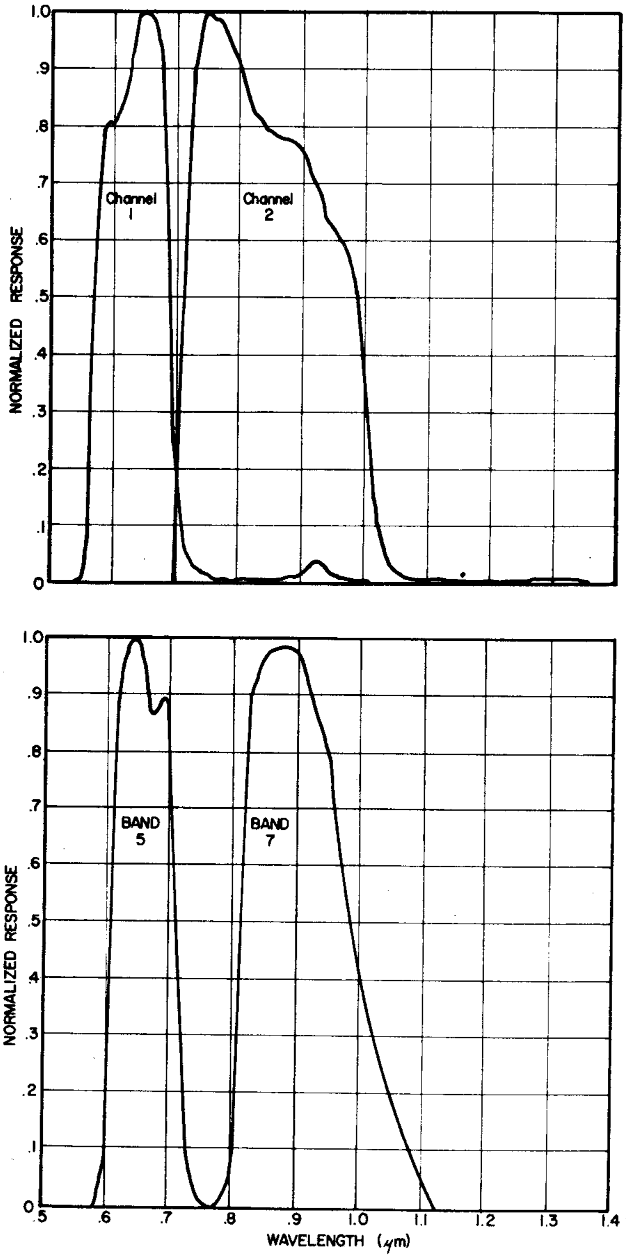

Figure 1. Spectral response curves for NOAA-6 AVHRR Channels 1 and 2, top. Response for Landsat MSS Bands 5 and 7, bottom. Curves for NOAA-7 (not shown) are very similar to those for NOAA-6.

IV. CASE STUDIES/ONGOING PROJECTS

A. IMPERIAL VALLEY

The response of a green leaf (chlorophyll) in various wavelengths of light is shown in Figure 2. Note that green leaf reflectance is low in the visible wavelengths, reaching a minimum near .65μm. Response increases exponentially in the near-infrared portion of the spectrum (i.e., Landsat MSS band 7 and AVHRR Channel 2). Figure 3 shows a portion of the May 4, 1980 NOAA-6 pass, orbit 4436. The black bell-shaped feature on the center left of each image is the Salton Sea; immediately to the south is the Imperial Valley. Figure 4 contains Channel 1 and Channel 2 albedo traces for an 80-km profile line running W-E across the Imperial Valley cropland. This valley is irrigated by Colorado River water which is routed through the All American Canal. Primary crops include sugar beets, cotton, and citrus fruits. Imperial Valley has been studied in detail using Landsat MSS images and was the subject of detailed satellite analysis as far back as 1969 when multispectral color photographs of the area were taken by Apollo 9 astronauts (Short et al., 1976).[11] In NOAA-6 visible (Channel 1) data, Imperial Valley appears very dark and non-reflective when compared to the highly reflective desert to the west and east (see Figures 3 and 4). In Channel 2 albedoes over the cultivated area increase by almost .20 and can actually be seen to exceed desert brightnesses. Note that the peak Channel 2 albedoes coincide with sharp dips in Channel 1 albedoes. This agrees with the green leaf response curve shown in Figure 2.

A detailed study of Imperial Valley throughout the 1980 season was the subject of Gatlin, et al., 1981.[1] The project was carried out through the cooperation of NOAA/NESS and NASA scientists.

