Lecture 1
Tropical Climates (I): Climatic Zones in the Tropics

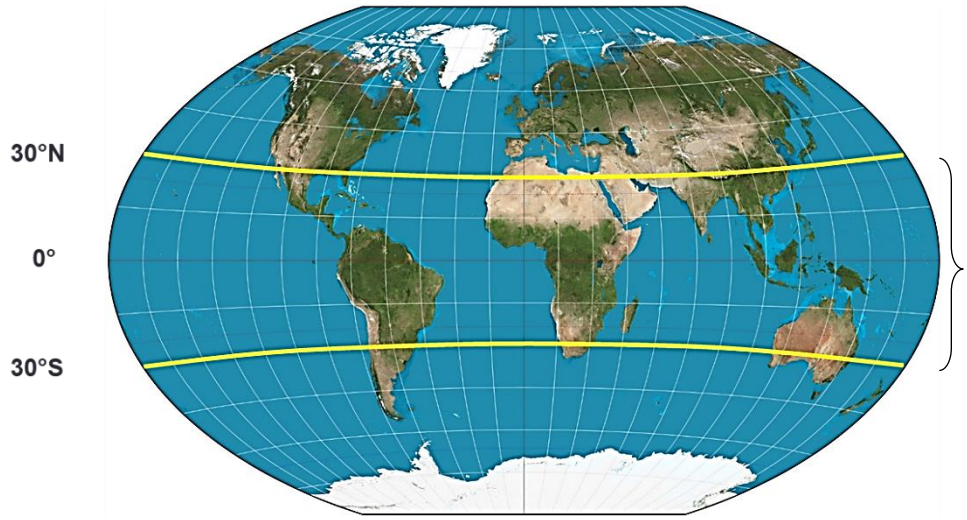
KEY QUESTION:

What are the similarities and differences in the temperature and rainfall patterns in the tropics?

With the completion of this lecture, attached readings and tutorial, you should be able to understand that:

- Locations in the tropics are classified into climatic zones according to their temperature and rainfall characteristics.
- High temperatures are the key distinguishing characteristics of the tropics.
- There are variations in the amount of rainfall between the humid and arid tropics.
- There are seasonal variations in rainfall patterns in parts of the tropics.

Lecture Outline



The Tropics:
A climatic region of radiation surplus delimited by boundaries fluctuating between 30° and 35° latitude, north and south of the equator.

1.1 Introduction: Where is "the Tropics"?

- The Tropics may be described as…

A climatic region of solar radiation surplus delimited by boundaries fluctuating between 30° and 35° north and south latitudes. Common to all areas in this region (at sea level) is high temperature. Significant variations in the amount and pattern of rainfall differentiate these areas into different tropical climate zones, primarily the humid tropics and the arid tropics.

1.2 The Tropics and the Köppen-Geiger Climate Classification System

- A climatic zone is an area designated by broadly similar weather statistics, especially temperature and precipitation. For our purpose, the **Köppen-Geiger climate classification system** will serve as our reference.
- The Köppen-Geiger system is by far the most widely used climatic classification system. It uses a numerical basis of classification (either average temperatures or average amounts of precipitation), and zone boundaries are determined by vegetation patterns.
- As Fig. 1 shows, the world's climate can be broadly classified into are five major climatic zones (**A** through **E**) plus a sixth zone (**H**) called highland climates.

Tropical Climates

- Tropical climates are classified in Humid Tropics (or A climates) and Arid Tropics (or B climates) (see **Table 1**).

Table 1: The Sub-Types of Tropical Climatic Zones

Type	Sub-type	Letter Code	Characteristics
A climates or Humid Tropics	Tropical rainforest	Af	No dry season, Wet throughout the year
	Tropical monsoon	Am	Short dry season, Long wet summer season
	Tropical savanna	Aw	Long dry winter season, Short wet season
B climates or Arid Tropics	Subtropical steppe	BSh	Low-latitude semi dry throughout the year
	Tropical desert	BWh	Low-latitude dry throughout the year

- **Mean annual temperature is high everywhere in the tropics (both humid and arid regions). This is the key characteristic that distinguishes the tropics from other climatic zones in the world.**
  - For example**:** Places in different latitudes within the tropic experiences high mean annual temperature as these are all located in the low latitudes. Mean annual temperature of Singapore (Af) (1°N) is 26.5°C, Kolkata (Am)(23°N) is 26.8°C, Cairo (BWh)(30°N) is 23.1°C.
- However, annual temperature range varies over time and space.
- In case of rainfall characteristics, there is variations in amount and pattern of rainfall in the tropics.

