ANALYSIS OF THE RELATIONSHIP BETWEEN GLOBAL VEGETATION INDEX AND CLIMATE FACTORS

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ABSTRACT

The status of the vegetation which is growing at a place largely reflects the climate conditions of the site. In this study, the relationships between vegetation and climate factors were studied at global scale, especially the relationship between vegetation and precipitation. The Global Vegetation Index (GVI) from the AVHRR aboard the NOAA-7 satellite was used for vegetation monitoring, along with weather station data from all over the world. It was found that the GVI shows a stronger relationship to annual precipitation in areas with annual precipitation lower than about 1200-1500mm. The different of the relationships between the GVI and precipitation at different latitudes and different ranges of E. de Martonne's AI (aridity index) were also studied. By analyzing the results, the possibility of estimating annual rainfall at global scale by using NOAA GVI data was discussed.

KEY WORDS: Global, GVI, Vegetation, Climate Factors, Relationship

1. INTRODUCTION

Changes of the earth's biology and hydrology are closely related, and it is very important to understand the interaction between these two aspects. The GVI data from the NOAA-7 AVHRR are the most commonly used satellite data for monitoring vegetation changes, especially global vegetation change (Murai and Honda, 1990). Some recent studies of the relationships between vegetation and climate factors have been carried out (Nicholson & Davenport,1990; Bai & Murai, 1991 etc.), which showed the GVI was strongly related to the annual precipitation at regional level. It was also found that the GVI is closely related to actual evapotranspiration (Box et al, 1989). This study investigates the effect of meteorological factors on global vegetation change, especially the effect of the amount of annual precipitation on vegetation, based on the GVI and meteorological data, and discusses the possibility of estimating annual precipitation from the GVI.

2. BRIEF DESCRIPTION OF DATA AND DATA PROCESSING

The data used in this study include GVI data and meteorological data.

2.1 GVI Data

GVI is the resampled data-set of the weekly maximum component of the Normalized Difference Vegetation Index (NDVI), which can be obtained from the visible band (ch1) and near-infrared band (ch2) of the NOAA AVHRR by the following equation:

$$NDVI = \frac{ch2 - ch1}{ch2 + ch1} \qquad (1)$$

The NDVI value, which is related to the land vegetation cover, usually ranges from 0 to 0.6, with larger values indicating higher density of land vegetation cover. GVI images are based on the polar-stereo projection, with 1024 by 2048 pixels covering the area from 75°N to 60°S latitude. Because of the relatively higher frequency of observation of the NOAA-7 satellite, relatively (but not completely) cloud-free images can be obtained by taking the weekly maximum component. The monthly maximum components of the GVI, from 1983 to 1987, were used.

2.2 Meteorological Data

The meteorological data used in this study were provided by the Japan Meteorological Agency, and were collected from 2344 weather stations all over the world. The data-set includes digital data for monthly temperature, rainfall, humidity etc., from January 1983 to December 1988. Since there were many stations with no data collected for a certain year or for a certain month, only around 600-900 station data could be used in this study, depending on the year. Fig. 1 shows the distribution of weather stations that could be used for 1983. Many station data were available from Europe, North America, and East Asia, while few station data were available from Australia, Africa and South America.

2.3 Data Processing

Since the weather station data are point data, the GVI values for the sites should be calculated from the two-dimensional GVI images. This can be done by calculating the line and pixel number of the site on a GVI image, using the longitude and latitude of the station. In order to reduce error, a 3-by-3 pixel-window average of GVI was calculated for every site. As can be seen from Fig. 1, there are many weather stations along the coastline. Therefore, some of the 3-by-3 pixel windows will include sea pixels, which should be excluded from the GVI calculation of the site. The GVI shows very low values for ground objects other than vegetation. If the GVI has a value less than 0 at a site, the land cover of the site can be considered to be non-vegetation. This characteristic of GVI was used to separate the sea pixels from the land pixels, by making a simple assumption: if the GVI value of a pixel is less than 0 for month in which the vegetation should be very active (assumed to be July in the Northern Hemisphere and January in the Southern Hemisphere), the pixel is a sea pixel. This processing can prevent sea pixels from being calculated. , There were however still problems remaining unsolved: (a) Some pixels with very low values may be judged as sea pixels and lost; (b) Mixed pixels can not be identified, and the GVI value of these sites will show lower values than that of real vegetation.

