APPENDIX 2: KÖPPEN CLIMATE CLASSIFICATION SYSTEM

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INTRODUCTION

Climate can be defined as the long-term trends observed in the **weather** (**temperature**, **precipitation**, **humidity**, etc.) on a time scale of years to decades. Understanding these trends allows us to predict what the weather may be like in the immediate future. Several systems have been developed to classify the climates of locations on our planet. Data classification is a standard process across all sciences. From classification, we can determine similarities and dissimilarities in the data. The classification process also helps us identify data patterns that are usually controlled by other factors. Across Earth's climate zones, we find that similar climatic factors often influence locations with comparable climates, despite being geographically separated by great distances.

The **Köppen Climate Classification system** is an empirical system that uses readily available precipitation and temperature data collected at weather stations. For the classification process, the data must be arranged as monthly precipitation totals, monthly temperatures, annual precipitation totals, and annual temperatures. The monthly temperature is calculated by averaging the daily maximum and minimum temperatures for each day in the month. All the daily means are added together and divided by the number of days in that particular month. Finally, monthly and annual temperature and precipitation data should be averaged over many consecutive years. This averaging evens out the natural variation normally found in climate data.

TROPICAL MOIST CLIMATES - "A" CLIMATES

Tropical moist climates extend northward and southward from the equator to about 15 to 25° of latitude. In these climates, all months have average temperatures greater than 18° Celsius (64° Fahrenheit). Annual precipitation is often greater than 1500 mm (59 in). Three minor Köppen climate types exist in the **A group**. The seasonal distribution of **rainfall** distinguishes these three categories of tropical moist climates.

Af – Tropical Wet

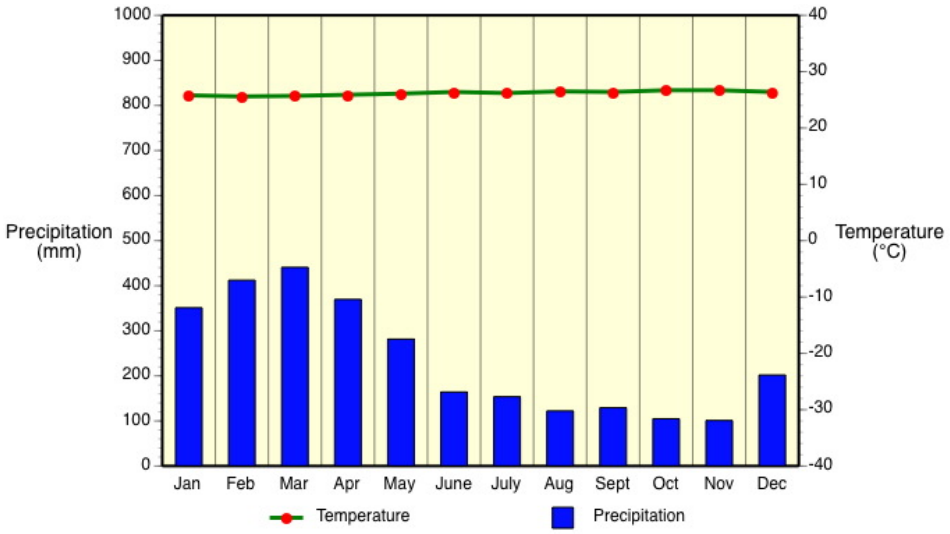
Af or **tropical wet** is a tropical climate where precipitation occurs year-round. Monthly temperature variations in this climate are usually less than 3°C (37°F). Intense surface heating and high humidity cause the development of **cumulus** and **cumulonimbus clouds** (**thunderstorms**) to form early in the afternoons almost daily. Daily highs are about 32°C (90°F). Radiative cooling during the evening is limited because of cloud cover and high humidity. Nighttime daily temperatures average about 22°C (72°F).

Locations: Amazon River Basin (South America), Congo River Basin (Africa), eastern coast of Central America, eastern coast of Brazil, the Philippines, the coast of Madagascar, eastern India, southern Bangladesh, Malaysia, and Indonesia.

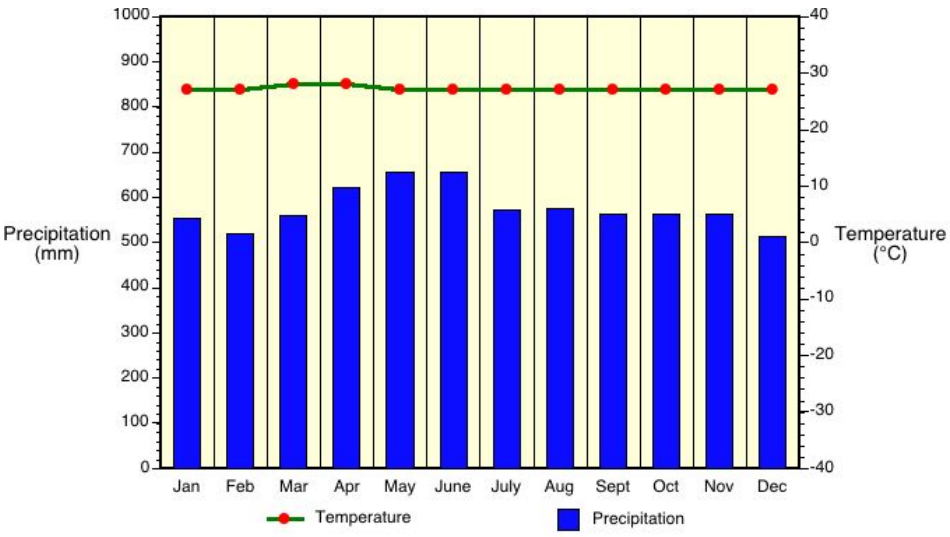
Controlling Weather Factors: High year-round input of high quantities of **solar radiation** (**insolation**). High and constant monthly precipitation is due to the presence of **thunderstorm** activity associated with the **Intertropical Convergence Zone**.

Climate Characteristics: Constant high temperatures throughout the year. Average monthly temperatures are very similar - the yearly range is about 2 to 3°C (36 to 37°F). Monthly precipitation is evenly distributed; annual amounts are usually greater than 1500 mm (59 in). These climates also have frequent cumulus cloud development, with some clouds becoming air mass thunderstorms. Humidity tends to be high.

Examples:



Af - Belem, Brazil 2° S, Elevation: 24 m (79 ft)



Af - Andagoya, Columbia 5° N, Elevation: 65 m (213 ft)

Aw – Tropical Wet and Dry

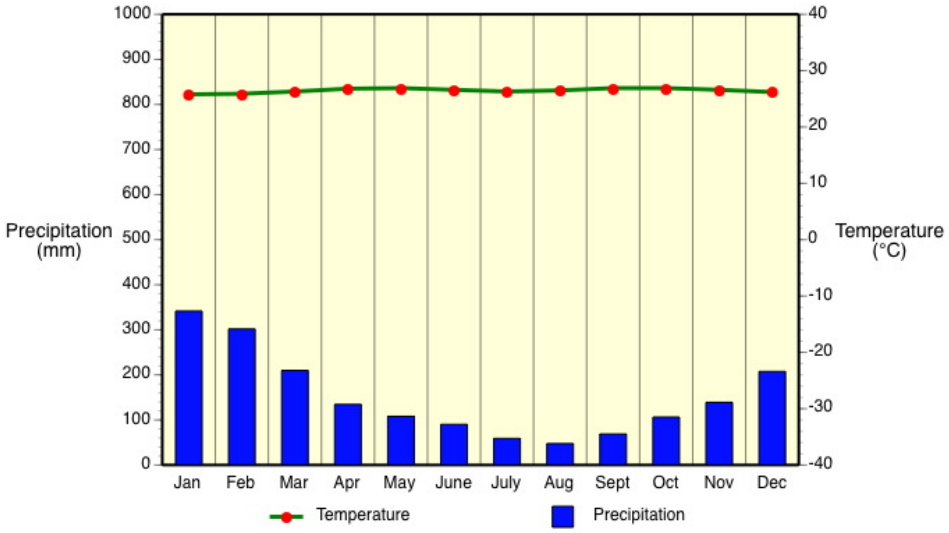
The **tropical wet and dry** or **savanna** (**Aw**) has an extended dry season during winter. Precipitation during the wet season is usually less than 1000 millimeters (39 in) and is mainly during summer. The average monthly temperature is greater than 18°C (64°F) in all months. More than two months have less than 60 mm (2.4 in) of precipitation. There is a distinct dry season during the low-sun period (winter) and a distinct wet season during the high-sun period (summer). These climates are generally poleward of **Af** climate areas.

Locations: Northern and eastern India, central Myanmar, the Indo-Chinese Peninsula, northern Australia, the region around the Congo River basin, south-central Africa, western Central America, parts of Venezuela, parts of Brazil, the southern tip of Florida, and the Caribbean Islands.

Controlling Weather Factors: Alternating wet and dry seasons are caused by the seasonal presence of the **Intertropical Convergence Zone** during the high-sun season and the **Subtropical High Pressure Zone** during the low-sun season.

Climate Characteristics: Monthly precipitation data show distinct high-sun wet and low-sun dry seasons. Annual rainfall averages between 750 and 1800 mm (30 and 71 in). This climate has the highest monthly temperature ranges of the **A climate** category.

