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Monitoring Vegetation in the Nile Delta with NOAA-6 and NOAA-7 AVHRR Imagery

Definite trends with respect to time were observed which correlated with growing conditions and agricultural practices.

Abstract: *Satellite data from the Advanced Very High Resolution Radiometer onboard NOAA-6 and NOAA-7 have been used to study large-scale vegetation dynamics in the Nile River Valley and Nile Delta of Egypt. Data were obtained for dates spanning the time period of May to October, 1981. Definite trends with respect to time were observed which correlated with growing conditions and agricultural practices. Results of the study indicated that these data were useful for monitoring large areas of vegetation, demonstrated that atmospheric effects must be understood quantitatively for specific inventory purposes, and showed that the addition of a thermal channel was valuable for detecting areas of visible and subvisible clouds.*

Introduction

Since the launch of the NOAA-6 satellite in June, 1979 a potential new source of satellite remote sensing data for studying terrestrial vegetation has been available from the Advanced Very High Resolution Radiometer (AVHRR) sensor. The principal new feature of AVHRR data from terrestrial vegetation targets is the high temporal frequency near-daily data acquisition for any given target. Associated with the high temporal frequency are a 1.1-km spatial resolution at nadir, a ±56° scanning configuration of the AVHRR, and an approximately 2700-km swath width. This paper describes some preliminary findings of a study which evaluated NOAA-6 and NOAA-7 AVHRR data for monitoring vegetation dynamics in the Nile River Valley and Nile Delta of Egypt.

NOAA-6 and NOAA-7 are polar orbiting, sun synchronous, operational satellites in the TIROS-N series of spacecraft. The satellites operate at an altitude of 850 km with local equatorial crossing times of 0730/1930 and 0230/1430, respectively, for NOAA-6 and NOAA-7. Their orbital periods are 102 minutes with an AVHRR instantaneous field-of-view (IFOV) of 1.4 milliradians. The AVHRR instrument has 1024 (10 bit) quantizing levels for all bands (Table 1). Data tapes (800 bpi) obtained from NOAA contain 3 orbital minutes of data acquisition, which translates into an area ~1100-km long (11° of latitude) and 2700-km wide. Each recorded scene consists of 1000 scan lines with 2048 pixels per line. Calibration coefficients, solar zenith angles, and Earth location data are embedded within each scan line (Schneider *et al.*, 1981).

Previous research using visible and near-infrared spectral bands for monitoring green vegetation have been reviewed in Tucker *et al.* (1981) and Kimes *et al.* (1981). Various combinations of these two bands have been shown to be highly correlated to the *in situ* green leaf area index. Although the 0.55 to 0.68-μm and 0.73 to 1.1-μm channels of the AVHRR are wider than the ~0.6 to 0.7-μm and 0.75 to 0.90-μm

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TABLE 1. ADVANCED VERY HIGH RESOLUTION RADIOMETER BANDS

Channel #	Bandwidth (μm)
1	0.55- 0.68
2	0.73- 1.1
3	3.5 - 3.9
4	10.5 -11.5
5*	11.5 -12.5

* NOAA-6 has only channels 1 to 4 while NOAA-7 has five channels.

spectral intervals usually recommended for green vegetation monitoring from satellite altitudes, the first two AVHRR bands are adequate for the same purposes as the narrower bands and are similar to Landsat MSS5 and MSS7 bands (Figure 1). This should not be interpreted as an endorsement of the AVHRR channels because better (i.e., narrower) AVHRR band selection would improve these channels for monitoring vegetation, largely through a reduction of atmospheric effects (Dave, 1979).