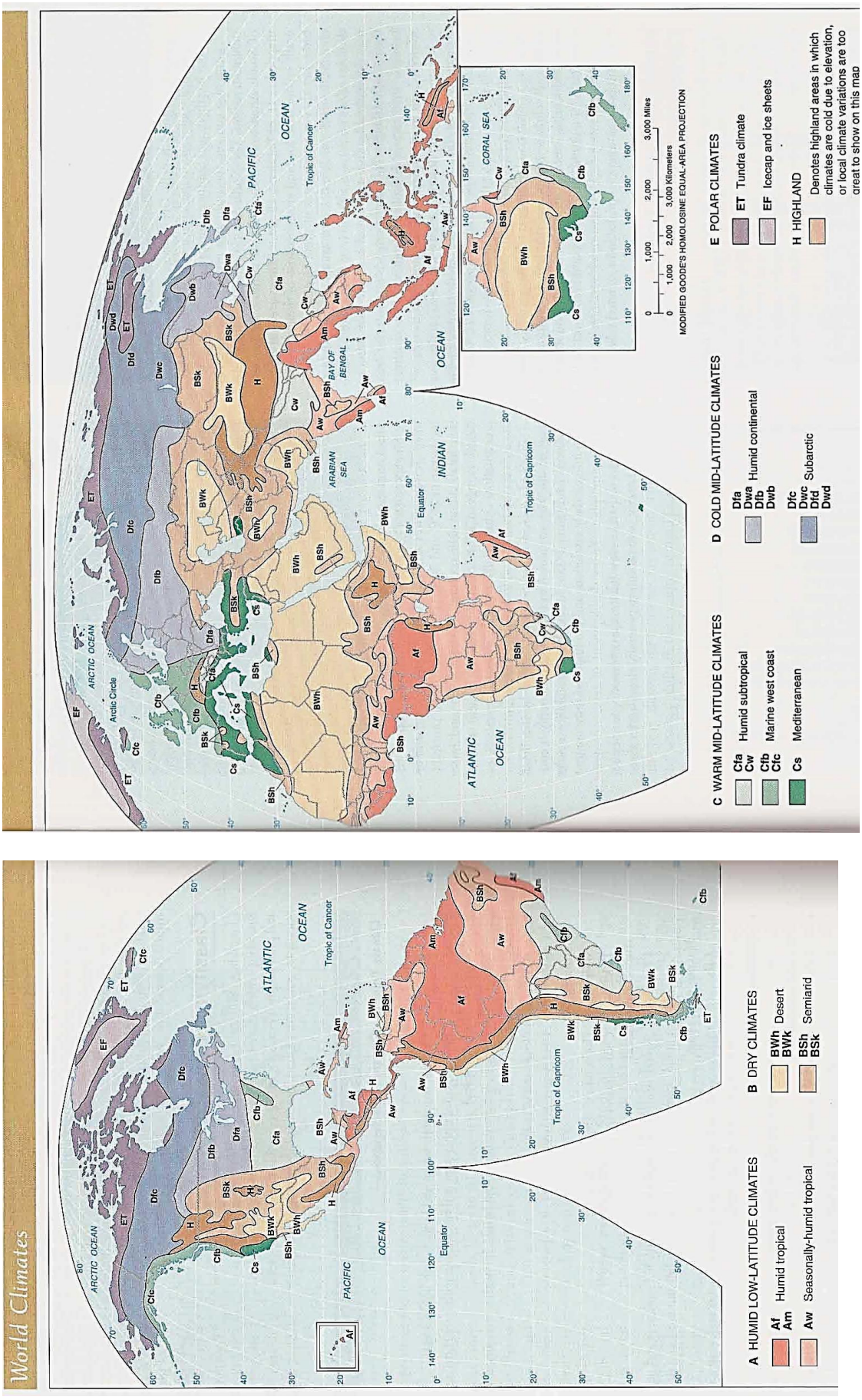


Fig. 1 This world map of climate patterns is largely based on Köppen-Geiger system of climate classification

1.3 Humid Tropical Climates (A climates)

- The humid tropical climates occupy almost all the land area of Earth within some 15-20° north and south of the equator.
- This globe-girdling belt of **A climates** is interrupted slightly here and there by mountains or small regions of aridity, but it dominates the equatorial regions and extends to the 25° latitude in some windward coastal lowlands (see **Fig. 2**).

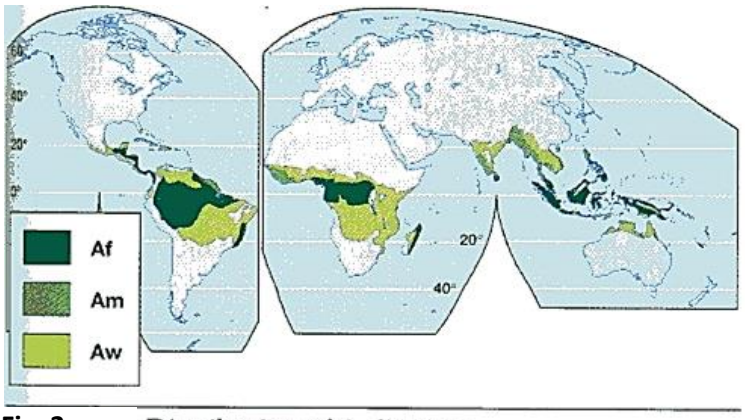


Fig. 2 Distribution of A climates.

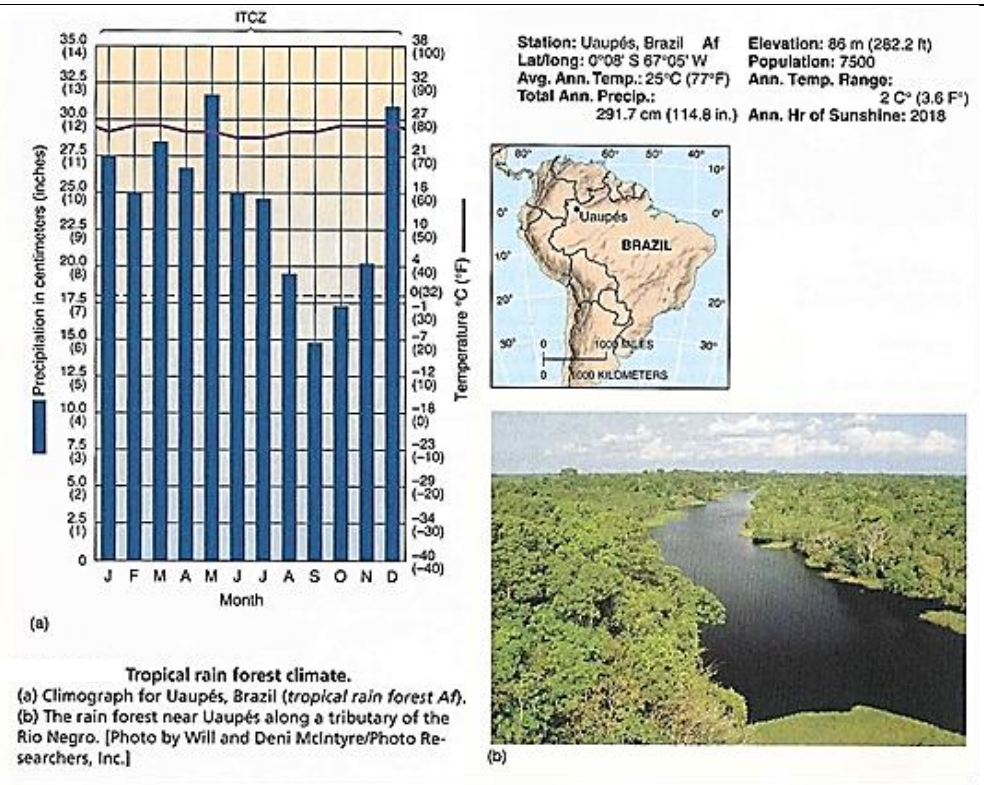
General Characteristics of A Climates

- The A climates are characterised by **high temperatures** throughout the year, as is to be expected from their near-equatorial location. (See **Lecture 2**)
  - The sun is high in the sky every day of the year. These are climates of perpetual warmth (although they do not experience the world's highest temperatures).
  - The fundamental character of the A climates, then, is moulded by their **latitudinal location**.

