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Monitoring Vegetation Dynamics in Israeli Transition Zone with Advanced Very High Resolution Radiometer Data

Anatoly GITELSON* and Heike SCHMIDT*

The use of satellite data gathered by the Advanced Very High Resolution Radiometer (AVHRR) flown on NOAA polar orbiting satellites for monitoring seasonal dynamics of vegetation cover in the Israeli transition zone between the Mediterranean and semi-arid regions was studied. The NDVI database used was developed from atmospherically- and radiometrically-corrected NDVI composites from observations spanning three years (March 1995-April 1998). The results show that three regions the Mediterranean region, the transition zone, and the semi-arid region - can be clearly separated by means of NDVI values. The NDVI of the Israeli transition zone was found to be very sensitive to rainfall. The difference between maximum and minimum NDVI values in the rainy season in the transition zone was at least three times higher than those in the Mediterranean and semi-arid regions. Therefore, this difference can be used as a sensitive indicator of environmental changes in this region.

Key Words: Remote Sensing, NOAA/AVHRR, Transition Zone, Monitoring of vegetation

I. Introduction

Land cover information is crucial for understanding processes such as global carbon cycling, terrestrial primary productivity, hydrologic cycles, and terrestrial energy balance (TUCKER *et al.*, 1985). Information on temporal variation of the vegetation cover is important for monitoring changes in amounts of biotic resources and the response of vegetation to rainfall. Remote sensing methods are being used to monitor vegetation changes over a number of semi-arid and arid regions (*e.g.*, TUCKER *et al.*, 1983, 1985; TUCKER, 1986; TOWNSHEND and JUSTICE, 1986; JUSTICE and HIERNAUX, 1986; MASELLI *et al.*, 1993; PRINCE *et al.*, 1995; BASTIN *et al.*, 1995; HOBBS, 1995). The results show that remote sensing can considered to be a useful method for studying arid and semi-arid ecosystems. The advantages of satellite data include the regular coverage of large areas, timely availability of data and the capability to discriminate between different types of vegetation. The multispectral and multitemporal nature of satellite imagery allows the monitoring of the vegetation cover and density by means of radiance in the red and nearinfrared (NIR) bands of the electromagnetic spectrum. Several sources of satellite data provide for an objective analysis of ecological variables. Among them, the Advanced Very High Resolution Radiometer (AVHRR), with a high temporal frequency, from the National Oceanic Atmospheric Administration (NOAA), plays a significant role (*e.g.*, GUTMAN, 1989; OHRING *et al.*, 1989; RASMUSSEN, 1997). AVHRR data include observations in the red and NIR ranges of the spectrum; these two bands have been extensively used for vegetation studies (*e.g.*, TUCKER, 1979; SELLERS, 1985). The characteristics of AVHRR and its relationship with ecological variables have been discussed in many publications (*e.g.*, HOLBEN, 1986; CHILAR *et al.*, 1991; EHRLICH *et al.*, 1994; GUTMAN and IGNATOV, 1995; PRINCE *et al.*, 1995).

The most important AVHRR-derived variable for ecological applications is the Normalized Difference

*Department of Environmental Physics and Energy Research, J. Blaustein Institute for Desert Research. Ben-Gurion University of the Negev, Sede Boker Campus 84990, Israel.

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Vegetation Index (NDVI) developed by ROUSE *et al.* (1974), which shows correlation with photosynthetic activity, vegetation cover, biomass, and Leaf Area Index. NDVI image data were shown to be a useful tool for monitoring seasonal growing conditions of semi-arid regions and for long-term productivity comparisons of different vegetation cover types (TAPPAN *et al.*, 1992; HIELKEMA *et al.*, 1986). It was demonstrated that multitemporal NDVI images are very useful in analyzing spatial vegetation patterns and in assessing vegetation dynamics (GUTMAN, 1991; TOWNSHEND and JUSTICE., 1986). Using NDVI images based on AVHRR data, vegetation-cover classes can be separated in a multitemporal space according to the phenological and seasonal variations in the vegetation (JUSTICE *et al.*, 1985; JUSTICE and HIERNAUX, 1986).

The NDVI quantifies both spatial differences between productivity of the ecosystems (ecosystem component) and year-to-year variation of each ecosystem due to precipitation and temperature fluctuations (weather component) as pointed out by KOGAN (1990). The weather component values are smaller than the ecosystem component; consequently, the weather impact on vegetation is not easily detectable from NDVI data. However, the weather component of NDVI was enhanced by separating it from the ecosystem component (KOGAN, 1990, 1997). The largest and the smallest NDVI values during study period were calculated for each week of the year for each pixel. They were then used as the criteria for estimating the upper (favorable weather) and the lower (unfavorable weather) limits of ecosystem resources. These limits characterize the "carrying capacity" of the ecosystems and range in which NDVI fluctuates due to weather changes from year to year. These fluctuations were estimated relatively to the maximum and minimum ($NDVI_{max}$ - $NDVI_{min}$) intervals of NDVI. The Vegetation Condition Index (VCI) was suggested by KOGAN (1990) as a modified version of the NDVI with reduced noise. It was shown that the VCI is almost not affected by land heterogeneity (soil type, geology, topography, and others), and thus facilitates the estimation of weather impacts on vegetation and their spatial and temporal changes (KOGAN, 1990, 1997; LIU and KOGAN, 1996; GITELSON *et al.*, 1996, 1998).

