Vegetation/Land Cover Changes in Monsoon Asia and its influence on Areal Evaporation

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Abstract

The existing vegetation/land cover map is created by using NOAA's vegetation index product based on the seasonality of the vegetation formations. Hydrological parameters are assigned to each class by using available global datasets, and potential evaporation is calculated. Natural vegetation is restored based on the relationship between climate and vegetation(of cause it is a challenge to be solved), and it enables to assess the change in potential evaporation due to anthropogenic vegetation/land cover changes.

The datasets currently available are limited, and we cannot say that the hydrological processes in global or continental scales are sufficiently understood. The author regards this research as a trial study on the methodology. It is necessary to improve the accuracy of datasets and models with the use of new datasets, including satellite data, that are available in near future.

I. Introduction

Most important influence of anthropogenic vegetation/land cover alterations on regional environment is the changes in water balance at the ground surface. Human history can be regarded as the history of vegetation/land cover alteration. Through the man's activity during the historic era, the water balance in a region should be changed considerably and current environment has thus been established. To get the perspective for future global environment, it is necessary to recognize properly the result of land cover alteration during past several thousand years. For the purpose of it, the precise recognition of existing land cover is necessary, and then potential vegetation must be restored to estimate the changes in land cover. Hydrological function of each vegetation class is another important issue to be searched to estimate the changes in water balance due to land cover alterations.

2. Datasets

Seven datasets, listed below, are employed from the *Global Ecosystem Data Base(GEDB) CD-ROM* compiled by NOAA/NGDC(National Oceanic and Atmospheric Administration / National Geophysical Data Center).

(i) EDC-NESDIS Monthly Experimental Calibrated Global Vegetation Index
(ii) Legates and Willmott Annual Temperature
(iii) Legates and Willmott Annual Corrected Precipitation
(iv) Leemans and Cramer IIASA Mean Monthly Cloudiness
(v) Matthews Seasonal Albedo
(vi) Leeman's Holdridge Life Zone
(vii) Global Elevation and Bathmetry(ETOPO5)

It is easy to point out defects or problems of the datasets, however, the datasets are treated here as given data because they are currently the best datasets.

3. Existing Vegetation/Land Cover

Satellite remote sensing is the most suitable means to provide a existing land cover map in continental or global scales(Townshend *et al.*,1991). Vegetation/ land cover classification is made using seasonal trend of NDVI(Normalized Difference Vegetation Index).

EDC-NESDIS Monthly Experimental Calibrated Global Vegetation Index is used to classify land cover in Asia. The value of NDVI is sometimes smaller than zero. It means that red band reflectance is higher than that of near infrared band, and the signals on vegetation hardly contain in the index. The minus NDVI is replaced by zero, and produce new NDVI dataset.

Investigated area(60° N-20° S, 60° E-160° E) includes Monsoon Asia. Cluster analysis is applied to twelve monthly NDVIs, and forty-eight classes are obtained of which three are meaningless classes due to the effect of mixels.

Each class is expected to represent characteristic hydrological parameters. They are the parameters, such as albedo, air temperature, precipitation, etc., necessary for the calculation of hydrological model, and small variance in each class is expected. Several global datasets are superimposed on the classification map, and the average hydrological parameters for each class are extracted.

Table 1 Forest types by Kira's warmth index. Tropical forest is divided into tropical seasonal forest and tropical rain forest based on the number of months which exceed 50mm in monthly precipitation.

Forest Type	Code	Warmth Index	Pm>50mm
Tropical Rain Forest	FTR	240 <	12
Tropical Seasonal Forest	FTS	240 <	< 12
Subtropical Forest	FST	180 - 240	----
Evergreen Broad Leaf Forest	FEB	85 - 180	----
Deciduous Broad Leaf Forest	FDB	45 - 85	----
Coniferous Forest	FND	< 45	----
		(℃·month)	(Num. of month)

Kira(1945a,b) and Kira *et al.*(1976) revealed that the distribution of the warmth index is well correspond to the distribution of vegetation formation in Asia. The index is defined as:

$$WI=\Sigma(T_i-5) \quad i=1 \text{ to } 12, T_i>5,$$

where T_i is monthly mean air temperatures(℃).

