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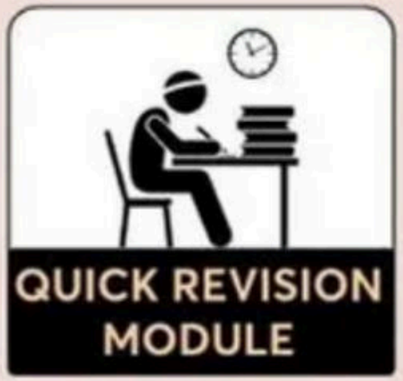
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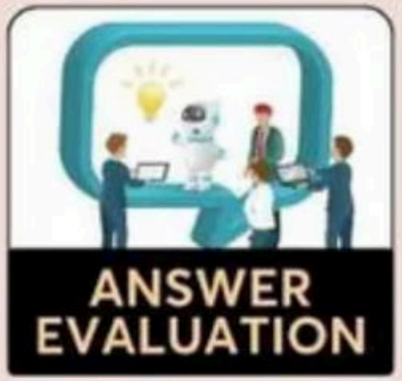
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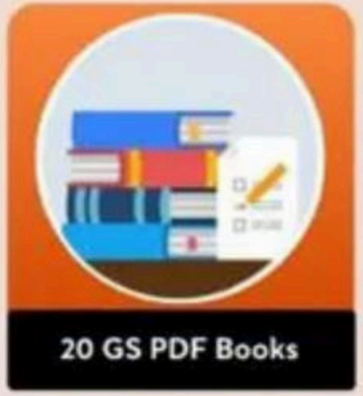


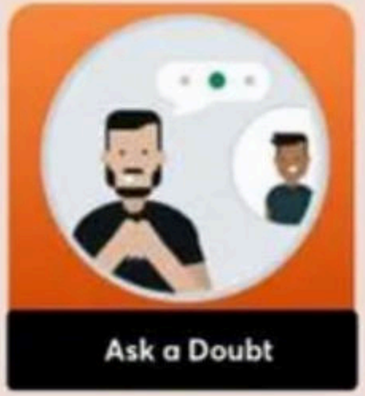


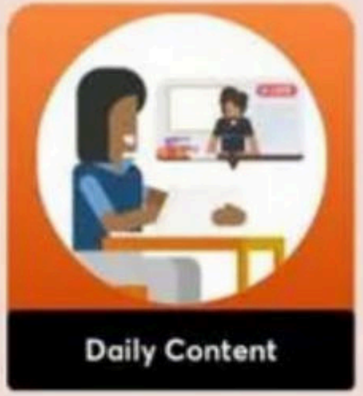
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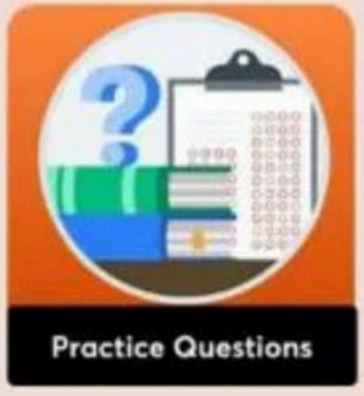












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Am climate : monsoon climate, one short dry season but sufficient annual precipitation and thus wet ground throughout the year, dense forest, precipitation of at le^st one month less than 6cm. The boundary between Aw and Am climates is demarcated on the basis ol annual precipitation and the precipitation of the driest moth as per formula given below ;

$$a = 3.94 - r/25$$

a = precipitation of driest month

r = annual precipitation

If the precipitation of the driest month of a place is less than the value of a, it will be Aw climate, if it is more than the value of a, it will be Am climate.

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2. **Dry climates (B climates) :** evaporation exceeds precipitation, precipitation not sufficient to maintain permanent stable water table of groundwater. B climates are divided into two types on the basis of annual temperature and the rainiest month of the year e.g. (i) dry desert climate (BW), and (ii) semi-arid or steppe climate (BS). The boundary between BW and BS climates is determined on the basis of the following formula :

$$r = \frac{0.44t - 8.5}{2}$$

where

r = annual precipitation (inches)

t = temperature (^{0}F)

If the annual precipitation of a given place is more than the value of r, the climate of that place will be BS but if it is less than r, the climate will be BW. For example, if the temperature of a place is 80^{0}F, the annual value of precipitation for dividing boundary between BS and BW climates will be 13.3 inches as given below:

