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A STUDY ON CLIMATE-VEGETATION INTERACTION IN CHINA: THE ECOLOGICAL MODEL FOR GLOBAL CHANGE[1]

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Abstract. This paper discusses the fundamental determinants of the climate-vegetation interaction in China: atmospheric circulation and weather systems, topographical-geological structure and geological history. A brief account of vegetation zones is presented. Multivariate analysis is used to detect zones according to their climatological and geographical parameters.

Introduction

Climate-Vegetation interaction is one of the most significant processes and prominent phenomena in the study of global climate change and its impact upon environment of human life. Vegetation is the basic source of photosynthetic products, essential organic substances that human beings and other organisms need for survival. Vegetation plays a significant role in the feedback processes for the atmosphere and climate and it also affects element circulation in the geosphere, water-soil conservation, and soil formation. The green of vegetation is the symbol of life on the earth. Vegetation is not only the foundation of the biome, but also an obvious index of climate and its change. Vegetation zonation, type, structure and composition, and its spatial and temporal succession are greatly determined by the climate in geological epochs and current time. It is also significantly affected and differentiated by the redistribution of topography, geomorphology, soil substances, hydrology and other edaphic factors. Human activities have become the most important affair impacting vegetation since the Quaternary. Therefore, the study of climate-vegetation interaction must be placed within a spatial and temporal pattern in which the atmosphere, hydrosphere, lithosphere, biosphere and noosphere all interacted together as an integrated system.

Eastern Asia is not only specialized in its geological plate tectonic structure and process, but also in its unique pattern of atmospheric circulation and ocean-continent interaction. Biomes, vegetation types and their distribution pattern in eastern Asia are also different from other continents, but there are some similarities in genesis and close comparability between eastern Asia and eastern North America. The research on China's pattern of climate-vegetation interaction should play a significant role and important contribution in global climate change study.

I. Physical background

The fundamental determinants of the climate-vegetation interaction in China are the atmospheric circulation and weather systems, topographical-geological structure and geological history, and the zonation pattern of vegetation of eastern Asia

I-1. Main atmospheric circulation and weather systems of eastern Asia

The weather and climate of the eastern Asia continent are mainly affected by six atmospheric circulation and weather systems. These systems include two jet streams, Westerlies and Easterlies; two high pressure centers, Mongolian and Tibetan; as well as two ocean-continent monsoon systems, southeastern (Pacific Ocean) and southwestern (Indian Ocean). The polar cold air-mass and tropical storm are also significant. Among them, the Mongolian high, Westerlies and polar cold air-mass are dominant in the winter half of the year, which have a controlling effect in northern China, and strongly affect southeastern China in the winter. The ocean monsoons, Easterlies and tropical storm play a great role in the summer half of the year, they could also extend toward the northwest for some degree to inland of the continent and bring some summer rainfall. The Tibetan high and the plateau itself

1 The study is a collective effort of the Laboratory of Quantitative Vegetation Ecology. Sun Cheng-yong, Pan Dai-yuan, Dai Lei, Li Xia, Guo Yu-ke, Zhao Shu-yu and Zhao Shi-yong are participants.

are also greatly affecting the weather systems in surrounding area (Figs. 1,2).

I-2. Topographic control and thermal effect of the Tibetan Plateau

The topographic control plays a significant role in atmospheric circulations of eastern Asia. The uplift of the Tibetan Plateau was the most important geological event in eastern Asian continent since the Tertiary. Owing to the obstacle of the Plateau, the high level west jet-stream detours through the north and push the high pressure zone into temperate latitudes. In addition, the downdraft from the Tibetan high to the north of the plateau form a high pressure center and enhance even more the aridity in northwestern China's desert zone. The heating effect of the plateau in summer represents a huge summer heat source and forms a warm low; but the cooling effect of the plateau in winter is an atmospheric cold source and forms a cold high. The high level Easterlies are established to the south of the plateau in the tropic latitudes and the southwestern Monsoon, caused by the downdraft from the Tibetan high to the south, move in from the Indian Ocean. The northward movement of the Westerlies caused by the Plateau also increases and maintains the stability and intensity of the southeastern Monsoon. This permits both the southeastern and southwestern Monsoons to reach northerly and southerly extremes bringing abundant summer rainfall and form subtropical moist summer climates in the eastern Asian continent. But, the Mongolian high pressure anticyclonic center which is caused also by the uplift of the plateau greatly enhances the aridity in the northwestern China's arid zone which is controlled by the Westerlies' high pressure zone. The dry and cold air-mass from the Mongolian high extends far to the south in the eastern China's plain in the winter and spring seasons. This makes the cold winter in southern China's subtropical zone and forces the tropical boundary to move towards south China's tropics at some sections of the South China Sea's coastline. Different from this, the western part of China's tropics is located to the south of the Plateau. It is protected by the Plateau and moistened by the southwestern Monsoon, thus, the tropical boundary is moving towards the north. Therefore, the distribution of China's tropical zone has a pattern of high (to the north) in the west and low (to the south) in the east. Generally speaking, the most prominent climatic features caused by the topographical control of the plateau include the desert climate in the north; the subtropical moist forest climate in subtropical China, rather than subtropical desert or savanna; the expansion of the arid steppe climate to the east an south and the related restriction of the deciduous broad-leaved forest climate on the eastern Asian continent. Thus, it is obvious that the uplift of the Tibetan Plateau has been a key factor in changing and controlling the atmospheric circulations and the weather systems in the eastern Asian continent (Chang 1983).

I-3. Distribution pattern of China's vegetation biomes

Vegetation is essentially the reflection of atmospheric circulations on the land surface (Chang 1983). Under the circumstances of the atmospheric circulations and topographic control of the weather systems already identified, China's vegetation zonation pattern has strong distinguishing features. According to the Vegetation of China (Editorial Committee 1980), there are eight vegetation zones or districts in China's continent. These zones or districts were subdivided into subzones based on differentiation in thermal or moisture conditions:

1. Boreal coniferous forest zone [Ii]
2. Temperate mixed coniferous-broad-leaved forest zone [IIi]
2a. Northern subzone [IIia]
2b. Southern subzone [IIib]
3. Temperate deciduous broad-leaved forest zone [IIIi]
3a. Northern subzone [IIIia]
3b. Southern subzone [IIIib]
4. Subtropical evergreen broad-leaved forest zone [IV]
4a. Northern subzone [IVAi]
4b. Intermediate subzone [IVAii]
4c. Southern subzone [IVAiii]
4d. Western subzone [IVB]
5. Tropical rainforest and monsoon forest zone [V]
5a. Northern subzone VA]
5b. Atoll in the South China Sea [VB]
5c. Western subzone [VC]
6. Temperate steppe zone [VI]
6a. Northern subzone [VIAia]
6b. Southern subzone [VIAib]
6c. Western subzone [VIB]
7. Temperate desert zone [VII]
7a. Western subzone [VIIAia]
7b. Eastern subzone [VIIBi]
7c. Southern subzone [VIIBii]
7d. Zaidam subzone [VIIBiii]
8. Tibetan Plateau vegetation district [VIII]
8a. Alpine meadow plateau zone [VIIIA]
8b. Alpine steppe plateau zone [VIIIB]
8c. Southern valley shrub-steppe zone [VIIIC]
8d. Alpine desert plateau zone [VIIID]
8e. Western desert plateau zone [VIIIE]

The distribution map of the zones is given as Fig. 3. It is noted that zones 1 to 5 are forest zones, arranged on a thermal gradient increasing from the north to the south. Zones 2, 3 along with the 6th (steppe zone) and 7th (desert) represent a series on the moisture gradient decreasing from the east to the west. District 8 is alpine, controlled by the topographic effect of the