While the AVHRR visible and near-infrared channels are satisfactory but not optimum for vegetated targets, there are other features of these data that are desirable for vegetation inventory purposes. The 10-bit data allows for a much wider radiometric dynamic range with an $NE\Delta\rho$ of ~0.3 percent under all illumination conditions, and the 2048 pixel swath width contains at least 800 to 900 km of useful data *vis-a-vis* 185 km from Landsat. The much wider swath width results in a greater temporal frequency of satellite observation for a given number of satellites. In addition, the AVHRR contains two or three thermal channels for NOAA-6 and NOAA-7, respectively (Table 1). The 3.5 to 3.9-μm thermal channel has been shown to be useful for monitoring objects in the 100 to 200+°C range (Matson *et al.*, 1978) while the 10.5 to 11.5-μm and/or 11.5 to 12.5-μm channel(s) are useful for objects in the −50°C to +50°C temperature range. With the 10-bit accuracy, noise equivalent changes in temperature of 0.3° to 0.4°C are possible from the 850-km high orbit.

Since 1981 several workers have reported on the use of the AVHRR for monitoring vegetation (Gray and McCrary, 1981; Schneider *et al.*, 1981; Townshend and Tucker, 1981; Ormsby, 1982; Cicone and Metzler, 1982; Schneider and McGinnis, 1982; Greegor and Norwine, 1981; Yates and Tarpley, 1982; Brown *et al.*, 1982; Tucker *et al.*, 1983). Duggin *et al.*, (1982) and Holben and Fraser (1983) have reported on various aspects of the atmospheric contributions to AVHRR data in the first two channels. Kimes (1983) has reported the surface directional reflectance from vegetation targets in the 0.55 to 0.68 and 0.73 to 1.1-μm AVHRR bands.

We became interested in NOAA-6 and NOAA-7 AVHRR data as a possible source of large-area satellite data which would have a wide field-of-view and hence embedded directional reflectance and atmospheric pathlength effects. The northern Egyptian coast was chosen as a test site because of the frequently dry and cloudless atmosphere, the presence of large areas of temporally and spectrally invariant desert, the proximity of the Red and Mediterranean Seas for calibration targets, and the presence of seasonally dynamic vegetation in the Nile Delta and Nile River Valley.

This is a report of an investigation in which NOAA-6 and NOAA-7 1.1-km AVHRR data of lower Egypt were analyzed for the time period of late May to late October, 1981, which corresponded to the summer crop and growing cycle in the Nile Delta and adjacent Nile River Valley. Our principal objective was to evaluate the usefulness of the 1.1-km AVHRR data for monitoring the seasonal flux of green leaf biomass within these areas. No attempt was

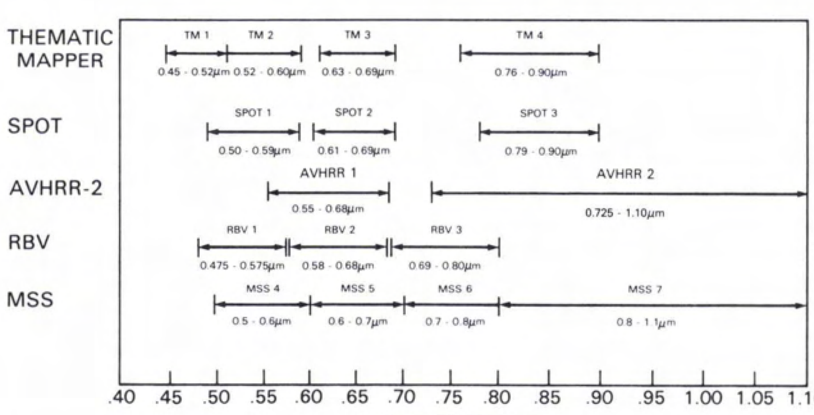

FIG. 1. Spectral band comparison between the Landsat multispectral scanner (MSS), Landsat return beam videocon (RBV), Landsat-D thematic mapper (TM), French solid state satellite SPOT, and the NOAA advanced very high resolution radiometer (AVHRR). Bandwidths given represent the approximately 50 percent relative response levels.

made to identify crop types or predict crop yields, or the such.