$$r = \frac{0.44 \times 80 - 8.5}{2} = 13.3 \text{ inches}$$

Letter Symbol			Precipitation and temperature
1st Order	2nd Order	3rd Order	
A			Average temperature of the coldest month is 18°C or above.
	f		Moist; Every month has 6 cm of precipitation or more; no dry season
	m		Short dry season in monsoon type of precipitation; driest month < than 6 cm but equal to or more than 10-R/25 (R is annual precipitation in cm)
	w		Well-defined winter dry season; precipitation in driest month <than 10-R/25.
	s		Well-defined summer dry season(rare distribution)
B			Potential evaporation exceeds precipitation. It is identified on the basis of average annual precipitation **(R),** average annual temperature (T) and seasonal distribution of precipitation in following manner:(i) R<2T+28, when 70 % or more of precipitation occurs in 6 warmer months.(ii) R<2T, when 70 % or more of precipitation occurs in 6 cooler months.(iii) R<2T+14, when neither half year has 70 % or more of precipitation.
	s		When **R** is more than ½ of the upper limit for B.
	w		When **R** is less than ½ of the upper limit for B.
		h	Average annual temperature is 18°C or above.
		k	Average annual temperature is less than 18°C.
C			Average temperature of the coldest month is < than 18°C and above -3°C; average temperature of the warmest month is greater than 10°C.
	w		At least ten times as much rain in the wettest month as in the driest winter month; precipitation in driest summer month < than 4 cm.
	s		At least three times as much rain in wettest winter month as in the driest summer months; precipitation in driest summer month < than 3 cm.
	f		Precipitation throughout the year and no dry season. Difference between the rainiest and driest months is less than that for w and s and the driest month of summer receives > 3 cm rainfall

Letter Symbol			Precipitation and temperature
1st Order	2nd Order	3rd Order	
		a	Hot summer; average temperature of the warmest month > 22°C; at least four months above 10°C.
		b	Cool summer; average temperature of the warmest month < 22°C; at least four months above 10°C.
		C	Cool short summer; average temperature of the warmest month < 22°c; at least one to three months above 10°C.
D			Average temperature of coldest month is - 3°C or below; average temperature of warmest month is greater than 10°C.
	s, w, f		Same as under C.
		a, b, c, d	Same as under C.
E			Average temperature of the coldest month is - 38°C or below. Average temperature of warmest month is below 10°c.
	T		Average temperature of warmest month is between 0°C and 10°C.
	F		Average temperature of warmest month is 0°C or below.

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Discuss the diversity of climates in midlatitudes as compared to tropical and polar areas in Koppen's climatic classification

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American climatologist Charles Warren Thornthwaite (1889-1963) put forward his first scheme of classification of climates in 1931. It was initially devised for North America but in 1933 he applied this scheme for global climatic classification. He propounded his second scheme of climatic classification in 1948 and further improved it in 1955. Thornthwaite's climatic classifications are empirical, quantitative and complex. Like Köppen's climatic classification, Thornthwaite identified the boundaries of climatic regions on quantitative basis but instead of temperature and precipitation criteria he used the concepts of precipitation effectiveness and thermal efficiency in his first climatic classification system.

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Thornthwaite's 1931 climatic classification was based on three criteria – precipitation effectiveness, seasonal distribution of precipitation and thermal efficiency.

Like Köppen, Thornthwaite also recognised the close relationship between climate and natural vegetation and their distribution patterns.However, he highlighted that precipitation effectiveness or precipitation efficiency is more important and indicative factor for the growth and type of natural vegetation. It is not necessary that two places receiving same amount of precipitation would have similar precipitation effectiveness. In these two places, the one having higher rates of evaporation will have lesser amount of moisture availability for the growth of natural vegetation as compared to the second place. Thus, Thornthwaite pointed out that it is not only precipitation that matters rather its availability as moisture depends upon differential rates of precipitation and evaporation. To measure precipitation effectiveness, he calculated mean monthly precipitation effectiveness by dividing the mean monthly precipitation by mean monthly temperature. In the absence of efficient instrumental measurements of evaporation, he used temperature data to estimate evaporation as the rate of evaporation depends on temperature. He propounded the following formulae to calculate precipitation effectiveness:

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Precipitation Effectiveness Ratio (P/E ratio) =
11.5 (P/T - 10)10/9

where P = Mean monthly precipitation (in inches)
T = Mean monthly temperature (in degree F)
P/E Index = sum of all twelve months P/E ratios.
First, he calculated the P/E Ratio for all the twelve months of a year and then he summed up all twelve months P/E ratios to get the P/E index. Based on P/E index values he identified five humidity provinces and associated them with specific major natural vegetation zones (Table 14.1).

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Table 14.1: Main Climatic Classes based on Precipitation Effectiveness

Humidity Provinces	Vegetation Zones	P/E Index
A (Wet)	Rainforest	Above 127
B (Humid)	Forest	64-127
C (Sub-humid)	Grassland	32-63
D (Semi-arid)	Steppe	16-31
E (Arid)	Desert	Below 16

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14.2.1.2 Seasonal Distribution of Precipitation

Based on seasonal distribution of precipitation, Thornthwaite further sub-divided these five humidity provinces into twenty sub-classes. The criteria and symbols used are as under:

r = rainfall adequate in all seasons

s = rainfall deficient in summer

w = rainfall deficient in winter

d = rainfall deficient in all seasons.

1. Ar	5. Br	9. Cr	13. Dr	17. Er
2. As	6. Bs	10. Cs	14. Ds	18. Es
3. Aw	7. Bw	11. Cw	15. Dw	19. Ew
4. Ad	8. Bd	12. Cd	16. Dd	20. Ed

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Thermal Efficiency Like precipitation effectiveness, Thornthwaite gave importance not to temperature rather to thermal effectiveness or thermal efficiency instead of only temperature. He considered thermal efficiency as an important determinant of growth and type and vegetation. He conceptualised thermal efficiency as positive departure of mean monthly temperatures from the freezing point. Higher departure outcomes represent higher thermal efficiency. To measure thermal effectiveness, he first calculated monthly thermal efficiency (T/E) ratios by applying the following formulae and by summing up the T/E ratios of all twelve months he calculated thermal efficiency index:

Thermal Effectiveness (T/E) ratio = (T–32)/4 where T is the mean monthly temperature (degree F).