This paper discusses the use of NOAA/AVHRR data for monitoring seasonal dynamics of vegetation cover in the Mediterranean vegetation region, the transition zone, and semi-arid region in Israel and remote estimation of rainfall impact on the spatial and temporal variation of vegetation cover in this region.

II. Study Area

Israel is geographically located between 29.5°- 4°N latitude and 34°- 35.5°E longitude. The map in Fig. 1 illustrates the region studied. Precipitation is concentrated in the rainy season (November-March), ranging from about 800 mm/year in the north through 100 mm/year in the semi-arid region and to practically zero in the south.

The AVHRR observations took place during three years (March 1995 - April 1998) with different rainfall rates. In semi-arid region near Sede-Boker (Fig. 1), in 1995/96, rainfall, cumulated from the beginning of rainy

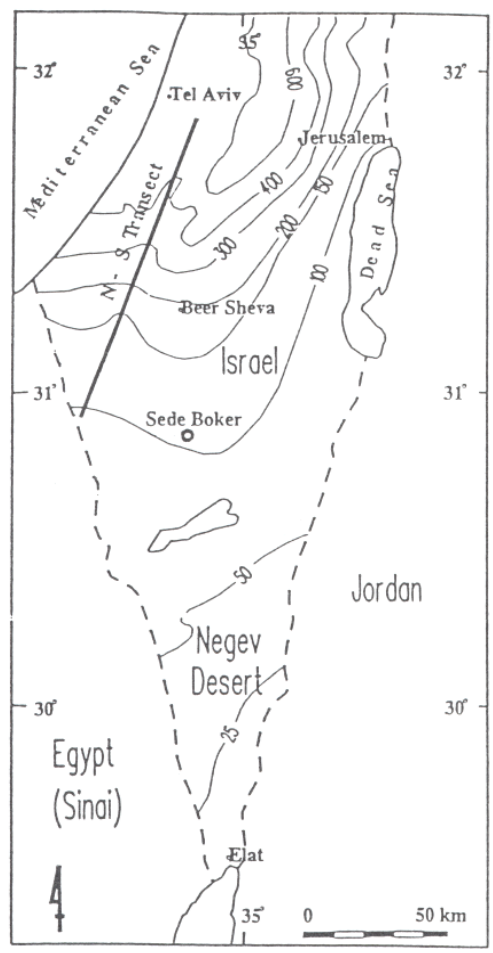

Fig. 1. Map of the southern part of Israel with location of studied transect.

season was 51.3 mm that is much lower than the average cumulated precipitation for this region -100 mm/a. 1996/97 was a year with slightly above the average rainfall - 116 mm/a. In 1997/98, rainfall was 96 mm/a that is very close to an average value.

The differences in the vegetation cover are mainly caused by the rainfall gradient from the north to the south. The country is divided into several vegetation zones (ZOHARY, 1962), ranging from typical Mediterranean vegetation in the north, through an Irano-Turanian phytogeographic region, to a Saharo-Arabian region with typical desert vegetation in the south. The southern Negev Desert has natural vegetation, mainly consisting of shrubs with a density, which decreases from 20% to less than 5% towards south. Thus, the vegetation cover in study area changes from almost 100% in the north to less than 5% in the south.

The central part of Israel, including the transition zone, was chosen as the study area. The Israeli transition zone is located between the Mediterranean region in the north and the semi-arid region in the south and is characterized by a distinctive spatial and seasonal variation of the vegetation cover. In the rainy season, the southern vegetation border moves towards south and shifts back to the north during the dry period, showing almost the same features as found in the southern semi-arid region. Figure 2 demonstrates a subset of NOAA/AVHRR image based on the red and NIR channels, which was acquired in March 1996.

NOAA-AVHRR (March'96)