Methods and Data Used

Relatively cloud-free imagery was obtained on 30 dates for our study area, which was centered at 31.5°E by 30°N. Because of the ±56° scan angle of the AVHRR instrument, a range of viewing perspectives resulted. The range of viewing perspectives necessitated a thorough understanding of atmospheric path length and phase function effects in order to compare data from different days. This report is limited to a general discussion of the 15 viewing perspectives which were within ±30° of nadir and to a more detailed examination of five dates in particular (Table 2). The five dates chosen were 6 June, 28 June, 11 August, 21 September, and 25 October 1981. The principal thrust of our investigation used the normalized difference vegetation index of (Ch2 − Ch1)/(Ch2 + Ch1), with incorporation of the 10.5 to 11.5-μm or 11.5 to 12.5-μm thermal channel as a cloud mask. A representative thermal image was prepared for 11 August, 1981 to illustrate the capabilities of this thermal channel.

The AVHRR digital tapes were analyzed on the Sensor Evaluation Branch's Hewlett Packard 1000 interactive image processing system at the NASA/Goddard Space Flight Center. All data were mapped to a mercator projection centered at 30.5°N by 31.5°E. Data were mapped for channel 1, channel 2, and channel 4; channel 5 was mapped in place of channel 4 for the NOAA-7 data only. Linear modification of the image data can be provided online in the form of image contouring, differencing, ratioing, differentiation, and combinations of these capabilities. Images can be enlarged, compressed, filtered, or profiled. Hardcopy output is available by means of a plotting device and a video camera system.

Data from NOAA-6 were used from 29 May 1981 until 2 September 1981. NOAA-6's AVHRR instrument began to malfunction in late August, 1981 and NOAA-7 AVHRR data were used from 13 September 1981 until the study concluded on 25 October 1981. All data used were mapped with the exception of the 2 September 1981 data which lacked any embedded geographic coordinate data. The embedded geographic coordinate data enable processing and mapping of the data simultaneously.

Table 2. Advanced Very High Resolution Radiometer Scenes for Nile Delta

No.	Date	Degrees Off Nadir	Satellite
1	29 May 1981	−16.2	NOAA-6
2	6 June 1981	13.6	NOAA-6
3	20 June 1981	−16.2	NOAA-6
4	28 June 1981	13.6	NOAA-6
5	8 July 1981	28.0	NOAA-6
6	16 July 1981	−0.2	NOAA-6
7	2 August 1981	19.9	NOAA-6
8	11 August 1981	12.7	NOAA-6
9	2 September 1981	−10.6	NOAA-6
10	13 September 1981	34.1	NOAA-7
11	21 September 1981	20.5	NOAA-7
12	1 October 1981	−12.2	NOAA-7
13	8 October 1981	10.3	NOAA-7
14	17 October 1981	14.4	NOAA-7
15	25 October 1981	−2.7	NOAA-7

Results and Discussion

The ±56° viewing angles of the AVHRR instrument result in atmospheric optical thicknesses ranging from 1.0 at nadir to 2.2 at ±56° (Holben and Fraser, 1983). This results in an increasing with-scan-angle atmospheric backscattered contribution to the radiances received by the AVHRR channel 1 and 2 sensors. The nature of this atmospheric pathlength contribution coupled with the non-Lambertian nature of surface reflectance resulted in our restricting this report to the qualitative use of AVHRR data during the May through October 1981 period for lower Egypt. Figure 2 shows the effect of the ±56° scan angle on the (2 − 1)/(2 + 1) normalized difference vegetation index.

An inspection of line plots for channel 1 and channel 2 from the geographical coordinates of 32°N by 32°E to 30°N by 30°E for 6 June, 28 June, 11 August, 21 September, and 25 October illustrated the different responses in these two channels (Figure 3). Figure 3 indicated why there are different degrees of atmospheric effects for these channels as a function of target green leaf density. In Figures 3a and 3e, the channel 1 response from the Nile Delta transect is two to three times higher than the same channel's response from water. For dense, green targets, however, the channel one response is almost equal to that of water (Figure 3c). Hence, the relative contribution of the atmospheric backscattered energy for channel 1 in a dense green leaf situation is high and increases as the scan angle increases. By contrast, the relative contribution of the atmospheric backscattered energy for channel 2 is not affected to the same degree with increasing scan angles and is not exaggerated by increasing densities of green leaf biomass. In the absence of atmospheric correction procedures for large scan angles, the atmospheric backscattered component in channel 1 limits the scan angles which can be used.