- The second typifying characteristic of the tropical climates is of course the **prevalence of moisture.** (See also **Lecture 2**). Much of the **A climates** is among the wettest in the world.
  - Warm, moist, unstable air masses frequent the oceans of these latitudes, and the **ITCZ** is in the **A climate** for much of the year.
  - Moreover, onshore winds and thermal convection are common phenomena.
  - Thus the **A climate** has not only abundant sources of moisture but also abundant mechanisms for uplift. High humidity and considerable rainfall are expectable results.

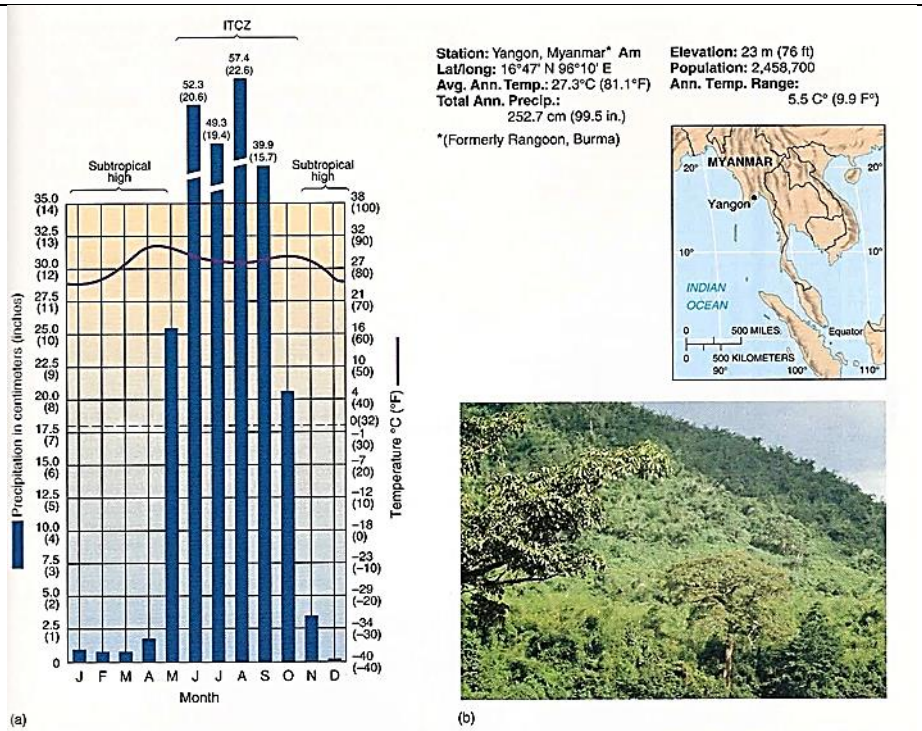
- The humid tropical climates are classified into three types **on the basis of annual rainfall**. We shall elaborate these in subsequent sub-sections.
  - The **tropical rainforest** climate (**Af**) has abundant rainfall throughout the year ranging between 1500 mm and 2500 mm annually.
  - The **tropical monsoon** climate (**Am**) has a **short dry winter** season and a **long rainy** or **wet summer** season with rainfall ranging between 2500 mm and 5000 mm annually.
  - The **tropical savanna** climate (**Aw**) is characterised by a distinct **short rainy** or **wet summer** season and a **long dry winter** season with rainfall ranging between 900 mm and 1800 mm annually.

1.3.1 Tropical Rainforest Climate (Af)

Climograph example **Fig. 3**	 **Tropical rain forest climate.** (a) Climograph for Uaupés, Brazil (*tropical rain forest Af*). (b) The rain forest near Uaupés along a tributary of the Rio Negro. [Photo by Will and Deni McIntyre/Photo Researchers, Inc.]
Location	Climates of the **Af type** characteristically occur in an east-west sprawl close to the equator, lying 5-10˚ N and S of the equator (See **Fig. 2**). The 3 largest tropical rainforest climates are found in: ◦ The Amazon Basin of South America ◦ The northern Zaire (Congo) basin of western equatorial Africa ◦ Southeast Asia (includes Singapore, Malaysia and Indonesia)
Characteristics of temperature pattern	***General temperature pattern:*** Tropical rainforest climate (Af) is known for **uniformly high mean annual temperature**. It is hot all the year round with an mean sea-level monthly temperature of about 27˚C. This is a seasonless climate. ***Annual Temperature Range (ATR):*** With almost no variation from day to day temperature, this is the world's most **monotonous** climate. Hence the ATR is low, ranging between 1˚ and 3˚C.
Characteristics of rainfall pattern	Tropical rainforest climate experiences **uniformly high rainfall throughout the year**. There are **no dry months** and no seasons in this climatic zone. **Annual rainfall** varies from **1500 mm** to **2500 mm**, although in some location it can be greater. **Yearly rainfall in the Af climate is exceeded by that of only one other type of climate (i.e. Am).**

1.3.2 Tropical Monsoon Climate (Am)

Climograph example
Fig. 4



Tropical monsoon climate.
(a) Climograph for Yangon, Myanmar (formerly Rangoon, Burma) (*tropical monsoon Am*).
(b) The monsoonal forest near Malang, Java, at the Purwodadi Botanical Gardens. [Photo by Tom McHugh/Photo Researchers, Inc.]

Location

Regions with **tropical monsoon climate (Am)** occur on the **equatorward-facing coasts of the largest land masses** where a **seasonal reversal** of air streams occurs (i.e. monsoon; see **Lecture 3**). They are found in the same latitudes as the other tropical climates, namely, 5-25˚N and S approximately (See **Fig. 2**).

The climate **does <u>not</u> extend far inland** and usually occurs **along tropical coastal areas subjected to predominant onshore winds that supply moist warm air to the region**. For instance, Am climate is most extensive on the **windward (west-facing)** coasts of Southeast Asia (primarily India, Myanmar, and Thailand) but it also occurs in more restricted coastal regions of western Africa and the Philippines. The north coast of Australia also has (Am) climate.

Regions on the **windward side of mountains** can also be subjected to the impact of monsoon winds. For example, the western slopes of Western Ghats of India, the southern slopes of the Himalaya Mountains and other highland areas of the Asian continent experience more than 5000mm of rainfall each year and some months may have more than 1000mm.