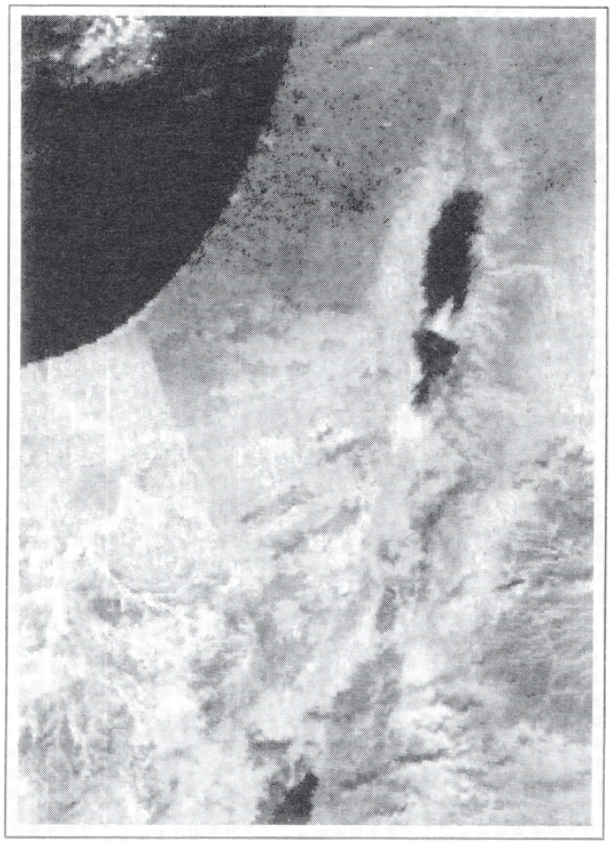

Fig. 2. NDVI distribution retrieved from NOAA/AVHRR image acquired on March 1996 at 2 p.m. local time.

III. Methods

This study is based on NOAA/AVHRR data, which were acquired in High-Resolution Picture Transmission (HPRT) format with a spatial resolution of 1.1 km at nadir in Sede Boker (Israel, the Negev Desert). NOAA-14 AVHRR images of Israel were obtained for the three year period from March 1995 to April 1998.

The process of data calibration in the visible and the NIR channels is based on radiometric calibration coefficients. Within this study, the results of the post-launch calibration of the NOAA-14 AVHRR channels 1 and 2 by the calibration group at the NOAA/NESDIS Office of Research Application were used (RAO and CHEN, 1996). Atmospheric correction of the top-of-atmosphere (TOA) reflectance was carried out using the 6S algorithm (VERMOTE *et al.*, 1997). Estimates of total precipitable water and optical thickness of the atmosphere were obtained from an automatic tracking sunphotometer (CIMEL), installed in Sede Boker. The AVHRR data were geometrically corrected by using well-distributed ground control points. The accuracy of the correction lies within the subpixel. Only AVHRR images with a satellite zenith angle of less than 30° were analyzed; as a result, 67 images were used in the study.

The NDVI was calculated for all AVHRR images with corrected surface reflectance values according to the following formula:

$$NDVI = (\rho_2 - \rho_1)/(\rho_2 + \rho_1) \quad (1)$$

where ρ_1 and ρ_2 are surface reflectances calculated from AVHRR radiances in channels 1 and 2, respectively.

The Maximum Value Composite technique (MVC) has been used on a monthly basis to overcome factors that reduce the NDVI: water vapor, aerosol content viewing

and illumination geometry (HOLBEN, 1986). On a pixel-by-pixel basis, each NDVI value is examined, and only the highest value is retained for each pixel for a given period of time.

The Vegetation Condition Index was calculated in the form (KOGAN, 1990):

$$VCI = (NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) \quad (2)$$

where NDVI, $NDVI_{max}$, and $NDVI_{min}$ are monthly average NDVI, its maximum, and minimum, respectively, for the three-year observation period for each pixel.

IV. Results and Discussion

The spatial variability of the NDVI from the east to the west was found to be quite small: less than 0.08-0.1 (bars in Fig. 3 show east-west spatial variability of NDVI). Therefore, vegetation cover along one north-south transect represented longitudal distribution of vegetation cover in the Israeli transition zone. Figure 3 shows a distinguishable difference in the NDVI values between the northern part, the Mediterranean region with quite dense vegetation, and the semi-arid southern region with very low vegetation cover. Between these regions, a narrow (width of about 20 km) transition zone is located; it is characterized by a significant drop (near three-fold) in the NDVI values towards south.

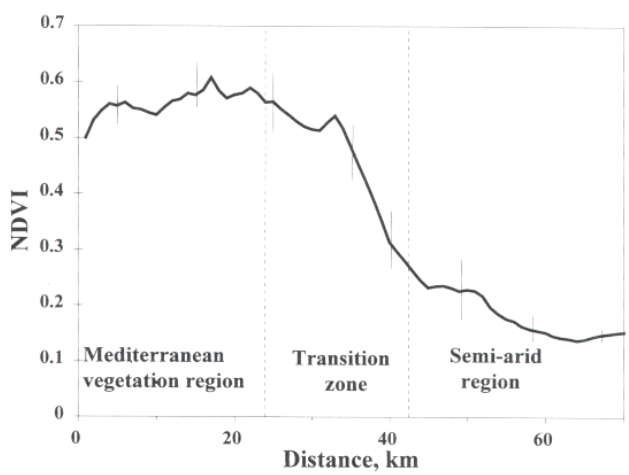

Fig. 3. Spatial variability of NDVI along a North-South transect (Fig. 1).
NDVI was calculated for three North-South transects, which are at about 30 km distance from each other. Average NDVI is presented by solid line; the error bars indicate the variability of NDVI from East to West. The transect shows a distinguishable difference in the NDVI values, from the northern Mediterranean region with dense vegetation to the semi-arid southern region. A significant drop in the NDVI values represents the transition zone that is located between Mediterranean and semi-arid regions.