The use of any spectrally-based green leaf vegetation index is dependent on the absence of clouds from the area being studied. This results from the fact that clouds reflect light differently than green vegetation. Clouds smaller than the pixel size and faint cirrus clouds pose the most difficult problems. The AVHRR instrument does contain thermal channels which are used to delineate clouds based upon

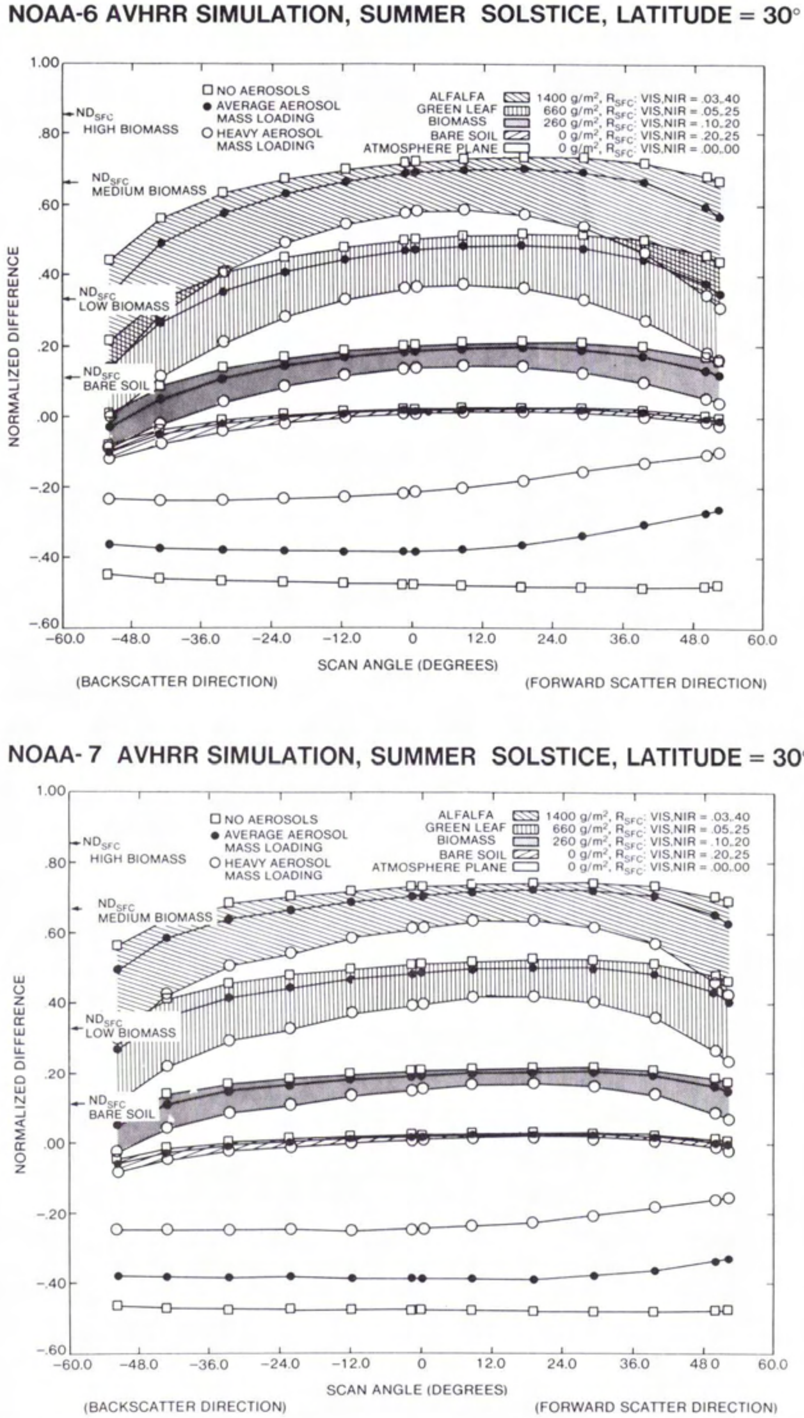

FIG. 2. NOAA-6 (A) and NOAA-7 (b) AVHRR normalized difference values plotted vs. scan angle for three atmospheric conditions and three green biomass levels (From Holben and Fraser (1983); used by permission).