In brief, **Am** are found in:

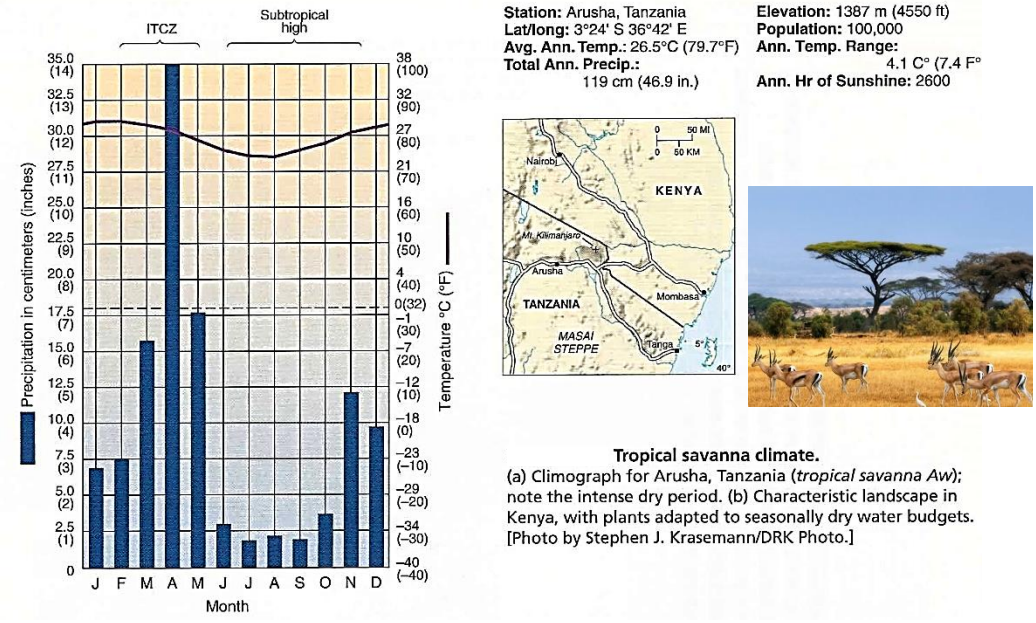
- Southwest India and Eastern Bay of Bengal and the Philippines
- Cairns Australia and
- Parts of African coasts.

Characteristics of temperature pattern	***General temperature pattern:***
	Similar to Af, tropical monsoon (Am) climates also have **high mean annual temperature**. However, there are more evidence of **seasonal variation of temperature**.
	
	Mean Summer/Winter Temperature:
	• Temperature is **relatively higher in summer** when the sun is overhead.
	• In the NH:
	  ○ In June, the overhead sun is at or near the Tropic of Cancer (23.5˚N). Summer temperatures lie in the high 20s˚C but, just before the start of the wet monsoon season, the maximum daily temperatures may exceed 40˚C.
	  ○ In December, the mean winter monthly temperatures are normally in the middle 20˚Cs as the overhead sun has shifted to the SH.
	• In the SH, the overhead sun is at or near the Tropic of Capricorn (23.5˚S) in December, giving summer. Winter occurs in June.
	
	Annual Temperature Range:
	ATR is slightly larger than that of Af climate. Usually about 5-8˚C but may be even more.

Characteristics of rainfall pattern	The distinctiveness of the Am climate is shown primarily in its rainfall pattern (**Fig. 4**). It has abundant rainfall (possible to be even more than Af) but unlike Af, it shows **a strong seasonal pattern with long wet summers** (e.g. May to Oct) **and short dry winters** (e.g. Dec to Mar). Total annual rainfall is still high and may vary from 1500 mm to 5000 mm (although for a typical Am station, it would be from 2500 and 5000 mm).

1.3.3 Tropical Savanna Climate (Aw)

Climograph example
Fig. 5



Tropical savanna climate.
(a) Climograph for Arusha, Tanzania (*tropical savanna Aw*); note the intense dry period. (b) Characteristic landscape in Kenya, with plants adapted to seasonally dry water budgets. [Photo by Stephen J. Krasemann/DRK Photo.]

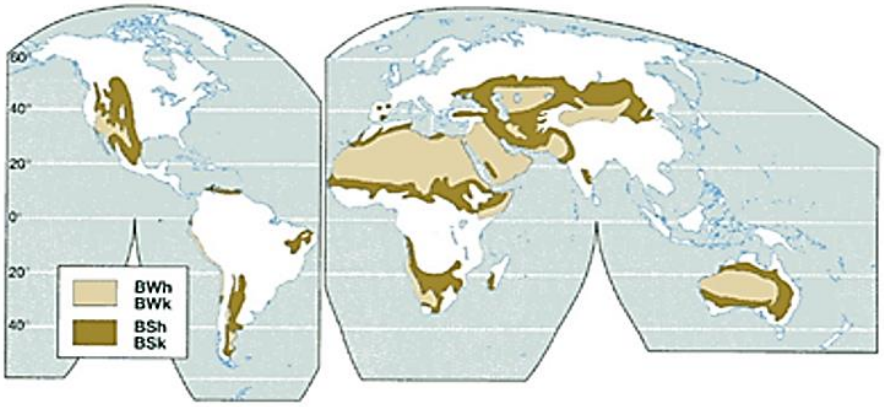
Location	The most extensive of the A climates, **Aw** climate, generally lies both to the north and south of Af climates. It is a transition zone between Af and B climates (see **Section 1.4** for B climates). Tropical savanna (**Aw**) climates are found in (see **Fig. 2** earlier): ○ Southern Africa between 5° and 25°N and S latitudes ○ South America, Central America and the Caribbean islands ○ Southeastern Asia ○ Northern Australia
Characteristics of temperature pattern	***General temperature pattern:*** Similar to both Af and Am, the **mean annual temperature** of Aw climate is also high. However, the temperature pattern of the tropical savanna (**Aw**) climates is characterised by **seasonal variation of temperature** (Fig. 9). Temperature is high in summer when the sun is overhead. In the NH the sun is overhead at or near the Tropic of Cancer in June. The temperature dips in December when the overhead sun shifts towards the Tropic of Capricorn in SH. ***Annual Temperature Range:*** • ATR shows more variability of about 3 – 10˚C. • The summer temperatures are hot – among the world's hottest conditions. Mean temperatures of the summer months are usually in the high 20s˚C and maximum daily temperatures hitting 40˚C are common in some of the tropical savanna regions. Winter seasons may be described as warm with the mean monthly temperatures in the 20s˚C.
Characteristics of rainfall pattern	Total annual rainfall is high and varies from 900 mm to 1800 mm. Although the total rainfall is considered to be high, it is not as high as Af and Am. The distinctive characteristic of Aw climate is its **distinct seasonal wet summers and dry winters** (Fig. 9) Note: Even though both Aw and Am have wet and dry seasons, there are some key differences: • The dry seasons of Aw are **longer** than the dry seasons of Am. • The wet seasons of Aw are usually **shorter** than the wet seasons of Am, hence making the amount of total annual rainfall in Aw lesser than Am. • While the summers are wet, there may be no rain at all in the winter. 90% of the rain falls in the hottest months, while the winters are characterised by a long, seasonal dry period. Unreliability is another feature of the rainfall. From year to year, the rainfall may vary by more than 50% from its average. In some years it has the characteristic features of the desert; in other years it is almost like the equatorial lands.