3. THE RELATIONSHIP BETWEEN ANNUAL GVI AND PRECIPITATION

3.1 The Effect of Annual Precipitation on GVI

Annual precipitation is one of the most important factors for vegetation. The annual precipitation and annual GVI (the sum of the twelve months monthly maximum GVI components) of all usable weather stations, with annual precipitation larger than 0 and annual GVI larger than 0, were plotted in Fig. 2. From the figure it can be seen that: (a) During 1983 and 1984, which were both abnormal drought years all over the world, vegetation activity also shows a lower level as compared with other years, indicating the importance of water supply to vegetation; (b) The annual GVI shows stronger relationships to annual precipitations in areas with precipitation lower than about 1200-1500mm. When the annual precipitation is higher than this threshold, the GVI does not increase any more and the plotted points in the figure become more scattered. This may indicate the value of effective annual precipitation for vegetation. With increasing annual precipitation, the most important factor for the vegetation may change from water supply to other factors like sunshine, soil conditions, etc.. Two other possible reasons can be considered: one is that the GVI reflects the leaf area chlorophyll but not the volume of chlorophyll, and thus can not show vegetation higher than a certain level; the second is that, with increasing rainfall, the possibility of getting cloud-free images from the weekly maximum value of GVI becomes lower, and therefore the GVI shows a value lower than that of the real vegetation.

In order to improve the reliability of the results, the data were resampled by calculating the density of the plotted points in a certain window, and only those high-density points remain. Here density means the

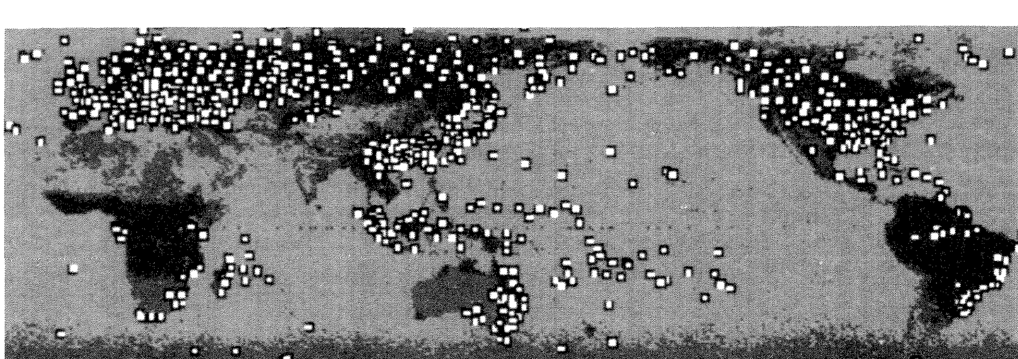
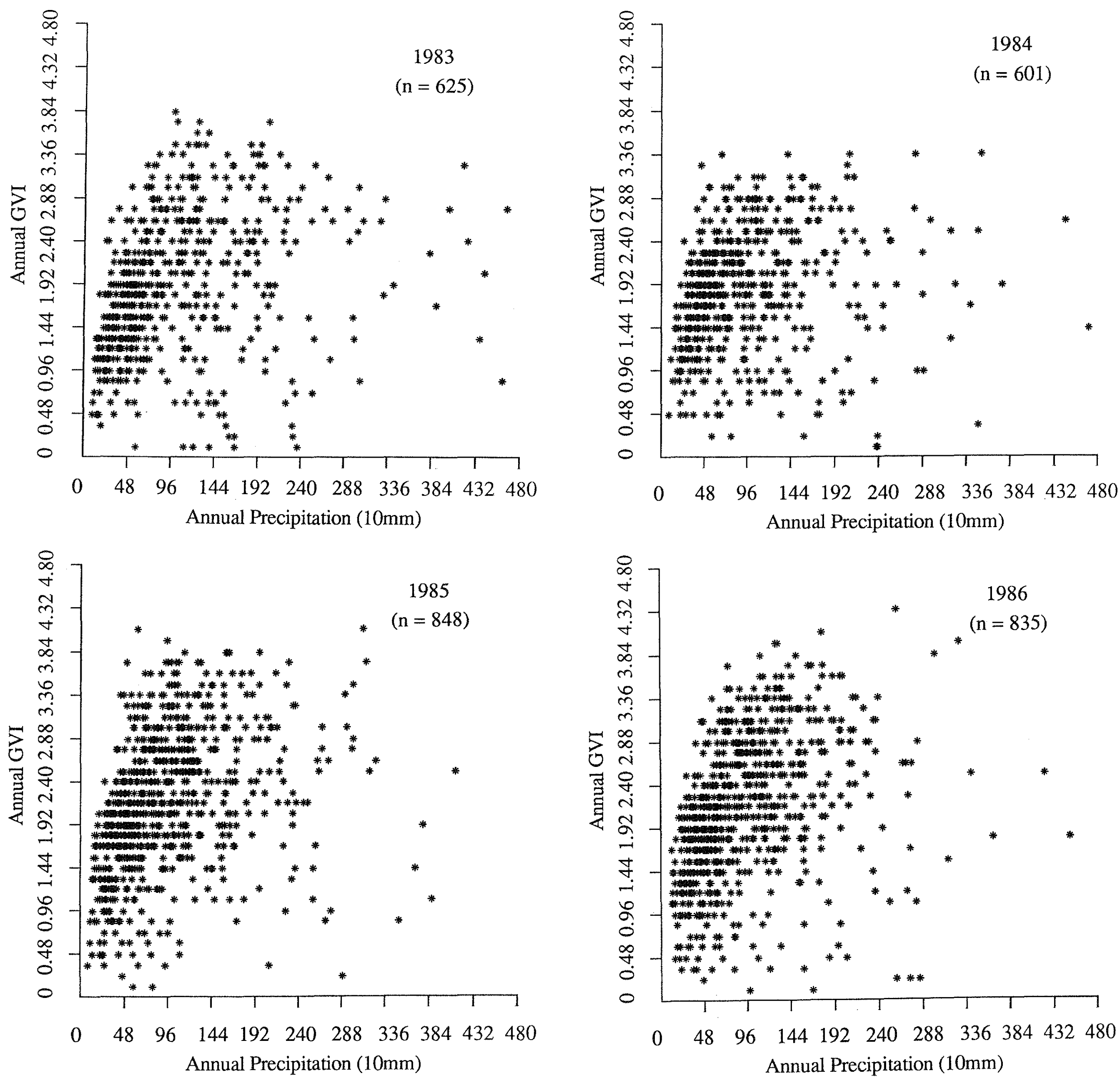