Thermal Efficiency (T/E) index = Sum of 1 to 12 months T/E ratios Finally, based on positive departures of T/E index values he identified six major thermal efficiency provinces.

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Table 14.2 Thermal Efficiency Index and Thermal Provinces

Thermal Provinces	T/E Index
A′ – Tropical	Above 127
B′ – Mesothermal	64-127
C′ – Microthermal	32-63
D′ – Taiga	16-31
E′ – Tundra	1-15
F′ – Frost	0

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Thornthwaithe, based on criteria of precipitation effectiveness (5 Humidity Provinces), seasonal distribution of precipitation (4 Humidity subclasses) and thermal efficiency (6 Thermal Provinces), identified following 32 climatic classes at world level out of statistically probable combinations of 120 (5 × 4 × 6) classes.

1. A A'r – Tropical wet climate with adequate rainfall in all seasons.
2. A B'r - Mesothermal wet climate with adequate rainfall in all seasons.
3. AC'r – Microthermal wet climate with adequate rainfall in all seasons.
4. B A'r – Tropical humid climate with adequate rainfall in all seasons.
5. B A'w – Tropical humid climate with deficient rainfall in winter.
6. BB'r - Mesothermal humid climate with adequate rainfall in all seasons.
7. B B'w – Mesothermal humid climate with rainfall deficient in winter season.
8. B B's – Mesothermal humid climate with rainfall deficient in summer season.
9. B C'r – Microthermal humid climate with adequate rainfall in all seasons.
10. B C's – Microthermal humid climate with rainfall deficient in summer season.
11. C A'r – Tropical subhumid climate with adequate rainfall in all seasons.
12. C A'w – Tropical subhumid climate with deficient rainfall in winter season.
13. C A'd – Tropical subhumid climate with deficient rainfall in all seasons.
14. C B'r – Mesothermal subhumid climate with adequate rainfall in all seasons.
15. C B'w – Mesothermal subhumid climate with deficient rainfall in winter season.
16. C B's – Mesothermal subhumid climate with deficient rainfall in summer season.
17. C B'd – Mesothermal subhumid climate with deficient rainfall in all seasons.
18. C C'r – Microthermal subhumid climate with adequate rainfall in all seasons.
19. C C's – Microthermal subhumid climate withrainfalldeficient in summer season.
20. C C'd – Microthermal subhumid climate with rainfall deficient in all seasons.
21. D A'w – Tropical semiarid climate with deficient rainfall in winter season.
22. D A'd – Tropical semiarid climate with deficient rainfall in all seasons.
23. D B'w- Mesothermal semiarid climate with deficient rainfall in winter season.
24. D B's – Mesothermal semiarid climate with deficient rainfall in summer season.
25. D B'd – Mesothermal semiarid climate with deficient rainfall in all seasons.
26. D C'd – Microthermal semiarid climate with rainfall deficient in all seasons.
27. E A'd – Tropical arid climate with deficient rainfall in all seasons.
28. E B'd – Mesothermal arid climate with deficient rainfall in all seasons.
29. E C'd – Microthermal arid climate with deficient rainfall in all seasons.
30. D' – Taiga type climate.
31. E' – Tundra type climate.
32. F' – Permanently snow-covered polar climate.

THORNTHWAITE'S SECOND SCHEME OF CLIMATIC CLASSIFICATION

Thornthwaite propounded his second scheme of climatic classification in 1948 and revised it in 1955. In this classification he devised and applied the concept of potential evapotranspiration. He applied potential evapotranspiration as an index of thermal efficiency. Potential evapotranspiration represents the potential loss of moisture through evaporation from the water bodies and soil surface and through transpiration from vegetation. Due to non-availability of instruments to measure evapotranspiration he indirectly estimated it by using temperature criterion. Temperature varies from place to place and time to time even at a particular place, depending upon the amount of insolation received. Thus, Thornthwaite considered mean monthly temperature, number of days in a month and duration of sunshine to calculate the potential evapotranspiration of different locations.

Potential Evapotranspiration

First, he calculated monthly Heat Index (i) using the following formula:

Monthly Heat Index (i) = (t/5)1.514

where t is the mean monthly temperature in degree Celsius.

After that, he calculated Annual Heat Index (I) which has been defined as the sum of the Monthly Heat Indices (i) as follows:

Annual Heat Index (I) = the sum of 12 months of (t/5)1.514

He calculated potential evapotranspiration for each month of a year based on the following formula and then he calculated the annual potential evapotranspiration (in cm) which has been defined as the sum of the potential evapotranspiration for all the months of the year.

