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GLOBAL ANALYSIS OF THE RELATIONSHIP BETWEEN PRECIPITATION AND VEGETATION DYNAMICS DERIVED FROM NOAA/AVHRR-NDVI

(Analisis Global Dinamika Curah Hujan dan Vegetasi Berdasarkan Indeks Vegetasi NOAA/AVHRR)

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ABSTRAK

Studi perubahan pola hujan merupakan fokus penelitian mengenai perubahan iklim global, termasuk perubahan mengenai penutupan lahan seperti vegetasi yang sangat berkaitan erat dengan hujan. Oleh karena itu, sangat diperlukan pemahaman mengenai hubungan curah hujan dan indeks vegetasi pada berbagai variasi waktu dan tempat. Penelitian ini mengkaji hubungan curah hujan dan dinamika vegetasi global yang diidentifikasikan oleh indeks vegetasi (*Normalized Difference Vegetation Index,* NDVI). Data NDVI diperoleh dari *Twenty-year Global 4-minute AVHRR NDVI Dataset produced by Chiba University* (July 1981 *to* December 2000), sedangkan data iklim bulanan diperoleh dari *The Climatic Research Unit, University of East Anglia, CRU05 0.5 Degree Monthly Climate Time-Series (1901-1995) CD-ROM,* Ver.1. April 1999. Analisis regresi linear dan non linear serta analisis korelasi secara global telah diaplikasikan dengan skala resolusi 0.5x0.5°. Untuk memahami hubungan tersebut, juga telah dilakukan analisis di stasiun iklim di Asia. Hasil penelitian menunjukan hubungan yang signifikan antara curah hujan dan indeks vegetasi baik data tahunan maupun musiman, sehingga hubungan ini dapat dijadikan sebagai salah satu indikator di dalam studi mengenai perubahan iklim global.

Kata kunci : pola hujan, vegetasi, NDVI, regresi, dan korelasi

INTRODUCTION

The study of changes in global precipitation patterns is a key element in the ongoing research of climate change. There are also changes that occur over the land surface, such as in vegetation, which are associated with changes in precipitation. However, a better understanding of precipitation- vegetation relationships on various time and space scales is needed.

There were many studies on relationship between rainfall to NDVI such as in East Africa1), Bostwana2), Sahel3), Amazon and Northeastern Brazil4), China5), and also in global scale6)7). From those studies, the relation of precipitation and NDVI is complex, such as reported by Kerr8) that its relationship was linear in Senegal, while by Lu5) the relationship was quadratic in China. Additionally, Milich and Weiss3) found that the relationship was inconsistent from the year to the year in Sahel, Africa.

Hence, this paper attempts to explore the relationship between climate variables and the vegetation dynamic derived from NOOA/AVHRR-NDVI value, based on either spatial scale or

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point data. The authors also tried to investigate the possibility to study the global environmental change by using satellite data.

METHOD

To examine the relationship between precipitation and satellite remotely sensed NDVI data, both linear and non-linear regression models were applied spatially based on the annual and the seasonal data. For accuracy purpose, we also applied punctually (point) to the10-day period data based on the climatic stations in Asian region for 1995-1998 periods. A simple "rain green ratio" was applied to investigate the possibility to study the global environmental change by using satellite data.

DATA

The data used here are precipitation and satellite remote sensed NDVI data from January 1982 till December 1995 for spatial analysis. For the point analysis, the data is January 1995 to December 1998, due to the limitation of the available data.

(1) Spatial analysis

Briefly, the NDVI data was derived from Twenty-year Global 4-minute AVHRR NDVI Dataset of Chiba University (July 1981 to December 2000), while the monthly climate data were obtained from The Climatic Research Unit, University of East Anglia, namely CRU05 0.5 Degree Monthly Climate Time-Series (1901-1995) CD-ROM, Ver.1. April 1999. To enable in regression analysis, all of the image have been resampled to 0.5x0.5° spatial resolution.