Example:



Aw - Jakarta, Indonesia 6° S, Elevation: 8 m (26 ft)

Am – Tropical Monsoon

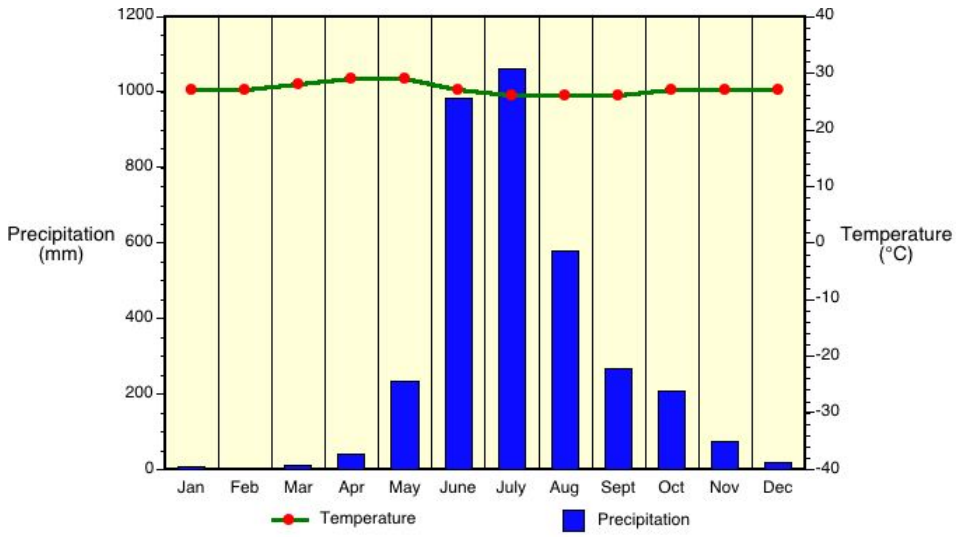
Am is a **tropical monsoon climate**. Annual rainfall is equal to or greater than **Af**, but most of the precipitation falls during the 7 to 9 hottest months. Have a very pronounced wet season. During the dry season, rainfall is very scarce. The average monthly temperature is greater than 18°C (64°F) in all months. Have one or more months with less than 60 mm (2.4 in) of precipitation.

Locations: Coastal areas of southwestern India, Sri Lanka, Bangladesh, Myanmar, southwestern Africa, Guyana, Surinam, French Guiana, and parts of northeast and southeast Brazil.

Controlling Weather Factors: **Monsoonal** summer onshore and winter offshore air mass movement is related to seasonally shifting Intertropical Convergence Zone and changing surface atmospheric pressure conditions over the landmasses and ocean areas.

Climate Characteristics: The climate of this category is transitional between **Af** and **Aw**. The heaviest rainfall records in the world occur in this climate type (Cherripunji, India – 12,000 mm (472 in)). Heavy rainfall is associated with the high-sun (summer) season. Precipitation can be significantly enhanced by **orographic uplift**. Yearly precipitation totals range from 1500 to 4000 mm. The dry season is associated with the low-sun (winter) period. The annual temperature range of monthly averages is about 2 to 6°C (36 to 43°F). The highest monthly temperature often occurs just before the start of the rainy season.

Example:



Am - Mangalore, India 13° N, Elevation: 22 m (72 ft)

DRY CLIMATES - "B" CLIMATES

The most prominent feature of this climate is that **potential evapotranspiration** exceeds precipitation. These climates extend from 20 - 35° North and South of the equator and in large continental regions of the mid-latitudes, often surrounded by mountains. Four minor types of this climate occur:

BW - Dry Arid (Desert)

BW is a true desert climate. It covers 12% of the Earth's land surface and is dominated by **xerophytic** vegetation. The additional letters **h** and **k** are generally used to distinguish whether a dry, arid climate is found in the subtropics or the mid-latitudes, respectively.

BWh – Dry Arid Low Latitudes

BWh is a dry arid climate found in low-latitude deserts. The most distinguishing aspect of this climate is that precipitation is less than 50% of potential evapotranspiration. The annual average temperature is over 18°C (64°F). Daily minimum temperatures infrequently go below 0°C (32°F) during winter.

Locations: Northern Mexico, southwestern United States, northern Africa, Saudi Arabia, Iran, western India, central and western Australia, and southern and western Africa.

BWk – Dry Arid Mid-Latitudes

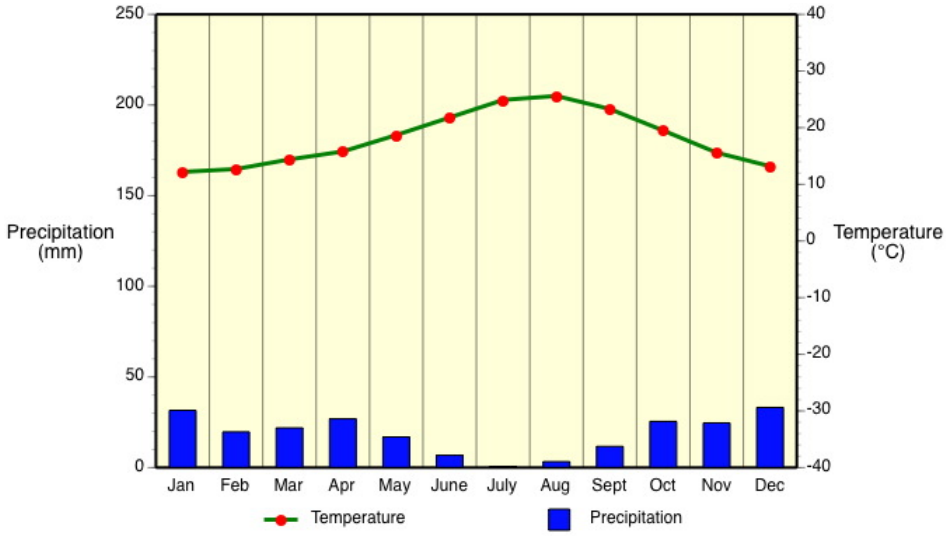
BWk is a **dry arid climate** found in middle-latitude deserts. Like **BWh**, precipitation is less than half of potential evapotranspiration. The annual average temperature is below 18°C (64°F). Daily minimum temperatures often drop below 0°C (32°F) during winter.

Locations: From the Caspian Sea eastward to northern China, Mongolia, and parts of southern South America.

Controlling Weather Factors (both **BWh** and **BWk**)**:** The **Subtropical High Pressure Zone** dominates during most of the year. Locations are often far inland (**continentality**) and influenced by the **rainshadow effect**.

Climate Characteristics (both **BWh** and **BWk**)**:** This climate is very arid, with low relative humidity. Rainfall is very irregular and unreliable. Annual rainfall totals less than 250 mm (10 in). **BWh/k** has the highest percentage of sunshine of all climate types. Diurnal (day-to-night) temperature ranges are the greatest among all climate types. Daily maximum temperatures are very high. Generally, winds persist throughout the day.

Example:



BWh - Almeria, Spain 37° N, Elevation: 7 m (23 ft)

BS - Dry Semiarid (Steppe)

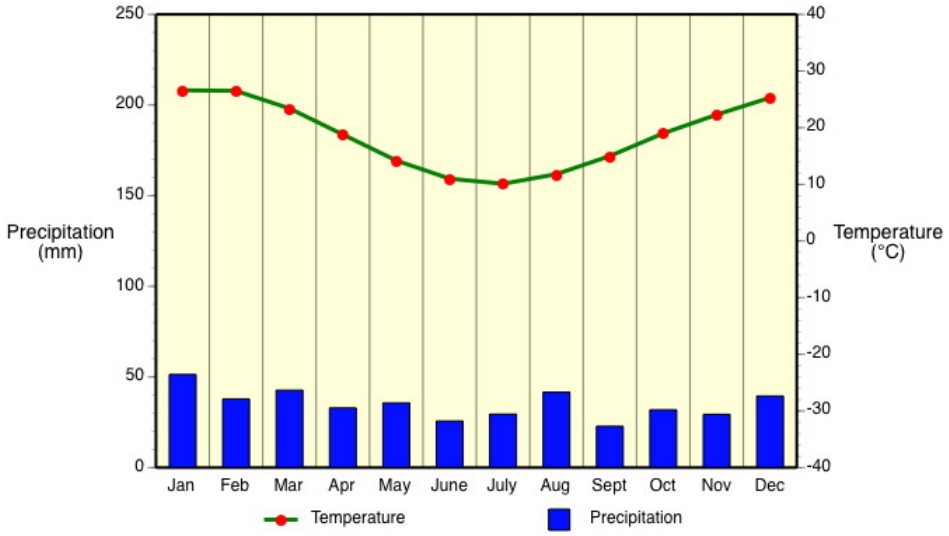
This **grassland** climate covers 14% of the Earth's land surface. It receives more precipitation than the **BW** from short incursions of the **Intertropical Convergence Zone** or occasional **mid-latitude cyclones**. Again, the additional letters **h** and **k** are generally used to distinguish whether the dry semiarid climate is found in the subtropics or the mid-latitudes, respectively.

BSh – Semiarid Low Latitudes

BSh is a semiarid climate found in the low latitudes. Potential evapotranspiration exceeds precipitation on average, but the difference between these measures is less than in a **BWh** climate. The annual average temperature is over 18°C (64°F). Yearly precipitation totals are greater than those for the **BWh** climate.

Locations: About 13 to 15° North latitude in Africa, about 20° South latitude in southern Africa, border areas around the Australian desert, parts of southern South America, parts of India, and areas marginal to **BWh** climates of northwestern Africa, Saudi Arabia, and western India.