Fig. 1. The Distribution of Weather Stations that could be Used for 1983, Overlapped With the GVI Image of Jun. 1985.



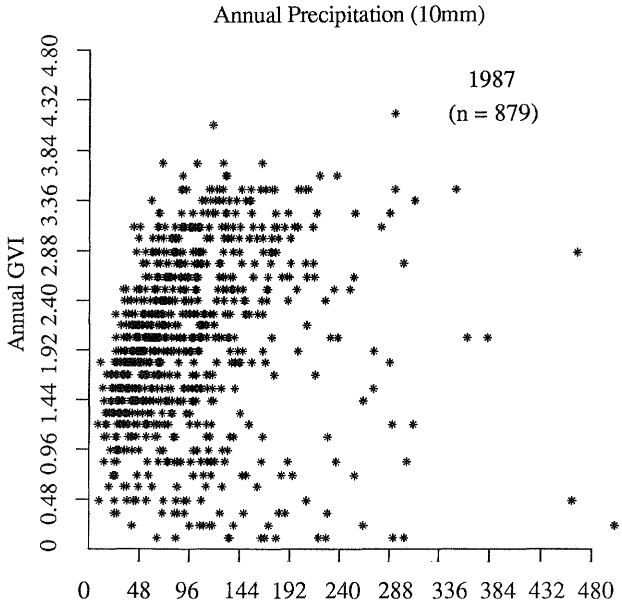
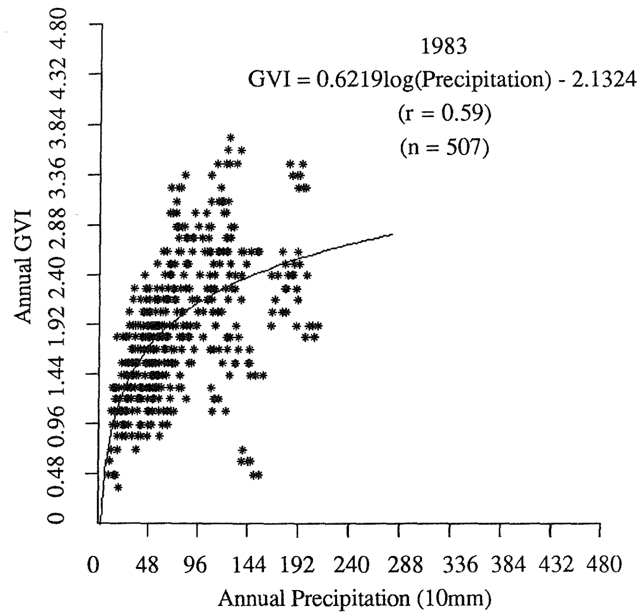