(2) Point analysis

The point climate data was derived from Global Summary of Day (GLOBALSOD) dataset that consists of the daily air temperature and precipitation since 1995 to 1998, with approximately 21.900 stations over the world. In this study, the precipitation data in Asian region for about 2200 stations was used. The analysis was emphasized into diverse actual vegetation type resulted from Runtunuwu12). The coordinates of climatic stations from GLOBALSOD have been corresponded with nearest pixels of NDVI and vegetation types images considered in order to obtain the NDVI values and vegetation types of each station.

RESULTS AND DISCUSSION

Figures 1 shows the mean annual of the 15-year period (1981-1995) of the precipitation (mm) and integrated NDVI. For the climate figures must be considered as rough sketches, since they are based on 0.5 spatial resolutions. Glance at this figure, there is a good corresponding between the mean annual integrated NDVI (INT) and the precipitation.

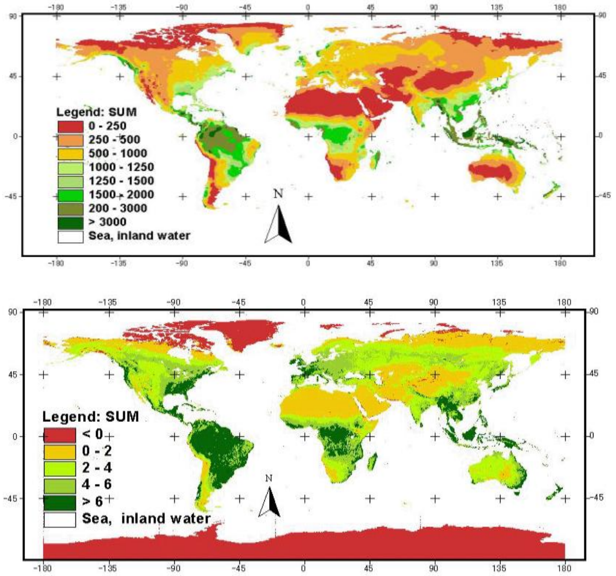

Figure 1. Mean annual precipitation (atas) and integrated NDVI for the period 1981-1995 (bawah).

For example, the lower NDVI (less than 2) distributed in Sahara, Saudi Arabia, and central Asia, is associated with the low amount of precipitation (less than 250 mm/year). For the tropics of the north part of northern America, Central Africa, and Southeast Asia the two maps show a match expression, which all parameters show a high value, the NDVI is more than 6 and precipitation is more than 2000 mm/year. The specific relation also appears when looked at the seasonal (DJF, MAM, JJA, and SON distributions (not shown here).

Figure 2 shows the 14 years time series of precipitation and integrated NDVI from 1982 till 1995 correlation, using linear correlations. From these figures, the highest correlation between both variables occurs in eastern Asia, northern of northern America, middle Africa (western Sahara), and eastern Asia.

According to Schultz and Halpert (1995), the strongest negative correlations occur in region where the precipitation trends to occur in winter, while the NDVI maximum occurs in summer. In such regions, the annual activity of vegetation is driven primarily by temperature.

Many regions have near to zero correlations between NDVI and precipitation. Monsoon regions and tropical rain forest such as Indonesia and Brazil and other regions have near to zero or slightly negative correlation.

Figure 3 shows the correlation between the ground stations precipitation and the NDVI data over the climate stations in Monsoon Asia. These data represented the correlation between both variables over the 10-day time series precipitation and NDVI data during January 1995 till 1998. From this figure, some places of central and western China has a good correlation, while the other places such as the tropical region the correlation is near to zero or negative. The result looks almost the same with previous result, which suggested the tropical region has a low or negative correlation between both variables.