Example:



BSh - Cobar, Australia 31° N, Elevation: 264 m (866 ft)

BSk – Semiarid Mid-Latitudes

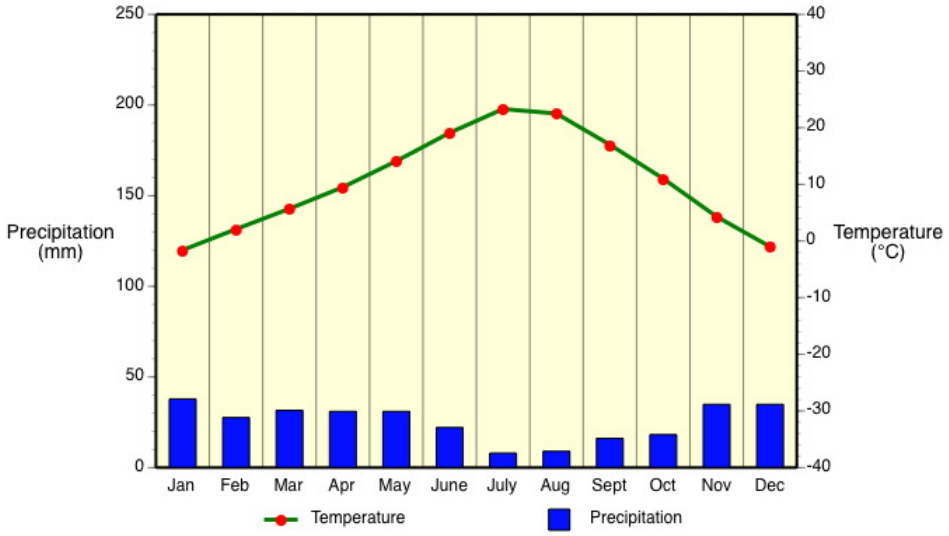
BSk is a semiarid climate usually found in the middle latitudes. Potential evapotranspiration exceeds precipitation on average, but the difference between these measures is less than in a **BWk** climate. The annual average temperature is below 18°C (64°F).

Locations: Western plains of the United States, south-central Canada, and borders **BWh** climate areas from the Caspian Sea eastward to China and Mongolia.

Controlling Weather Factors (both BSh and BSk): Weather is transitional between deserts and humid climates. The Subtropical High Pressure Zone dominates most of the year. Precipitation comes from brief **Intertropical Convergence Zone** incursions or sporadic **mid-latitude cyclones**. Locations are often far inland (continentality) and influenced by the **rainshadow effect**.

Climate Characteristics (both BSh and BSk): This climate is arid, with low **relative humidity**. Rainfall is sporadic; annual rainfall totals range from 250 to 500 mm (10 to 20 in). Air temperatures at locations with this climate type vary significantly due to latitude, elevation, and continentality.

Example:



BSk - Boise, Idaho, USA 44° N, Elevation: 865 m (2838 ft)

MOIST SUBTROPICAL MID-LATITUDE CLIMATES - "C" CLIMATES

This climate generally features warm, humid summers and mild winters. Its extent is from 30 ° to 50° of latitude, mainly along the eastern and western borders of most continents. During the winter, the main weather feature is the **mid-latitude cyclone**. Convective **thunderstorms** provide **precipitation** in the summer months. Several dominant minor types exist:

Cfa – Humid Subtropical

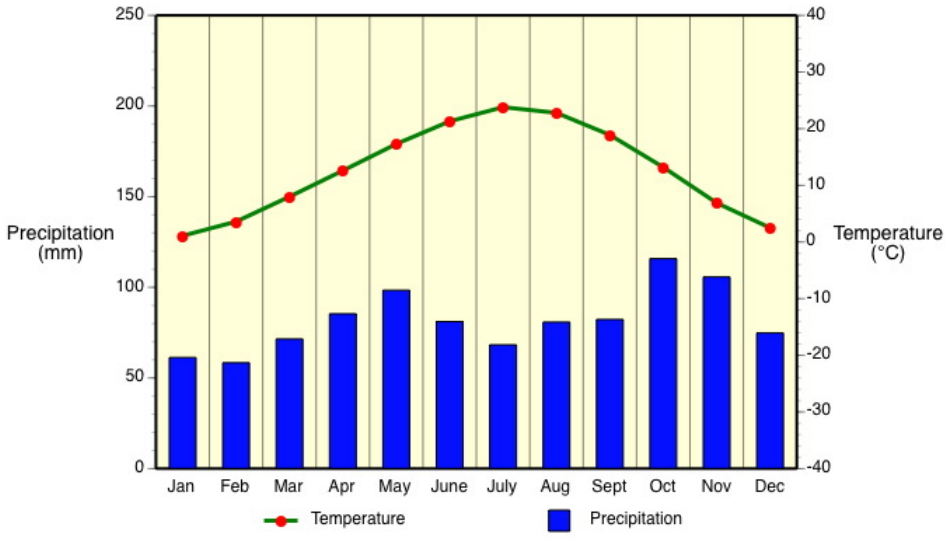
The humid subtropical climate (**Cfa**) has hot, muggy summers and frequent thunderstorms. Winters are mild, and precipitation during this season is driven by mid-latitude cyclones. This climate type is quite common on the east coasts of continents. An excellent example of a world region with a **Cfa** climate is the southeastern USA. The average temperature of the warmest month is above 22°C (72°F). The average temperature of the coldest month is below 18°C (64°F) but above -3°C (27°F). Rainfall is evenly distributed throughout the year.

Locations: Southeastern United States, northern Argentina, Uruguay, southern Brazil, southern Japan, and southern China.

Controlling Weather Factors: **Mid-latitude cyclones** in winter. Frequent thunderstorms dominate summer because of the presence of **Maritime Tropical Air** masses and intense surface heating. **Tropical storms** and **hurricanes** during late summer and early fall can influence coastal regions of this climate type.

Climate Characteristics: High humidity occurs in the summer months. The summer climate is much like the humid tropics. Frost can occasionally happen with the presence of **Continental Polar Air** masses in winter. Precipitation varies from 650 to 2500 mm (26 to 98 in).

Example:



Cfa - Milano, Italy 45° N, Elevation: 107 m (351 ft)

Cfb/Cfc – Marine

Cfb/Cfc marine climates are often found on the western coasts of continents. They have a humid climate with short dry summers. Heavy precipitation occurs during the mild winters due to the continuous presence of mid-latitude cyclones.

Cfb: Marine - Mild Winter

The average temperature for all months is below 22°C (72°F). At least four months have an average temperature greater than 10°C (50°F). The average temperature of the coldest month is below 18°C (64°F) but above -3°C (27°F). Precipitation is distributed evenly throughout the year.

Cfc: Marine - Cool Winter

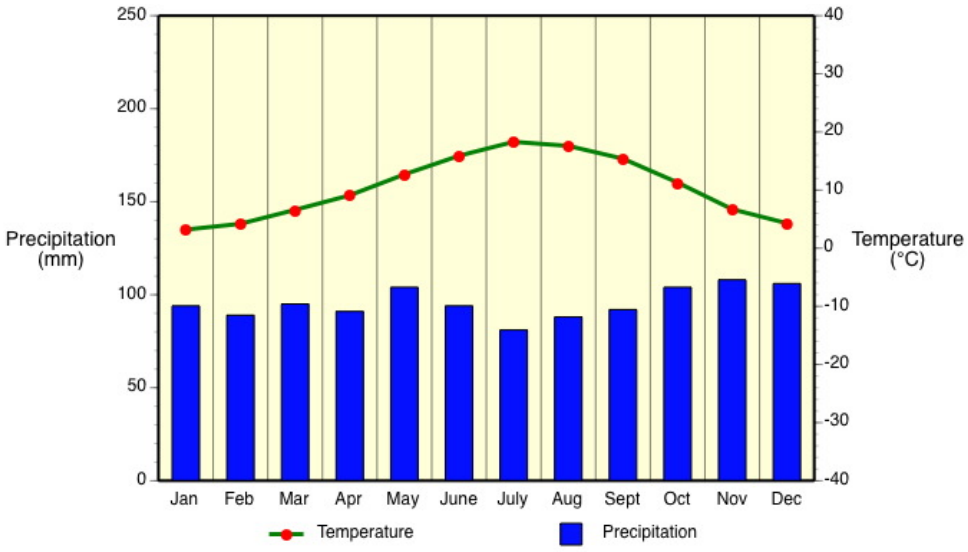
The average temperature for all months is below 22°C (72°F). Only 1 to 3 months have an average temperature above 10°C (50°F). The average temperature of the coldest month is below 18°C (64°F) but above -3°C (27°F). Precipitation is distributed equally throughout the year.

Locations: Coastal Oregon, Washington, the west coast of Canada, the southern west coast of Alaska, central and northwest Europe, southern Chile, the southern coast of South Africa, southeast Australia, and New Zealand.

Controlling Weather Factors (both Cfb and Cfc): **Mid-latitude cyclones** influence weather for most of the year. Warm **ocean currents** keep these climates mild in winter and cool in the summer. **Maritime Polar Air** masses influence these climates during the winter season.

Climate Characteristics (both Cfb and Cfc): These climates have mild winters and cool summers with a low annual temperature range. Weather activity at **frontal zones** produces heavy cloud cover and high humidity during fall, winter, and spring. Long periods of **rain** and **drizzle** are caused by the frequent occurrence of **mid-latitude cyclones**. Frost can sometimes occur during the winter season.