The AVHRR digital tapes were analyzed on the Hewlett-Packard (H.P.) 1000 interactive system located at the NASA/Goddard Space Flight Center. All 10 bits of the AVHRR data may be displayed on this system with grid overlays and with the data mapped to several different projections; gray shade and color enhancement capability is provided. A color bar of up to 64 levels can be selected from a possible 2048 different colors. Linear modification of image data can be performed on-line in the form of contouring the image, integration of images, ratio of two images, differentiation of an image and combinations of these capabilities. A selected portion of an image may be enlarged or compressed by a floating point factor such as 2.2 or 3.0. On-line filtering and enhancement techniques are selectable. The methods available are median, laplacian, triangular convolution, and gaussian convolution. Profiles of the image data may be obtained by horizontal, vertical, radial, or circular sampling of the pixels. Hardcopy output is available by means of a plotting device and a video camera system. The camera uses Polaroid 8x10 color film which can be exposed and developed in less than two minutes for any selected image (Schneider, et al., 1981).[9]

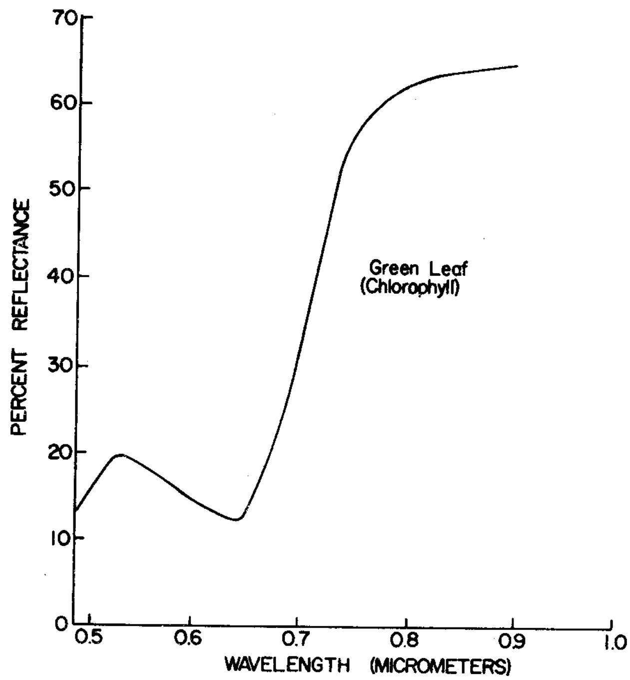

Figure 2. Spectral response curve for a green leaf (chlorophyll pigment) after Hoffer and Johannsen (1969).[4]

B. LAKE CHAD PROJECT

The United Nations Food and Agriculture Organization (FAO) has expressed a continuing interest in the monitoring of water levels in northern Africa's Lake Chad and, especially in the fertile crop regions adjacent to the lake's shoreline (UNESCO, 1970).[15] The lake has maximum depths of only 11 meters and varies in area from year to year because of its variable inflow and shallow basin. It drains an immense 1,500,000 km^2 region and is a recharge area for water-bearing aquifers important to several African nations. Four nations border the lake: Niger, Chad, Cameroon, and Nigeria.

Figure 5 contains visible (Channel 1) and near-infrared (Channel 2) images of the Lake Chad region as viewed by NOAA-7 on November 30, 1981. A map of the lake is included in Figure 6 for comparison. In the visible image, the lake bed appears as dark gray; the shallow sediment laden waters of the lake appear as light gray. In the Channel 2 image the water-covered areas show up as black because there is little or no water penetration in the near-infrared (Specht et al., 1973).[12] The "brightening up" of the remainder of the lake bed in the near-infrared is indicative of lush vegetation or cropland. A survey of 10 years of Landsat imagery shows that the lake now has less than 20 percent of its December 1972 surface area.

The lake and its surroundings are currently being monitored from AVHRR data by NOAA/NESS hydrologists. To date, tapes have been analyzed on the NASA/GSFC H.P. 1000 for six cases beginning in November 1981. A decline in vegetative green leaf response was found to have taken place between November 1981 and January 1982.

C. NILE DELTA PROJECT

The Nile Delta region has been scrutinized by NASA and NOAA scientists for the past two years (Tucker et al., 1982).[14] Composite vegetation index images for the Nile Delta were created in the H.P. 1000 interactive system using the following algorithm:

$$\frac{\text{Channel 2} - \text{Channel 1}}{\text{Channel 2} + \text{Channel 1}}$$

A colored-coded vegetation index picture for a July 10, 1980 NOAA-6 overpass was published in the April 1981 issue of Aviation Week and Space Technology. Thirty-five (35) NOAA-6 and NOAA-7 AVHRR tapes over the Nile Delta were analyzed between May and October 1981. Vegetation indices were found to increase from .01 in late May to 0.60 in early August (see Figure 7). The decrease in crop indices during the fall was so abrupt as to permit monitoring of regional harvesting patterns.