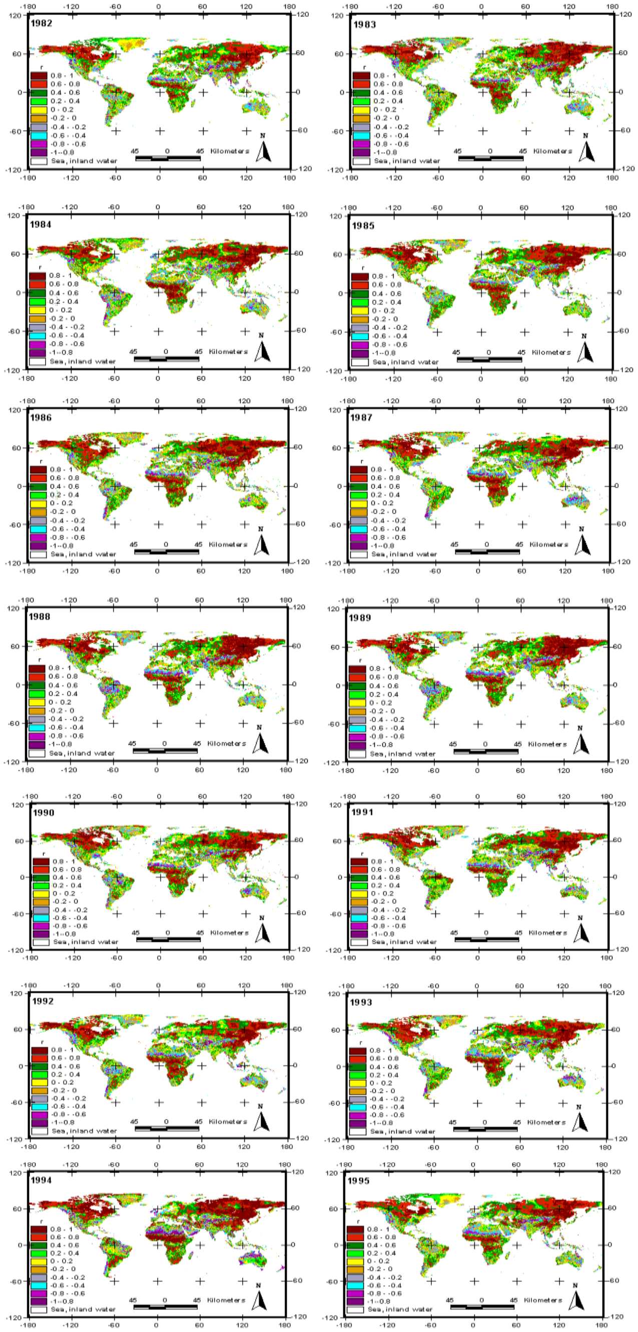

Figure 2. Correlation coefficient between annual precipitation (mm) and annual integrated NDVI from 1982 till 1995.

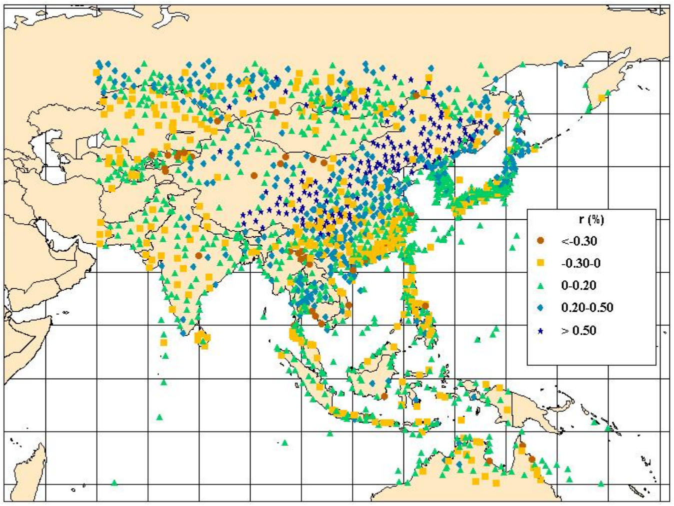

Figure 3. The distribution of correlation between 10-days integrated NDVI and precipitation January 1995 till December 1998 period over Monsoon Asia.