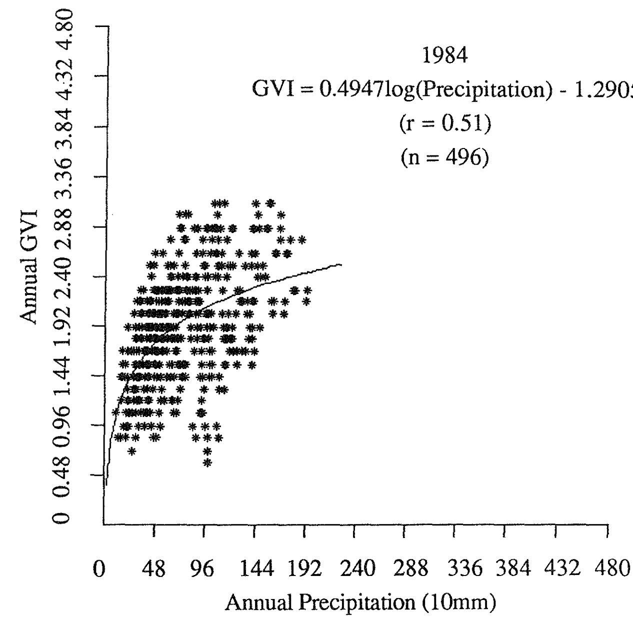
Fig. 2. The Annual GVI and Precipitation from 1983 to 1987

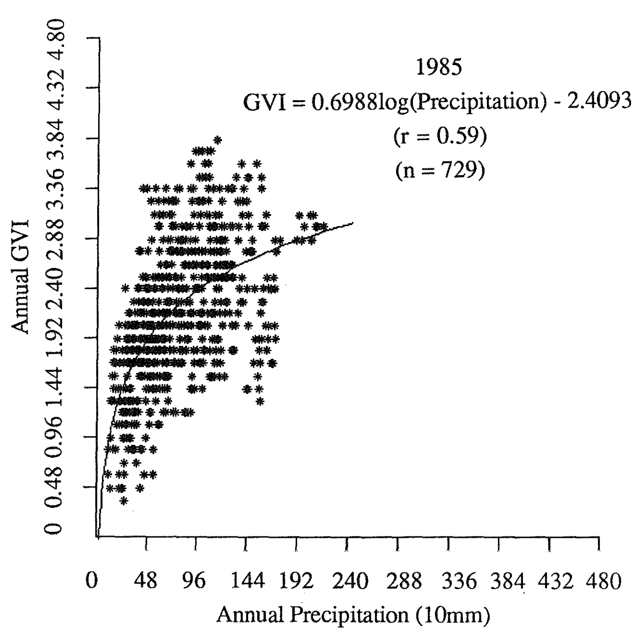
number of points in a window, defined as 150mm of precipitation(in the x direction) and a GVI value of 0.4 (in the y direction). All points with density higher than 4 were plotted in Fig. 3. Around 100 sites were excluded after this calculation, including almost all the data from small Pacific islands and some other unstable data. Fig. 3 shows a higher relationship between annual precipitation and annual GVI as compared to the ones before resampling.

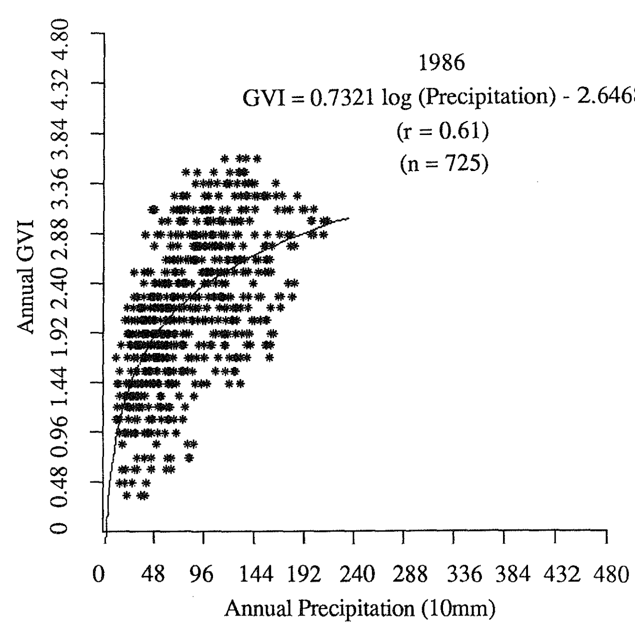
3.2 The Annual GVI-Precipitation Relationship of Different Latitude