SCHMIDT and GITELSON (2000) show that seasonal distribution of vegetation cover in the transition zone was very notable. According to their results, maximal values of NDVI (0.35-0.55) occurred in the rainy season from February until April. The long dry season, from May until October, had very low (about 0.05) and virtually unchanged NDVI values. In the following months, November - January, a slight increase of the NDVI values was found.

Seasonal variation of vegetation cover in the present studies can be seen clearly in Fig. 4, where monthly minimal and maximal NDVI values along the same transect were plotted. In the rainy season, the $NDVI_{min}$ in the Mediterranean region and the transition zone was much higher than that in dry and pre-rainy seasons. In the semi-arid region, seasonal variation of NDVI was small; maximal difference in the $NDVI_{min}$ between all three seasons was only 0.05, indicating minimal rainfall impact on the $NDVI_{min}$ in this region. It's not clear whether small differences in the $NDVI_{min}$ are significant or they represent the margin of error in registration, calibration, and processing. Further investigation is required to support the $NDVI_{min}$ variation with season in the semi-arid region.

The $NDVI_{max}$ values were very different for all three seasons (Fig. 4B). The short rainy season was characterized by the highest $NDVI_{max}$ values in all three climatic regions. During this season, the $NDVI_{max}$ in the transition zone was almost the same as that in the Mediterranean region. As a result, the geographical position of a sharp boundary in the $NDVI_{max}$ values shifted 5-7 km towards the south (compare the position of sharp decrease in the $NDVI_{max}$ in Fig. 4B with that in the $NDVI_{min}$ in Fig. 4A).

In the dry season, $NDVI_{max}$ (Fig. 4B) in the Mediterranean region was almost invariable with location, but dropped remarkably in the transition zone, and became far smaller in the semi-arid region. At the end of the rainy season and at the beginning of the dry season, the

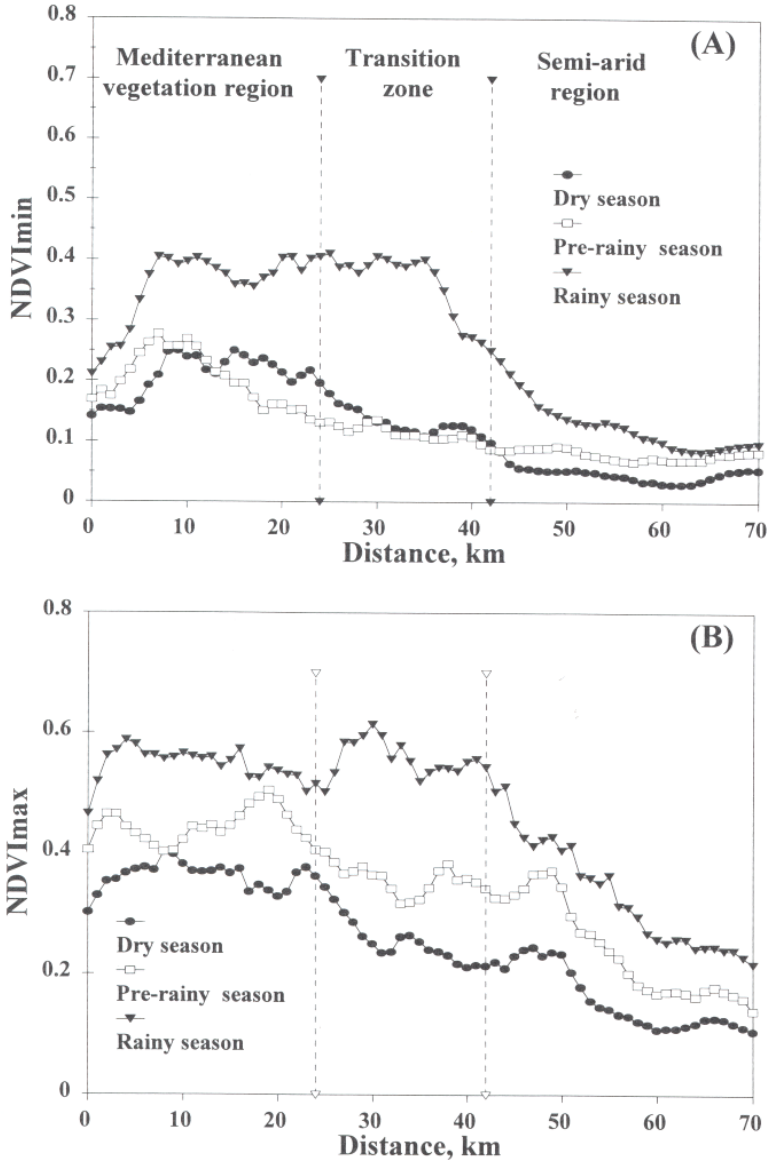

Fig. 4. The $NDVI_{min}$ (A) and $NDVI_{max}$ (B) along the North-South transect (Fig. 1) for three seasons: dry, pre-rainy, and rainy.

position of sharp decrease in the $NDVI_{max}$ moved back to the north. During the short pre-rainy season, November-January, a significant spatial variability of the $NDVI_{max}$ and $NDVI_{min}$ existed in the Mediterranean region and the transition zone.