The correlation between the annual integrated NDVI and mean annual precipitation based on point data is shown in Figure 4. The relationship characteristic is exponential with correlation coefficient and standard deviations are 0.54 and 1.48, respectively. In areas with annual precipitation less than 1500 mm per year 125 mm/month, the integrated is linearly correlated, although the variance is large. In contrast, in areas with annual rainfall greater than 1500 mm per year, NDVI saturates and there was no relationship.

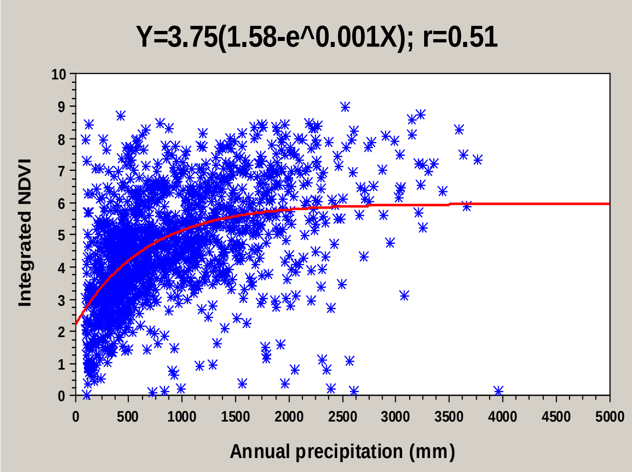

Figure 4. Scatter plots between integrated NDVI versus mean annual precipitation (mm) for the stations in Monsoon Asia; the red line is approximate best fit of dataset.

This result points out the NDVI relates to changing patterns of rainfall in dry climates, while it is not in wet region, as shown in Figure 5.

Figure 5 shows the scatter diagrams for these stations, presented in order of increasing average annual precipitation. The legend shows the station code, and means annual precipitation for 4-yr period of study. In general, stations with lower annual precipitation display more linear relationship (correlation coefficient more than 0.60) between precipitation and the NDVI.