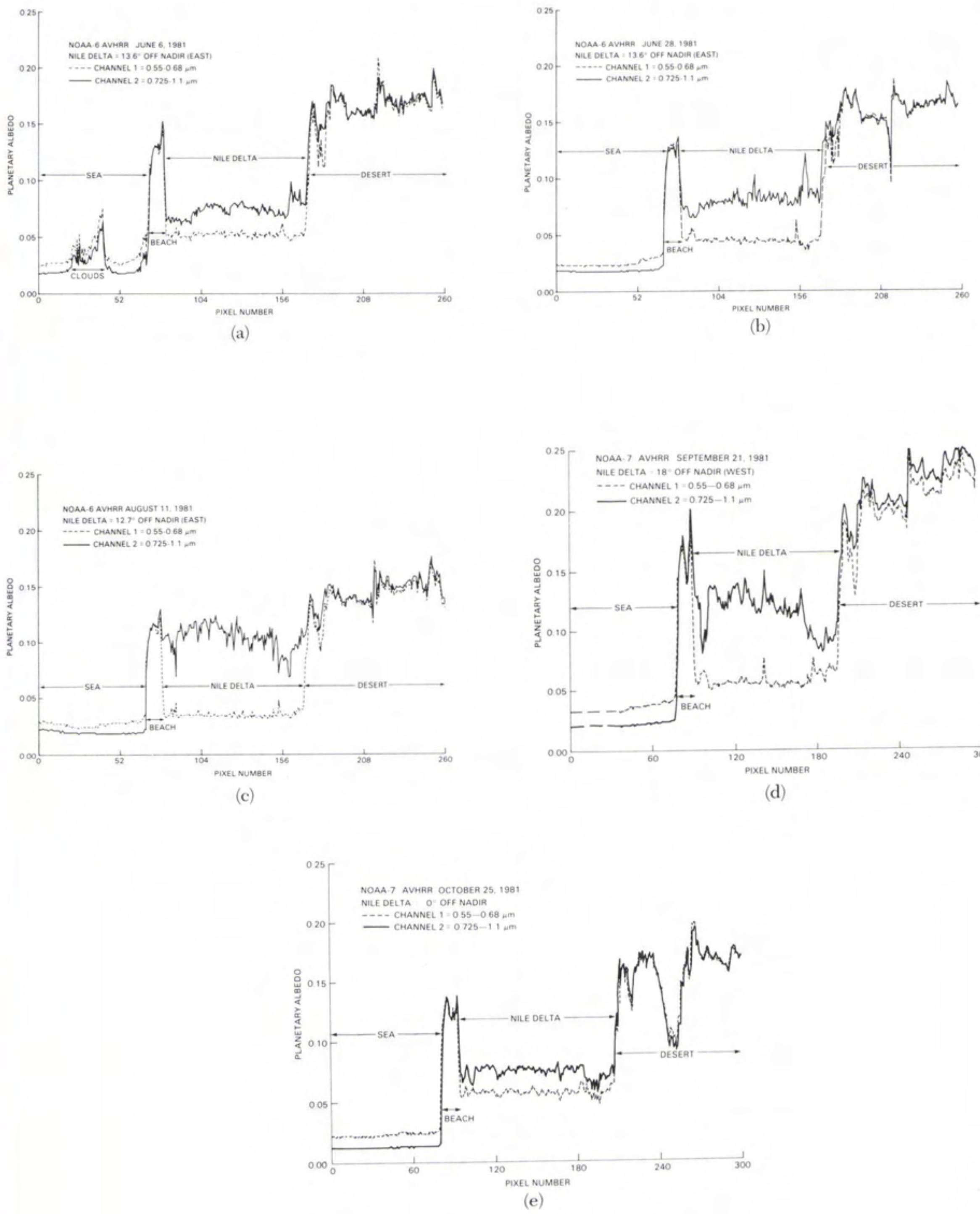

FIG. 3. Channel 1 and channel 2 transect plots from 32°N by 32°E to 30°N by 30°E for (a) 6 June 1981; (b) 28 June 1981; (c) 11 August 1981; (d) 13 September 1981; and (e) 25 October 1981. Note the different responses for the Nile Delta for these five dates and similar responses for the sea, beach, and desert.