Example:



Cfb - Limoges, France 46° N, Elevation: 284 m (932 ft)

Cwa/Cwb/Cwc – Dry Winter, Wet Summer

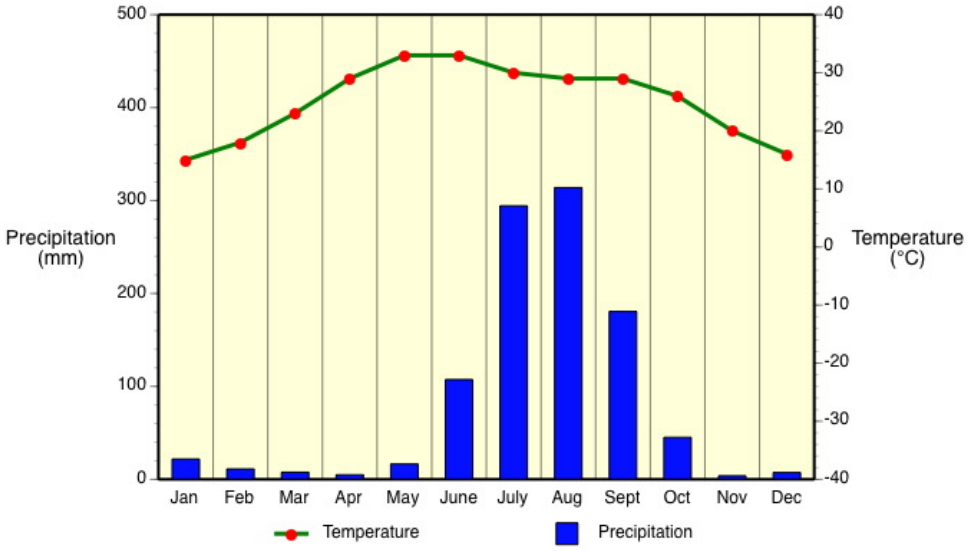
Cwa/Cwb/Cwc dry winter, wet summer climates are generally found in the interiors of continents at the mid-latitudes. They have a humid climate with short dry summers. Heavy precipitation occurs during the summer because of the seasonal presence of unstable, humid air masses, which favor the development of thunderstorms. These climates are pretty limited in their distribution.

Locations (Cwa/Cwb/Cwc): Interior of central Mexico, northwestern Argentina, parts of Bolivia, Nepal, northern India, northern Bangladesh, northern Myanmar, parts of China, Angola, Zambia, Zimbabwe, and eastern South Africa.

Controlling Weather Factors (Cwa/Cwb/Cwc): This climate is influenced by hot, unstable, humid air masses that generally dominate in late spring, summer, and early fall. The relatively dry winter season is often due to the presence of dry **Continental Polar Air** masses.

Climate Characteristics (Cwa/Cwb/Cwc): High humidity occurs in the summer months. The summer climate can be very similar to the humid tropics. Winters tend to be dry and cool.

Example:



Cwa - Lucknow, India 27° N, Elevation: 128 m (420 ft)

Csa/Csb – Mediterranean

Mediterranean climates (Csa/Csb) receive rain primarily during the winter season from the mid-latitude cyclone. Extreme summer aridity is driven by the sinking air of the subtropical highs and can persist for up to 5 months. Locations in North America are from Portland, Oregon, to all of California.

Csa: Interior Mediterranean

Warm mid-latitude climate with a distinctly dry hot summer caused by continental high-pressure influence. The average temperature of the coldest month is less than 18°C (64°F) but above -3°C (27°F). The wettest winter month receives about three times as much precipitation as the driest summer month. Precipitation in the driest summer month is less than 40 mm (1.6 in). The warmest month has an average temperature above 22°C (72°F), and at least four months have average temperatures above 10°C (50°F).

Csb: Coastal Mediterranean

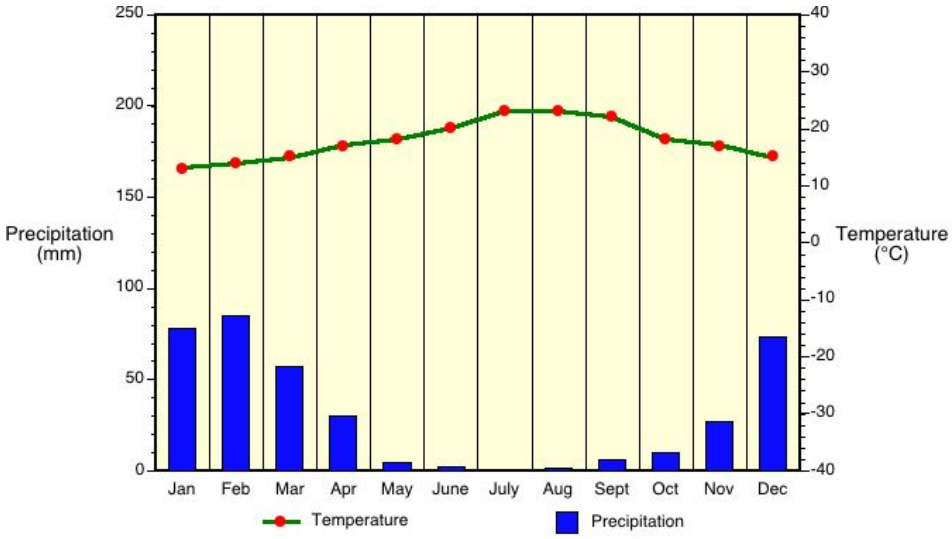
Cool mid-latitude climate with a distinctly dry cool summer caused by maritime high-pressure influence. The average temperature of the coldest month is less than 18°C (64°F) but above -3°C (27°F). The wettest winter month receives about three times as much precipitation as the driest summer month. Precipitation in the driest summer month is less than 40 mm (1.6 in). No month in this climate type has an average temperature above 22°C (72°F), and at least four months have average temperatures above 10°C (50°F).

Locations (both Csa and Csb): Interior and coastal areas of California, interior and coastal areas of Chile, the area around the Mediterranean Sea, the Iranian highlands, the southwest tip of South Africa, and the southern and southwestern regions of Australia.

Controlling Weather Factors (both Csa and Csb): This climate is influenced by subtropical highs in fall, summer, and spring and **mid-latitude cyclones** in winter.

Climate Characteristics (both Csa and Csb): Climate switches from mild, wet winters to hot, arid summers. This climate has a high percentage of sunshine. The diurnal range between maximum and minimum daily temperatures is quite large. Has some danger of **frost** during the winter season. Coastal locations can often experience low clouds and **fog**.

Example:



Csa - Los Angeles, USA 34° N, Elevation: 37 m (121 ft)

MOIST CONTINENTAL MID-LATITUDE CLIMATES - "D" CLIMATES

Moist continental mid-latitude climates have warm to cool summers and cold winters. These climates are poleward of the **C climates**. The average temperature of the warmest month is greater than 10°C (50°F), while the coldest month is less than -3°C (27°F). Winters are severe with snowstorms, strong winds, and bitter cold from **Continental Polar** or **Arctic Air** masses. This climate has three second-level types: **Dw - dry winters**; **Ds - dry summers**; and **Df - wet all year**.

Dfa/Dwa

Dfa: Humid Continental Hot Summer, Wet All Year

The average temperature of the coldest month is -3°C (27°F) or lower. The average temperature of the warmest month is greater than 10°C (50°F). Precipitation is evenly distributed throughout the year.

Dwa: Humid Continental Hot Summer, Dry Winter

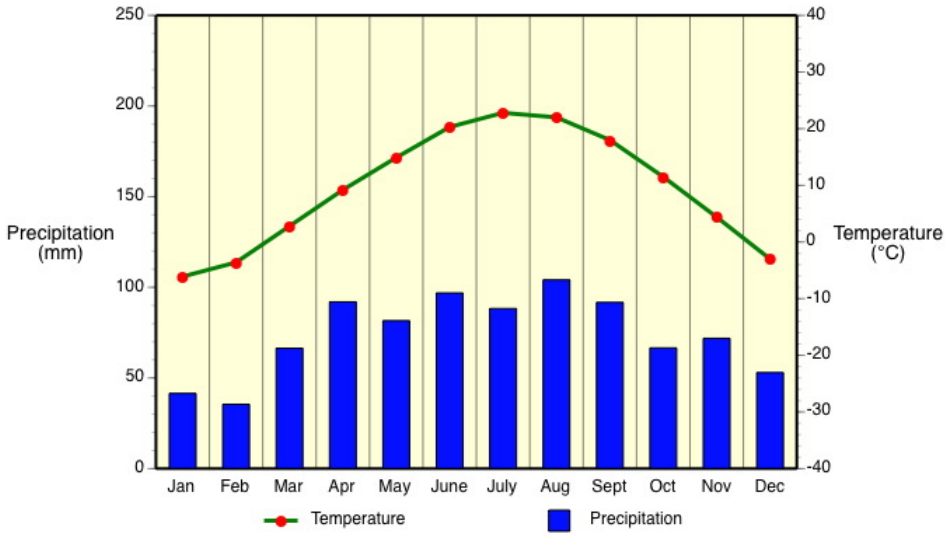
The average temperature of the coldest month is -3°C (27°F) or lower. The average temperature of the warmest month is greater than 10°C (50°F). The wettest summer month has about 10 times as much precipitation as the driest winter month.

Locations (both Dfa and Dwa): Northeastern and midwestern United States, east-central Europe, northern China, and northern Korea.

Controlling Weather Factors (both Dfa and Dwa): Weather is influenced by **mid-latitude cyclones** that form along the **polar front** in fall, winter, and spring. Winter weather can be clear and cold when **Continental Polar Air** dominates. Occasional thunderstorms during the summer months.

Climate Characteristics (both Dfa and Dwa): This climate has hot, often humid summers. Occasional winter spells with very cold temperatures and clear skies. Immense weather variability on a yearly basis and quite large annual temperature ranges. The yearly precipitation total is between 500 and 1150 mm (20 and 45 in).