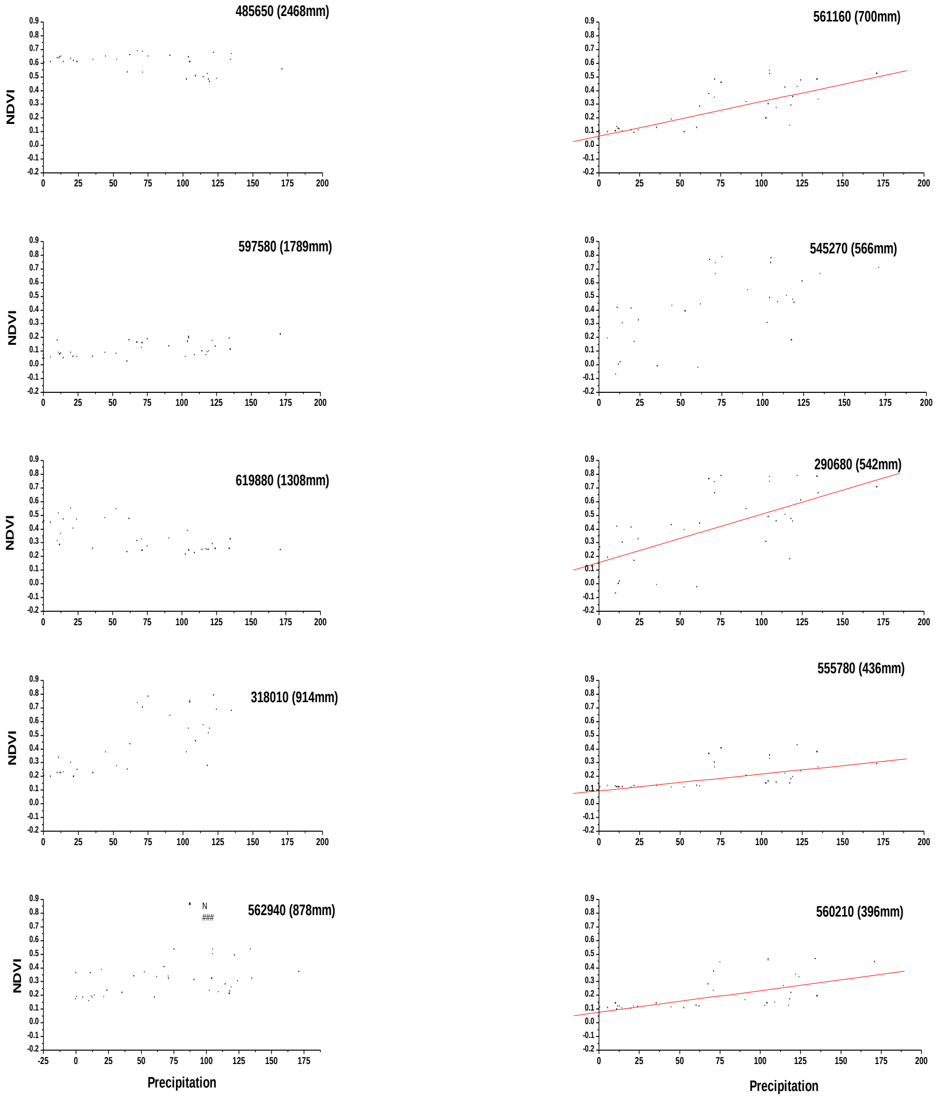

Figure 5. Scatter plot of mean annual 10 day NDVI versus precipitation (mm) for the numbered stations over Monsoon Asia. Stations are in order of increasing annual precipitation.

Therefore, the NDVI might be a sensitive indicator of precipitation only in drier climates. In other explanation, when the precipitation increases, the canopy becomes dense, and NDVI values increase until the threshold value is reached. On that time, the NDVI remains constant although increasing precipitation still occurred. It means rainfall is no longer as the limiting factor in plant growth that is other experimental variables becomes increasingly important.

Differences in the timing of the NDVI response to precipitation on diverse types of vegetation could be used to understand the relation between both annual precipitation and integrated NDVI. Santos 4), Nicholson and Farrar2), Farrar9), Runtunuwu10)11) done this analysis in a number of different regions based on the monthly data. However, none of these studies have investigated in the less of then one unit monthly data.

This section analyzed based on the ten-day data on precipitation and NDVI data. Thus, for each of the third-teen vegetation types resulted in Runtunuwu12), the linear correlation were utilized between concurrent ten-day values of NDVI with the precipitation data for the same time (time lag = 0), previous data (time lag = 1), and so on until the time lag equal to 9 that associated with the precipitation condition of three months before. The result is summarized in Table 1. As shown in this table, the dense canopy such as the tropical forests, the time lag is more than 3, while the dense canopy such as savanna, cropland, rice paddy, and grass/crop, is varied 0 and 1. It suggests the NDVI appears respond to rapidly in rare canopy rather than the dense canopy. It seemed consistent with the result in the seasonal section, that sometimes the NDVI and precipitation has a different peak of time. The bold values indicate the highest of correlation coefficient.

Table 1. Linear correlation between NDVI and precipitation for several vegetation types in various time lags. The bold values indicate the highest of correlation coefficient.