D. UNITED NATIONS/FAO-SPONSORED PROJECTS

Scientists at the United Nations Food and Agriculture Organization (FAO) are currently examining possible uses of AVHRR data for crop studies in the Sudan, Kenya, and Zambia-Botswana. Additional FAO studies are being directed towards (a) supplementing Landsat in mapping desert locust breeding grounds and (b) mapping the spread of the Sahara Desert into the sub-Sahel nations of northern Africa.

Desert locust breeding grounds in southern Algeria were identified on AVHRR "vegetative index" pictures of August 31 and September 10, 1981. The data were analyzed on the NASA/GSFC H.P. 1000 interactive system. Ground confirmation was provided through FAO headquarters in Rome, Italy (Hielkema, 1981).[3]

Rainy season satellite vegetation assessments for the sub-Sahel nations of Senegal and Mauritania were also done for the first time in 1981 using AVHRR data. The sparse vegetation, which blooms during the rainy season, must supply grazing herds during the rest of the year. No cloud-free Landsat data had even been obtained

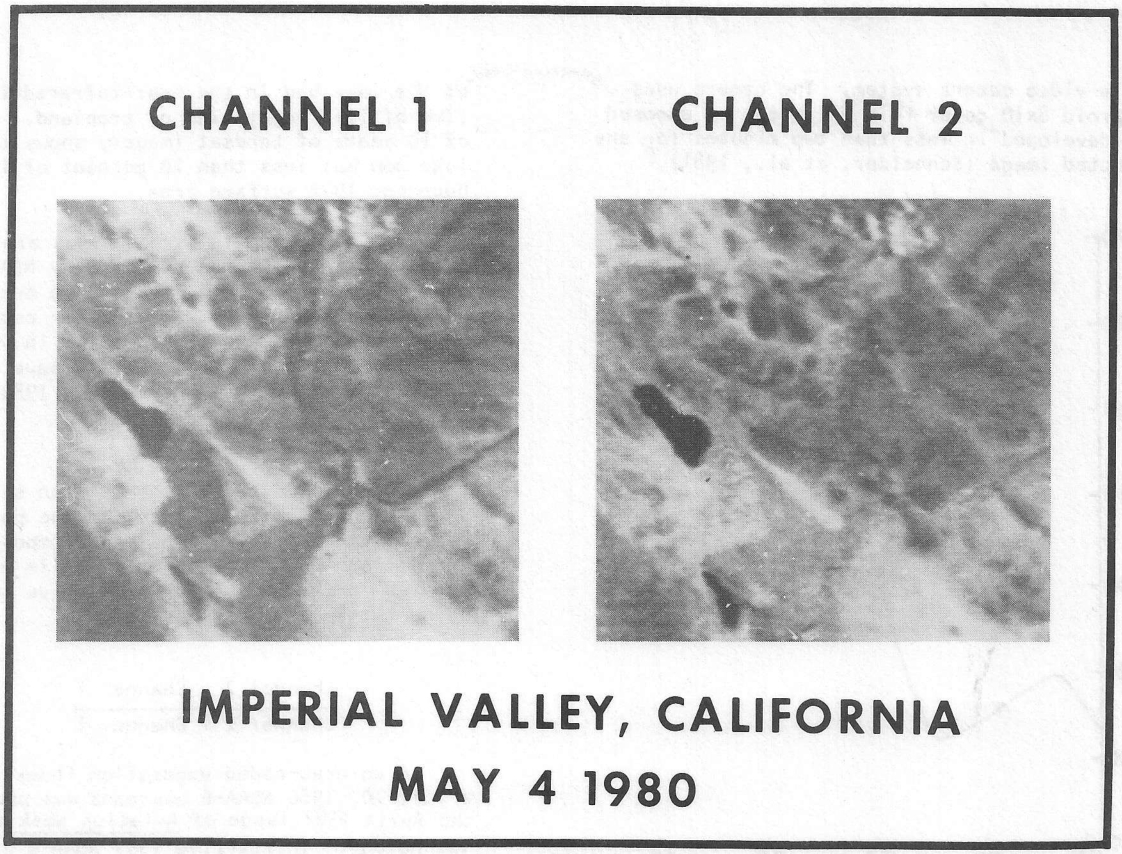

Figure 3. Visible (left) and near-infrared (right) images of the southern California-Arizona regions. These are enlargements of NOAA-6 images, orbit 4432, 5/4/80.

over this region during the wet season (Tucker, 1981).[13] During late August and September 1981, five such images were obtained by utilizing both NOAA-6 and NOAA-7. The data were collected and analyzed through the cooperation of NOAA, NASA, and the FAO.