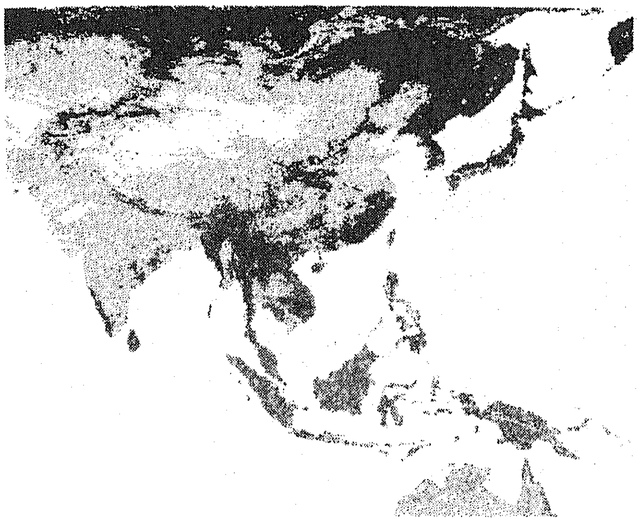

Figure 1 Current land cover. Grey level(0-255) denotes the vegetation/land cover classes. FND(32), FDB(64), FEB(96), FST(128), FTS(160), FTR(192), FBS(208), AGR/GRS(224), SEA(240) and DES(255).

The average indices of each class are calculated from the *Legates and Willmott Annual Temperature* dataset. Based on the criterion shown in Table 1, current forest type is assigned to each class. Other class is interpreted by referring geographic locations, ΣNDVI, and so on.

Table 2 shows the characteristic values of hydrological parameters for each vegetation/land cover class. Fig. 1 shows current vegetation/land cover map over Monsoon Asia. Forest is drawn by darker tones, and grass and agriculture land looks bright. Ocean and deserts are white.

4. Restoration of Natural Vegetation

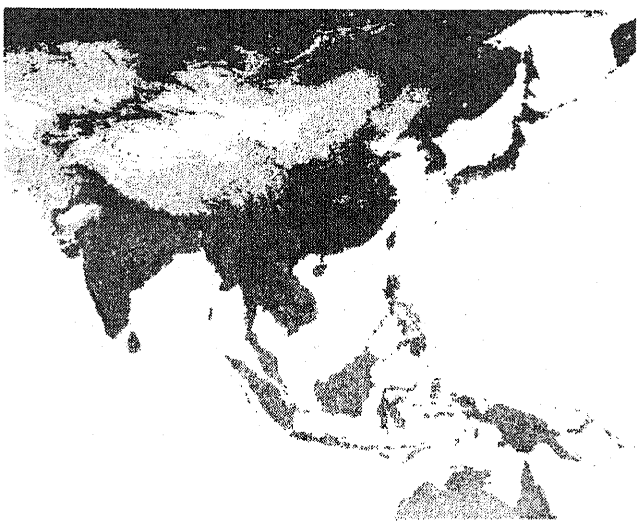

Figure 2 Natural land cover. Grey level(0-255) denotes the vegetation/land cover classes. FND(32), FDB(64), FEB(96), FST(128), FTS(160), FTR(192), FBS(208), AGR/GRS(224), SEA(240) and DES(255).

Table 2 contains the classes of *Leeman's Holdridge Life Zone(LHLZ)* dataset, which means possible vegetation formations under given climatic conditions. It is obtained as the most frequent *LHLZ* class within a vegetation/land cover class. The classes with aster(*) mean that current vegetation/land cover is grassland or cropland, but climatic condition allows the existence of the forest. Namely, the areas of these classes are subject to change in land cover by humans' activity in the historic era.

These classes account for about 24 per cent of the land area within the calculated region. Most of which occupies India and

Table 2 Results of vegetation/land cover classification by cluster analysis based on seasonal trend of NDVI. Characteristic values of ΣNDVI, warmth index(WI), annual precipitation(Pa) and the number of months which exceed 50mm in monthly precipitation(Pm>50mm), and they are used to determine the vegetation/land cover classes.