The $NDVI_{max}$ contains the information on both rainfall impact and ecosystem resources, whereas the $NDVI_{min}$ corresponds to unfavorable weather (minimal rainfall) condition, and, as a result, is mainly an indicator of the ecosystem resources (KOGAN, 1997). Thus, the difference between maximal and minimal NDVI $\Delta_{NDVI} = NDVI_{max} - NDVI_{min}$ primarily represents rainfall impact on the NDVI (Kogan, 1990, 1997; GITELSON *et al.*, 1996). To obtain rainfall component, Δ_{NDVI} should include $NDVI_{min}$ obtained in extremely dry year. In 1995/1996, rainfall cumulated from the beginning of rainy season was 51.3 mm. It was very close to minimum rainfall recorded in this region. Our ground observations in rainy season 1995/96 estimated vegetation cover of less than 20%, and the $NDVI_{min}$, retrieved from AVHRR data ranged between 0.04 and 0.05. Thus, Δ_{NDVI}, calculated with $NDVI_{min}$ = 0.04-0.05 represented rainfall impact with reasonable degree of certainty. Additional validation of this statement has been done during 1998-1999 winter with extremely low rainfall rate (rainfall in December was 1.5 mm and 2.5 mm in January). Thus, rainfall cumulated

from the beginning of rainy season until January 1999 was 4 mm. $NDVI_{min}$ values, retrieved from AVHRR data in this period were within a range of 0.04-0.05 used in this study.

To study seasonal variation of the Δ_{NDVI}, four areas along the North-South transect were selected: the Mediterranean region, the northern and southern transition zones, and the semi-arid region. A remarkable feature of the seasonal variation of the rainfall-driven component of the NDVI (Δ_{NDVI}) is a pronounced peak in rainy season (Fig. 5). In the rainy season, a minimal Δ_{NDVI} value was found in the Mediterranean region (0.095), and the highest values took place in the transition zone (0.36 for the north and 0.3 for the south). In the semi-arid region, the Δ_{NDVI} was significantly larger than in Mediterranean region - 0.13.

During dry period from May to October, the Δ_{NDVI} in the semi-arid region and the transition zone was very small (not more than 0.05) and kept nearly constant; in Mediterranean region, the Δ_{NDVI} was also almost invariant but considerably higher than in the transition zone and semi-arid region. In the pre-rainy season (November -January), Δ_{NDVI} in the transition zone and semi-arid region increased slightly up to 0.1, while in Mediterranean region the increase of Δ_{NDVI} was more remarkable.

Thus, the Δ_{NDVI} can be used to describe quantitatively the NDVI response to rainfall. In addition, regional variation of the Δ_{NDVI} can be expressed as a ratio of the Δ_{NDVI} in rainy season to that in dry season: $(\Delta_{NDVI})_{rainy}/(\Delta_{NDVI})_{dry}$. In the transition zone, the ratio ranged from 12 to 17, and it decreased down to 6 in the semi-arid region, and to 2.7 in the Mediterranean region. Therefore, in transition zone the response of the index $(\Delta_{NDVI})_{rainy}/(\Delta_{NDVI})_{dry}$ to rainfall was at least two times higher than that in the other climatic regions.

To estimate the current state of vegetation in different regions, the Vegetation Condition Index was used. Figure 6 shows the VCI in the Israeli transition zone and the semi-arid region for selected dates. AVHRR data, acquired in December 1995, 1996, and 1997, represented the pre-rainy and rainy seasons. The VCI shows remarkable differences in vegetation cover. The maximal VCI in the southern part of the semi-arid region was recorded in April 1997 (when the cumulated rainfall was 105.7 mm). In April 1998, the cumulated rainfall was 93.7 mm and the VCI was found to be less than in 1997. A minimal VCI in the semi-arid region for April was found in 1996, when the cumulated rainfall was only half (51.3 mm) that of the amount for April 1997. In Fig. 7, the VCI values are plotted together with the rainfall, cumulated from the beginning of each rainy season, measured in the Sede

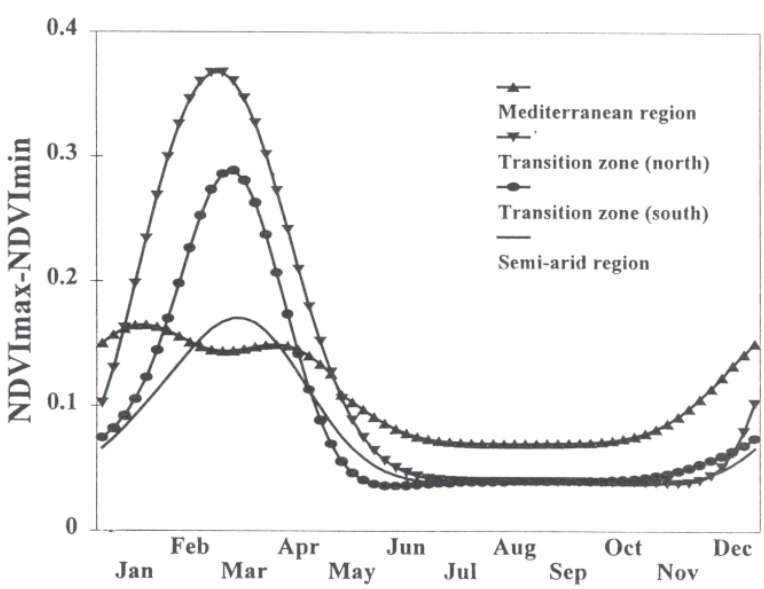

Fig. 5. Temporal variation of Δ_{NDVI} = $NDVI_{max}$ - $NDVI_{min}$ for four different environments: the Mediterranean region in the North - the site is located 30 km south of Tel Aviv; the northern part and southern part of the Israeli transition zone, and the semi-arid region in the South. The distance between each observed area is about 20 km.