Example:



Dfa - Chicago, Illinois, USA 42° N, Elevation: 200 m (656 ft)

Dfb/Dwb

Dfb: Humid Continental Mild Summer, Wet All Year

The average temperature of the coldest month is -3°C (27°F) or lower. The average temperature of the warmest month is greater than 10°C (50°F). No month has an average temperature over 22°C (72°F). Precipitation is equally distributed across the year.

Dwb: Humid Continental Mild Summer, Dry Winter

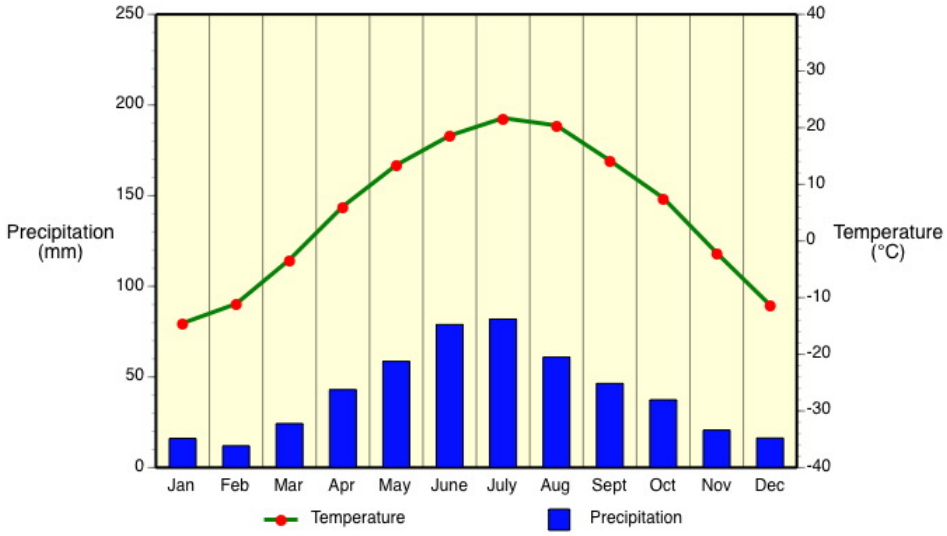
The average temperature of the coldest month is -3°C (27°F) or lower. The average temperature of the warmest month is greater than 10°C (50°F). No month has an average temperature over 22°C (72°F). The wettest summer month has about 10 times as much precipitation as the driest winter month.

Locations (both Dfb and Dwb): New England and around the Great Lakes in the United States, south-central and southeastern Canada, southeastern Scandinavia, eastern Europe, west-central Asia, and northeastern China.

Controlling Weather Factors (both Dfb and Dwb): Weather is influenced by **mid-latitude cyclones** that form along the polar front in fall, winter, and spring. Winter weather can be clear and cold when **Continental Polar Air** and **Continental Arctic Air** masses are present. Occasional thunderstorms during the summer months.

Climate Characteristics (both Dfb and Dwb): This climate has mild summers. Long winters with frequent periods of very cold temperatures and clear skies. Immense weather variability on a yearly basis and quite large annual temperature ranges. The yearly precipitation total is less than **Dfa** or **Dwa** climates.

Example:



Dfb - Fargo, North Dakota, USA 47° N, Elevation: 274 m (899 ft)

Dfc/Dwc/Dfd/Dwd

Dfc: Subarctic With Cool Summer, Wet All Year

The average temperature of the coldest month is -3°C (27°F) or lower. The average temperature of the warmest month is greater than 10°C (50°F). One to three months with an average temperature over 10°C (50°F). Precipitation is equally distributed across the year.

Dfd: Subarctic With Cold Winter, Wet All Year

The average temperature of the coldest month is -38°C (-36°F) or lower. The average temperature of the warmest month is greater than 10°C (50°F). Precipitation is evenly distributed over the year.

Dwc: Subarctic With Cool Summer, Dry Winter

The average temperature of the coldest month is -3°C (27°F) or lower. The average temperature of the warmest month is greater than 10°C (50°F). One to three months with an average temperature over 10°C (50°F). The wettest summer month has about 10 times as much precipitation as the driest winter month.

Dwd: Subarctic With Cold Winter, Dry Winter

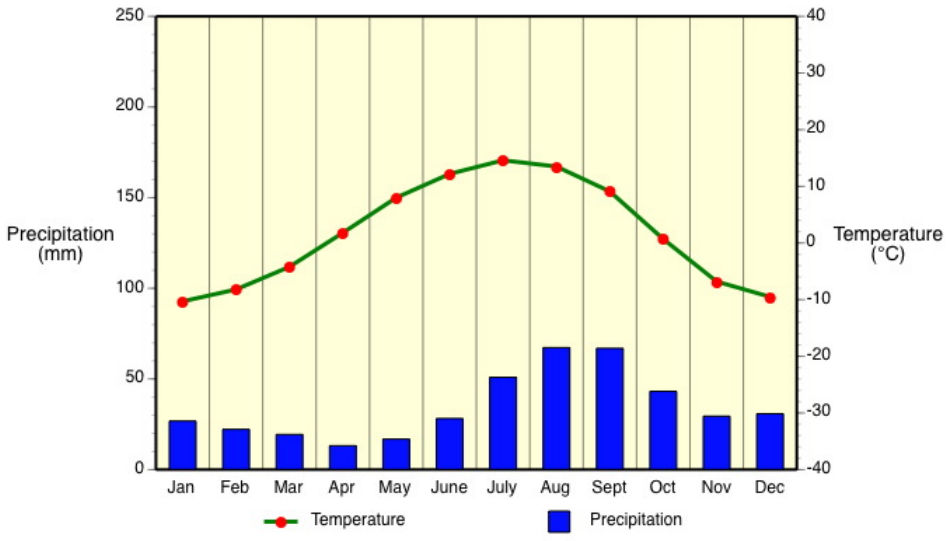
The average temperature of the coldest month is -38°C (-36°F) or lower. The average temperature of the warmest month is greater than 10°C (50°F). The wettest summer month has about ten times more precipitation when compared to the driest winter month

Locations (Dfc, Dwc, Dfd, and Dwd): Northern North America and northern Eurasia.

Controlling Weather Factors (Dfc, Dwc, Dfd, and Dwd): Occasional mid-latitude cyclones influence weather in spring, summer, and fall. **Continental Polar Air** and **Continental Arctic Air** masses dominate much of the year.

Climate Characteristics (Dfc, Dwc, Dfd, and Dwd): This climate has a brief cool summer. Winters are very long, with extended periods of extremely cold temperatures and clear skies, resulting in immense yearly weather variability and quite large annual temperature ranges. **Permafrost** is common in the ground. The yearly precipitation total is between 250 and 500 mm (10 and 20 in).

Example:



Dfc - Anchorage, Alaska, USA 61° N, Elevation: 58 m (190 ft)

POLAR CLIMATES - "E" CLIMATES

Polar climates have year-round cold temperatures, with the warmest month less than 10° Celsius. Polar climates are found in the northern coastal areas of North America, Europe, Asia, and on the landmasses of Greenland and Antarctica. Two minor climate types exist. **ET** or **polar tundra** is a climate where the soil is permanently frozen to depths of hundreds of meters, a condition known as **permafrost**. Vegetation is dominated by mosses, lichens, dwarf trees, and scattered woody shrubs. **EF**, or **polar ice cap**, has a surface permanently covered with **snow** and ice.

ET - Polar Tundra

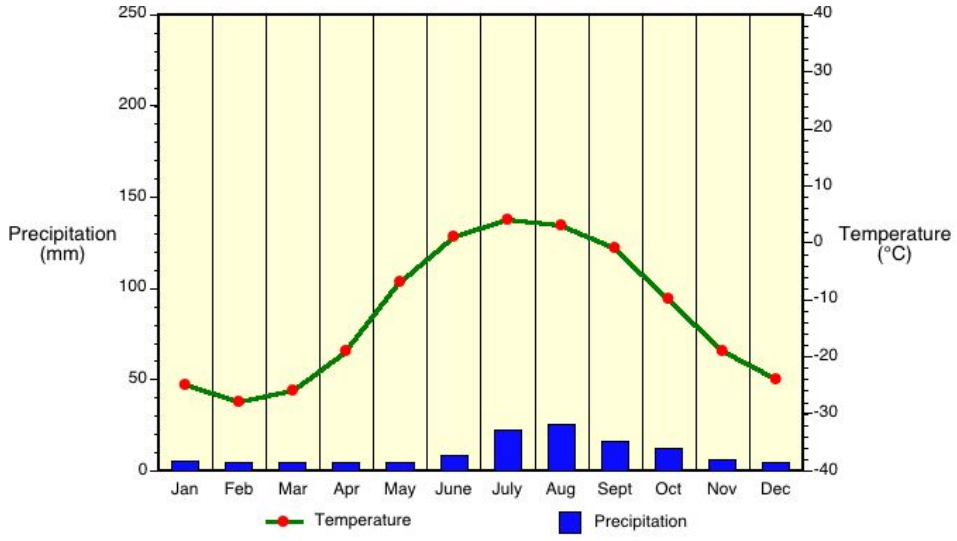
The average temperature of the warmest month in this climate is below 10 °C (50°F) but above 0°C (32°F). Precipitation generally is greater than potential evaporation.

Locations: Regions in North America, Greenland, and Eurasia that border the Arctic Ocean, Antarctic Peninsula, and many polar islands.

Controlling Weather Factors: The continual presence of **Continental Arctic Air** and **Antarctic Air** masses, **polar vortex**, and closeness to oceans.

Climate Characteristics: This climate essentially has no summer. At least nine months have average temperatures below freezing. Very low **evaporation** because of cold temperatures. Precipitation is typically less than 250 mm (10 in). Winds tend to be strong and cold.