The influence of latitude on the relationship between annual GVI and precipitation was also investigated. The station data were divided into 4 groups according









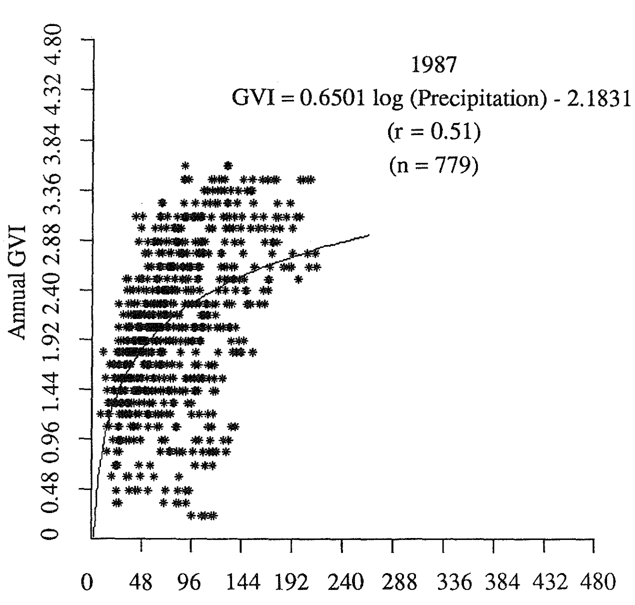


Fig. 3. The Annual GVI and Precipitation after Resampling by Window-Density Calculation

to the latitude of the site: <22.5; 22.5-40; 40-60; >60. The number of data in each group is showed in Table 1. Fig. 4 shows the plotted results, with (a) corresponding to the group with latitude lower than 22.5°N/S, (b) to latitude 22.5-40°N/S, (c) to latitude 40-60°N/S, and (d) to latitude higher than 60°N/S. From the results of all five years, the distribution pattern of vegetation and precipitation of every group can be shown as in Fig. 5. At low latitude, the ranges of both variables are widest: precipitation 100-4500mm, GVI 0.04-3.84. The highest values of both precipitation and GVI appeared in this group, and almost all the sites with annual precipitation higher than 2800mm are included. The (b) group appears as a circle, with the GVI level in the middle (0.96-3.36) and precipitation