Potential Evapotranspiration (PE) = 1.6 $(10t/I)^{\alpha}$

where t is mean monthly temperature in degree Celsius of a particular month and I is annual heat index of that particular year and it is calculated based on summation of twelve months heat indices (i) as mentioned above; and

$\alpha = 6.75\text{-}7 \times 10 \times I\,3 + 7.771 \times 10\text{-}5 \times I\,2 + 0.01792 \times I + 0.49239$

The above equation represents the non-corrected potential evapotranspiration because the values are estimated by assuming a month of 30 days and sunshine duration of 12 hours. To make corrections for potential evapotranspiration for different places, the following equation is used:

PE (Potential Evapotranspiration) = PE non-corrected $\times N/12 \times d/30$

where N is the average number of hours in a day between sunrise and sunset in a month and d is the actual number of days in a particular month.

Humidity index is the percentage ratio of water surplus and water need (PE).

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Thornthwaite's Thermal Regime Classifcation The key parameter to evaluate 'Thermal regime' of a region is Potential Evapotranspiration (PE) which is the index of thermal potential for vegetation growth. Thornthwaite's major thermal provinces based on the annual values of PE which is also called as' Thermal efficiency' (TE). Based on the annual values of PE/TE, 5 major thermal providences namely:

1. Megathermal
2. 2. Mesothermal
3. Micro thermal
4. Tundra
5. Frost

A megathermal climate is the climate which experience highest temperature throughout the year with PE/TE above 114.0 cm Mesothermal climate experiences persistent cold or heat conditions and experience PE between 570 cm and 114 cm Microthermal climate is one where mean annual temperatures are very low and PE is in between 28.5 and 57.0 cm. Tundra (28.5-14.2 cm) and Frost (below 14.2 cm) are the cold climates with low atmospheric demands (PE).

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Scheme of Climatic Classification- Thermal regime (major categorisation)

Annual TE (cm)	Thermal Provinces	Symbol
Above 114.0	Mega thermal	A’
114.0-99.7		B'_4
99.7-85.5		B'_3
85.5-71.2		B'_2
71.2-57.0		B'_1
57.0-42.7		C'_2
42.7-28.5	Micro thermal	C'_1
28.5-14.2	Tundra	D’
14.2 below	Frost	E’

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Thermal regime-Supplementary classification- Summer Concentration of Thermal Efficiency (SCTE)

As thermal efficiency is the element of temperature and day-length, it also indicate seasonal variations. To emphasise the seasonal variations in thermal energy. Thornthwaite added a supplementary classification by analyzing percentage of Summer Concentration of Thermal Efficency (SCTE). SCTE is the percentage ratio of the sum of the thermal effcienceis (PE) of the three successive moths of highest themal efficiency to the total annual themal efficiency, as calculated as:

SCTE= Sum of the Thermal Efficiency (PE) of the three maximum consecutive months X 100

Total Annual Potential Evapotranspiration

Scheme of supplementary Classification of Thermal effiency based on SCTE percentages

SCTE(%)	Supplementary Climate type	Symbol
Below-48.0	Mega thermal	a'
48.0-51.9	Meso thermal	b'_4
51.9-56.3		b'_3
56.3-61.6		b'_2
61.6-68.0	Micro thermal	b'_1
68.0-76.3		c'_2
76.3-88.0		c'_1
Above 88.0	tundra	d'

Thermal regime of particular region is represented by two letters. First letter represents major climatebased on Annual TE and second letter represents sub class based on SCTE %. For example A'a' indicates Megathermal and mega thermal.

Thornthwaite's Mositure Regime classification

Thornthwaite's in his climatic analyses, realised the fact that precipitation alone is not an index to assess the moisture conditions of the environment. In the water balance analysis, comparing Precipition (P) with Potential Evapotranspiration (PE) various water balances elements can be derived which in turn useful to evaluate certain indices such as, Aridity index (Ia), Humidity index (Ih) and Index of moisture (Im).

Index of Aridity= Annual water defict X 100

Annual P.E

Index of humidity = Annual water surplus X 100

Annual P.E

Moisture Index (Im) = Ih – Ia

(Im) = Ih – Ia

Where

Im = Index of moisture

Ih= Index of humidity and

Ia= Index of aridity

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Categorisation of Moist Climates (Major climates)

Humid climates (Im > 0)		
Climatic type	**Symbol**	**Moisture Index (Im %)**
Pre humid	A	100 and above
Humid	B_4	80 to 100
	B_3	60 to 80
	B_2	40 to 60
	B_1	20 to 40
Moist Sub humid	C_2	0 to 20
Dry climats (Im < 0)		
Dry Sub humid	C_1	-33.3 to 0
Semi arid	D	-33.3 to -66.7
Arid	E	-66.7 to -100

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Moisture regime- Supplementary classification (Based on seasonal variations) The moisture index of a region in general indicates whether a region is humid or arid. But it does not indicate wheather a region is continuously under wet or dry condition. In the moist climate, if the dry season occurs, it is important to know the intensity of dryness. Similarly, in the dry climates, if wet season occurs the knowledge of intensity of wetness is essential. In moist climates, the intensity of water deficit may be large, moderate, little or non-existent. Similarly, in dry climates the intensity of water surplus may large, moderate, little or non-existent. Thus, keeping the seasonal variations of moisture in view. Thornthwaite proposed supplementary classification in moisture regime classification considering seasonal variation of effective moisture (SVEM).