1.4 Arid Tropical Climates (B climates)

- The arid tropical climates cover about 30% of the land area of the world, more than any other climatic zone (note however, we are not covering all in this zone) (see **Fig. 6**).
- Arid tropical climates are widespread in the subtropics between 25° and 35°N and S latitudes.
- Although at first glance their distribution pattern appears erratic and complex, it actually has a considerable degree of predictability. These climates are mostly found along the **western coast of continents** or are located **further inland**.

Fig. 6

Pay more attention to BWh and BSh



<u>General Characteristics of B Climates</u>

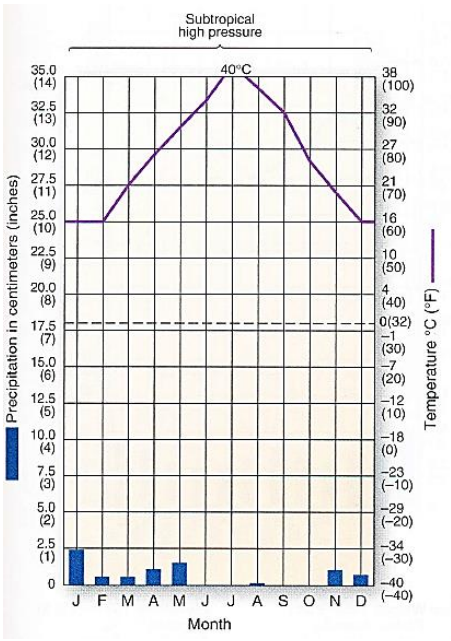
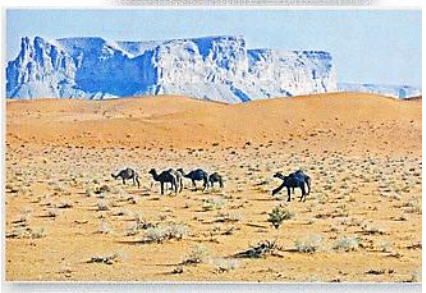
- Similar to A climates, the main characteristics of B climates is **high mean annual temperature**. (Recall that collectively, the tropics is different from other zones in temperature.) However, there is greater **seasonal variations** in temperatures compared to A climates (i.e. warmer summers, cooler winters).

- However, when it comes to **rainfall characteristics, B climates experience low to very low rainfall**.
  - Most desert areas are **dry not because the air lacks moisture content**; but rather, they **lack mechanisms for the upward air motion** necessary for cloud formation and rainfall as this is a zone of sinking air (see **Lect 2**).

- The arid tropical climates are classified based on the amount of rainfall received:
  - The **tropical desert climate** or **BWh** climate is **extremely arid** and receives very low rainfall being less than 250 mm annually.
  - The **subtropical steppe climate** or **BSh** climate is **semi-arid** with low total annual rainfall varying between 250 mm and 630 mm.

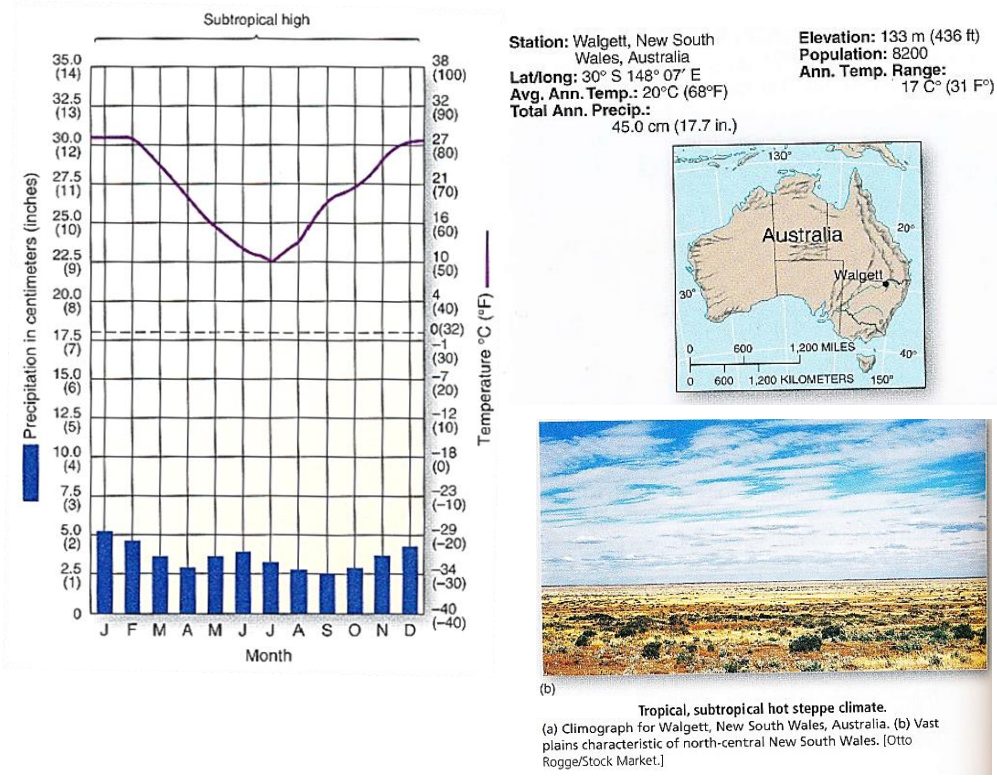
- Our discussion here focuses on the deserts (BWh) because they represent the epitome of dry conditions – the arid extreme. Most of what is stated about deserts applies to steppes (BSh) but in moderate intensity.