Example:



ET - Barrow, Alaska, USA 72° N, Elevation: 9 m (30 ft)

EF - Polar Ice Cap

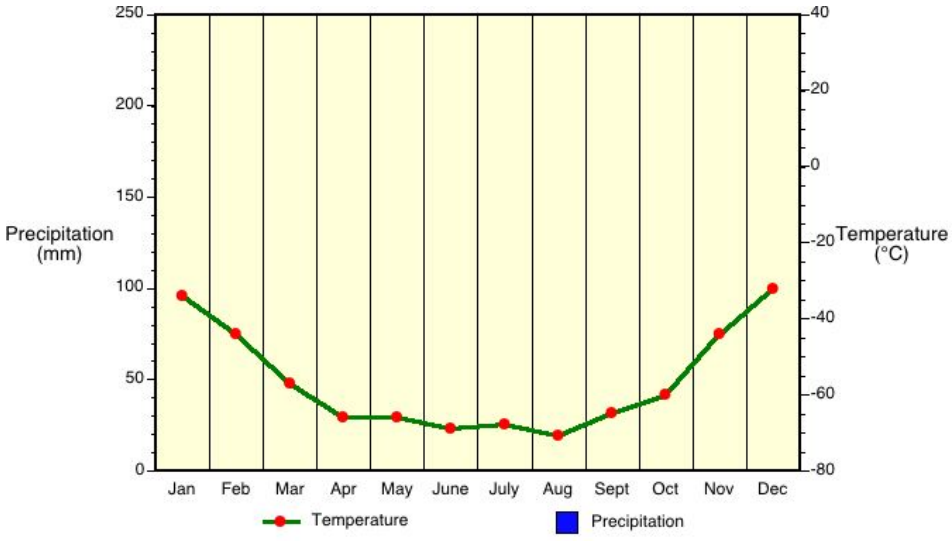
The average temperature of the warmest month for the EF climate is 0°C (32°F) or less. Precipitation generally is greater than potential evaporation.

Locations: Interior Greenland, most of Antarctica, and most Arctic Islands.

Controlling Weather Factors: The continual presence of **Continental Arctic Air** and **Antarctic Air** masses and **polar vortex** produces the planet's coldest temperatures. Permanent ice cover and high elevations enhance the coldness of this climate.

Climate Characteristics: No summer, and all average monthly temperatures are below freezing. Very low evaporation because of cold temperatures. Very small amounts of precipitation occur, mainly falling as snow.

Example:



EF - Plateau Station, Antarctica 79° S, Elevation: 3625 m (11,893 ft)

IMPORTANT TERMS

Air Mass - A large body of air whose temperature and humidity characteristics remain relatively constant over a horizontal distance of hundreds to thousands of kilometers (miles). Air masses develop their climatic characteristics by remaining stationary over a source region for several days. Air masses are classified according to their temperature and humidity characteristics.

Climate - General pattern of weather conditions for a region over a long period of time (at least 30 years).

Continental Antarctic Air Mass (A) - Air mass that forms over the Antarctic landmass in the Southern Hemisphere. These air mass systems form during the entire year. Continental Antarctic air masses are very cold and extremely dry. These air masses are very stable.

Continental Arctic Air Mass (**A**) - Air mass that forms over extensive landmass areas of the high latitudes. In the Northern Hemisphere, these systems form only in winter over Greenland, northern Canada, northern Siberia, and the Arctic Basin. Continental Arctic air masses are very cold and extremely dry. These air masses are very stable.

Continental Polar Air Mass (**cP**) - Air mass that forms over extensive landmass areas of middle to high latitudes. In North America, these systems form over northern Canada. Continental Polar air masses are cold and very dry in the winter and cool and dry in the summer. These air masses are also atmospherically stable throughout the year.

Continental Tropical Air Mass (**cT**) - Air mass that forms over extensive landmasses in the low latitudes. In North America, these systems form over the southwestern United States and northern Mexico. Continental Tropical air masses are warm and dry in the winter and hot and dry in the summer. These air masses are also generally unstable in the winter but stable in the summer.

Continentality - The tendency of terrestrial surfaces on Earth to experience more temperature variation than ocean surfaces. The main factor responsible for this fact is that the soil, sediment, and rock that make up land have a lower specific heat than water.

Cumulonimbus Cloud - A well-developed vertical cloud that often has a top shaped like an anvil. These clouds are very dense with condensed water and deposited ice. Weather associated with this cloud includes: strong winds; hail; lightning; tornadoes; thunder; and heavy rain. When this weather occurs, these clouds are then called thunderstorms. Can extend in altitude from a few hundred meters above the surface to more than 12,000 meters (39,400 feet).

Cumulus Cloud - Puffy clouds with relatively flat bases. Cumulus clouds form when moist warm air bubbles vertically escape from the Earth's surface. Found in an altitude range between 300 and 2000 meters (984 and 6560 feet).

Drizzle - A form of precipitation where the water droplets are smaller than rain. Drizzle has a diameter of 0.2 and 0.5 mm (0.008 and 0.02 in).

Evaporation - The process by which liquid water is converted into a gaseous state. Evaporation can only occur when water is available. It also requires that the humidity of the atmosphere be less than the evaporating surface (at 100% relative humidity, there is no more evaporation). The evaporation process requires large amounts of energy. For example, the evaporation of 1 gram of water at 100°C requires 540 calories of heat energy (600 calories at 0°C).

Fog - An atmospheric condition near the Earth's surface where minute water droplets, ice crystals, or smoke

particles reduce visibility. Fog exists if the atmospheric visibility near the Earth's surface is reduced to 1 kilometer (0.62 miles) or less. Fogs composed primarily of water droplets are classified according to the process that cools the air to saturation.

Frontal Zone - A transition area that exists between two air masses with different air temperature and/or humidity characteristics. Differences in air temperature and/or humidity cause the lower-density air mass to be pushed over the denser one. This process, known as frontal lifting, can lead to the development of clouds and precipitation.

Frost - Deposition of ice crystals on the surface of an object because of atmospheric cooling.

Grassland - An ecosystem whose dominant species are various types of grass. Found in regions where average precipitation is not great enough to support the growth of shrubs or forest.

Humidity - A general term used to describe the amount of water vapor found in the atmosphere.

Hurricane - An intense cyclonic storm consisting of an organized mass of thunderstorms that develops over the warm oceans of the tropics. To be classified as a hurricane, wind speeds in the storm must be greater than 118 kilometers per hour (73 miles per hour).

Insolation - Direct or diffused shortwave solar radiation that is received in the Earth's atmosphere or at its surface.

Intertropical Convergence Zone (**ITCZ**) - Zone of low atmospheric pressure and ascending air located at or near the equator. Rising air currents are driven by global wind convergence and thermal convection. Location of the thermal equator.

Köppen A: Tropical Moist Climates - Locations with very warm climates and experience high quantities of precipitation. These climates are found in the tropics. The primary distinguishing characteristic of these climates is that all months have average temperatures above 18°C (64°F).

Köppen B: Dry Climates - Locations with climates that experience little precipitation during most of the year. Further, potential losses of water from evaporation and transpiration greatly exceed atmospheric input of precipitation.

Köppen C: Moist Mid-latitude Climates with Mild Winters - Locations with warm-to-hot summers and mild winters. The primary distinguishing characteristic of these climates is that the coldest month has an average temperature between 18°C (64°F) and -3°C (27°F).

Köppen Climate Classification - System that uses monthly precipitation and temperature data and total annual precipitation data to classify a location's climate into one of five main categories: Tropical Moist Climates (A); Dry Climates (B); Moist Mid-latitude Climates with Mild Winters; (C) Moist Mid-Latitude Climates with Cold Winters (D); and Polar Climates (E). These categories are further divided into subcategories. First developed in 1918 by the German biologist W. Köppen, this system has undergone several modifications.

Köppen D: Moist Mid-Latitude Climates with Cold Winters - Locations with summer temperatures that are warm and winters are cold. The primary distinguishing characteristic of these climates is that the average temperature of the warmest month exceeds 10°C (50°F), and the average temperature of the coldest month is below -3°C (27°F).

Köppen E: Polar Climates - Locations with climates that have very cold winters and summers, with no real summer season. The primary distinguishing characteristic of these climates is that the warmest month has an average temperature below 10°C (50°F).

Maritime Polar Air Mass (mP) - Air mass that forms over extensive ocean areas of the middle to high latitudes. Across North America, these air mass systems form over the Atlantic and Pacific Oceans at middle latitudes. Maritime Polar air masses are mild and humid in summer and cool and humid in winter. In the Northern Hemisphere, maritime polar air masses are normally unstable during the winter. In the summer, atmospheric stability depends on the position of the air mass relative

to a continent. Around North America, Maritime Polar air masses found over the Atlantic are stable in summer, while Pacific systems tend to be unstable.

Maritime Tropical Air Mass (mT) - An air mass that forms over extensive ocean areas of the low latitudes. Around North America, these systems form over the Gulf of Mexico and the eastern tropical Pacific. Maritime Tropical air masses are warm and humid in both winter and summer. In the Northern Hemisphere, maritime tropical air masses can normally remain stable during the whole year if they form just west of a continent. If they form just east of a continent, these air masses will be unstable in both winter and summer.

Mid-Latitude Cyclone - Cyclonic storm that forms primarily in the middle latitudes. Its formation is triggered by the development of troughs in the polar jet stream. These storms also contain warm, cold, and occluded fronts. Atmospheric pressure in their center can get as low as 970 millibars. Also called wave cyclones or frontal cyclones.

Monsoon - A zone of low atmospheric pressure and ascending air located at or near the equator. Rising air currents are driven by global wind convergence and thermal convection. Location of the thermal equator.