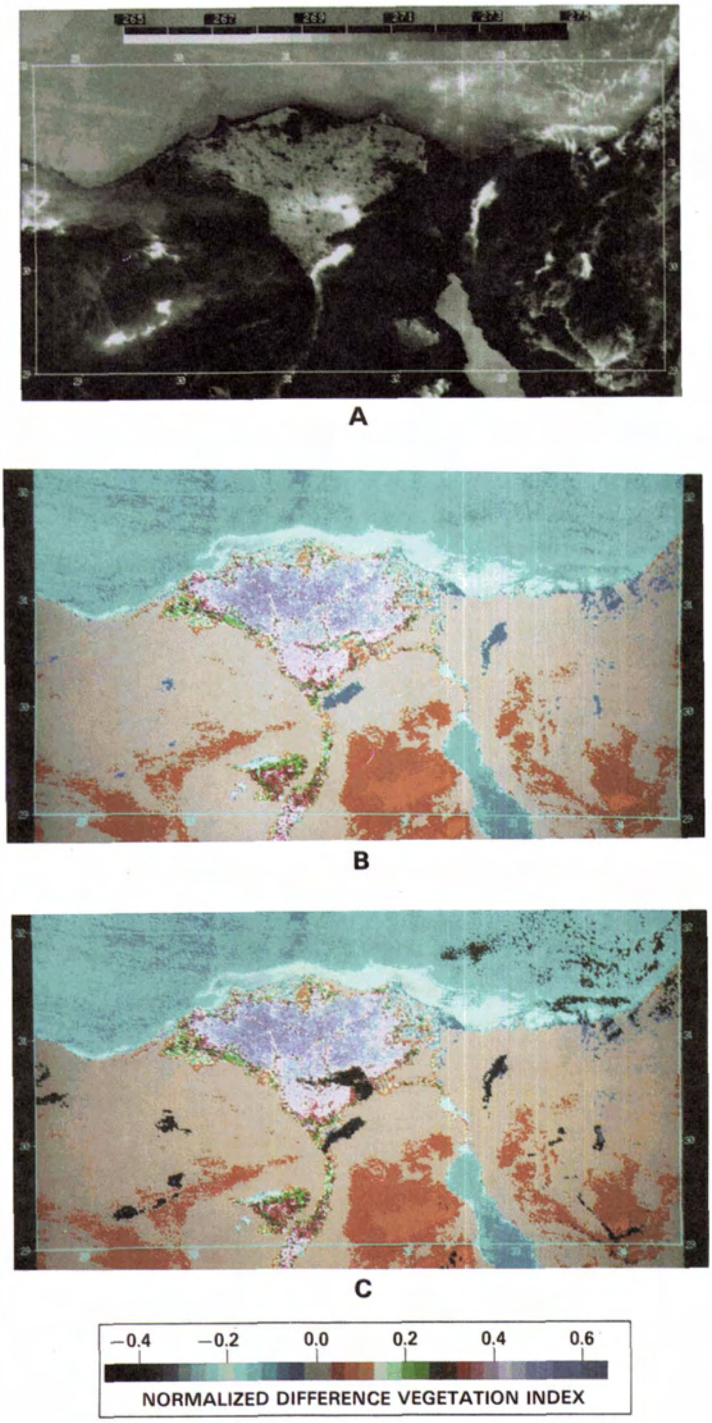

PLATE 1. Illustration of the use of the 10.5 to 11.5-μm thermal channel as a temperature-based method for detecting clouds for the NOAA-6 orbit 11030 at 0600 hours GMT on 11 August 1981 (A) the 10.5 to 11.5-μm processed image. (B) The (CH2 − Ch1)/(Ch2 + Ch1) normalized difference for the same scene. (C) The normalized difference from (B) with a cloud mask for temperatures below 21°C. Note the exclusion of cloud areas by comparing A, B, and C.