1.4.1 Tropical Desert Climate (BWh)

Climograph example **Fig. 7** Note: This example is taken from the Northern hemisphere, hence the temperature graph takes an 'A' shape, with summer in the middle of the year. Compare this with **Fig. 8**, which shows a 'V' shape temperature graph. This is because in the Southern hemisphere, winter occurs in the middle of the year.	 **Station:** Ar Riyāḍ (Riyadh), Saudi Arabia **Lat/long:** 24° 42′ N 46° 43′ E **Avg. Ann. Temp.:** 26°C (78.8°F) **Total Ann. Precip.:** 8.2 cm (3.2 in.) **Elevation:** 609 m (1998 ft) **Population:** 5,024,000 **Ann. Temp. Range:** 24 C° (43.2 F°)   (b) **Tropical, subtropical hot desert climate.** (a) Climograph for Ar Riyāḍ (Riyadh), Saudi Arabia. (b) The Arabian desert landscape of Red Sands near Ar Riyāḍ. (c) The
Location	In both the Northern and Southern Hemispheres, tropical desert climates lie either in or very near the band of the *subtropical highs* (see **Lect 2**), centered between 25° and 35°N and S latitude, especially along the west coasts of continents (see **Fig. 6**). Where tropical deserts are located: ○ The vast expanse of North Africa (the Sahara) and southwestern Eurasia (the Arabian Desert) represents more desert area than is found in the rest of the world combined – here, the adjacency of Eurasia makes Africa a continent without an eastern coast north of 10°N (and so this region lacks maritime moisture sources from the east). ○ Tropical desert climate is also expansive in Australia (50% of the continental area).
Characteristics of temperature pattern	***General temperature pattern:*** • Similar to A climates, the **mean annual temperature** of BWh climate is also high. • However, the temperature pattern of the B climates is characterised by **seasonal variation of temperature**. Summers are very hot and winters are relatively mild. Summers are long and blisteringly hot, with month averages in the middle to high 30s°C - significantly hotter than most equatorial regions. Midwinter months have mean temperatures below 20s°C, which gives **moderate annual temperature range of 8 to 14°C**.

Characteristics of rainfall pattern	The essential characteristic of this climate is, of course, the **very low rainfall throughout the year**. All parts of these hot desert regions receive total annual rainfall of less than 250 mm; many areas receive less than 100 mm each year. Three adjectives are particularly applicable to precipitation conditions in tropical deserts. ○ **Scarce** – Subtropical deserts are the most nearly rainless regions on earth. Most BWh regions, however, are not totally without rainfall. Total annual rainfall between 20mm and 200mm are characteristic, and some places receive as much as 380mm. ○ **Unreliable** – An important climatic axiom is that the lower the total annual rainfall, the greater its variability. The very concept of an "average" yearly rainfall in a BWh location is misleading because of year-to-year fluctuations. Yuma, Arizona, for example, has a long-term average rainfall to 84mm, but over the last two decades it has received as little as 4mm and as much as 188mm in a given year. ○ **Intense** – Most rainfall in these regions fall in vigorous convective showers that are localised and of short duration. Thus the rare rains may bring brief floods to regions that have been lacking in surface moisture for months.

1.4.2 Subtropical Steppe Climate (BSh)

Climograph example **Fig. 8** Note: This example is taken from the Southern hemisphere, hence the temperature graph takes a 'V' shape, with winter in the middle of the year. Compare this with **Fig. 7**, which shows an 'A' shape temperature graph. This is because in the Northern hemisphere, summer occurs in the middle of the year.	 **Tropical, subtropical hot steppe climate.** (a) Climograph for Walgett, New South Wales, Australia. (b) Vast plains characteristic of north-central New South Wales. [Otto Rogge/Stock Market.]

Location	The **BSh** climates characteristically surround **BWh** climates (except on the western side), the former separating the latter from the more humid climates beyond. The subtropical steppe climate is located on the periphery of deserts. o Subtropical steppe climate is found bordering the Great Australian desert, o the Sahara of northern Africa, and o Southwest Asia. Temperature and precipitation conditions are not significantly unlike those just described for BWh regions, except that the extremes are more muted in the steppes (**Fig. 8**).
Characteristics of temperature pattern	Similar to A climates, the **mean annual temperature** of BSh climate is also high. Mean annual temperature is approximately 20˚C. However, just as is the case with BWh, the temperature pattern of the BSh climate is characterised by **seasonal variation of temperature**. This climate tends to have hot, sometimes extremely hot, summers and warm to cool winters. Annual temperature range vary from 10˚C to above 20˚C.
Characteristics of rainfall pattern	• Total rainfall received in BSh is low. However, when compared to BWh, rainfall is somewhat greater and more reliable. • The less arid fringes surrounding the deserts – the semi-arid steppes – receive between 250 and 600 mm of total annual rainfall and form transitional zones between the desert and the humid climates. • On the equatorward side of the desert, low rain occurs in summer.

1.5 Summary

- Locations in the tropics are classified into climatic zones according to their temperature and rainfall characteristics. Using the **Köppen-Geiger climate classification system**, the tropics can be classified into:

Humid Tropics (A climates)	**Arid Tropics (B climates)**
▪ Af – tropical rainforest (*f* for forest) ▪ Am – tropical monsoon (*m* for monsoon) ▪ Aw – tropical savanna (*w* for winter dry)	▪ BWh – tropical desert (*W* for German word, Wüste = desert; *h* for hot) ▪ BSh – sub-tropical steppe (*S* for German word, Steppe; *h* for hot)
▪ High mean temperatures, small ATR	▪ High mean temperatures, larger ATR
▪ High rainfall. But variations exist in total volume (i.e. Am > Af > Aw) as well as seasonality within the year.	▪ Low or scarce rainfall throughout the year. But total rainfall differs (i.e. BSh > BWh).

Refer to **Page 14** to view examples of the climographs at a glance.

Box 1: The Shifting Location of the Overhead Sun Relative to the Earth's Surface

- Earth has two principal motions – rotation and revolution.
  - **Rotation** is the spinning of Earth about its axis that produces the daily cycle of daylight and darkness.
  - **Revolution** refers to Earth's movement in orbit around the Sun.
- While revolving around the Sun, the Earth rotates about an imaginary axis, tilted about 23.5° away (see Fig. 9) from the perpendicular. Because the axis is always remains pointed in the same direction as Earth journeys around the Sun, the angle at which the Sun's rays strike Earth changes (i.e. angle of incidence) throughout the year.
- In **June**: (see Fig. 10 below)
  - the Northern Hemisphere is tilted towards the Sun, experiences summer. The position of the overhead sun is here, hence, more insolation.
  - the Southern Hemisphere experiences less insolation, and goes through winter.
- In **December**, the situation is reversed in each hemisphere.
- In **March** and **September**, as neither hemispheres are tilted towards the Sun, the position of maximum solar heating is at the Equator.
- The result is the variation in insolation received throughout the year as the Sun's rays apparently moves away from the equator and towards the Tropics of Cancer and Capricorn.