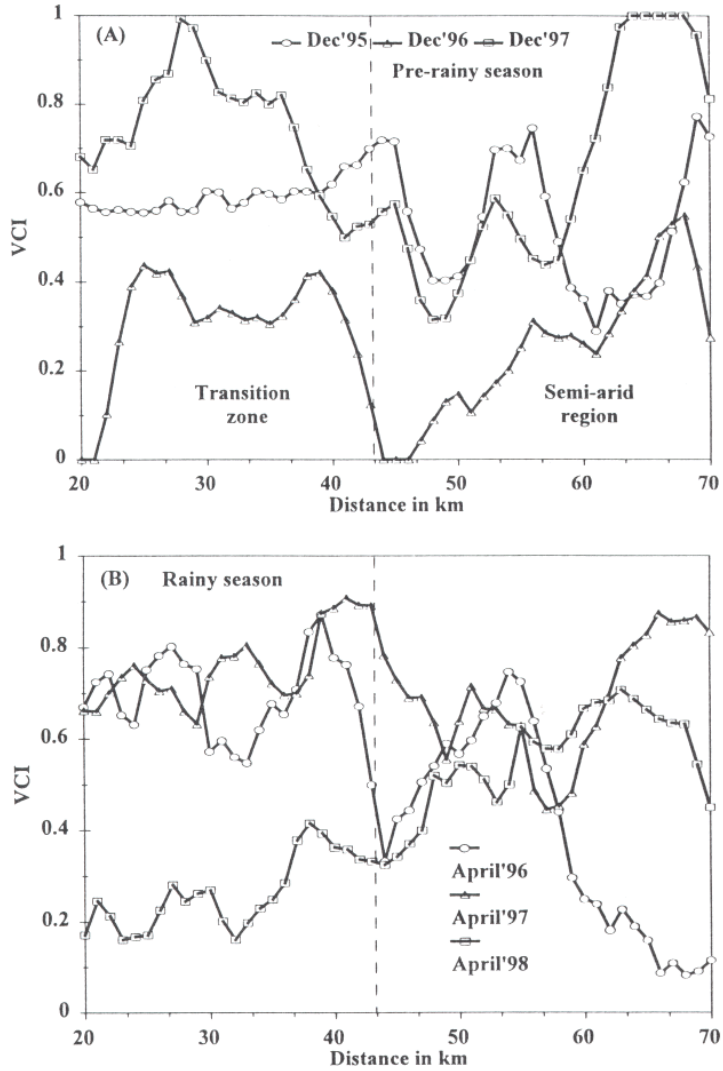

Fig. 6. The spatial distribution of the Vegetation Condition Index (VCI) in the transition zone and semi-arid region in the pre-rainy season (A) and the rainy season (B) in the years 1995-1998.

Boker area (the southern part of semi-arid region). As can be seen, the temporal behavior of the VCI is in a good agreement with that of cumulated rainfall. The VCI was even sensitive enough to reflect quite a small decrease in cumulated rainfall (not more than 20 mm) between April'97 and April'98 (Fig. 7B).

V. Conclusion

The ability of NOAA/AVHRR data to monitor the spatial and temporal distributions of the vegetation cover in the Israeli transition zone was studied. The results demonstrate the strong potential of AVHRR data to distinguish different vegetation zones and their temporal variability along a North-South transect in Israel. The spatial variability of vegetation cover from north to south was found to be very high over a distance of only 100 km, while the variability from east to west along the entire North-South transect was very small.

The highest sensitivity of the NDVI to rainfall was found in the Israeli transition zone (at least two times higher than those in the Mediterranean and the semi-arid regions). The Vegetation Condition Index was very sensitive to cumulated rainfall. It was found that besides the high seasonal variability of vegetation cover in the transition zone and the semi-arid region, the inter-annual change of the vegetation cover has to be considered as well. The change in vegetation cover in the Israeli transi-