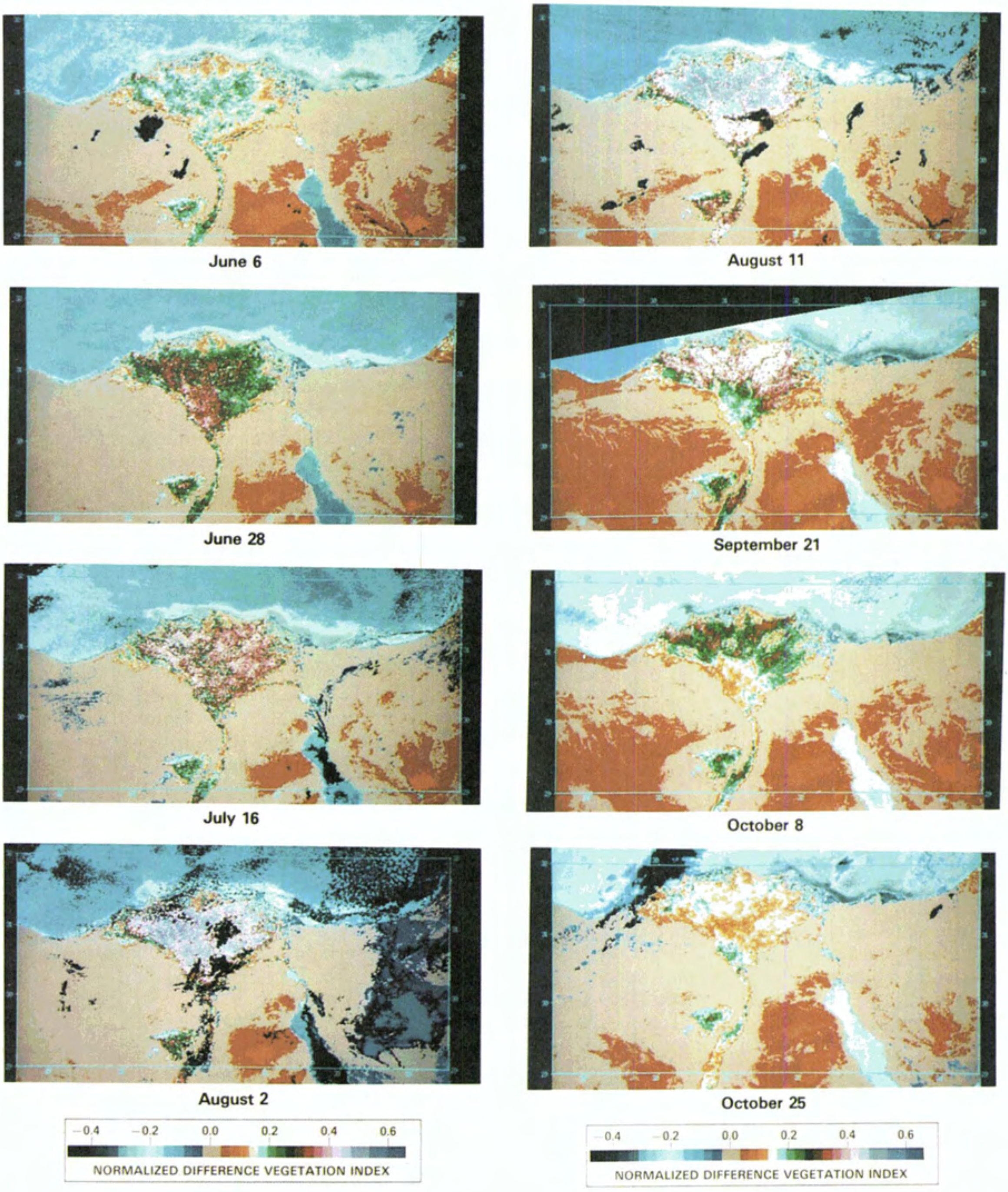

PLATE 2. The normalized difference with cloud mask for eight selected dates. The color scale indicates different densities of green leaf material. The black areas are clouds (See Plate 1).