E. BUREAU OF LAND MANAGEMENT/WILDFIRE APPLICATIONS

The Bureau of Land Management (BLM) and the EROS Data Center (EDC) are initiating a program to utilize NOAA AVHRR Channel 1 and 2 data to determine fuel loading conditions in wildfire hazard areas. The AVHRR data will be analyzed to make estimates of standing green biomass loading within previously Landsat-mapped wildfire fuels types. These estimates (high, medium, low) shall then be incorporated as part of the BLM fire management Initial Attack Wildfire System data base. Initial spring 1982 test areas are located in southeastern Oregon, northwestern Arizona, and the Fairbanks region of Alaska. If the experiment is successful, this technique will be used operationally in fuel loading models beginning in 1983 for the entire western United States and Alaska (Moore, 1982).[7] The NOAA/NESS field stations in Anchorage and San Francisco are screening the data for cloud-free cases. BLM, EDC, and the EROS program have budgeted 190K in funds for this project for the FY 1983-1985 period.

F. USDA/CROP COMMODITY ASSESSMENT DIVISION

The USDA Crop Commodity Assessment Division (CCAD) has the responsibility for monitoring commercially important agricultural regions and must be prepared to issue special crop stress reports when called upon. The CCAD at the Johnson Space Center (JSC) in Houston, Texas, began obtaining NOAA-7 data operationally in May 1981 to "fill in the gaps" between Landsat overpasses. Data for the CCAD target areas are ingested onto a NOAA-7 tape recorder and are then transmitted to NESS receiving stations at Gilmore Creek, Alaska and Wallops Island, Virginia. The data are retransmitted via a communications satellite to the TBM mass storage system at NESS headquarters in Suitland, Maryland where the Channel-1 and -2 data are copied to nine-track 1600 BPI tapes each night. Each morning the tapes are delivered by air express to JSC, where they are operationally analyzed on the Integrated Multivariate Data Analysis and Classification System (IMDACS) by CCAD personnel (Oney et al., 1980)[8] The CCAD target areas are located in five continents. Frequency of NOAA-7

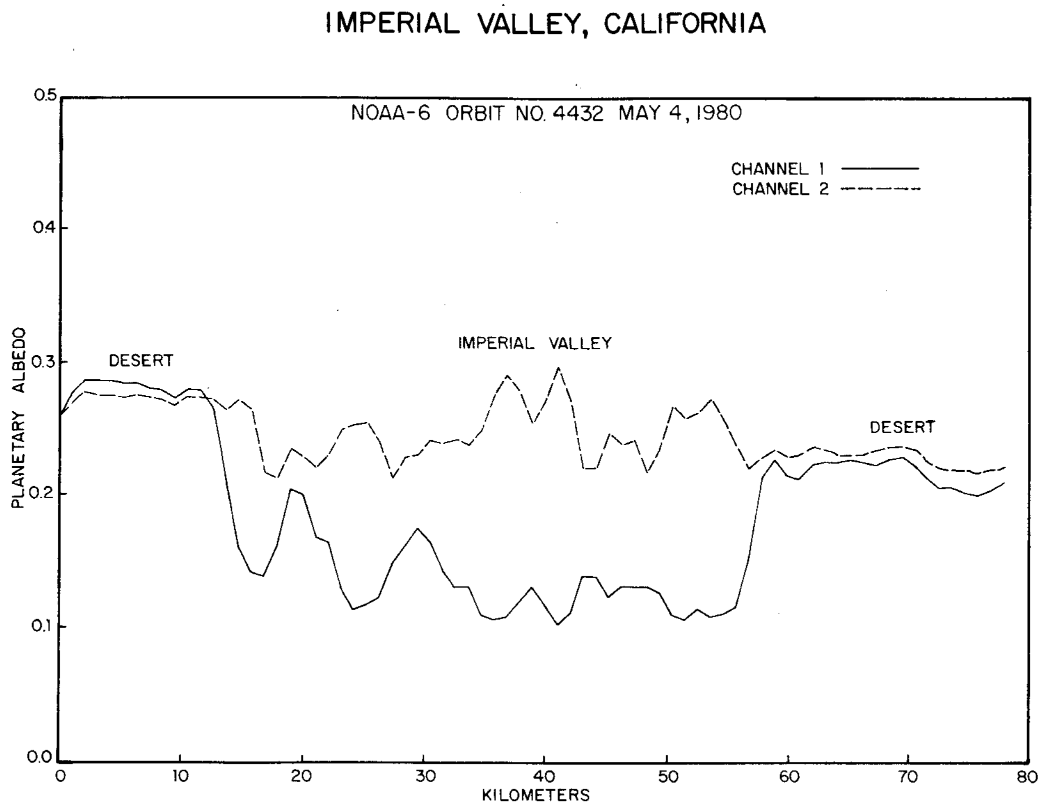

Figure 4. Albedo trace extending W-E across Imperial Valley in southern California.