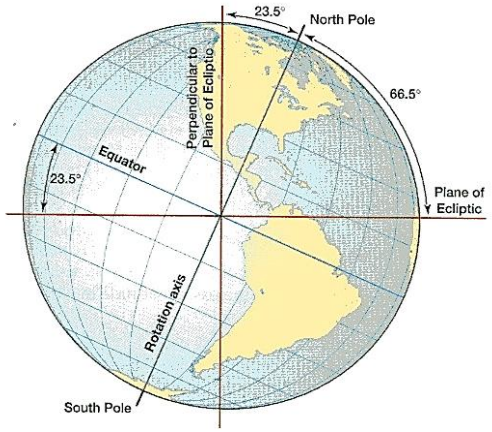


Fig. 9 Earth's rotation axis forms an angle of 66.5° with the plane of the ecliptic, and this tilt is called the inclination of the axis. It is commonly described not in terms of this angle, however, but rather as being 23.5° from a line perpendicular to the plane of the ecliptic.

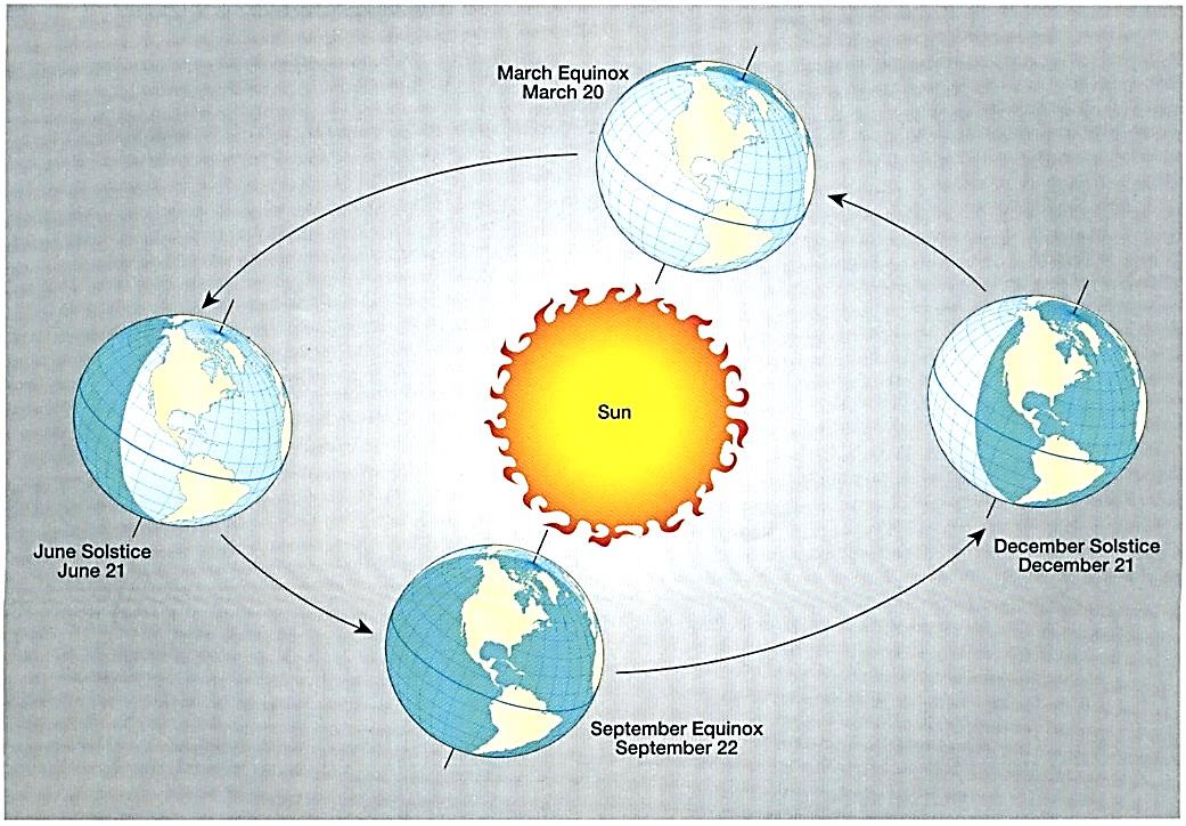


Fig. 10 One-half of Earth is illuminated at any time during the day and during the year. Here light blue is the illuminated half and dark blue is the unilluminated half. As noted earlier, the line between the two halves is called the circle of illumination. Note its position relative to the polar circles on June 21, date of the summer solstice in the Northern Hemisphere, and December 21, date of the winter solstice in the Northern Hemisphere.

Box 2:

Reading climographs

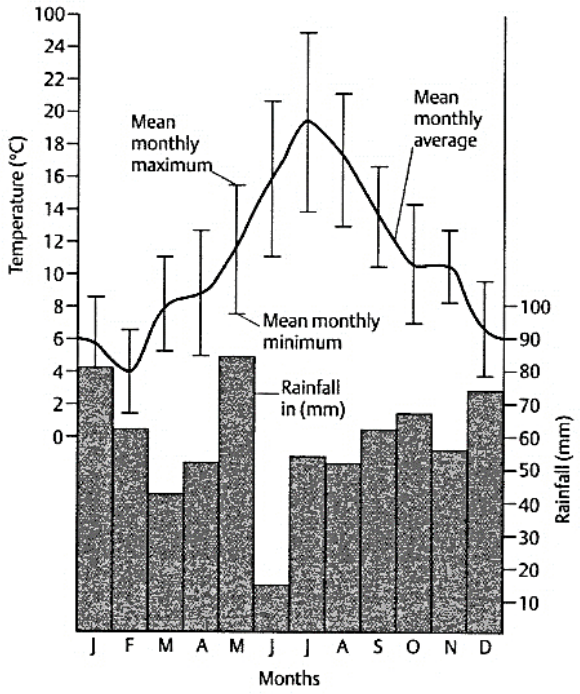
Climatic graphs or climographs describe the seasonal pattern of rainfall and temperature. The diagram shows:

- the mean monthly average
- the mean monthly maximum - the average of all the maximum temperatures for each day of the month
- the mean monthly minimum - an average of all the minimum temperatures recorded for that month
- rainfall - generally shown as a series of bars
- different scales – in this example the temperature scale is shown on the left-hand margin and the rainfall scale is shown on the right.