		Current	Restored	Leeman's	Number of		ΣNDVI		WI		Pa		Pm>50mm		
	No.	Class	Class	Holdridge	Pixels	(%)	mean	std.	mean	std.	mean	std	mean	std.	mode
	1	FND	FND	Bor Mois	6124	2.1	2.2	0.1	35.5	12.0	517.5	152.8	4.0	1.8	3
	2	DES	DES	ClTmp D/B	1767	0.6	0.2	0.1	114.9	69.9	390.0	733.5	0.0	0.0	0
	3	GRS	GRS	Po Des	2250	0.8	1.0	0.2	83.4	64.4	612.4	705.0	2.8	3.0	0
	4	GRS	GRS	ClTmp Ste	3928	1.4	1.4	0.2	51.4	25.6	411.8	224.6	2.5	2.0	3
*	5	AGR	FEB	WmTmp DryF	936	0.3	2.6	0.3	126.5	28.7	806.0	437.9	5.1	2.4	3
*	6	GRS/AGR	FND	Bor Mois	4303	1.5	1.9	0.2	38.8	20.7	483.1	185.4	3.5	1.8	3
	7	GRS	GRS	ClTmp Ste	3663	1.3	0.9	0.2	70.5	32.7	417.9	331.2	1.6	2.1	0
	8	FND	FND	Bor Mois	3050	1.1	2.4	0.2	38.1	15.5	594.4	206.3	5.2	2.4	4
*	9	AGR	FST	SbTrp MsF	2358	0.8	3.7	0.3	205.5	59.0	1573.1	582.1	6.9	1.7	6
	10	GRS	GRS	Po Des	5290	1.8	0.7	0.2	91.6	61.2	522.0	594.2	2.7	2.5	0
	11	GRS	GRS	SbTrp ThnS	3176	1.1	1.1	0.2	222.8	61.8	650.3	632.9	3.5	2.0	4
	12	FDB	FDB	ClTmp MsF	2819	1.0	3.2	0.3	58.4	15.0	711.7	220.0	5.8	2.2	5
	13	FEB	FEB	ClTmp MsF	1900	0.7	3.7	0.3	90.6	28.1	1076.7	454.9	7.9	2.7	7
*	14	AGR	FEB	WmTmp MsF	1462	0.5	2.6	0.3	137.8	44.1	1260.9	489.3	8.4	2.7	11
	15	FND	FND	Bor Mois	4734	1.6	2.5	0.2	37.6	12.9	454.3	158.3	3.2	1.7	2
	16	FDB	FDB	Bor Mois	3659	1.3	2.7	0.2	52.4	22.7	598.1	233.1	4.6	2.0	5
	17	FBS	FBS	Trp VDryF	1888	0.7	2.0	0.3	245.2	48.3	1008.7	710.1	4.9	2.0	5
*	18	GRS	FDB	Bor Mois	2246	0.8	2.0	0.2	54.2	29.9	516.9	259.9	3.7	2.5	3
	19	GRS	GRS	ClTmp Ste	3070	1.1	1.5	0.3	70.4	40.8	475.0	426.2	3.1	2.2	2
	20	FND	FND	Bor Mois	5304	1.8	2.7	0.2	41.3	8.7	511.3	155.8	4.1	1.7	4
	21	GRS	GRS	ClTmp Ste	4436	1.5	2.0	0.2	56.8	27.1	467.1	239.6	3.7	1.7	3
	22	FST	FST	SbTrp MsF	1467	0.5	4.3	0.3	212.9	42.4	1795.4	532.9	8.4	1.7	7