coverage varies from daily to once-every-nine-days depending upon location and number of requestors. An average of five tapes are shipped daily to JSC, generally arriving within 36 hours of a satellite pass.

G. NESS/EDIS GLOBAL PRODUCTS

NOAA's NESS and Environmental Data and Information Service (EDIS) have jointly begun an effort to produce daily global vegetation index images of the northern and southern hemispheres. The data base to be used is referred to as GAC (Global Area Coverage); it consists of AVHRR 4-km resolution data recorded daily over the entire world. The Channel-1 and -2 data will be extracted from this data base and mapped into 1024 x 1024 polar stereographic arrays for each hemisphere. Vegetation indices will then be generated by differencing Channel 1 from Channel 2 and dividing by cosine of the solar zenith angle. The highest vegetation index recorded over a seven-day period will then be printed out at each array position thus creating a "7-Day Composite Maximum Vegetation Index Image." The purpose of this 7-day composite is to filter out those vegetation indices which may have been attenuated by cloud or poor nadir angles. This effort is being funded by the AgRISTARS project. Initial operation is scheduled for September 1982; the data will be marketed to other agencies and the public by EDIS. It is expected that these global vegetative indices will be of particular interest to climatologists.

H. LANDSAT COMPARISONS

Recent studies have shown that NOAA-6 AVHRR and Landsat MSS vegetative indices were in close agreement when compared over a primary crop growing region along the Brazil-Argentina border (Gray and McCrary, 1981).[2] Figure 8 is a graph from that report showing the AVHRR Channel 2-1 vs. MSS Band 7-5 relationship. The significant correlation obtained was all the more impressive considering that (a) the Landsat MSS data were collected over a three-day period (March 15-17, 1980) and the AVHRR data were collected on a single day (March 16, 1980), (b) Landsat has an overpass time some two hours later than NOAA-6 (9:20 A.M. vs. 7:20 A.M.), and (c) Landsat MSS Band 7 and NOAA-6 AVHRR Channel 2 differ somewhat in spectral characteristics (see Figure 1). The study was conducted using the IMDACS interactive system located at the Johnson Space Center in Houston, Texas.