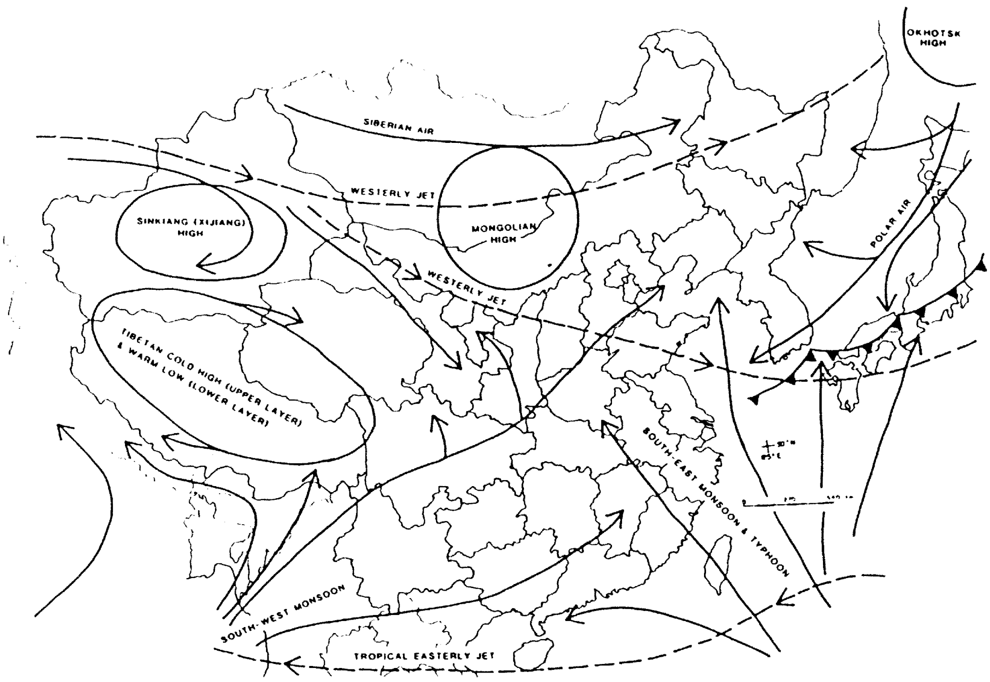

Figure 1. Summer circulation pattern above East Asia.

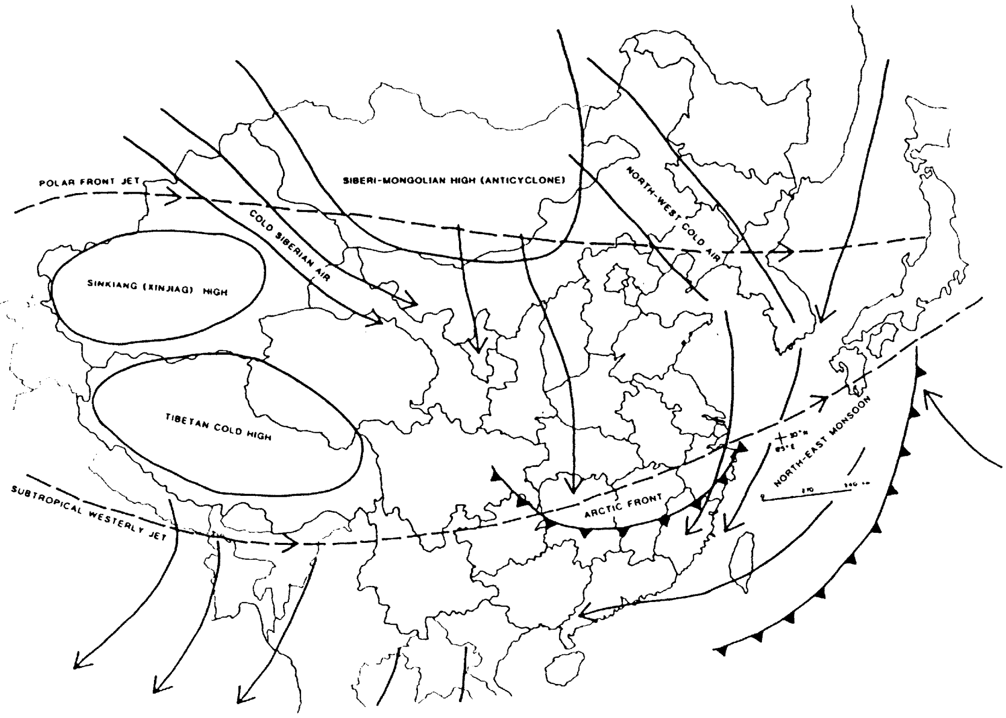

Figure 2. Winter circulation pattern above East Asia.

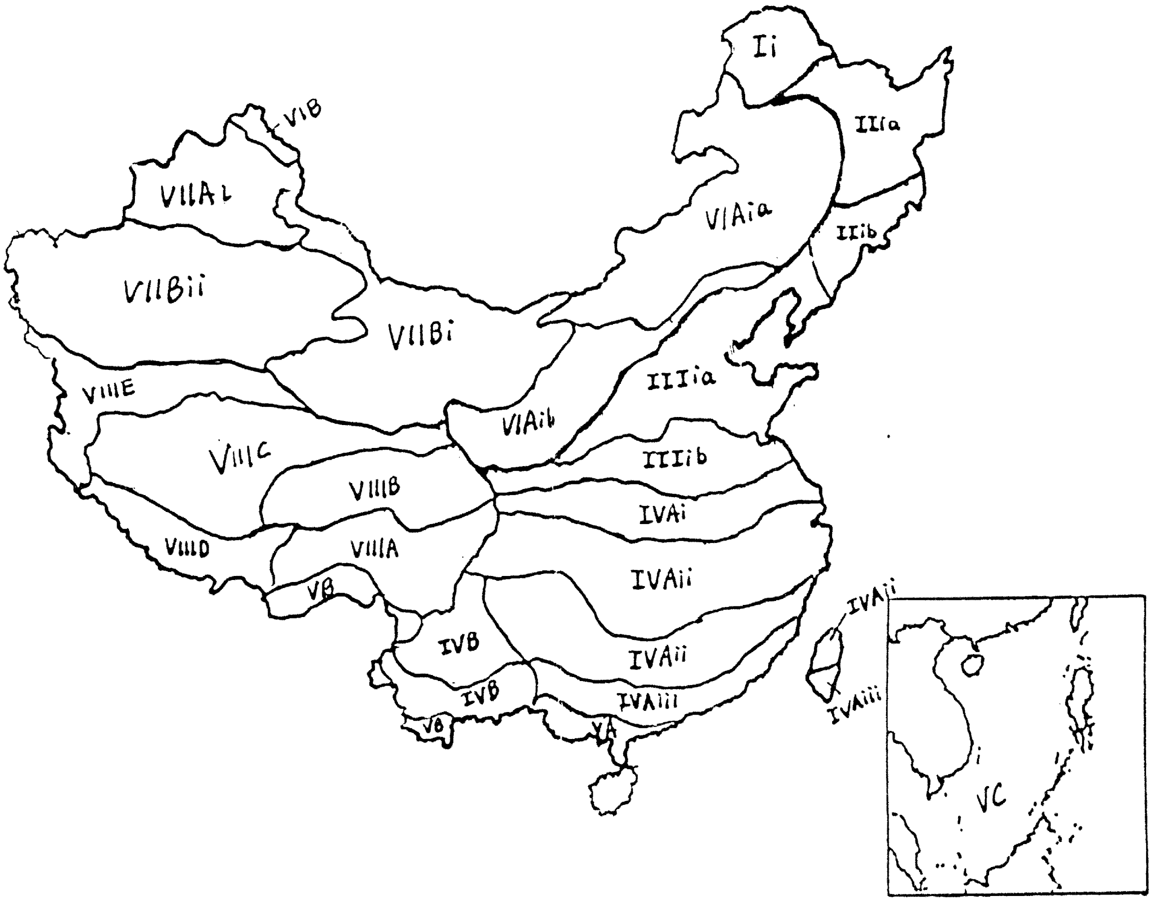

Figure 3. Vegetation division of China. The code refers to zones described in the text.