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Scheme of Mositue regime- Supplementary classification

Moist climates (A, B C_2)		**Aridity index (%)**
r	Little or no water deficit	0-10
s	Moderate summer deficit	10-20
w	Moderate winter deficit	10-20
sz	Large summer deficit	Above 20
wz	Large winter deficit	Above 20
Dry climates (C1, D, E)		Humidity index (%)
d	Little or no water surplus	0-16.7
s	Moderate winter surplus	16.7-33.3
w	Moderate summer surplus	16.7-33.3
sz	Large winter surplus	Above 33.3
wz	Large summer surplus	Above 33.3

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The first scheme of climatic classification (1931) of Thornthwaite was based on the criteria of precipitation effectiveness, seasonal distribution of rainfall and thermal efficiency.In this classification Thornthwaite established strong relationship between climate and vegetation elements and viewed ‘plants as meteorological instruments.’ He identified 32 types of climates at global level with clearcut boundaries based on quantitative criteria and plotted them on the map.

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In his second scheme (1948) of climatic classification he used four criteria - moisture index, thermal efficiency index or potential evapotranspiration, summer concentration of thermal efficiency and seasonal moisture adequacy. In this classification he viewed 'plants as the machinery of evaporation' through which moisture is transported from soil to atmosphere. He applied the concept of potential evapotranspiration, but due to instrumental limitations, used complex mathematical formulae to estimate it based on mean monthly temperature. Scholars have pointed out this as a limitation, as the actual evapotranspiration varies from the potential one. Another limitation of this classification is the huge number of classes which cannot be represented at global level. However, his concept of potential evapotranspiration and moisture balance is very popular and applied frequently in the fields of soil and agricultural sciences and hydrology. Thornthwaite's climatic classification is not a genetic classification, though it has impressed geographers and hydrologists but could not satisfy meteorologists and climatologists, it failed to incorporate causative factors of weather and climate and their interactions.

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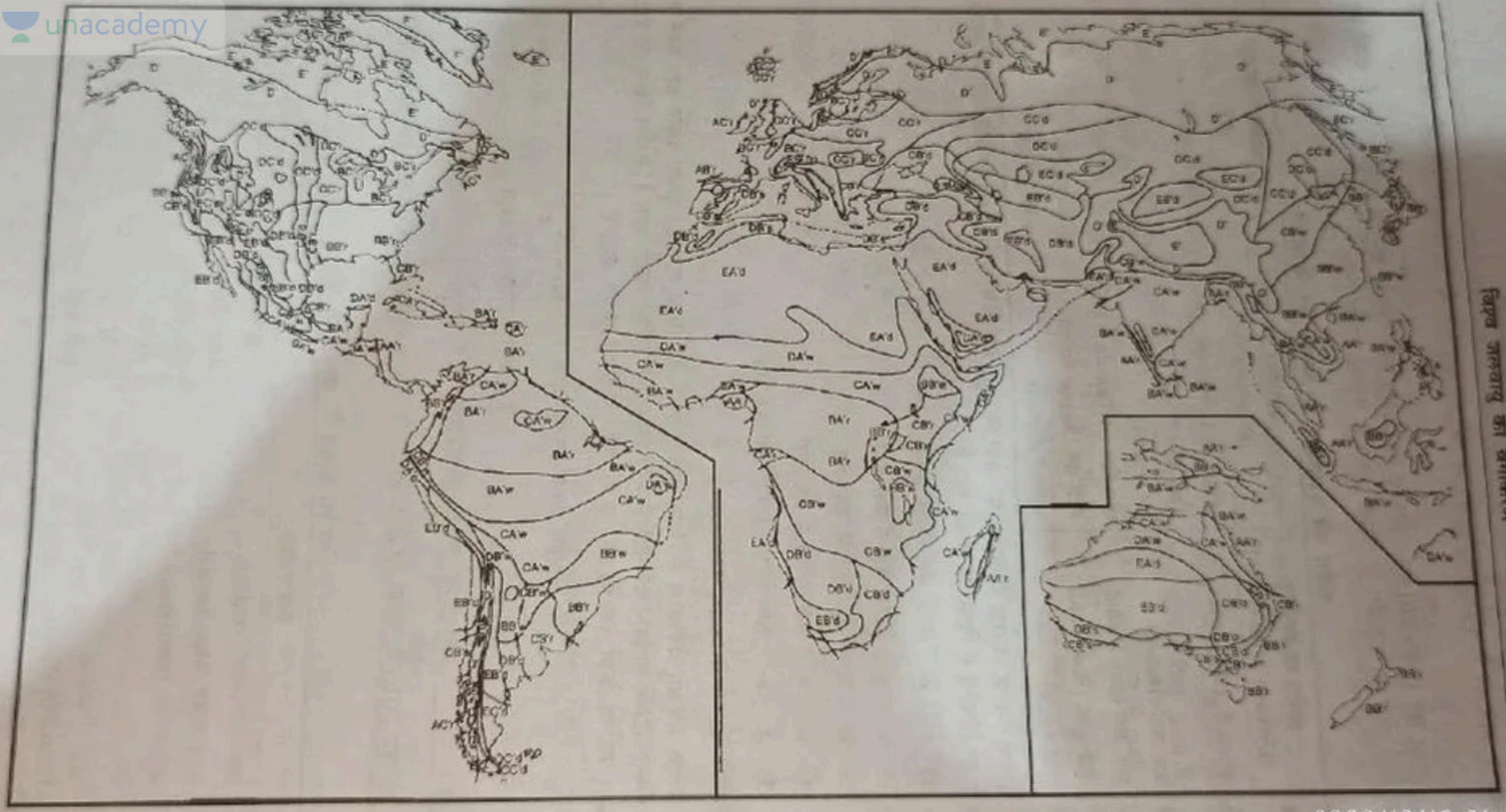
COMPARISON OF KÖPPEN'S AND THORNTHWAITE'S CLIMATIC CLASSIFICATIONS