	23	GRS	GRS	Po Des	8402	2.9	0.4	0.1	104.6	61.9	369.0	510.0	1.4	2.1	0
	24	GRS	GRS	Po Rain T	1465	0.5	3.0	0.3	60.6	31.9	663.7	313.9	5.3	1.7	5
	25	FTR	FTR	SbTrp WetF	2403	0.8	6.0	0.4	248.6	28.9	2827.6	694.0	11.2	1.6	12
*	26	AGR	FEB	WmTmp DryF	1485	0.5	2.6	0.3	110.7	55.2	937.2	539.0	6.4	2.9	7
*	27	AGR	FTR	Trp DryF	1448	0.5	2.3	0.3	243.4	16.1	920.7	595.0	4.1	2.0	4
*	28	GRS/AGR	FTR	Trp VDryF	1862	0.6	1.5	0.4	246.6	34.9	1108.5	748.5	5.7	1.9	5
*	29	AGR	FEB	WmTmp DryF	979	0.3	3.3	0.3	135.3	30.0	928.8	465.2	6.4	2.1	6
	31	FTR	FTR	Trp MsF	1547	0.5	4.3	0.3	242.4	36.0	2343.7	691.3	10.6	2.3	12
	32	FTR	FTR	Trp MsF	2289	0.8	5.2	0.3	250.1	23.3	2736.2	653.7	11.2	1.5	12
	33	GRS/AGR	GRS/AGR	ClTmp Ste	900	0.3	1.7	0.3	100.1	52.2	616.5	590.8	3.2	3.0	2
	34	FEB	FEB	SbTrp MsF	1144	0.4	3.7	0.3	173.3	38.6	1620.1	310.8	9.7	1.5	10
*	35	AGR	FEB	WmTmp MsF	1921	0.7	3.3	0.2	147.0	35.0	1362.0	360.6	9.1	2.1	9
*	36	AGR	FST	SbTrp DryF	663	0.2	3.3	0.4	226.4	22.8	1012.5	646.8	4.7	2.3	4
*	37	GRS/AGR	FTR	SbTrp DryF	1639	0.6	1.9	0.3	246.7	23.2	1103.8	537.5	4.6	1.5	4
*	38	AGR	FTR	SbTrp MsF	1101	0.4	2.9	0.4	246.7	33.6	1678.9	803.4	6.7	1.5	7
*	39	GRS/AGR	FTR	Trp DryF	1440	0.5	3.2	0.3	247.3	34.6	1512.2	729.1	7.0	2.5	6
	40	FTR	FTR	SbTrp WetF	2023	0.7	5.2	0.3	250.5	35.5	2740.2	633.2	11.7	1.1	12
*	41	GRS/AGR	FTR	Trp DryF	1654	0.6	2.6	0.3	248.0	22.9	1375.2	466.3	5.5	1.3	5
	42	FST	FST	SbTrp MsF	963	0.3	4.3	0.4	238.6	34.9	2323.0	890.9	8.0	1.9	7
	43	FST	FST	SbTrp MsF	2237	0.8	4.9	0.3	216.3	40.4	1861.9	635.0	7.9	1.7	8
*	44	AGR	FST	SbTrp MsF	1587	0.6	2.8	0.3	217.3	62.3	1539.0	638.0	7.2	1.7	7
	46	FEB	FEB	WmTmp MsF	1193	0.4	4.2	0.3	150.2	56.7	1738.9	582.3	10.4	2.1	12
	47	FST	FST	SbTrp MsF	1265	0.4	5.5	0.3	220.0	29.9	2299.6	784.0	8.0	1.4	7