Plateau, with thermal and moisture differentiation into zones. Comparing with the vegetation zonation in coastal regions of western Europe and the northern Africa, an asymmetric distribution pattern of vegetation zones is presented (Hou 1983, Chang 1983). The vegetation zonation of western Europe and northern Africa is characterized by a feature "dry in the south, moist in the north". Its southern part is occupied by subtropical desert and Mediterranean sclerophyllous woodland and shrubland, but, its northern part is covered by forest zones. The vegetation zonation of eastern Asia is characterized by a feature of "dry in the north, moist in the south". Its southern part is originally covered by tropical and subtropical forests; its northern part is mostly an arid zone.

II. Information systems for the study of climate-vegetation interaction in China

The information system - including data base, analysis, simulation and prediction methods - is the basis for the study of climate-vegetation interaction. The research project, undertaken by the Laboratory of Quantitative Vegetation Ecology, Institute of Botany, Chinese Academy of Sciences (LQVE), has access to the following prerequisites:

- Data base of the national three dimensional geographic parameters. The basic map is on the scale of 1:1,000,000. The grid cells are $48^2=2304$ Lat x Long
- NDVI image data set from AVHRR (NOAA and Fy-1c) for eastern Asia. The meteorological Satellite image is received, processed and provided by the National Satellite Meteorological Center.
- Data base of national eco-climatological data. It covers about 1000 climatological stations in the entire country with records in the period 1951-1980. Besides monthly data, the data base also has some derived values, such as potential evapotranspiration, aridity/moisture index, thermal coefficient, and others.
- Data base of the national vegetation map. The basic map is on the scale of 1:4,000,000.
- Data base of the national soil map. The basic map is on the scale of 1:4,000,000.
- Data base of the national map of sand deserts and Gobi. The basic map is on the scale of 1:4,000,000.

Table 1. Climate indices of vegetation zones in China based on 671 national meteorological stations and recording period 1951- 1980. Key to abbreviations: Bor. for. - Boreal Forest; Con.-bro. for. - Coniferous-broad- leaved forest; Dec. bro. for. - Deciduous broad-leaved forest; Evg. bro. for. - Evergreen broad-leaved forest; Rain. mon. for. - Rain and monsoon forest; Temp. steppe - Temperate steppe; Temp. desert - Temperate desert;

Vegetation zone / subzone		Temperature		Coldest monthly temperature		Warwest monthly temperature		Precipiation	
		mean	stdev	mean	stdev	mean	stdev	mean	stdev
Bor. for.	/S	-3.30	1.534	-27.83	2.328	18.32	1.390	451.1	31.8
Con.-bro.	/N	2.02	1.563	-20.91	2.778	21.34	0.963	556.2	47.9
for.	/S	4.90	1.805	-15.68	2.557	22.13	1.558	764.2	157.0
Dec. bro.	/N	9.84	1.905	-6.96	3.257	24.47	1.608	584.1	91.7
for.	/S	13.00	2.121	-1.34	2.012	25.85	2.616	742.7	142.6
Evg. bro.	/N	15.04	1.090	2.05	0.850	27.12	2.285	960.0	180.8
for.	/S	21.24	1.089	12.74	1.741	28.20	0.617	1465.2	262.1
Rain.mon.	/N	22.74	1.029	15.22	2.215	28.36	0.319	1638.0	389.5
for.	/S	24.26	1.167	18.76	1.686	28.08	0.920	1684.0	591.0
Temp.	/N	2.62	2.601	-18.65	4.045	21.43	1.846	349.2	102.4
steppe	/S	7.34	1.282	-9.00	2.089	21.44	2.036	378.3	104.6
Temp.	/N	6.00	1.796	-15.92	3.100	23.82	2.309	175.6	77.8
desert	/S	10.75	1.387	-8.73	2.265	25.67	1.887	41.4	18.5
Tibetan	/E	0.48	2.641	-10.93	3.319	10.57	1.945	566.3	127.4
Plateau	/N	-2.85	2.460	-13.77	3.230	7.62	1.656	287.1	19.9
	/S	5.00	2.597	-4.85	2.960	13.01	2.094	386.1	65.6

The establishment of data base for the national geological map and Quaternary geological map is under way. Also available is software for multivariate analysis and statistics; GIS including EIS, Epp17, ARC/INFO, and others; multiple regression models on climate-geographical parameters for China; GCM systems for simulation of climatic scenarios (processed and provided by Dr. Alan Robock, University of Maryland and Dr. Mark A. Harwell, University of Miami).

III. Climate-Vegetation Interaction in China

After preliminary studies (Chang 1988) the statistical climatic characteristics of China's vegetation zones have been calculated from 671 national climatological stations grouped according to their belonging to vegetation zones. Multivariate analysis and geographical information systems (GIS) have been used to perform gradient analysis, mapping and statistical computations.

III-1. Annual mean temperature (T), precipitation (P) and vegetation zones

The order of China's vegetation zones on the thermal gradient according to the range of their annual mean temperature is as follows:

Tropical rainforest and monsoon forest zone: >22 °C

Subtropical evergreen broad-leaved forest zone: 14- 22 °C

Temperate deciduous-broad-leaved forest zone: 7.5-15 °C

Temperate mixed coniferous-broad-leaved forest zone: 1-7 °C

Boreal coniferous forest zone: -5-1.5 °C

Temperate steppe zone: 0.5-9 °C

Temperate desert zone: 3-14 °C

Alpine meadow plateau zone: -4-0 °C

Alpine steppe plateau zone: -5.5-0.4 °C

The precipitation gradient from the extreme desert to rainforest is 0 to 2823 mm [a precipitation record for a station (Baxika) in lower southern slope of the eastern Himalayas is more than 3500 mm]. The range of precipitation in desert zone is 0-250 mm, steppe zone 250-500 mm. Because of a complete lack of equatorial rainforest in China, the precipitation of China's tropical forest is between 1000-2800 mm. It is much lower than in other tropical forest areas of the world. The subtropical evergreen forest zone has relatively abundant rainfall, 900-2400 mm, but, the precipitation of the temperate deciduous broad-leaved forest zone in China is on the low side, 450-800 mm. The precipitation in the mixed coniferous-broad-leaved forest zone is higher, 500-1100 mm. The boreal coniferous forest has high continentality, its precipitation is only 350-500 mm. The general pattern of temperature/precipitation- vegetation interaction is presented in Fig. 4 and Table 1.