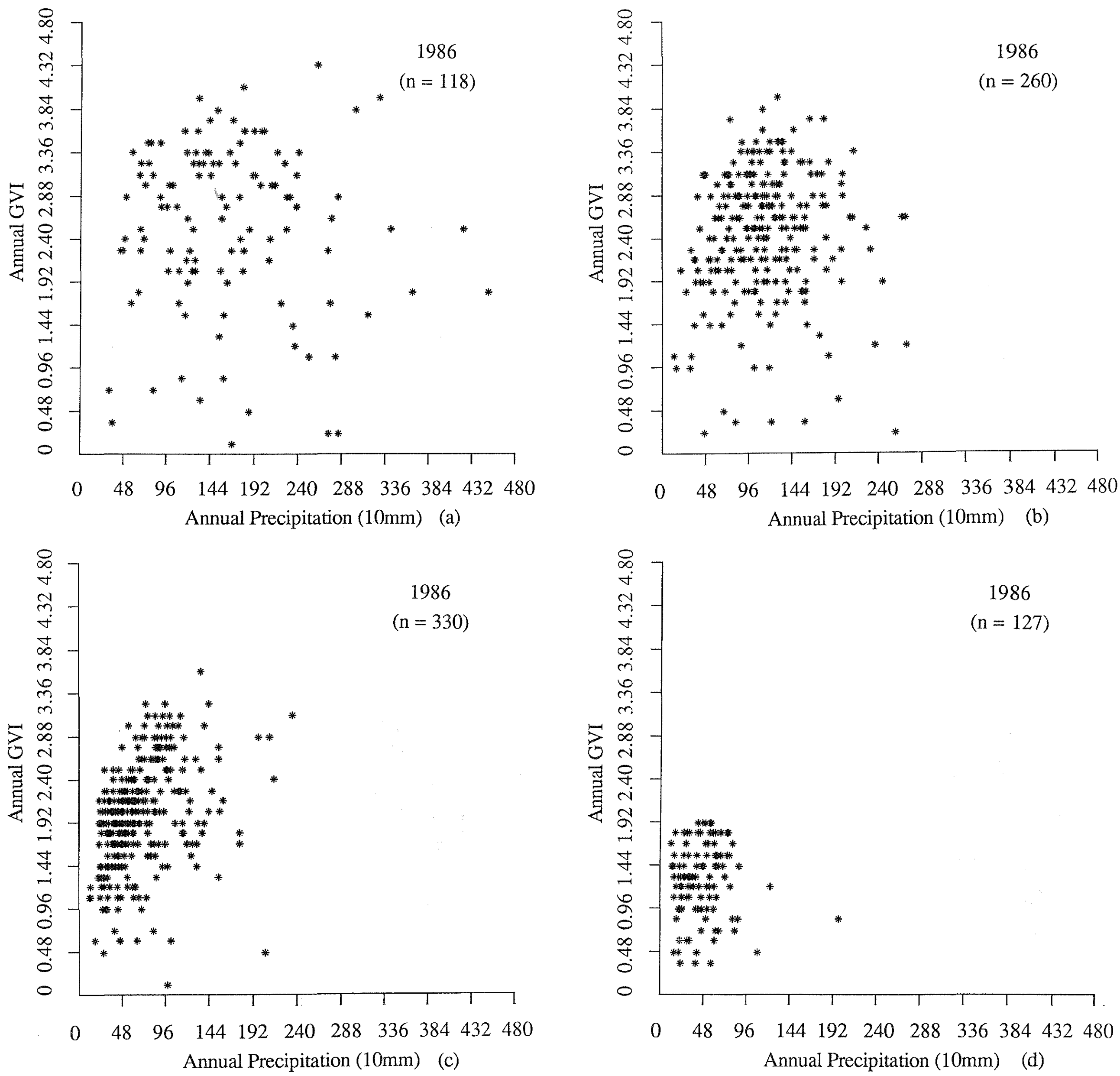


Fig. 4. The Annual GVI and Precipitation of different Latitude of 1983
(a) : lat.<= 22.5; (b) : 22.5 < lat.<=40;
(c) : 40< lat. <=60; (d) : lat. < 60.

Table 1. The Number of Data in Each Latitude Range

YEAR	LATITUDE			
	<22.5	22.5-40.0	40.0-60.0	>60.0
1983	102	157	264	102
1984	97	139	271	94
1985	102	267	356	123
1986	118	260	330	127
1987	110	256	381	132

ranging from 100 to 2400mm. The (c) group is a narrow long orbit, showing GVI well related to the annual precipitation. The annual precipitation ranges from 100 to 2000mm, and the GVI ranges from 0.2 to 3.4. Data in the (d) group concentrate at the lowest levels for both precipitation and GVI, which may show the low levels of vegetation activity and annual precipitation in the high latitude regions.

3.3 The Annual GVI-Precipitation Relationship Under Different Aridity Conditions

The relationship between the annual precipitation and GVI should differ under different climate

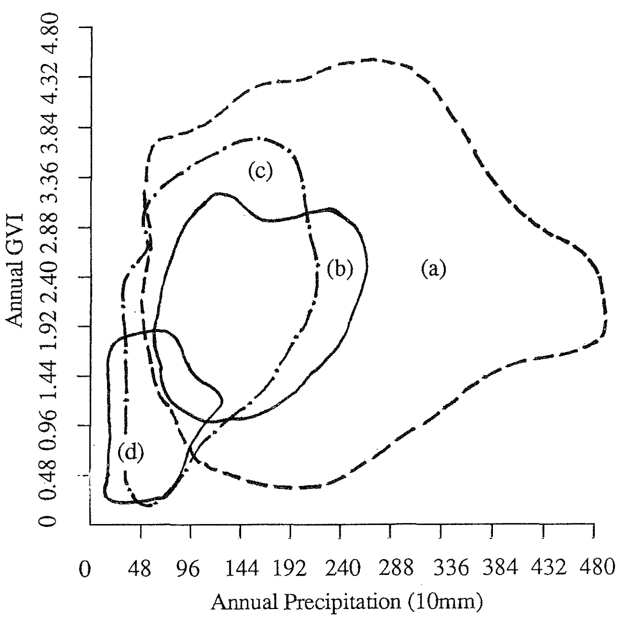


Fig. 5. The General Distribution Pattern of Annual GVI and Precipitation of Different Latitude

conditions. In this study, the Martonne AI (aridity index) (Yoshiaoka, 1978), which can be expressed by the following equation was used:

$$AI = \frac{P}{T+10} \quad (2)$$

where,

AI : E. de Martonne's aridity index
P : annual precipitation (mm)
T : the sum of monthly mean temperature of those months with monthly mean temperature >0.0, divided by 12 (cf Holdridge's (1959) Biotemperature).