China. Central plains of Myanmar and Thailand are also experienced large land cover changes.

Natural vegetation is restored based mainly on the warmth index. Fig.2 shows the natural vegetation in Monsoon Asia. Darker impression compared with Fig.1 indicates the restoration of forest. Forest class, FTS(Tropical Seasonal Forest), appears in the restored classes based on the number of months with monthly precipitation over 50mm.

5. Areal Evaporation and its changes due to vegetation/land cover changes

Ahn and Tateishi(1994) developed a method to calculate the global potential evaporation(*Ep*) by using datasets contained in *GEDB*. Their method is based on the Priestley and Taylor method(Priestley and Taylor,1972). It is possible to incorporate the variation of land cover through albedo.

Table 3 shows the class means of seasonal albedos from *Matthews Seasonal Albedo* dataset in the *GEDB*. Meteorological parameters are extracted from *GEDB*. With these values, monthly potential evaporations(*Ep*) are calculated. As for the details of the method, refer to Ahn and Tateishi(1994).

Fig.3 shows annual *Ep* in Monsoon Asia for current vegetation cover. The magnitude of the evaporation seems appropriate in the mid latitudes and in the humid tropics, however, it is obvious that *Ep* overestimates actual evaporation in the semi-arid and arid areas.

Table 4 shows the average seasonal albedo for forest classes. It is determined as an average of the same class in Table 2. Albedo distribution for natural vegetation is restored by converting natural vegetation map to albedo map using Table 4, and *Ep* is recalculated with the same method as Fig.3.

No.	Current Class	Winter mean	Winter std.	Spring mean	Spring std.	Summer mean	Summer std.	Fall mean	Fall std.
1	FND	12.5	1.7	14.7	2.0	17.6	1.5	13.6	1.8
2	DES	24.8	6.3	26.8	6.4	26.4	4.6	25.5	5.5
3	GRS	17.5	5.5	19.9	5.5	21.4	4.5	19.2	5.0
4	GRS	15.9	4.0	18.5	4.3	20.3	3.2	17.8	3.8
5	AGR	14.9	1.1	14.9	3.0	19.3	1.4	16.6	1.3
6	GRS/AGR	13.2	2.2	15.3	2.7	17.9	1.9	14.6	2.5
7	GRS	17.9	5.0	20.4	5.2	22.6	3.9	20.0	4.3
8	FND	13.1	2.1	14.9	2.7	17.4	1.9	14.2	2.1
9	AGR	14.7	3.1	14.9	3.0	15.5	3.2	14.6	2.9
10	GRS	20.0	6.5	22.0	6.0	23.8	4.8	21.7	5.5
11	GRS	20.3	5.9	19.6	6.3	19.5	6.1	19.8	5.9
12	FDB	12.9	2.1	15.0	2.6	17.7	2.2	14.1	2.4
13	FEB	13.2	1.8	15.2	2.2	17.7	2.1	14.5	2.2
14	AGR	14.4	2.7	16.0	3.0	17.4	3.1	15.6	2.9
15	FND	11.5	1.1	13.1	1.8	16.0	1.6	12.6	1.2
16	FDB	13.0	2.0	15.2	2.5	17.8	2.0	14.3	2.4
17	FBS	14.4	4.1	14.6	3.6	15.9	3.6	14.7	3.5
18	GRS	14.9	4.1	17.2	4.4	19.2	3.3	16.4	4.1
19	GRS	17.4	5.1	19.6	4.9	22.1	4.3	19.5	4.6
20	FND	12.2	1.3	14.1	1.6	17.0	1.5	13.2	1.3
21	GRS	16.1	3.9	18.2	3.7	21.2	3.9	18.2	3.8
22	FST	14.0	2.9	14.3	2.7	15.0	3.0	14.2	2.7
23	GRS	22.7	6.7	24.7	6.8	25.1	4.8	23.7	5.8
24	GRS	15.6	3.9	17.9	4.0	19.2	3.5	16.9	4.0
25	FTR	11.7	1.9	11.6	1.6	11.7	1.7	11.6	1.5
26	AGR	13.8	2.9	15.5	3.1	17.4	3.1	15.0	3.0
27	AGR	17.2	2.4	18.1	2.7	19.0	2.7	17.9	2.5
28	GRS/AGR	16.7	2.9	18.2	3.4	19.1	3.3	17.7	3.1
29	AGR	14.8	1.4	17.0	1.4	19.1	1.6	16.4	1.6
31	FTR	12.5	2.8	12.5	2.4	12.6	2.5	12.4	2.4
32	FTR	12.2	2.4	12.1	2.1	12.3	2.4	12.1	2.1
33	GRS/AGR	20.7	6.6	22.8	6.7	23.0	5.1	21.7	5.9
34	FEB	13.5	2.1	14.5	2.3	15.6	2.6	14.4	2.2
35	AGR	13.6	1.8	15.0	2.3	16.5	2.8	14.7	2.3
36	AGR	16.6	2.1	18.1	2.6	19.0	2.9	17.5	2.4
37	GRS/AGR	16.8	1.9	17.4	2.1	18.2	2.5	17.3	1.9
38	AGR	16.3	3.2	17.1	3.9	17.7	3.8	16.8	3.3
39	GRS/AGR	13.7	3.2	13.9	2.6	14.7	2.8	13.9	2.6
40	FTR	11.6	1.5	11.7	1.6	11.8	2.0	11.6	1.5
41	GRS/AGR	16.7	2.0	16.7	2.0	17.1	2.7	16.7	1.9
42	FST	13.3	2.9	13.3	2.8	13.6	3.1	13.2	2.7
43	FST	13.2	2.9	13.2	2.5	13.5	2.9	13.1	2.5
44	AGR	15.2	2.9	16.1	3.0	17.1	3.3	15.9	3.0
46	FEB	13.0	2.1	14.2	2.5	15.5	3.1	13.7	2.4
47	FST	13.0	2.9	12.7	2.4	12.6	2.4	12.7	2.4