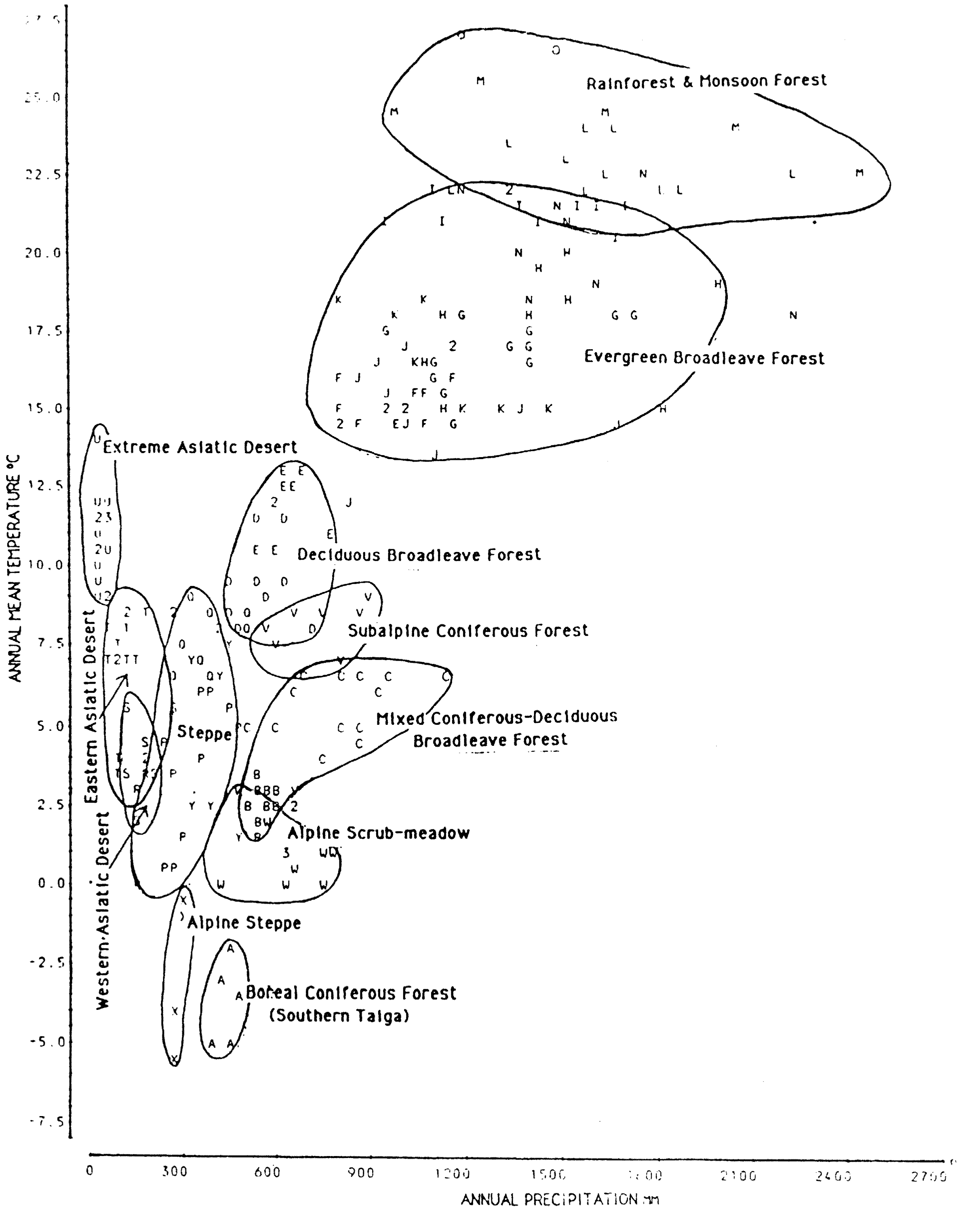

Figure 4. Distribution of China's main vegetation types grouped by selected meteorological stations in annual precipitation (mm) and annual mean temperature (°C) space.

III-2. Potential evapotranspiration (PET) and vegetation zones

Some methods and results on this have been published in Chang 1989a,b). Regarding the relationship of Penman's aridity (A=PET/P) and the vegetation zones in China (Fig. 5, Table 2), the average aridity value (A) is 15 and the maximum is 62 (extreme desert). The western deserts have aridity levels 4.6 and 10.6, the eastern steppe zone 2.2-2.4, and the forest zones 0.6-1.0. But the temperate deciduous broad-

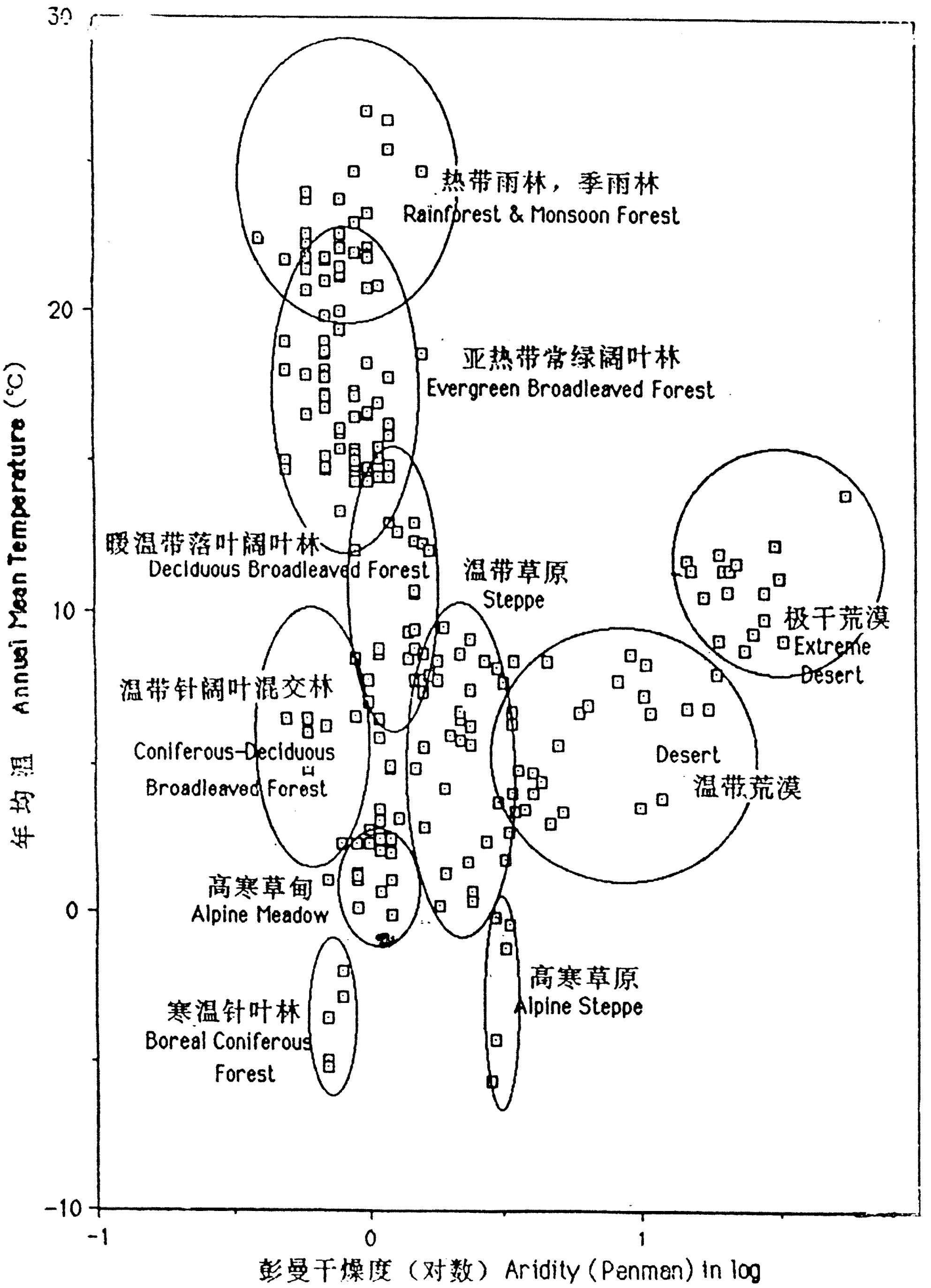

Figure 5. Distribution of China's main vegetation types in the space of annual mean temperature and Penman's aridity index.