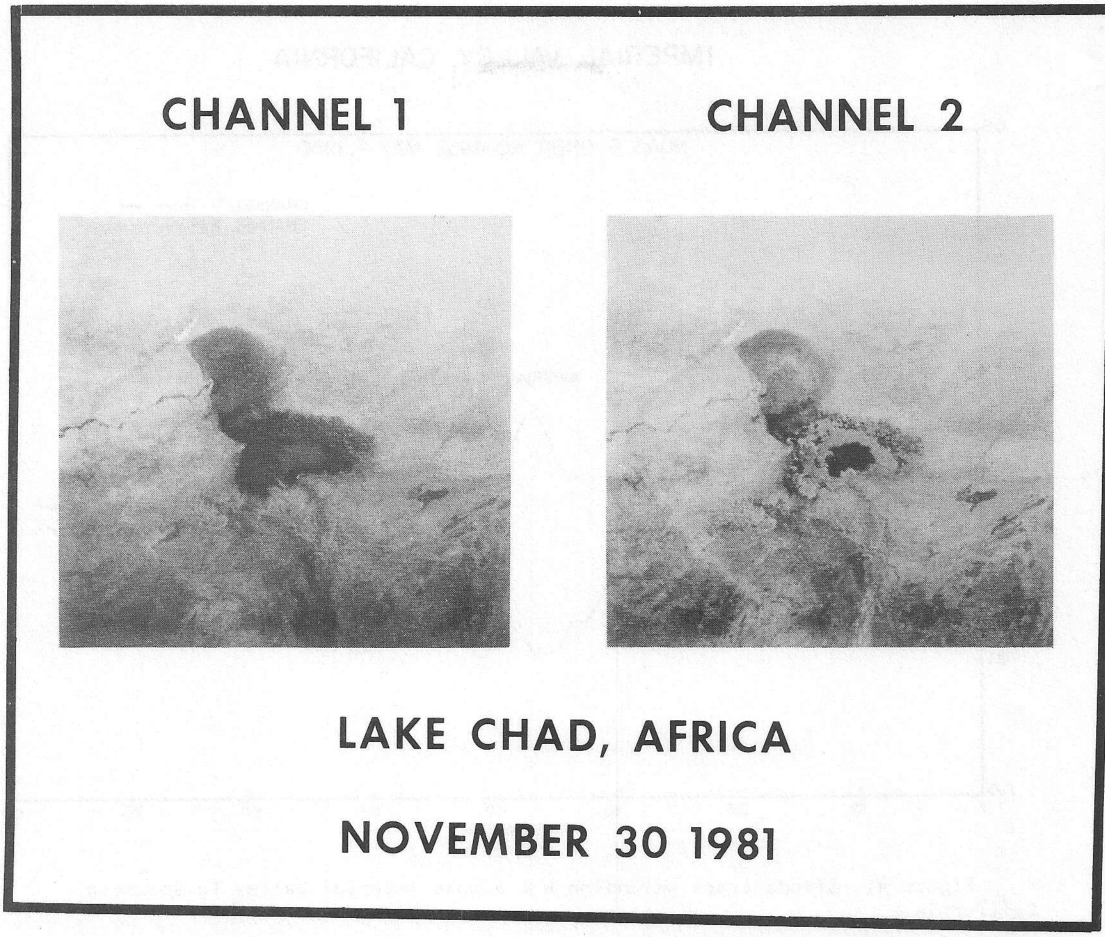

Figure 5. Visible (left) and near-infrared (right) images of Lake Chad and vicinity. These are enlargements of NOAA-7 images, orbit 2260, 11/30/81.

V. FUTURE RESEARCH AND DEVELOPMENT

Areas of current and anticipated NOAA/NESS-sponsored research regarding the use of AVHRR data for crop studies include:

1. Water vapor attenuation of the vegetative index.

2. AVHRR calibration

3. Correlation of vegetative indices between Landsat and NOAA satellites.

4. Effects of early morning dew on the vegetative index.

5. Creation of seasonal or monthly integrated vegetation index images.

6. Scan angle corrections.

7. Determination of optimum spatial needs of users.

8. Cloud masking techniques utilizing thermal (AVHRR Channel 4) data.

VI. CONCLUSIONS AND RECOMMENDATIONS

Initial investigations have shown the NOAA/AVHRR data to be of use in monitoring vegetation and crop lands. An increasing number of Federal and international agencies are incorporating AVHRR data into their operational programs. The authors would encourage all those involved in crop inventory and monitoring to become acquainted with these data.