Ocean Current - Large-scale horizontal flow of ocean water that is persistent and driven by atmospheric circulation.

Orographic Uplift - The forced uplift of an air mass because of the presence of a topographic obstruction. This uplift also cools the air mass. If sufficient cooling occurs, condensation can form orographic precipitation. Also called orographic lifting.

Permafrost - Zone of permanently frozen water found in high latitude soils and sediments. Five types of permafrost have been recognized: continuous permafrost, discontinuous permafrost, sporadic permafrost, alpine permafrost, and subsea permafrost.

Polar Front - A weather front located typically in the mid-latitudes that separates arctic and polar air masses from tropical air masses. Along the polar front, we get the development of the mid-latitude cyclone. Above the polar front exists the polar jet stream.

Polar Vortex - High pressure system located in the upper atmosphere at the polar regions. In this system, air in the upper troposphere moves into the vortex center and then descends to Earth's surface, creating the polar highs.

Potential Evapotranspiration - Is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration, assuming no limitation on water supply.

Precipitation - Is any aqueous deposit, in liquid or solid form, that develops in a saturated atmosphere (relative humidity equals 100%) and falls to the ground generally from clouds. Most clouds, however, do not produce precipitation. In many clouds, water droplets and ice crystals are too small to overcome natural updrafts found in the atmosphere. As a result, the tiny water droplets and ice crystals remain suspended in the atmosphere as clouds. Some forms of precipitation include rain, snow, drizzle, hail, ice pellets, and snow pellets.

Radiative Cooling - Process where an object cools in temperature and experiences a reduction in internal heat energy because of the net loss of radiation. This net loss of radiation occurs because outgoing radiation exceeds incoming radiation for the object.

Rain - A form of precipitation. It is any liquid that falls from clouds in the atmosphere to the ground. Rain normally has a diameter between 0.5 and 5.0 millimeters.

Rainfall - The occurrence of rain falling from clouds to the Earth’s surface.

Rainshadow Effect - Reduction of precipitation commonly found on the leeward side of a mountain. The reduction in precipitation is the result of compression warming of descending air.

Relative Humidity - The ratio between the actual amount of water vapor held in the atmosphere compared to the

amount required for saturation. Relative humidity is influenced by temperature and atmospheric pressure.

Snow - A type of solid precipitation that forms in clouds with an air temperature below freezing. Snow forms when water vapor deposits directly as a solid on a deposition nucleus. Snowflakes begin their life as very tiny crystals developing on a six-sided hexagonal deposition nucleus. The developing snowflake then grows fastest at the six points of the nuclei as these surfaces are more exposed to the atmosphere's water vapor. Snowfall is most common during fall, winter, and spring months, when air temperatures are below freezing, with frontal lifting associated with mid-latitude cyclones.

Solar Radiation - Electromagnetic radiation that originates from the Sun. Most of the Sun's radiation is emitted at wavelengths between 1.0 and 0.1 microns (μm). Also see insolation, direct solar radiation, and diffused solar radiation.

Subtropical High Pressure Zone - Surface zone of atmospheric high pressure located at about 30° North and South latitude. These high pressure systems are produced by vertically descending air currents from the Hadley Cell.

Temperature - Temperature is defined as the measure of the average speed of atoms and molecules. The higher the temperature, the faster they move.

Thunderstorm - A storm that typically ranges in size from several kilometers (several miles) to over 50 kilometers (30 miles) in diameter, created by the rapid lifting of moist warm air, which creates a cumulonimbus cloud. Thunderstorms can occur in isolation as a single-celled storm or as a multicelled storm arranged in a cluster or as a line of adjacent cells (called a squall line) found along or in front of a mid-latitude cyclone cold front. Thunderstorms can be accompanied by severe weather, including strong winds, hail, lightning, tornadoes, thunder, and heavy rain.

Tropical Storm - An organized group of thunderstorms often found over a tropical ocean that generates a cyclonic flow of between 64 and 118 kilometers per hour (39 to 73 miles per hour). Often develops into a hurricane.

Xerophyte - A plant that has adaptations to survive long periods of drought**.**

Weather - The state of the atmosphere in terms of measured meteorological variables and observed atmospheric phenomena for a particular place or region, for a moment or period in time.

Simple Köppen Climate Classification Decision-Making System

Go through the following eight sequential steps to determine which Köppen Climate Classification system chart applies to the location you are trying to categorize.

A. Divide the calendar year for each location into two six-month periods: April to September and October to March.

B. Determine the associated seasons to these periods by recognizing the location's hemisphere.

C. If the average temperature of EACH of the twelve months is below 10°C (50°F), go to the **E Climate Chart** (page 22).

D. If the total annual precipitation for your location is less than 890 mm (35 in), continue to **STEP E**. If the total annual precipitation for your location is more than 890 mm (35 in), continue to **STEP F**.

E. Determine if the location being investigated is a B Climate by using the **B Climate Chart** (page 19). If your location is not a B Climate, proceed to **STEP F**.

F. If the average temperature of EACH of the twelve months is above 18°C (64°F) go to the **A Climate Chart** (page 18).

G. If the average temperature of at least ONE month is below -3°C (27°F) go to the **D Climate Chart** (page 21).

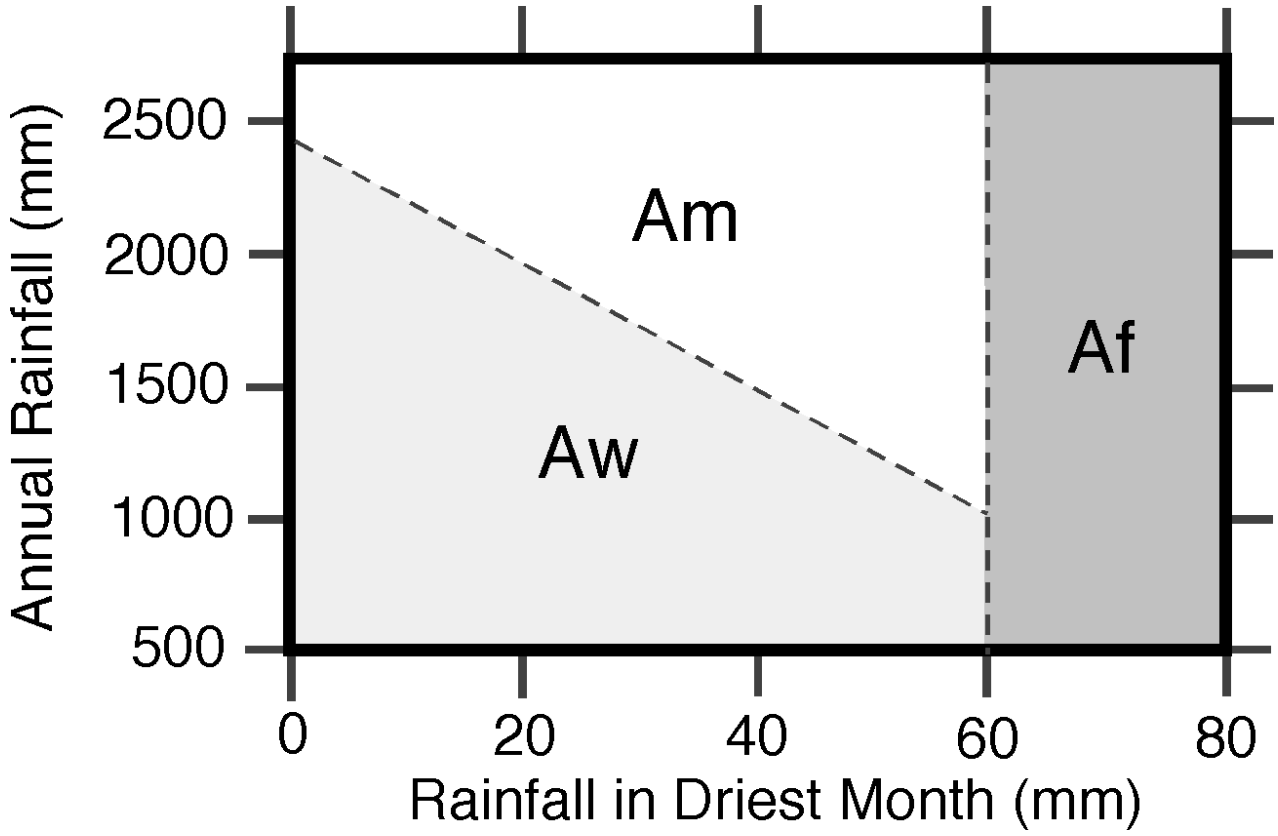
H. If the average temperature of the COLDEST month is between -3°C (27°F) and 18°C (64°F) go to the **C Climate Chart** (page 20).

A CLIMATE CHART

Group A Climate Types (average temperature of all months above 18°C (64°F))

Af – Tropical Wet
Am – Tropical Monsoon
Aw – Tropical Wet and Dry

Use the figure below to determine the exact classification of the location in question. On this figure, plot the intersection of **average annual rainfall** and the **average rainfall of the driest month**.