Table 2. The potential evapotranspiration and aridity/moisture index for vegetation zones of China according to the Penman and Thornthwaite methods based on 671 national meteorological stations and recording period 1951-1980. The abbreviations are the same as in Table 1.

Vegetation zone / subzone	Penman's PET		Penman's A		Thornthwaita's APE		Thornthwaita's IM	
	mean	stdev	mean	stdev	mean	stdev	mean	stdev
Bor. for./S	329.3	43.7	0.75	0.05	487.0	29.5	-8.15	8.76
Con.-bro./N	538.7	74.1	0.98	0.17	575.8	26.13	-4.02	9.82
for. /S	613.9	70.4	0.82	0.21	607.6	40.57	25.39	24.58
Dec. bro./N	864.2	76.6	1.51	0.26	713.42	63.02	-18.58	14.89
for. /S	948.8	82.8	1.30	0.27	795.05	53.76	-6.09	17.02
Evg. bro./N	926.9	60.6	0.98	0.22	853.57	40.61	14.06	17.14
for. /S	1079.6	153.3	0.76	0.15	1124.80	59.00	30.86	21.63
Rain.mon./N	925.3	79.0	0.57	0.16	1218.20	80.10	33.74	27.46
for. /S	942.4	138.9	0.64	0.32	1333.80	108.50	29.20	56.00
Temp. /N	687.9	174.5	2.19	1.59	576.70	51.93	-38.27	15.68
steppe /S	845.6	83.6	2.41	1.09	618.99	45.46	-38.91	18.48
Temp. /N	695.2	134.8	4.64	2.73	679.10	66.70	-76.31	11.26
desert /S	951.1	107.7	26.98	15.07	772.46	37.84	-95.18	2.53
Tibetan /E	737.5	49.5	1.38	0.37	401.70	48.70	41.09	27.12
Plateau /N	883.0	129.3	3.05	0.26	329.50	23.90	-14.65	2.79
/S	1058.4	90.3	2.84	0.59	492.30	59.80	-25.04	10.99

Table 3. Biotemperature (BT) and potential evapotranspiration rate (PER) in the vegetation zones of China based on 671 national meteorological stations and recording period 1951-1980. The abbreviations are the same as in Table 1.

Vegetation zone / subzone	Biotemperature (BT)		Potential evapotranspiration rate (PER)	
	mean	stdev	mean	stdev
Bor. for./S	5.62	0.571	0.73	0.1033
Con.-bro./N	7.78	0.624	0.83	0.0979
for. /S	8.68	0.977	0.68	0.1325
Dec. bro./N	11.16	1.313	1.14	0.2030
for. /S	13.16	1.818	1.06	0.2245
Evg. bro./N	15.01	1.077	0.92	0.2076
for. /S	21.25	1.091	0.87	0.1858
Rain.mon./N	22.74	1.029	0.84	0.2087
for. /S	24.26	1.167	0.96	0.397
Temp. /N	7.84	1.179	1.42	0.687
steppe /S	9.19	0.979	1.56	0.686
Temp. /N	9.84	1.209	3.89	2.079
desert /S	12.10	1.205	19.26	9.27
Tibetan /E	3.72	1.281	0.40	0.1276
Plateau /N	2.17	0.768	0.45	0.1291
/S	6.05	1.769	0.94	0.2774

leaved forest zone is drier. Its average A is 1.3-1.5. Thornthwaite's potential evapotranspiration (APE) and moisture index (IM) are also related to the vegetation zonation of China (Fig. 6 and Table 2).

III-3. Life zone classification in China

Holdridge's life zone classification has been widely used for worldwide comparison and for the study of climate-vegetation (biomes) interaction (Emanuel *et al.* 1985). The biotemperature (BT) and potential evapotranspiration rate (PER) being two basic indices for Holdridge's classification have been related to the vegetation zonation of China (Fig. 7, Table 3). The Life zone map of China coincides quite well with the vegetation zonation map of China. This provides a common basis for comparative study of China's

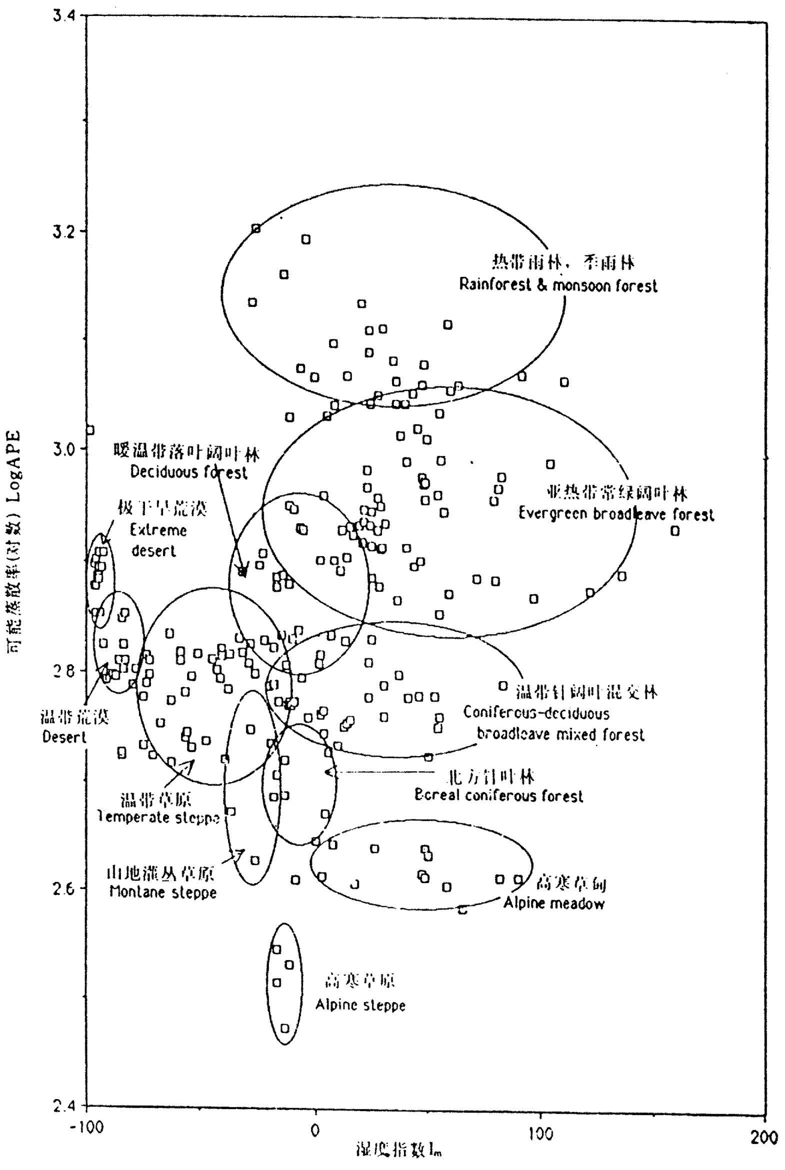

Figure 6. Distribution of China's main vegetation types in the space of Thornthwaite's potential evapotranspiration (APE) and moisture index (Im).

climates and vegetation in relation to other parts of the world, establishing linkage between China's scenario of climate change and the course of Global Change.