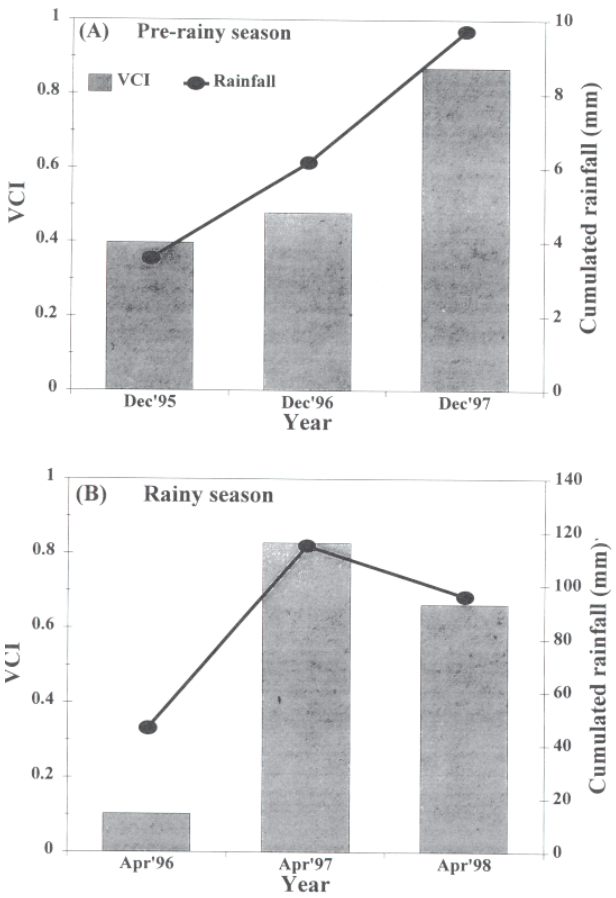

Fig. 7. (A) The rainfall, cumulated from the beginning of each rainy season, measured in the Sede Boker area (the southern part of semi-arid region) and Vegetation Condition Index (VCI) retrieved from AVHRR data in the pre-rainy season. The cumulated rainfall in Sede Boker is given for 21 December 1995, 22 December 1996, and 14 December 1997. The VCI was calculated from the data obtained on the same dates. The VCI was found to be sufficiently sensitive to reflect even small variations in cumulated rainfall in the pre-rainy season (at about 4 mm against a background of 10 mm).

(B) The VCI and the cumulated rainfall in the rainy season (April). The cumulated rainfall is given for 1 April 1996, 11 April 1997, and 10 April 1998. The VCI was retrieved from AVHRR data obtained on the same dates. The VCI was sensitive to small variations in rainfall (about 20 mm) against a background of 100 mm.

tion zone, recorded remotely, can be used as a sensitive indicator of environmental changes.

It's evident that three years of data hardly satisfy statistical requirements to formulate reliable conclusions. However, the concept of minimal NDVI suggests the existence the only one year in the study period with extremely small rainfall. Such a winter in the study period appeared in 1995/96, when cumulated rainfall was twice less than average value. Maximal NDVI was selected as a criterion approximating the ecological potential of the area (KOGAN, 1997). During study period ecological potential of the Negev Desert probably was not achieved; maximal cumulated rainfall was little bit large than average. Thus, the $\Delta_{NDVI} = NDVI_{max} - NDVI_{min}$ was underestimated, and the VCI was overestimated. When $NDVI_{max}$ will be achieved, the estimates may be more accurate, nevertheless, seasonal and spatial dynamics of vegetation cover in southern Israel , revealed in this study likely remain the same.

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References

BASTIN, G.N., PICKUP, G. and PEARCE, G. (1995): Utility of AVHRR data for land degradation assessment: a case study. *International Journal of Remote Sensing*, **16**: 651-672.

CHILAR, J., ST-LAURENT, L. and DYER, J.A. (1991): Relationship between the normalized difference vegetation index and ecological variables. *Remote Sensing of Environment*, **35**: 279-298.

EHRLICH, D., ESTES, J.E. and SINGH, A. (1994): Review article: Applications of NOAA-AVHRR 1 km data for environmental monitoring. *International Journal of Remote Sensing*, **15**: 145-161.

GITELSON, A., KOGAN, F., SPIVAK, L., ZAKARIN, E. and LEBED, L. (1996): Estimation of seasonal dynamics of pasture and crop productivity using NOAA/AVHRR data. *1996 International Geoscience and Remote Sensing Symposium (IGARSS'96), May 27-31, Lincoln, Nabraska, IEEE*, **1**: 209-211.

GITELSON, A.A., KOGAN, F., ZAKARIN, E., SPIVAK, L. and LEBED, L.

(1998): Using AVHRR data for quantitative estimation of vegetation conditions: calibration and validation. *Advances in Space Research*, **22**: 673-676.

GUTMAN, G.G. (1989): On the relationship between monthly mean and maximum-value composite normalized vegetation indices. *International Journal of Remote Sensing*, **10**: 1317-1325.

GUTMAN, G.G. (1991): Vegetation Indicies from AVHRR: an update and future prospects. *Remote Sensing of Environment*, **35**: 121-136.

GUTMAN, G.G. and IGNATOV, A. (1995): Global land monitoring from AVHRR: potential and limitations. *International Journal of Remote Sensing*, **16**: 2301-2309.

HIELKEMA, J.U., PRINCE, S.D. and ASTLE, W.L. (1986): Rainfall and vegetation monitoring in the Savanna zone of Sudan using the NOAA AVHRR data. *International Journal of Remote Sensing*, **17**: 1499-1513.