There are a lot of similarities and dissimilarities in climatic classifications of Köppen and Thornthwaite. The similarities include - (i) both the scholars sincerely researched for decades to devise satisfactory schemes of climatic classification; (ii) both the classifications are empirical but not genetic as both are based on observable elements of climate like temperature and precipitation but not on genetic factors like air masses, atmospheric circulations etc.; (iii) both the classifications are based on quantitative criteria therefore boundaries of climate classes are well defined;(iv) both the classifications have given weightage to relationship of climate and vegetation and finally, (v) both the scholars used letter symbols to represent different climatic classes and sub-classes to make the schemes simple and convenient.

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The dissimilarities of their classifications include – (i) Köppen used mean monthly and average annual temperature and precipitation criteria whereas Thornthwaite applied the criteria of thermal efficiency, precipitation effectiveness and potential evapotranspiration and seasonal variations in thermal and moisture concentration. Conceptually and practically,Thornthwaite's criteria are better. But practically, it is difficult to measure these indices; (ii) Köppen used simple statistical methods whereas Thornthwaite used complex mathematical formulae to determine climatic classes; (iii) the number of climatic classes is limited in case of Köppen's classification to about 14 major climate classes but in case of Thornthwaite, the number of climatic classes or regions is huge (32 in 1931 classification and huge number of probable classes in 1948); (iv) Köppen's climatic classification is easy to understand and has applicability at all educational levels but Thornthwaite's classification can be understood only at higher educational levels; (v) Köppen's climaticclassification is most suitable for macro level generalisations but for micro-level detailed analysis of climatic variations Thornthwaite's climatic classification is preferred, especially the second scheme of classification and finally, (vi) Köppen's climatic classification is empirical and generic but Thornthwaite's classification is empirical, generic and applied and it's concept of potential evapotranspirationis frequently used in soil-moisture balance studies, agriculture science and regional planning and in hydrological studies.