III-4. RDI/NPP - Vegetation interaction in China

Budyko's radiative dryness index (RDI) (Budyko 1956, Chang *et al.* 1990) and potential annual net primary productivity (NPP) derived from it (Uchijima and Seino 1985) also have been examined in the vegetation zones of China (Figs. 8,9, Table 4). RDI closely accords with vegetation zones. It is 0.6 in the Boreal coniferous forest zone and 0.72 in the mixed coniferous-broad-leaved forest zone. But, it is more than 1 in the temperate deciduous broad-leaved forest zone. This shows, again, the dryness in that forest zone is excessive. The RDI in subtropical forest zone is

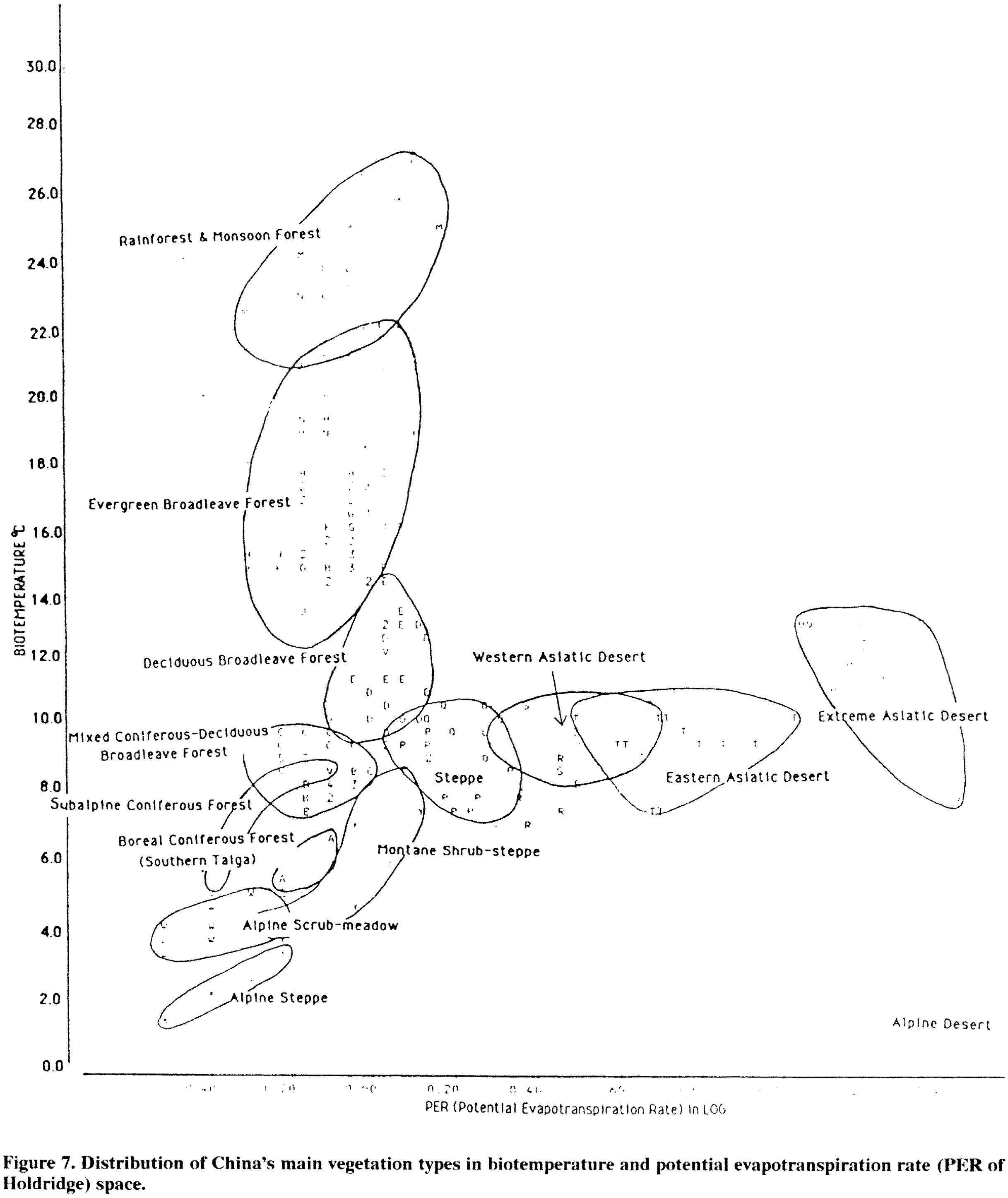

Figure 7. Distribution of China's main vegetation types in biotemperature and potential evapotranspiration rate (PER of Holdridge) space.

generally 0.4-0.5 and in the tropical forest zone 0.5-0.6. The temperate steppe zone has an average RDI of 1.2-2.2, but in the desert zone has 9.6 with highest value 48.7. The RDI of the Tibetan Plateau is 0.54 in the alpine meadow plateau zone, 1.13 in the alpine steppe plateau zone, and 1.56 in the southern valley's shrub-steppe plateau zone.

The gradient of derived NPP (t.dm/ha.yr.) of the forest zones increases from north to south. It is 4.3 in the Boreal coniferous forest zone, 7.2 in the mixed forest zone, 9.4 in the temperate deciduous forest zone, 10.8 in the subtropical evergreen forest zone, and 12.3 in the tropical forest zone. The highest NPP is 19.5 on the tropical islands of the South China Sea. Compared to other tropical forest areas in the world, China's terrestrial tropics are very limited in area and have much lower NPP. The average NPP is 5.2 in temperate steppe zone, 0.4 in temperate desert zone, and less than 0.1 or 0 for the most part of extreme desert. It is 4.5 in the alpine meadow plateau zone, 4.4 in the alpine steppe plateau zone, and 6.3 in the southern shrubsteppe plateau zone. RDI and NPP both are appropriate indices for the study of climate-vegetation interaction and climate change.