Table 3 Average albedos for current vegetation/land cover classes and standard deviations.

Table 4 Average albedos(%) for each forest type. Tropical seasonal forest does not appear in the current vegetation cover map(Figure 1).

Class	N	SPRING	SUMMER	FALL	WINTER
FND	9	14.6	17.2	13.8	12.7
FDB	5	15.5	17.7	14.7	13.4
FEB	1	14.2	15.7	13.8	12.8
FST	3	13.0	13.6	12.9	12.8
FTR	2	10.6	10.7	10.6	10.6

Fig.4 shows *Ep* for natural vegetation over Monsoon Asia, and Fig.5 shows the amount of changes in *Ep* between natural and current vegetation. The region which subject to large areal change in *Ep* is India and eastern and southern China. Central plain of Myanmar and Thailand is the largest affected area next to India and China. The amount of change is large in India, Myanmar and Thailand.

6. Concluding Remarks

This paper describes a result of tentative work concerning the global hydrological changes due to fundamental transformations of Earth's surface by human's activity. We still have to consider more about several issues to approach the conclusion. They are, (1) to improve the accuracy of the global datasets, (2) to get precise recognition on the hydrological phenomena and vegetation dynamics, and (3) to enhance the skills of the model.

Among the global datasets, land cover map is crucial for distributed hydrological modeling. Several international projects are progressing to make high resolution global land cover map with the use of satellite data. The GLI(*GLobal Imager*) is one of the most promising sensor, which is planning to board ADEOS-II satellite.

In the hydrological viewpoints, it is important to search proper definition of existing land cover that minimizes the variance of hydrological parameters within a class. In other words, it is desirable that a number of hydrological parameters can be derived from the land cover definition for use in the flux calculations. It is the significant subject that must be resolved at an early date.

Regarding the third problem, many sophisticated models are appeared in recent days(for example, Shukla *et al.*, 1990). The accuracy of the results, however, depends on that of input data and its spatial distributions. After solving the problem, these complicated models will be useful to understand the dynamic behavior of the vegetation and the climate.

The most important problem is concerning the appropriate recognition of the natural phenomena concerned. Many field investigations, that appear in the journals, reveal that there are many factors that must be considered in the model. For example, energy advection, plant growth stage, degree of soil conservation, etc., can influence the water balance at the ground surface. Nonequilibrium phenomena between vegetation and climate is the most important issue but difficult to solve.

It is possible to state further difficulties concerning the method adopted in this paper. Such an empirical method is one possible way to assess the anthropogenic change in global water balance, and it is an urgent theme in the context of Earth environmental changes. There must be a simple