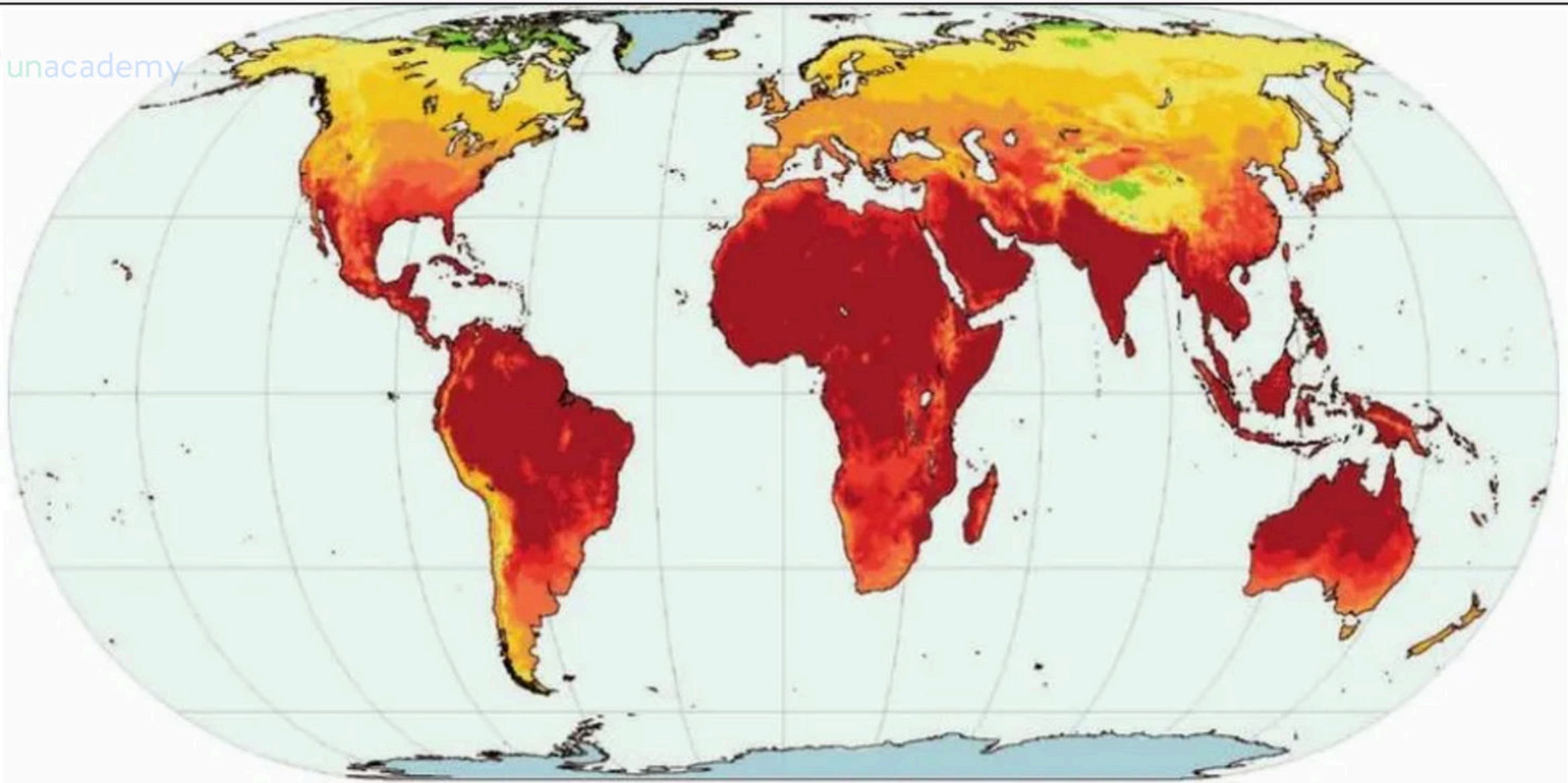
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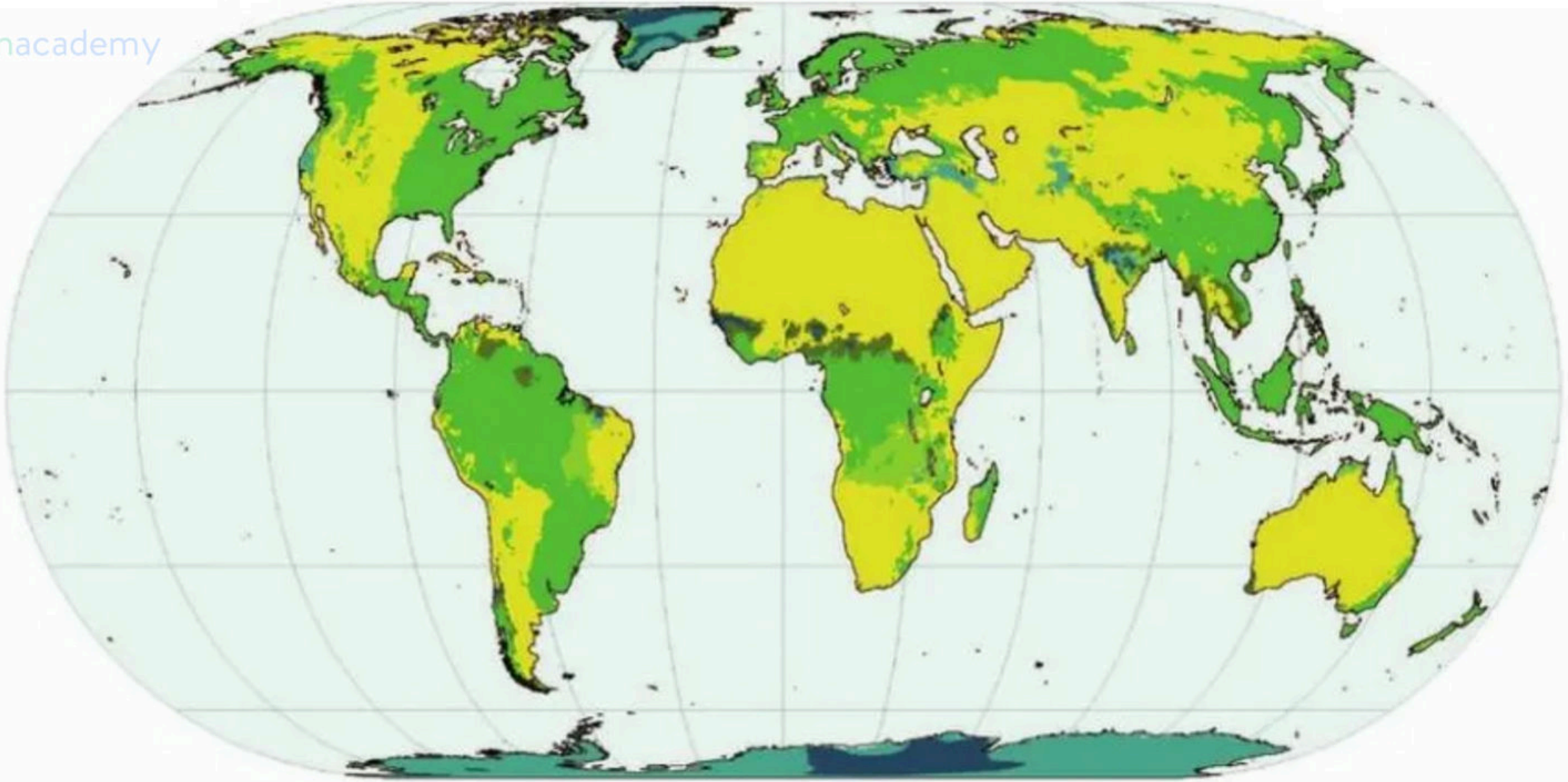
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Thermal efficiency based on annual PE