VII. ACKNOWLEDGEMENTS

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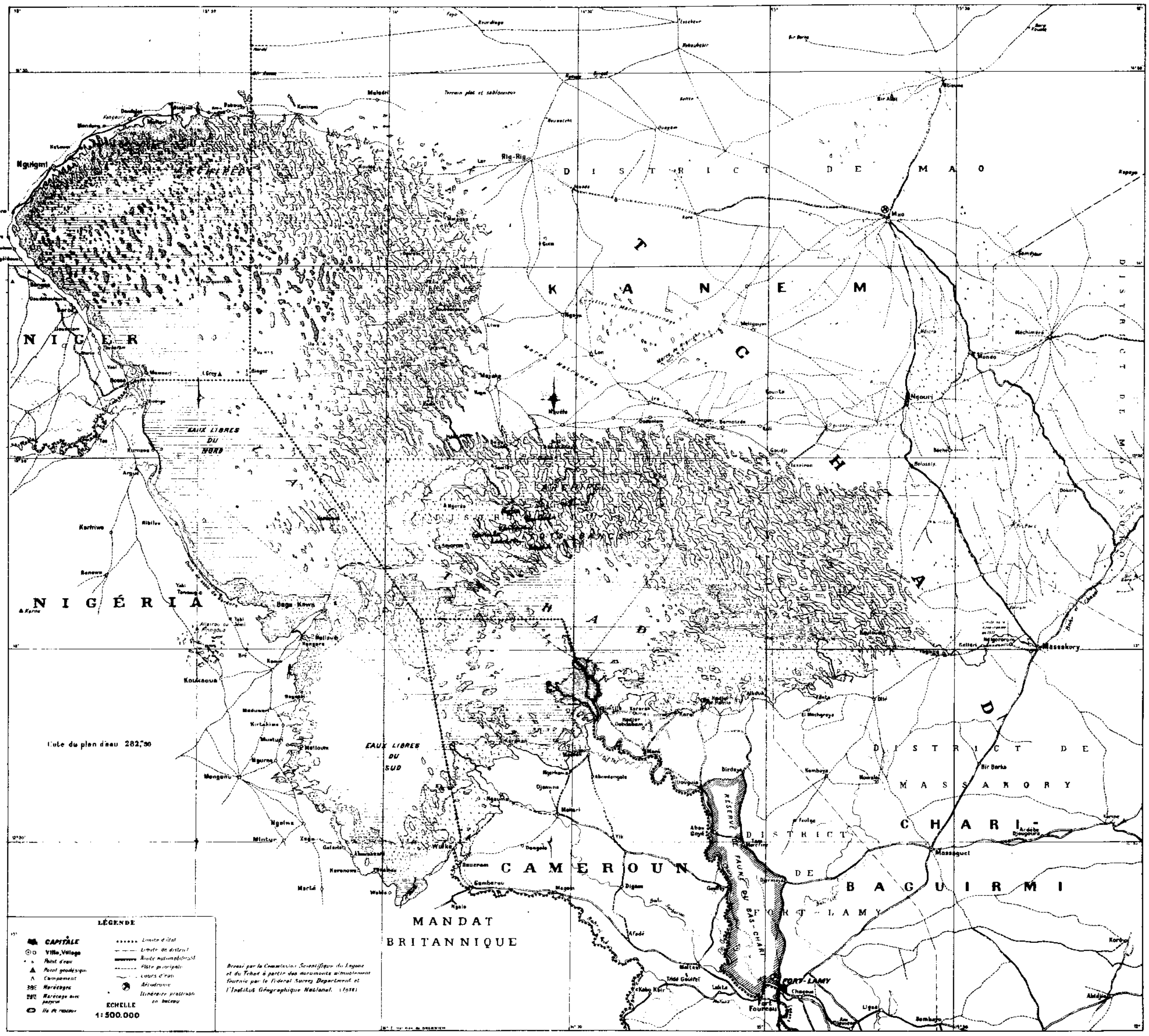

Figure 6. Map of Lake Chad and vicinity.

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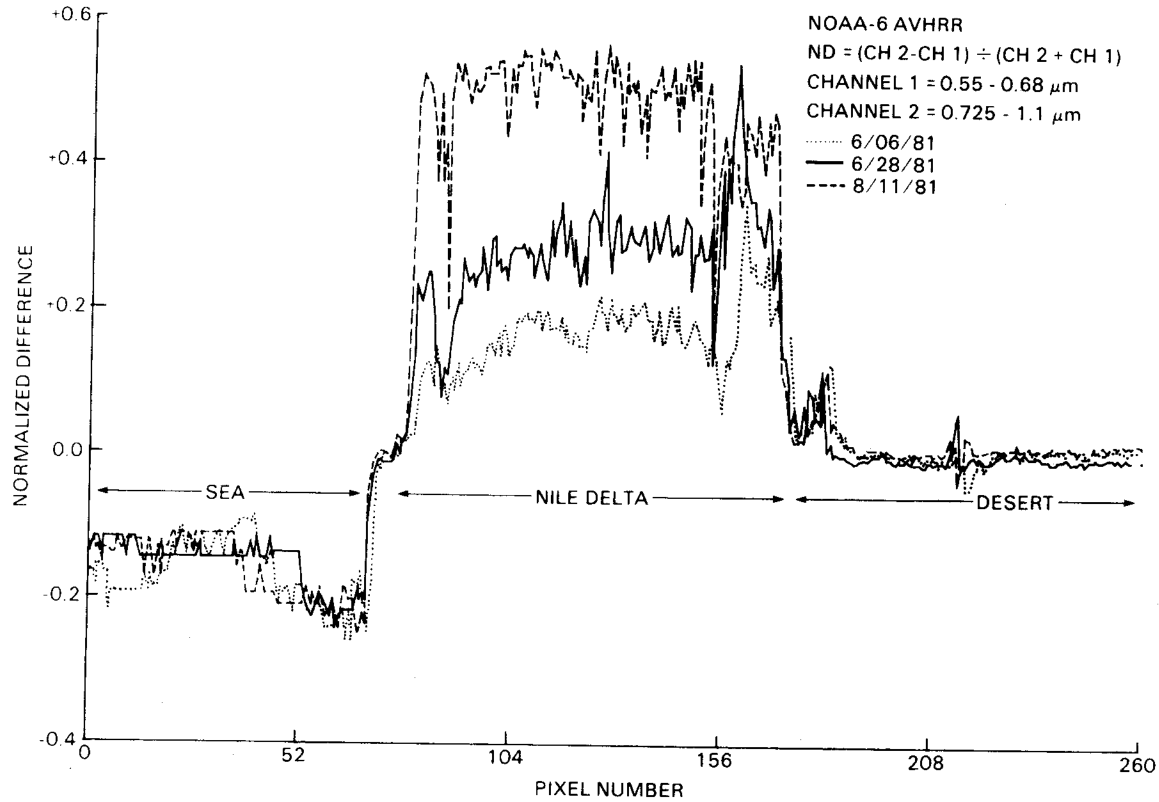

Figure 7. Vegetative index profiles for N-S transects through the Nile Delta on 6/6/81, 6/28/81, and 8/11/81.