temperature differences between clouds and non-clouds (plate 1). This technique offers an improvement for cloud detection in studies using satellite-based spectral green leaf biomass techniques. The technique we illustrate in plate 1 is an interactive technique where an analyst is required to determine where clouds exist in the image using the channel 1, channel 2, and thermal channel data. Once the analyst determines the area occupied by clouds using either the 10.5 to 11.5 or 11.5 to 12.5-μm channel and the temperature range of the clouds, a thermal mask is overlaid onto the normalized difference image. Comparisons to channel 1 and channel 2 data are often useful to confirm the accuracy of the temperature-based cloud mask. We have found this technique valuable in detecting faint high cirrus clouds as well as routine cloud delineation (Plate 1). This same technique can also be applied to Landsat-D thematic mapper imagery.

Comparisons among the 15 images we used in our study indicated a marked increase in the normalized difference vegetation index within the Nile Delta beginning in early June and continuing until a peak was reached in the 11 August 1981 image. No usable images were obtained between 11 August 1981 and 2 September 1981 because of intermittent NOAA-6 power problems and extensive cloud cover when the satellite was functioning properly. The 2 September 1981 image showed a lower normalized difference vegetation index than the 11 August 1981 image, and a successive decrease in the normalized difference was observed until late October, 1981 (see plate 2).

The regularity of the growing season within the Nile Delta results largely from the fact that all crops grown there are irrigated. The summer growing season begins in mid-May and continues until harvest in October. The principal crops grown during the summer growing period are corn, cotton, and wheat. The average field size is small and is on the order of approximately 1 to 4 acres. Few fields are larger than 10 acres and almost all cultivatable land is cultivated (Elgin, 1983). It is thus apparent that the AVHRR sensor records the 1.1-km integrated response from many fields containing several crops. Therefore, AVHRR data from the Nile Delta are suitable for inferring the integrated growing season responses and are not suited for specific inventory purposes such as specific crop yields or specific crop acreages.

In order to express the seasonal dynamics of a particular area, we selected an area of approximately 50 by 50 km located in the lower Nile Delta between 30.9° to 30.4°N and 20.8° to 31.3°E. This area was cloud-free on each of our 15 dates, and an average and variance was computed for each date, thus expressing the seasonal growing dynamics (Figure 4). Figure 4 should be interpreted qualitatively because we cannot at this time quantify the directional reflectance and atmospheric effects interaction for the range of viewing perspectives indicated in Table 2 as well as the overpass time differences between NOAA-6 (0730) and NOAA-7 (1430).

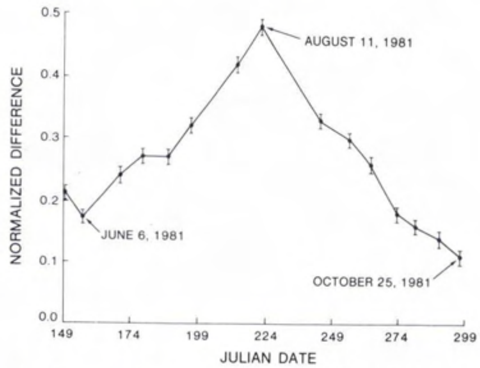

FIG. 4. The averaged normalized difference for a 50 by 50-km area for each of the 15 selected dates plotted against time for an area in the south-central portion of the Nile Delta. The same area was averaged for each date and was cloud-free for every date.

CONCLUSIONS

NOAA-6 and NOAA-7 AVHRR data were shown to be useful for monitoring large-scale green leaf biomass dynamics in the Nile Delta and lower Nile River Valley of Egypt. NOAA AVHRR data cover sizeable areas, are frequently obtained, and represent another source of satellite remote sensing data of the terrestrial surface. Additional research in directional reflectance coupled with atmospheric effects understanding is necessary to identify the magnitude of uncertainty present in AVHRR data as a function of overpass time, scan angle, atmospheric composition, and surface conditions.

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