A' - Megathermal	B'2 - Mesothermal	C'1 - Microthermal
B'4 - Mesothermal	B'1 - Mesothermal	D' - Tundra

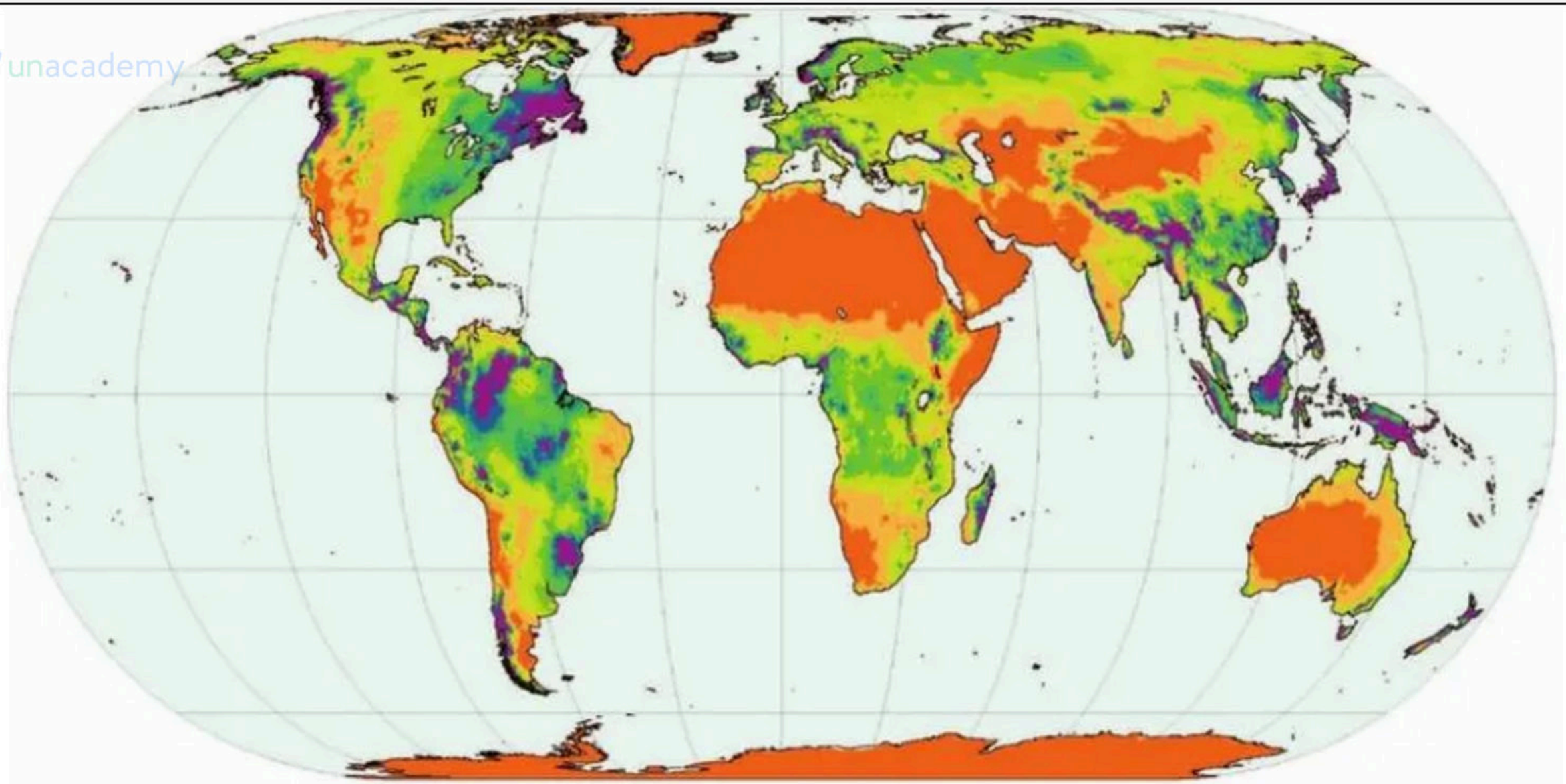
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Seasonal variation of effective moisture

- r - Little or no moisture deficiency in any season (moist climates only)
- d - Little or no water surplus in any season (dry climate only)
- s - Moderate seasonal moisture variation with summer the driest season
- w - Moderate seasonal moisture variation with winter the driest season
- s2 - Large seasonal moisture variation with summer the driest season
- w2 - Large seasonal moisture variation with winter the driest season

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Climatic types based on the 1948 Thornthwaite moisture index

A - Perhumid	B2 - Humid	C1 - Dry subhumid
B4 - Humid	B1 - Humid	D - Semiarid
B3 - Humid	C2 - Moist subhumid	E - Arid