Reading the climograph

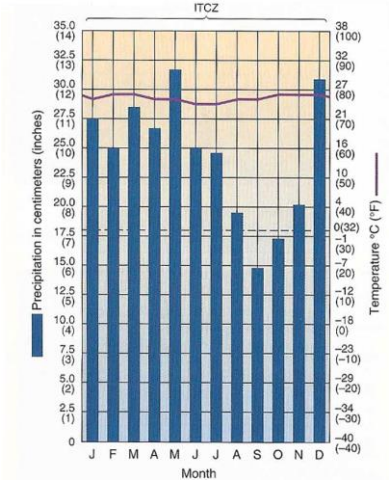
Look out for:

- total rainfall
- seasonality - when most of the rain occurs
- maximum temperature
- minimum temperature
- range of temperature (maximum - minimum temperature)
- length of time (if any) below freezing.

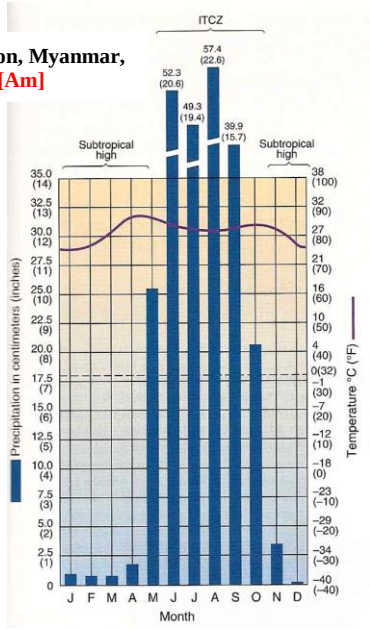


Overview of *A* and *B* Climates – Climographs and their Characteristics

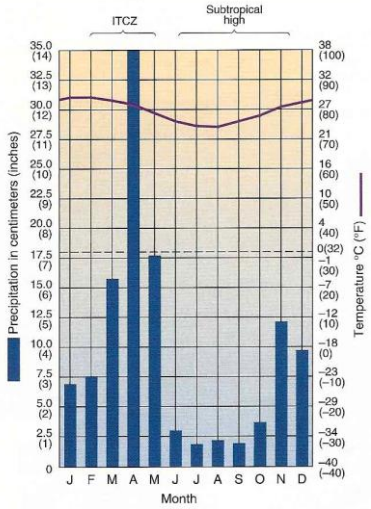
Uaupes, Brazil, 0° lat [Af]



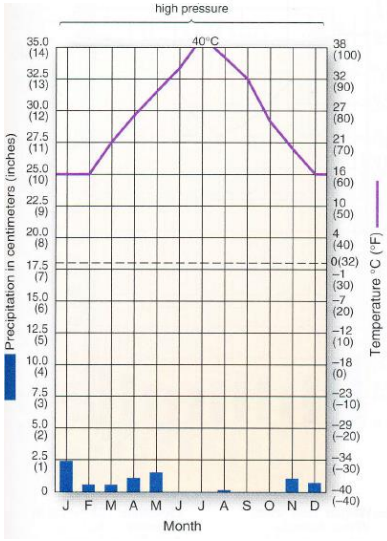
Yangon, Myanmar, 16°N [Am]



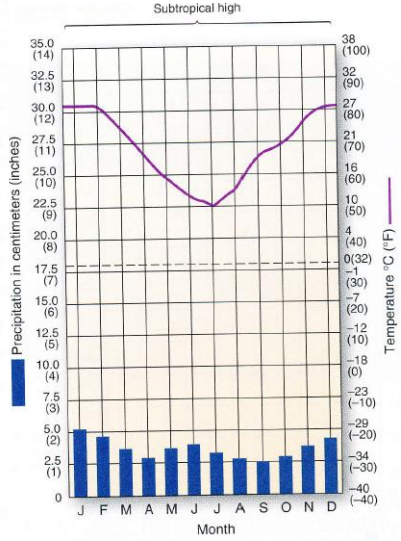
Arusha, Tanzania, 3°S [Aw]



Riyadh, Saudi Arabia, 24°N [BWh]



Walgett, NSW, Australia 30°S [BSh]



Humid Tropics / A climates

Left to Right: Af, Am, Aw

Type	*Location*	*Temperature*	*Precipitation*	*Dominant Controls of Climate*
Tropical wet (Af)	5–10° either side of equator; farther poleward on eastern coasts	Warm all year; very small ATR; small DTR; high sensible temperature	60–100 in. (152–254 cm) annually; no dry season; many thunderstorms	Latitude; ITC zone; trade-wind convergence; onshore wind flow
Tropical monsoonal (Am)	Windward tropical coasts of Asia, Latin America, Guinea coast of Africa	Similar to Af with slightly larger ATR; hottest weather just before summer monsoon	100–200 in. (254–508 cm) annually; very heavy in summer; short winter dry season	Seasonal wind-direction reversal associated with ITC zone movement; continental pressure changes
Tropical savanna (Aw)	Fringing Af between 25° N and S	Warm to hot; moderate ATR and DTR	35–70 in. (90–180 cm) annually; distinct wet and dry seasons	Seasonal shifting of tropical wind and pressure belts, especially ITC zone

All A climates lie within 25° of the equator, with the vast majority within 20°. All are winterless, with no monthly average temperature below 64°F (18°C). All are always very humid and have high rainfall totals.

ATR = annual temperature range; DTR = daily temperature range.

Arid Tropics / B climates

Left to Right: BWh, BSh

Note: These examples are taken from different hemispheres.

Type	*Location*	*Temperature*	*Precipitation*	*Dominant Controls of Climate*
Subtropical desert (BWh)	Centered at latitudes 25–30° on western sides of continents, extending into interiors; most extensive in northern Africa and southwestern Asia	Very hot summers, relatively mild winters; enormous DTR, moderate ATR	Rainfall scarce, unreliable, intense; little cloudiness	Subtropical anticyclonic subsidence; rain shadow of mountains; cold ocean currents
Subtropical steppe (BSh)	Fringing BWh except on west	Similar to BWh but more moderate	Semiarid	Similar to BWh