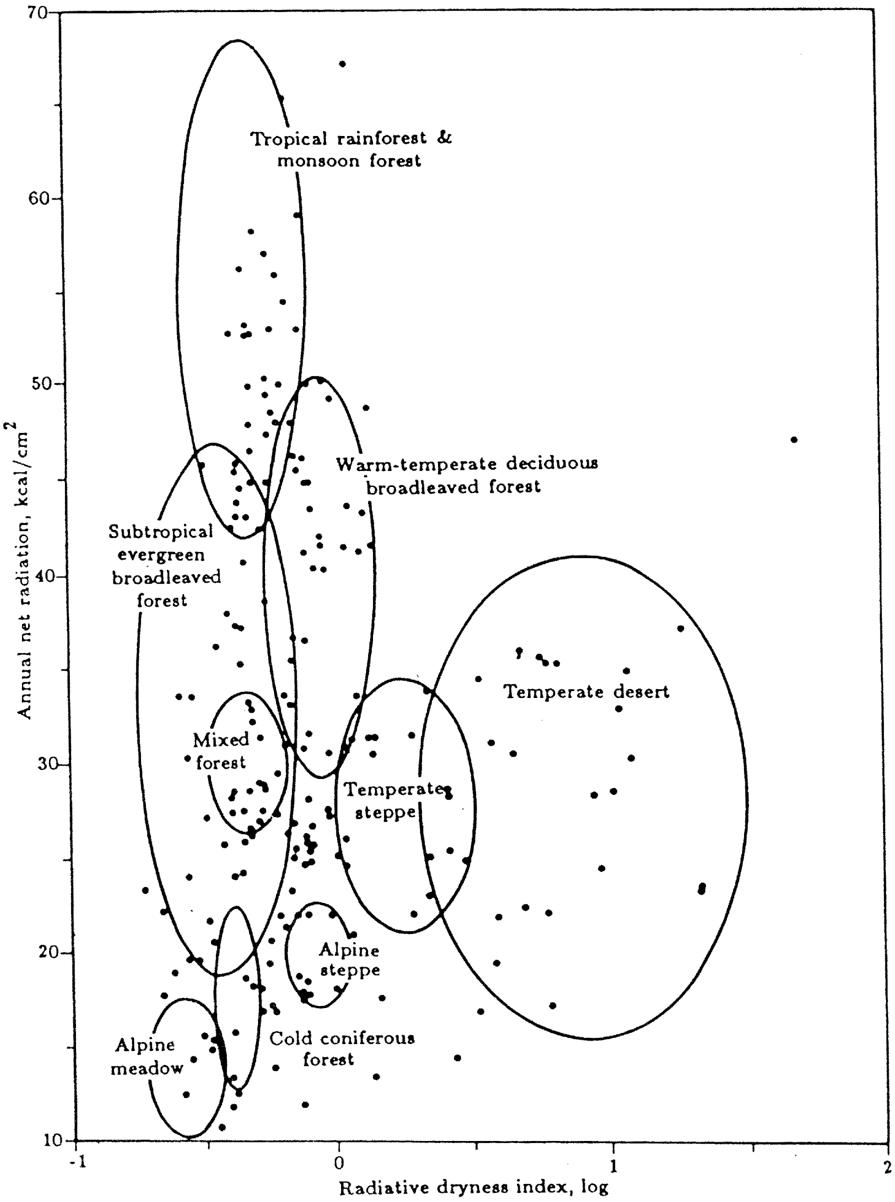

Figure 8. Distribution of China's main vegetation types in radiative dryness index (RDI) and annual net radiation space.

III-5. Multivariate analysis of climate-vegetation interaction in China

The multivariate analysis method (DCA [Detrended Correspondence Analysis], a multivariate program for ecological ordination, developed by M. Hill and included in the Cornell Ecological Program [CEP]) was used to ordinate and classify vegetation zones according to their climatological and geographical parameters. DCA not only processes the integrated ordination and classification, but also provides quantitative environmental interpretation for the significant ecological gradient. The analysis yielded the following results (Fig. 10, Table 5):

- 4 ordination axes were given by DCA, but only the first 2 axes (Axis land 2) are ecologically significant.

- Correlation analysis of the ordination axes with the climatic factors provides the essential indices for the ecological gradient (Table 5).

- DCA Axis 1 is mainly a thermal gradient. It correlates highly with most thermal indices, such as, biotemperature (BT), mean annual temperature (T), latitude

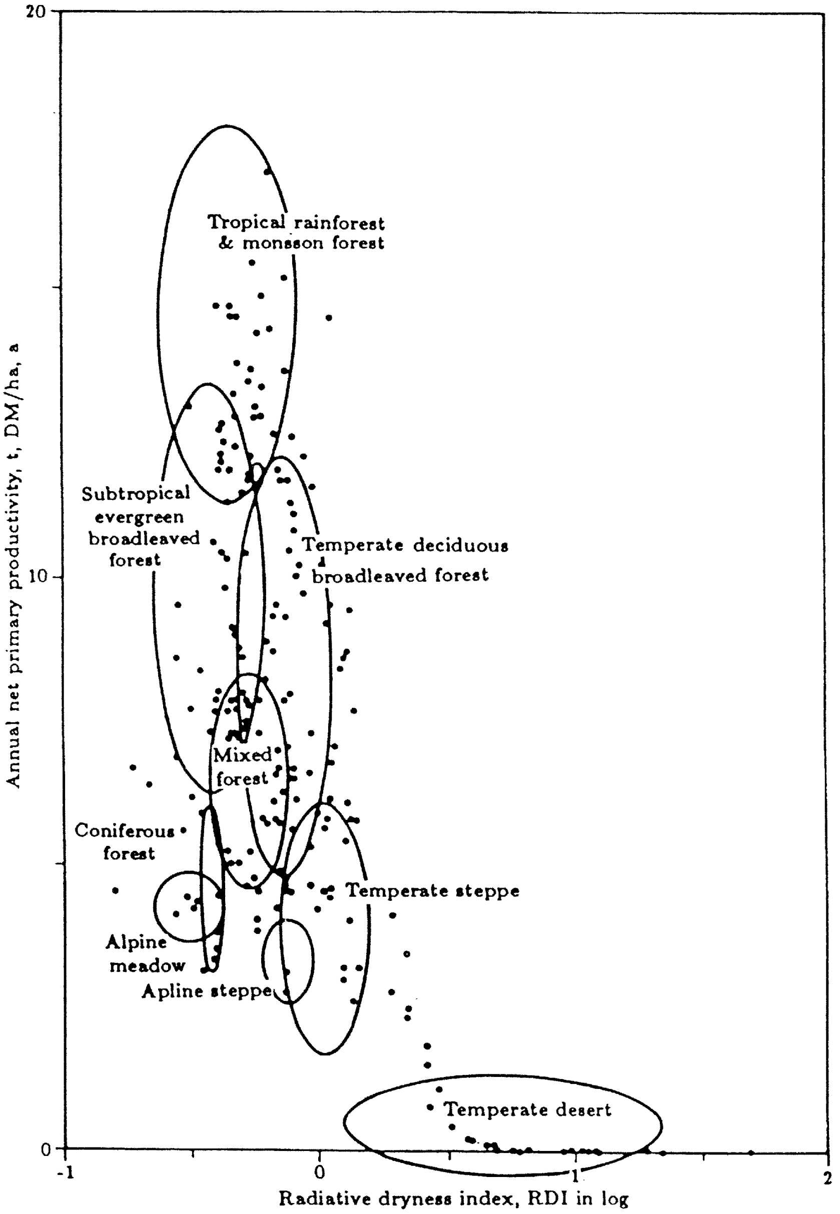

Figure 9. Distribution of China's main vegetation types in radiative dryness index (RDI) and annual net primary productivity space.

Table 4. Radiative dryness index (RDI) and potential net primary productivity (NPP) in the vegetation zones of China based on 671 national meteorological stations and recording period 1951-1980. The abbreviations are same as in Table 1.

Vegetation zone / subzone	Radiative dryness index (RDI)		Potential net primary productivity (NPP)	
	mean	stdev	mean	stdev
Bor. for.	0.60	0.1705	4.27	1.046
Con.-bro. for.	0.72	0.1355	7.17	0.869
Dec. bro. for.	1.11	0.2040	9.43	1.46
Evg. bro. for.	0.53	0.1501	10.78	2.156
Rain.mon. for.	0.58	0.1954	14.55	1.675
Temp. steppe	1.23	0.4925	5.18	1.313
Temp. desert	9.58	8.62	0.39	0.861
Tibetan Plateau /E	0.54	0.1723	4.47	0.4468
/N	1.13	0.1620	4.38	0.407
/S	1.55	0.249	6.27	1.005

Table 5. Correlation of ordination values, geographic positions and climatic indices.

	ax1	ax2	ax3	ax4	lat	long	alt	cmt	wmt	t	p	pe	pa	bt
lat	**0.616**	0.468	0.466	0.187										
long	-0.322	**0.715**	0.178	-0.024										
alt	**0.804**	-0.459	**-0.659**	-0.079										
cmt	**-0.796**	-0.425	-0.292	-0.166	**-0.911**	0.012	-0.305							
wmt	**-0.871**	0.138	**0.527**	0.047	-0.260	0.282	**-0.899**	**0.506**						
t	**-0.942**	-0.255	0.022	-0.099	**-0.791**	0.135	**-0.592**	**0.935**	**0.757**					
p	**-0.735**	-0.086	-0.280	-0.343	**-0.771**	0.277	-0.345	**0.821**	0.398	**0.767**				
pe	-0.468	**-0.659**	-0.246	-0.150	**-0.709**	-0.281	-0.020	**0.728**	0.297	**0.642**	0.420			
pa	0.196	-0.383	0.485	0.115	0.341	-0.396	0.021	-0.287	0.092	-0.174	-0.497	0.102		
bt	**-0.975**	-0.043	0.128	-0.105	**-0.685**	0.280	**-0.714**	**0.851**	**0.812**	**0.960**	**0.772**	**0.509**	-0.255	
per	0.145	-0.352	**0.574**	0.150	0.366	-0.434	-0.066	-0.287	0.163	-0.140	**-0.519**	0.088	**0.967**	-0.202