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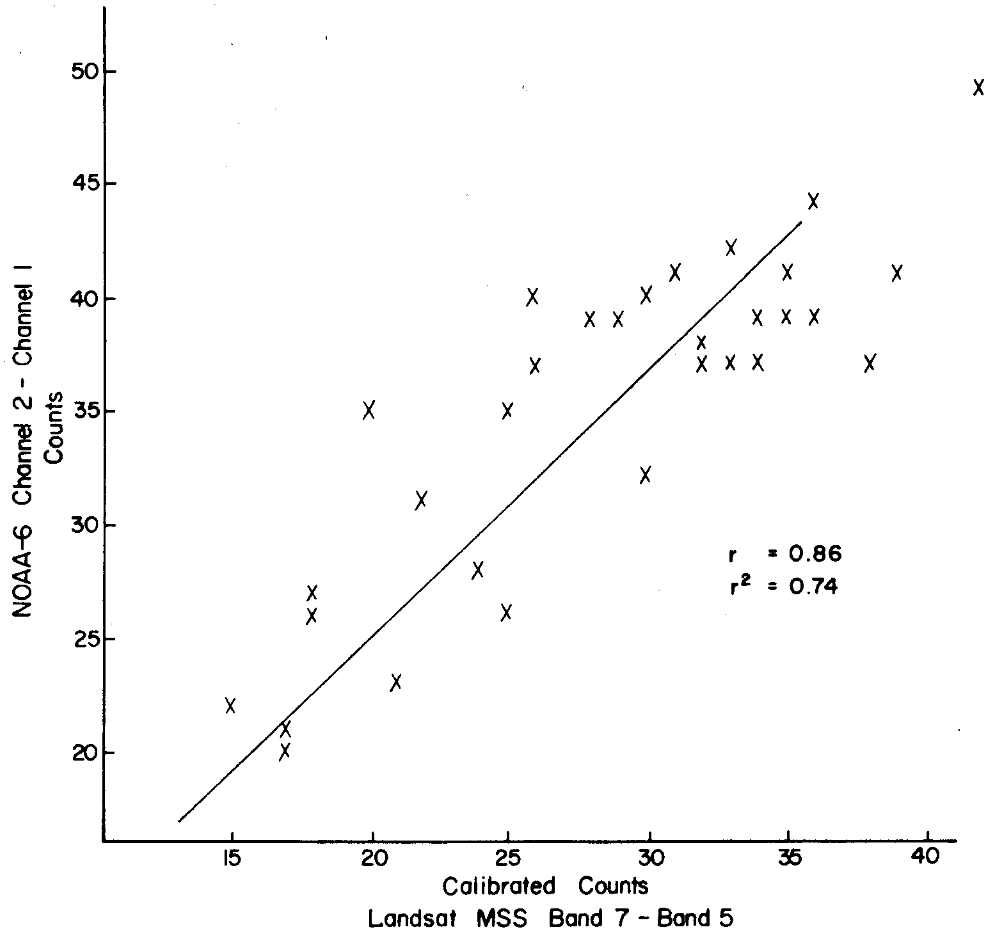

Figure 8. Comparison of NOAA-6 vegetative index (Channel 2 - Channel) with Landsat index (MSS Band 7 - Band 5).

BIOGRAPHICAL SKETCHES

Stanley R. Schneider received a B.S. degree (Cum Laude) in Geology from the City College of New York, subsequently serving on active duty for two years as an officer in the United States Army Corps of Engineers. He worked for the National Academy of Sciences as an information technician and for the Department of the Navy as a computer programmer. Mr. Schneider is presently a senior hydrologist with the National Oceanic and Atmospheric Administration/National Earth Satellite Service, specializing in the applications of satellite data to solution of water resource problems. He participates in the United States Army Reserves where he holds the rank of Major in the Corps of Engineers. Mr. Schneider is a member of the American Geophysical Union, the Society of American Military Engineers, and the American Society of Photogrammetry.

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