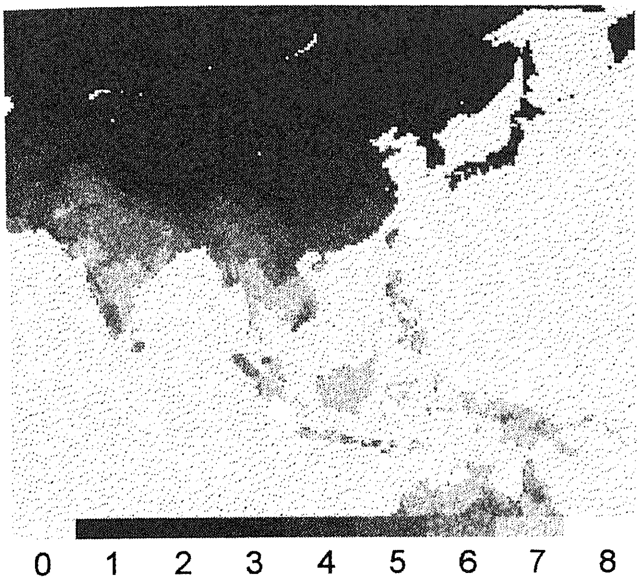

Figure 3 Potential evaporation for current land cover. 0: Ocean, 1: 0-400, 2: 400-600, 3: 600-800, 4: 800-1000, 5: 1000-1200, 6: 1200-1400, 7: 1400-1600, 8: 1600- (mm/year)

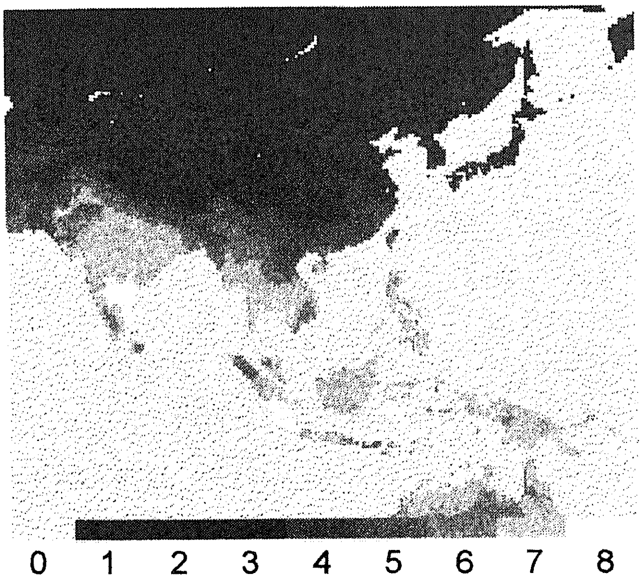

Figure 4 Potential evaporation for natural vegetation. 0: Ocean, 1: 0-400, 2: 400-600, 3: 600-800, 4: 800-1000, 5: 1000-1200, 6: 1200-1400, 7: 1400-1600, 8: 1600- (mm/year)

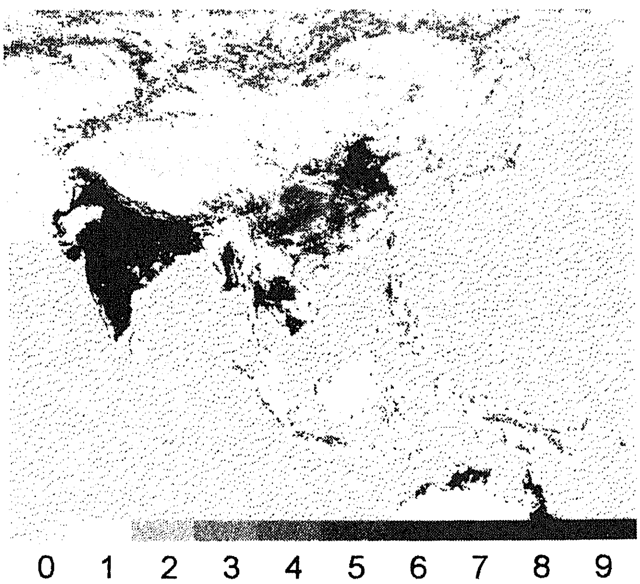

Figure 5 Changes in annual potential evaporation due to land cover changes. 0: Ocean, 1: no change, 2: 0-2, 3: 2-4, 4: 4-8, 5: 8-16, 6: 16-32, 7: 32-64, 8: 64-128, 9: 128- (mm/year)

relationship or rule between hydrological phenomena and surface parameters that could be detectable by satellite remote sensing(for example, Kondoh,1995), and it is a clue to understand global environmental change during the historic era.

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