(LAT), altitude (ALT), as well as potential evapotranspiration (PE & PER) and precipitation (P). The multiple factor regression equation of DCA Axis 1 is

$$\text{Axis 1} = 27.51 - 0.655BT - 1.07T + 0.582ALT - 0.178P - 2.26\text{sqrt}(PE) + 0.102PER$$

The coefficient of determination ($R^2 = 99.0\%$) indicates a perfect functional relationship. The vegetation zones from the boreal coniferous forest to tropical rainforest and monsoon forest are arrange in that order along this gradient (Fig. 10).

- DCA Axis 2 is basically a moisture gradient. It correlates highly with longitude (LONG), ALT, $PE < PER$, as well as T. The regression equation of Axis 2 is:

$$\text{Axis 2} = 106 + 0.314LONG - 0.806ALT - 1.38\text{sqrt}(PE) - 1.41T - 1.10PER$$

for which $R^2 = 94.6\%$. The vegetation types from desert to steppe and forest form an obviously successive series along this gradient.

Based on the above mentioned analyses, the quantitative (statistical) interaction models between vegetation zones/biomes and climatical-geographical indices are clearly established. These provide the basis of our fundamental scenario for comparative study of global climate change and its effect on the vegetation and biomes.

IV. The scenario of China's Climate-Vegetation Interaction in a $2xCO_2$ World

Four models GCMs, OSU, GISS, GFDL, and UKMO of the earth's atmosphere have been used to simulate the regional climate (temperature and precipitation) assuming the $2xCO_2$ and current $1xCO_2$ scenarios. [GCMs: general circulation models; OSU: GCM of Oregon State University; GISS: Goddard Institute for Space Studies; GFDL: Geophysical Fluid Dynamics Laboratory; UKMO: United Kingdom Meteorological Office. The GCM models are created by each of the Institutions using the name of the Institution. All GCM models are based on the same theory of conservation of mass, thermodynamics and the equations of motion with different modification of boundary condition, parameterization, numerical methods and grid sizes. Regarding sources we refer to

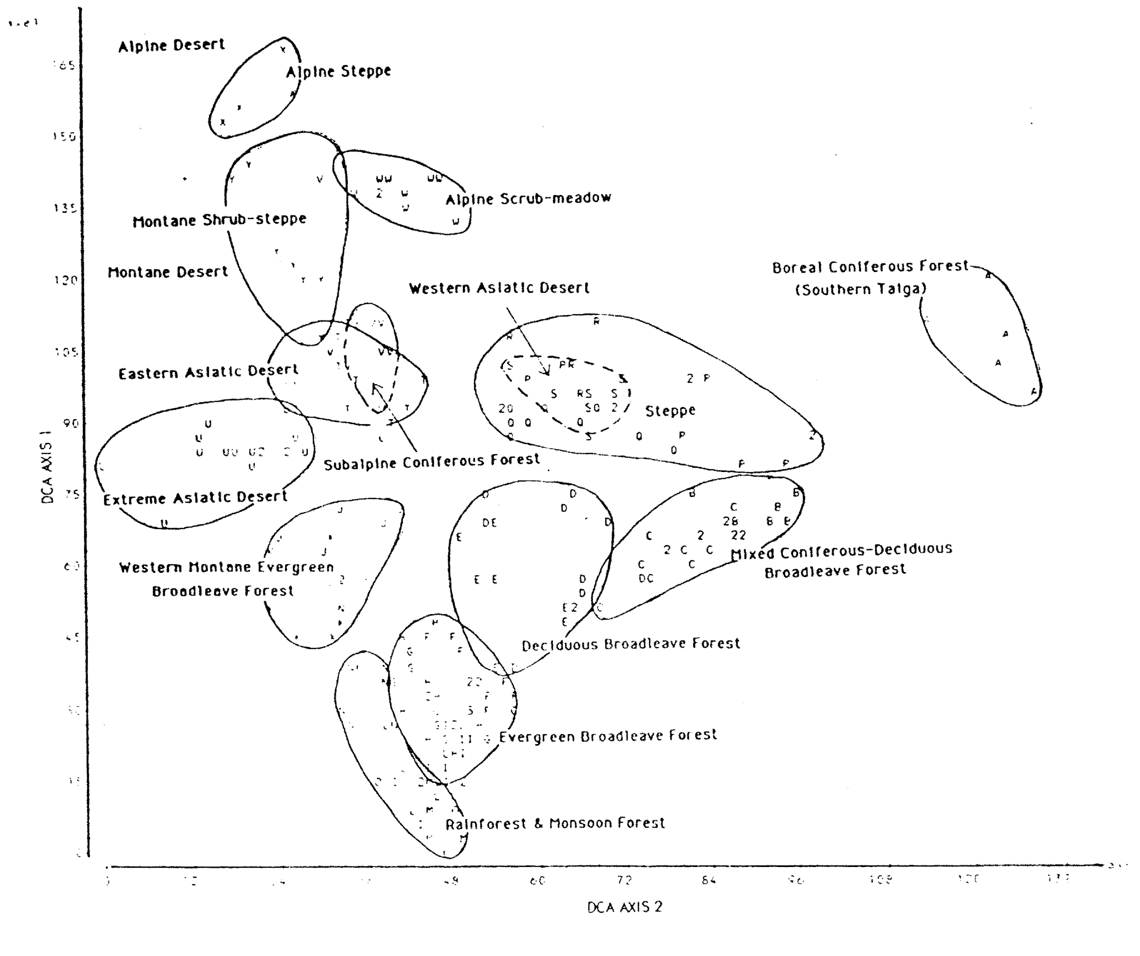

Figure 10. Distribution of main vegetation types in DCA's first two ordination axes space.

Table 6. The $2xCO_2$ greenhouse warming scenario for China (Robock, A. et al. 1993).

Temperature (°C)	Precipitation
-2	-20% no change +20% +40%
no change	-20% no change +20% +40%
+2	-20% no change +20% * +40%
+4	-20% no change +20% * +40%
+6	-20% no change +20% +40%
	* most likely scenarios for $2xCO_2$

Ghan et al. (1982), Gordon *et al.* (1982), and Slingo (1985).] The resolution is coarse (4°x5° or 8°x10° longitudes and latitudes) and the errors are high in the simulation of current regional monthly temperature and precipitation. Therefore, the simulation model is not very reliable to predict the climatic conditions under a $2xCO_2$ scenario. The scenario created using the general GCM patterns shows climate warming and increase precipitation in a $2xCO_2$ China (Table 6). A warming of 2°C - 4°C and an increase of precipitation of about 20% are the most likely outcome by doubling atmospheric CO_2 (Robock *et al.* 1991).

The simulated scenarios of temperature, precipitation, biotemperature, PER (potential evapotranspiration rate), pattern of life zone distribution, and NPP (net primary productivity) under $2xCO_2$ are displayed with EIS (Ecological Information System, IOB) in the Laboratory of Quantitative Vegetation Ecology, IOB (1991).

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