Martonne's original value ranges of the aridity index were modified by Murai and Honda(1991) through comparison with a world map of present actual vegetation, a world climate map, a world agricultural map, etc. The Martonne range criteria and the modified criteria are shown in Table 2. The modified range criteria were used in this study. The number of data in each zone (range) is shown in Table 3. Fig. 6 shows the annual precipitation and GVI of the different zones. In desert, semi-desert and grassland, annual precipitation shows very low value. In forest, annual precipitation ranges from 100 to 2880 and the GVI ranges from0.1 to 3.84. In tropical forest, the GVI and the annual precipitation are highest.

<u>3.4 Possibility for Estimating Annual Rainfall by Using GVI</u>

Table 2. The Martonne AI Range Criteria and the Modified Criteria by Murai and Honda

YEAR	AI				
	<=5	5-10	10-20	20-40	>40 (av.temp.>24)
1983	2	14	80	470	59
1984	0	5	71	470	55
1985	0	13	92	705	38
1986	0	15	101	663	56
1987	0	9	99	727	44

The status of vegetation is the result of the climate, soil and other conditions of the site. The non-climatic conditions are relatively fixed for a site. Among climatic conditions, water supply and energy supply are two of the most important factors. The energy supply is also relatively fixed for a site. Therefore, vegetation change at a site should reflect largely the change of water supply of that site. It must be of great interest if we could estimate the annual precipitation from the two-dimensional GVI data all over the world. It seems difficult to make a simple global model for estimating precipitation from GVI, partly because of the limitation of the GVI data themselves and partly because of the lack of available climatic and non-climatic data. From the results obtained up to now, however, it seems that in those areas with lower precipitation the GVI data are relatively sensitive to precipitation. The latitudes of these areas are usually higher than 20°N/S, and are semi-desert, grassland or forest according to the modified zoning based on Martonne's aridity index. Therefore, it may be possible to estimate from the GVI data in these areas. Since there may be a saturation point for water necessary for vegetation, it may be difficult to estimate the real precipitation from GVI in tropical areas. More indices are needed, and the result may be less effective than in lower precipitation areas.

4. CONCLUSIONS

(1) Vegetation can reflect the change of annual precipitation. In drought years, the vegetation obviously shows a lower level than in other years.
(2) The annual GVI shows stronger relationships to annual precipitation in areas with precipitation less than about 1200-1500mm.
(3) The latitude of the sites affects the relationship between annual precipitation and annual GVI. The annual GVI is very sensitive to annual precipitation within the latitude range of 40 to 60 °N/S.
(4) GVI in desert, semi-desert, grassland and some forests areas is more sensitive to annual precipitation than in tropical forest, according to the modified

Table 3. The Number of Data in Each Martonne AI Range

CLASS	AI	
	Martonne	Murai & Honda
Desert	<= 5	<= 5
Semi-desert	5 - 10	5 - 10
Grassland	10 - 30	10 - 20
Forest	> 30	20 - 40
Tropical Forest (annual average temp. over 24 C)	___	> 40