HOBBS, T.J. (1995): The use of NOAA-AVHRR NDVI data to assess herbage production in the arid rangelands of Central Australia. International Journal of Remote Sensing, **16**: 1289-1302.

HOLBEN, B. (1986): Characteristics of maximum-value composite images from temporal AVHHR data. *International Journal of Remote Sensing*, **7**: 1417-1434.

JUSTICE, C.O. and HIERNAUX, P.H.Y. (1986): Monitoring the grasslands of the Sahal using NOAA AVHRR data: Niger 1983. *International Journal of Remote Sensing*, **7**: 1475-1497.

JUSTICE, C.O., TOWNSHEND, J.R.G., HOLBEN, B.N. and TUCKER, C.J. (1985): Analysis of the phenology of global vegetation using meteorological satellite data. *International Journal of Remote Sensing*, **6**: 1271-1318.

KOGAN, F.N. (1990): Remote sensing of weather impacts on vegetation in non-homogeneous areas. *International Journal of Remote Sensing*, **11**: 1405-1419.

KOGAN, F.N. (1997): Global drought watch from space. *Bulletin of the American Meteorological Society*, **78**: 621-636.

LIU, W.T. and KOGAN, F. (1996): Monitoring regional drought using vegetation condition index. *International Journal of Remote Sensing*, **17**: 2761-2782.

MASELLI, F., CONESE, C., PETKOV, L. and GILABERT, M.A. (1993): Environmental monitoring and crop forecasting in the Sahel through the use of NOAA NDVI data. A case study: Niger 1986-89. *International Journal of Remote Sensing*, **14**: 3471-3487.

OHRING, G., GALLO, K., GRUBER, A., PLANET, W., STOWE, L. and TARPLEY, J.D. (1989): Climate and global change: Characteristics of NOAA satellite imagery. *EOS*, **70**: 889-901.

PRINCE, S.D., KERR, Y.H., GOUTORBE, J.-P., LEBEL, T., TINGA, A., BESSEMOULIN, P., BROUWER, J., DOLMAN, A.J., ENGMAN, E.T., GASH, J.H.C., HOEPFFNER, M., KABAT, P., MONTENY, B., SAID, F., SELLERS, P. and WALLACE, J. (1995): Geographical, biological and remote sensing aspects of the Hydrologic Atmospheric Pilot Experiment in the Sahel (HAPEX-Sahel). *Remote Sensing of Environment*, **51**: 215-234.

RAO, N. and CHEN, J. (1996): Post-launch calibration of the visible and near-infrared channels of the AVHRR on the NOAA-14 spacecraft. *International Journal of Remote Sensing*, **17**: 2743-2747.

RASMUSSEN, M.S. (1997): Operational yield forecast using AVHRR NDVI data: reduction of environmental and inner-annual variability. *International Journal of Remote Sensing*, **18**: 1059-1077.

ROUSE, J.W., HAAS, R.H., SCHELL, J.A., DEERING, D.W. and HARLAN, J.C. (1974): *Monitoring the Vernal Advancements and Retrogradation (Greenwave Effect) of Nature Vegetation*. NASA/GSFC Final Report, NASA, Greenbelt, MD, pp. 371.

SELLERS, P.J. (1985): Canopy reflectance, photosynthesis and transpiration. *International Journal of Remote Sensing*, **6**: 1335-1372.

SCHMIDT, H. and GITELSON, A. (2000): Temporal and spatial vegetation cover changes in the Israeli transition zone: AVHRR-based assessment of rainfall impact. *International Journal of Remote Sensing*, forthcoming.

TAPPAN, G.G., TYLER, D.J., WEHDE, M.E. and MOORE, D.G. (1992): Monitoring Rangeland Dynamics in Senegal with Advanced Very High Resolution Radiometer Data. *Geocarto International*, **1**: 87-98.

TOWNSHEND, J.R.G. and JUSTICE, C.O. (1986): Analysis of dynamics of African vegetation using the normalized difference vegetation index. *International Journal of Remote Sensing*, **7**: 1435-1445.

TUCKER, C.J. (1979): Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, **20**: 127-150.

TUCKER, C.J., VANPRAET, C., BOERWINKEL, E. and GASTON, A. (1983): Satellite remote sensing of total dry matter production in the Senegalese Sahel. *Remote Sensing of Environment*, **13**: 461-474.

TUCKER, C.J., TOWNSHEND, J.R.G. and GOFF, T.E. (1985): African Land-cover classificausing satellite data. *Science*, **227**: 369-375.

TUCKER, C.J. (1986): Maximum normalized difference vegetation index images for sub-Saharan Africa for 1983-1985. *International Journal of Remote Sensing*, **7**: 1383-1384.

VERMOTE, E., TANRE, D., DEUZE, J.L., HERMAN, M. and MORCETTE, J.J. (1997): Second simulation of the satellite signal in the solar spectrum (6S). *IEEE Transactions on Geoscience and Remote Sensing*, **35**: 675-685.

ZOHARY, M. (1962): *Plant Life of Palestine*. Ronald Press, New York.