Station	LON	LAT	0	1	2	3	4	5	6	7	8	9
Tropical rain forests												
485650	98.32	8.12	-0.41	-0.28	-0.14	-0.39	0.14	0.27	0.37	0.47	0.57	**0.62**
964910	118.1	5.9	-0.30	-0.24	-0.10	-0.13	0.15	0.36	0.46	0.61	**0.62**	0.58
485630	98.9	8.0	-0.43	-0.39	-0.23	-0.58	0.08	0.26	0.38	0.51	0.57	**0.60**
Tropical seasonal forest												
986440	123.8	9.6	0.15	0.37	0.39	0.27	0.48	**0.59**	0.45	0.42	0.30	0.34
619880	63.4	-19.6	0.59	0.50	0.45	**0.64**	0.29	0.19	0.15	0.12	0.08	0.01
485800	101.5	6.78	0.48	0.46	0.43	**0.63**	0.26	0.12	-0.1	-0.3	-0.3	-0.3
Sub tropical rain forest												
597580	110.3	20.0	0.56	0.61	**0.72**	0.60	0.66	0.55	0.40	0.18	0.06	-0.1
467410	120.2	23	0.52	0.52	**0.55**	0.50	0.47	0.36	0.19	0.03	-0.1	-0.2
477680	133.9	34.65	**0.65**	0.59	0.52	0.63	0.22	0.10	-0.0	-0.2	-0.3	-0.4
Temperate forest												
318010	136.2	47.66	0.88	**0.91**	0.89	0.86	0.79	0.68	0.53	0.37	0.22	0.04
540940	129.6	44.56	**0.87**	0.84	0.76	0.86	0.57	0.42	0.26	0.09	-0.1	-0.3
507880	131.9	47.23	**0.86**	0.92	0.72	0.85	0.51	0.39	0.23	0.04	-0.1	-0.3

Table 1. Continued

Boreal coniferous forest												
290680	91.02	59.5	0.59	0.65	0.67	0.58	**0.71**	0.68	0.66	0.56	0.43	0.24
295810	95.68	56.2	0.55	0.66	0.67	0.60	**0.70**	0.66	0.57	0.45	0.34	0.22
301650	116	58.6	0.72	0.66	0.81	**0.83**	0.67	0.55	0.39	0.20	0.01	-0.2
Savanna/grassland												
503530	126.6	51.72	**0.89**	0.83	0.75	0.88	0.56	0.42	0.25	0.05	-0.1	-0.3
555780	88.88	29.25	**0.90**	0.89	0.93	0.89	0.55	0.34	0.13	-0.1	-0.3	-0.4
504680	127.4	50.25	**0.81**	0.79	0.71	0.80	0.55	0.39	0.23	0.09	-0.1	-0.3
Cropland												
562940	104.0	30.67	0.86	**0.87**	0.83	0.85	0.61	0.40	0.24	0.09	-0.0	-0.0
541860	128.2	43.37	**0.85**	0.81	0.73	0.85	0.49	0.34	0.17	0.0	-0.2	-0.3
563850	103.3	29.52	**0.84**	0.81	0.76	0.84	0.50	0.32	0.15	0.0	-0.2	-0.3
Rice paddy												
545270	117.1	39.1	**0.81**	0.73	0.62	0.80	0.34	0.19	0.05	-0.1	-0.2	-0.4
548360	118.1	36.18	**0.79**	0.72	0.63	0.78	0.40	0.28	0.16	0.02	-0.1	-0.3
570670	111.0	34.05	**0.73**	0.65	0.56	0.71	0.34	0.23	0.11	0.02	-.09	-0.2
Grass/crop												
574470	109.5	30.28	**0.76**	0.68	0.56	0.74	0.29	0.14	0.0	-0.1	-0.2	-0.3
284930	74.38	56.9	0.71	**0.72**	0.68	0.69	0.62	0.55	0.46	0.35	0.24	0.08
296250	80.97	55.1	**0.71**	**0.71**	0.69	0.69	0.53	0.42	0.28	0.14	0.0	-0.1
Tundra												
561160	9506	31.41	**0.89**	0.85	0.78	0.88	0.52	0.34	0.14	-0.1	-0.3	-0.4
560460	96.65	33.75	**0.88**	0.82	0.73	0.87	0.41	0.22	0.02	-0.2	-0.4	-0.6
560290	97.02	33.02	**0.88**	0.81	0.70	0.88	0.40	0.22	0.02	-0.2	-0.4	-0.6
Semi desert and desert												
560210	95.78	34.13	**0.80**	0.70	0.55	0.79	0.20	0.02	-0.2	-0.3	-0.5	-0.6
537050	105.6	37.48	**0.75**	0.68	0.61	0.74	0.39	0.24	0.1	-0.1	-0.3	-0.4