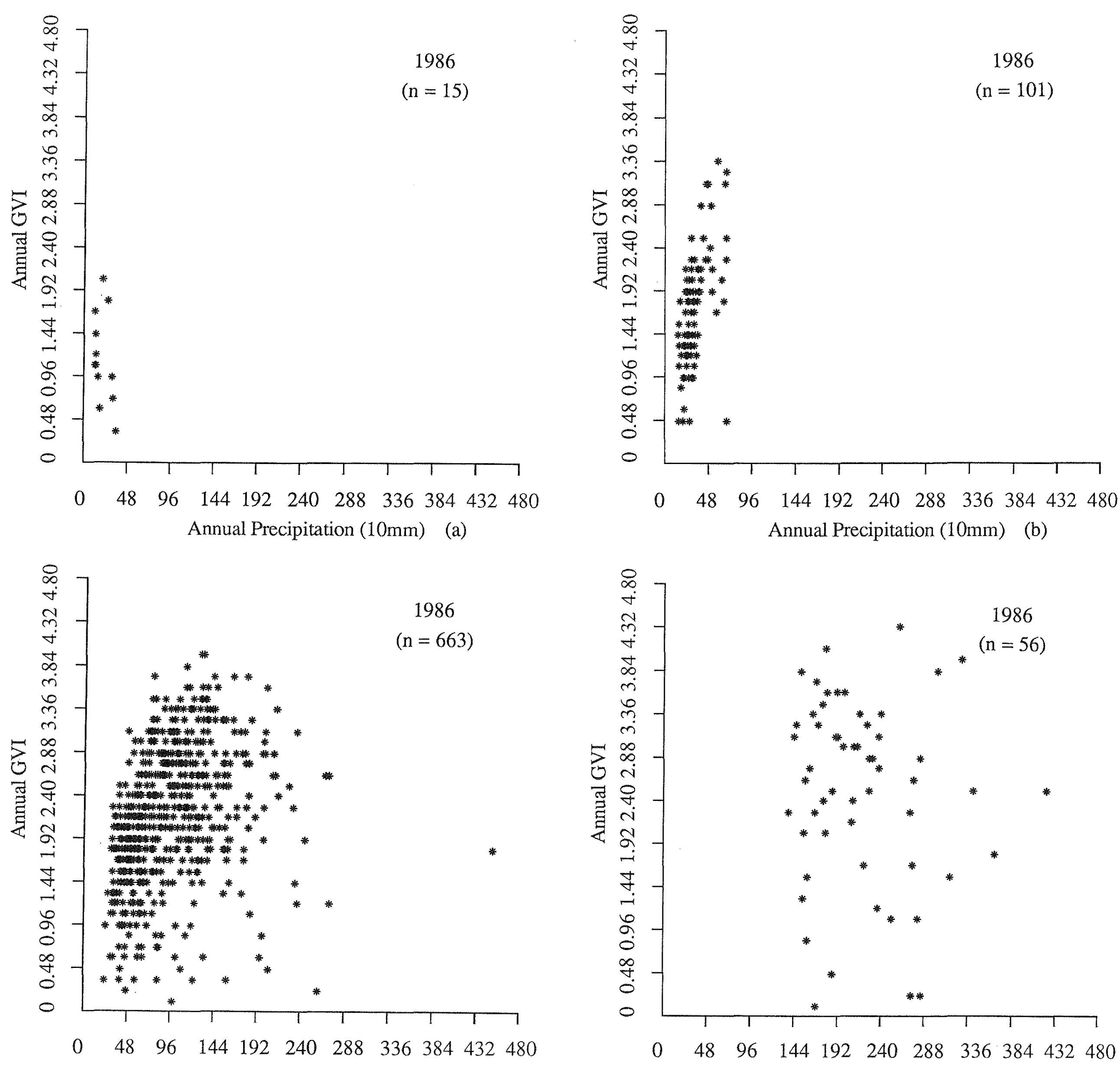


Fig. 6. The Annual GVI and Precipitation of Different Martonne's AI Ranges
(a) : AI < 10; (b): 10 < AI < 20;
(c): 20< AI <40; (d): AI > 40 (av. temp.>24)

Martonne AI zoning.

(5) To make a global model estimating precipitation from GVI is difficult, but there is the possibility to estimate annual precipitation in lower precipitation areas.

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REFERENCES

Bai, X.M. and Sh. Murai 1991. Habitability analysis in China. In: Applications of remote sensing in Asia and Oceania. (Sh. Murai, ed.), pp. 31-36.

Box, E. O.,B. N. Holben, and V. Kalb 1989. Accuracy of the AVHRR Vegetation Index as a predictor of biomass, primary productivity and net CO2 flux.Vegetatio 80: 71-89.

Holdridge, L. R. 1959. A simple method for determining potential evapotranspiration from temperature data. Science 130: 572.

Honda,Y. and Sh. Murai 1990. Vegetation mapping using Global Vegetation Index and weather data. In: Procs., the 10th ACRS (Asian Conference on Remote Sensing), Kualalumpur, Malaysia, pp. A-2-4-1-A-2-4-6.

Murai, Sh. and Bai X. M. 1990. Habitability analysis in China using Global Vegetation Index. In: 2nd GIS Workshop, Beijing, Aug. 6-8 1990,Beijing, China.

Murai Sh. and Y. Honda 1991. The evaluation for the Global human activities based on Eco-climate map. In: 12th ACRS, Singapore, pp. S-2-1-S-2-6.

Nicholson, Sharon E., M. L. Davenport and Ada R. Malo, 1990. A comparison the vegetation response to rainfall in the Sahel and East Africa, Using Normalized Difference Vegetation Index from NOAA AVHRR. Climate Change 17:209-241, 1990.

Yoshiaoka M. Climatology, Taimei-do, 1978