A simple "rain green ratio" that defined as the rate of primary productivity per unit rainfall or the amount of about-ground phytomass produced per hectare per year per millimeter of rain (Davenport and Nicholson, 1993) has been calculated in this study. This parameter is analogues to rain use efficiency, which noted as ratio of mean annual integrated NDVI to mean annual precipitation. The low value indicates wetter regions, while the high one indicates dry land. For this purpose, the spatial annual integrated NDVI and precipitation were used, and the result is presented in Figure 6. The dry region of Sahara is clearly shown on this figure, whit value more than 16. The humid regions of tropical forests and the glacier region are indicated by the low green ratio value (less than 4). The other semi arid and arid region such as the central of Australia has value ranged from 6 to12.

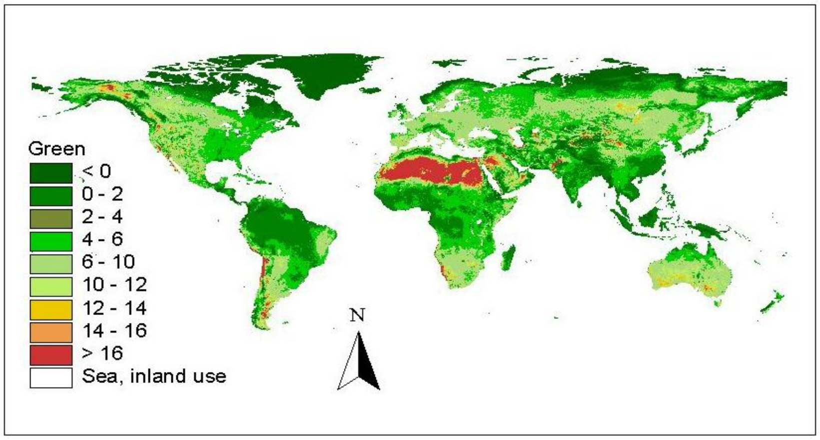

Figure 6. Rain-Green ratio; ratio of annual integrated NDVI (1981-2000) to mean annual precipitation (1981-1995).

CONCLUSION

By looking the distributions of the precipitation and integrated NDVI value for mean annual and the four groups of seasons (DJF, MAM, JJA, SON) data, there is a good agreement between the integrated NDVI value and precipitation. A long a year, precipitation seasonally changes and influences the activity of vegetation (associated to the integrated NDVI value). It is interesting to note that the responding of NDVI to precipitation is dominantly by two types. Firstly, that the NDVI directly responded the precipitation. For example, the NDVI became more intense when the precipitation increased in Peninsula Malaya on the SON season. Secondly, there is a phase lag between the phenology of NDVI and precipitation. For example, in the tropical region, the precipitation peaks in DJF while NDVI peaks in MAM. Also, the precipitation minimum in JJA season, but the NDVI continues decrease until SON. However, a precise lag cannot be determined since all the data based on the three months data.

More detail result was obtained from the point station analysis showing that the NDVI responds to the precipitation is varied depending on the vegetation type. The NDVI appears respond to rapidly in rare canopy rather than the dense canopy.

Another point is the differences activity between the high northern latitude and the tropical regions. The NDVI of the high latitude region peaks on the JJA, while the NDVI of tropical region peaks on the MAM season. However, the year-to-year variations in vegetation condition that are not associated with extreme bioclimatic events are much more difficult to detect using the NDVI as also concluded by Shultz and Halpert (1995).

By using the ground observe precipitation data, the relationship between precipitation and NDVI is exponential with correlation coefficient and standard deviations are 0.54 and 1.48. This result points out the NDVI relates to changing patterns of rainfall in dry climates, while it is not in wet region.

The ratio of NDVI to rainfall, as indicator of water use efficiency, shows a clearly performance for the dry and the humid regions. The dry land vegetation types such as Sahara region generally have high ratios, indicating more efficient water use. The tropical rain forest of Brazil and Indonesia has the lowest ratio representing the humid region. This concept might provide an alternative to investigate the global environmental change by satellite data.

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