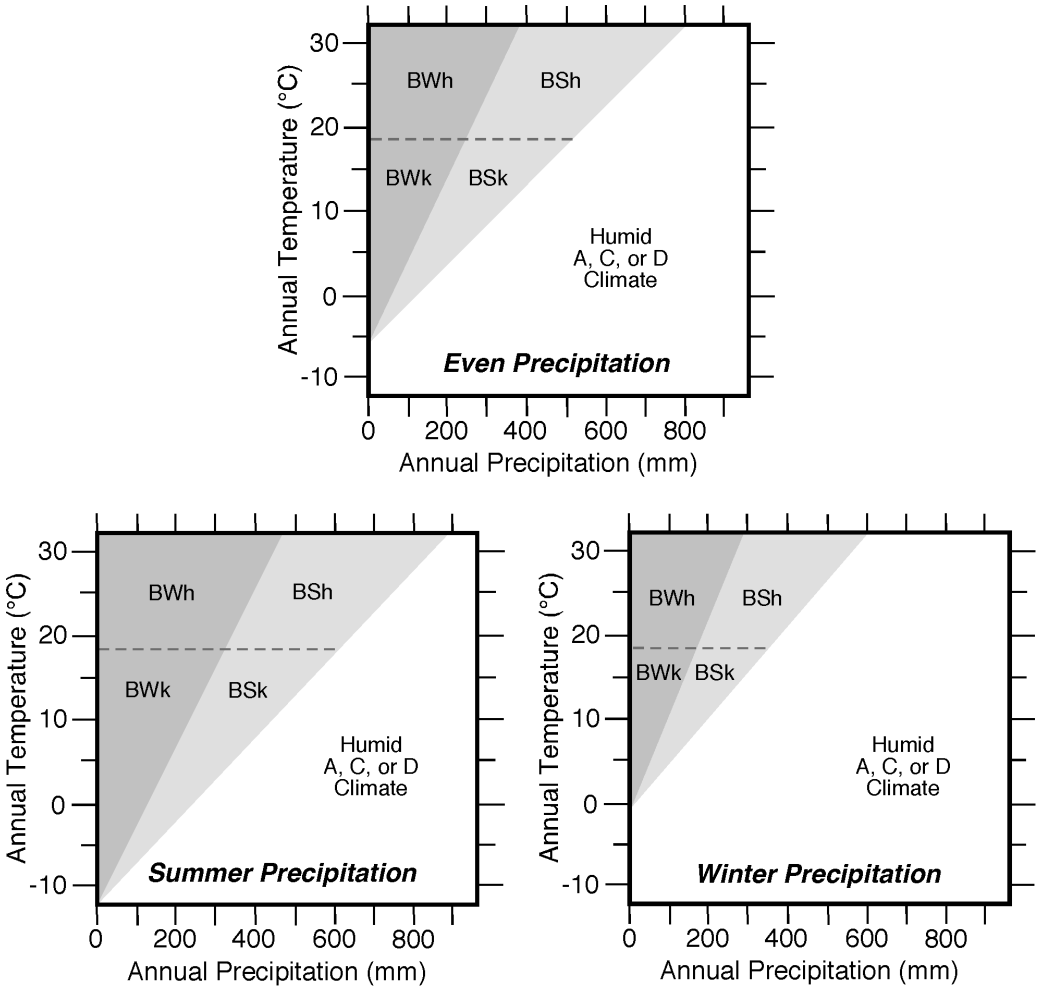


B CLIMATE CHART

Group B Climate Types (potential evaporation and transpiration exceed precipitation)

BWh – Dry Arid Low Latitudes
BWk – Dry Arid Mid-Latitudes
BSh – Semiarid Low Latitudes
BSk – Semiarid Mid-Latitudes

Plot the location's average annual precipitation and annual temperature values in one of the graphs below to determine the climate type. If more than 70% of the precipitation occurs in the 6 summer months (note the hemisphere), use the **Summer Precipitation** graph. If more than 70 % of the precipitation occurs in the 6 winter months (note the hemisphere), use the **Winter Precipitation** graph. Use the **Even Precipitation** graph if the previous two conditions are both false.



C CLIMATE CHART

Group C Climate Types (average temperature of coldest month between -3°C (27°F) and 18°C (64°F), warmest month above 10°C (50°F))

Cfa – Humid Subtropical
Cfb – Marine Coast - Mild Winter
Cfc – Marine Coast - Cool Winter
Csa – Interior Mediterranean
Csb – Coastal Mediterranean

Secondary Grouping

If the wettest winter month has three times as much precipitation as the driest summer month – secondary grouping is **s** (summer dry)

The climate is wet all year if the condition above cannot be met – secondary grouping will be **f**

Tertiary Grouping

If the warmest month has a temperature greater than 22°C (72°F), the climate has a hot summer – tertiary grouping is **a**

If the warmest month has a temperature less than 22°C (72°F) and there are four months with temperatures greater than 10°C (50°F), the climate has a warm summer – tertiary grouping is **b**

If the warmest month has a temperature less than 22°C (72°F) and there are one to three months with temperatures greater than 10°C (50°F), the climate has a cool summer – tertiary grouping is **c**

D CLIMATE CHART

Group D Climate Types (average temperature of coldest month is less than -3°C (27°F), warmest month above 10°C (50°F))

Dfa – Humid Continental Hot Summer, Wet All Year
Dfb – Humid Continental Mild Summer, Wet All Year
Dfc – Subarctic With Cool Summer, Wet All Year
Dfd – Subarctic With Cold Winter, Wet All Year

Dwa – Humid Continental Hot Summer, Dry Winter
Dwb – Humid Continental Mild Summer, Dry Winter
Dwc – Subarctic With Cool Summer, Dry Winter
Dwd – Subarctic With Cold Winter, Dry Winter

Secondary Grouping

If the wettest summer month has more than ten times as much precipitation than the driest winter month – secondary grouping is **w** (winter dry)

The climate is wet all year if the condition above cannot be met – secondary grouping will be **f**

Tertiary Grouping

If the warmest month has a temperature greater than 22°C (72°F), the climate has a hot summer – tertiary grouping is **a**

If the warmest month has a temperature less than 22°C (72°F) and there are four months with temperatures greater than 10°C (50°F), the climate has a warm summer – tertiary grouping is **b**

If the warmest month has a temperature less than 22°C (72°F) and there are one to three months with temperatures greater than 10°C (50°F), and the coldest month is above (-36°F), the climate has a cool summer – tertiary grouping is **c**

If the coldest month has a temperature less than -38°C (-36°F), the climate has a severe winter – tertiary grouping is **d**

E CLIMATE CHART

Group E Climate Types (average temperature of all months below 10°C (50°F))

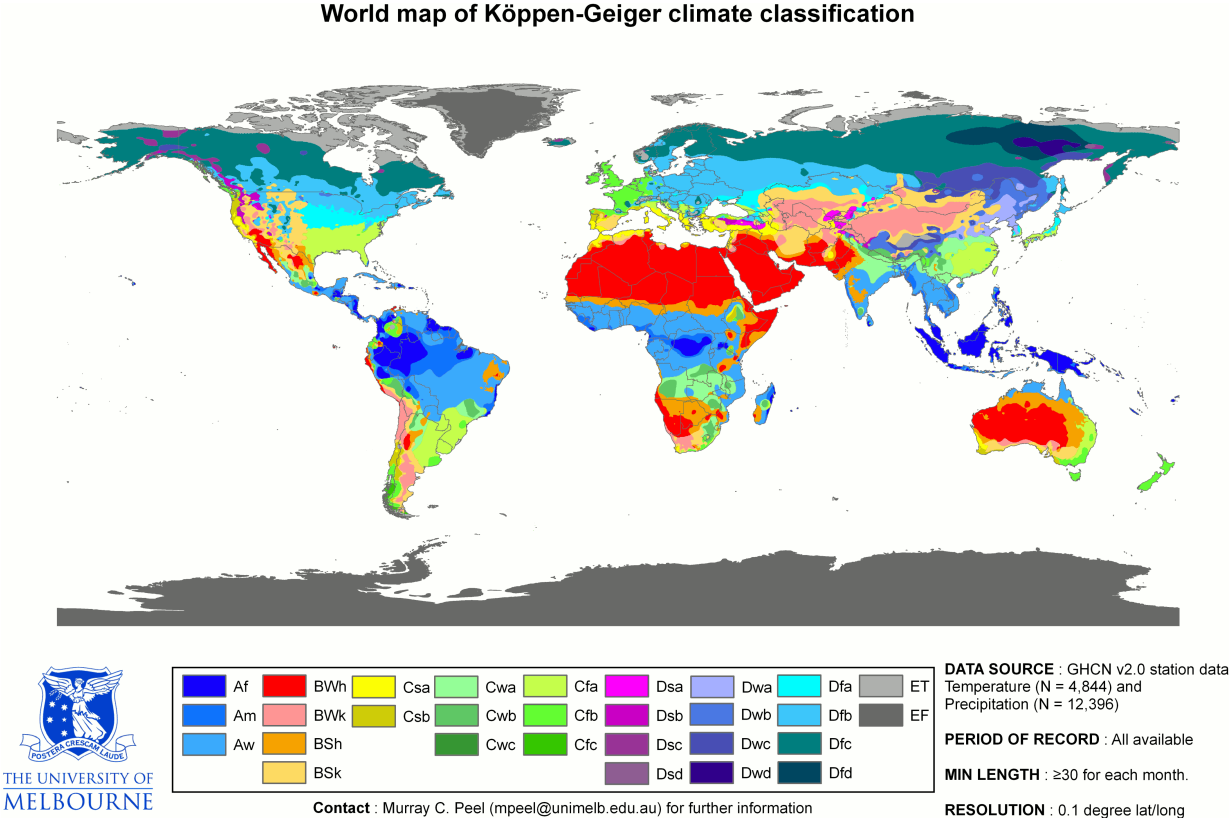
ET – Polar Tundra

EF – Polar Icecap

A location is defined as an **ET** climate if at least **one** average monthly temperature is **above** 0°C (32°F). If **all** of the average monthly temperatures are below 0°C (32°F) the location is classified as an **EF** climate.

Köppen Climate Classification System Maps

WORLD MAP



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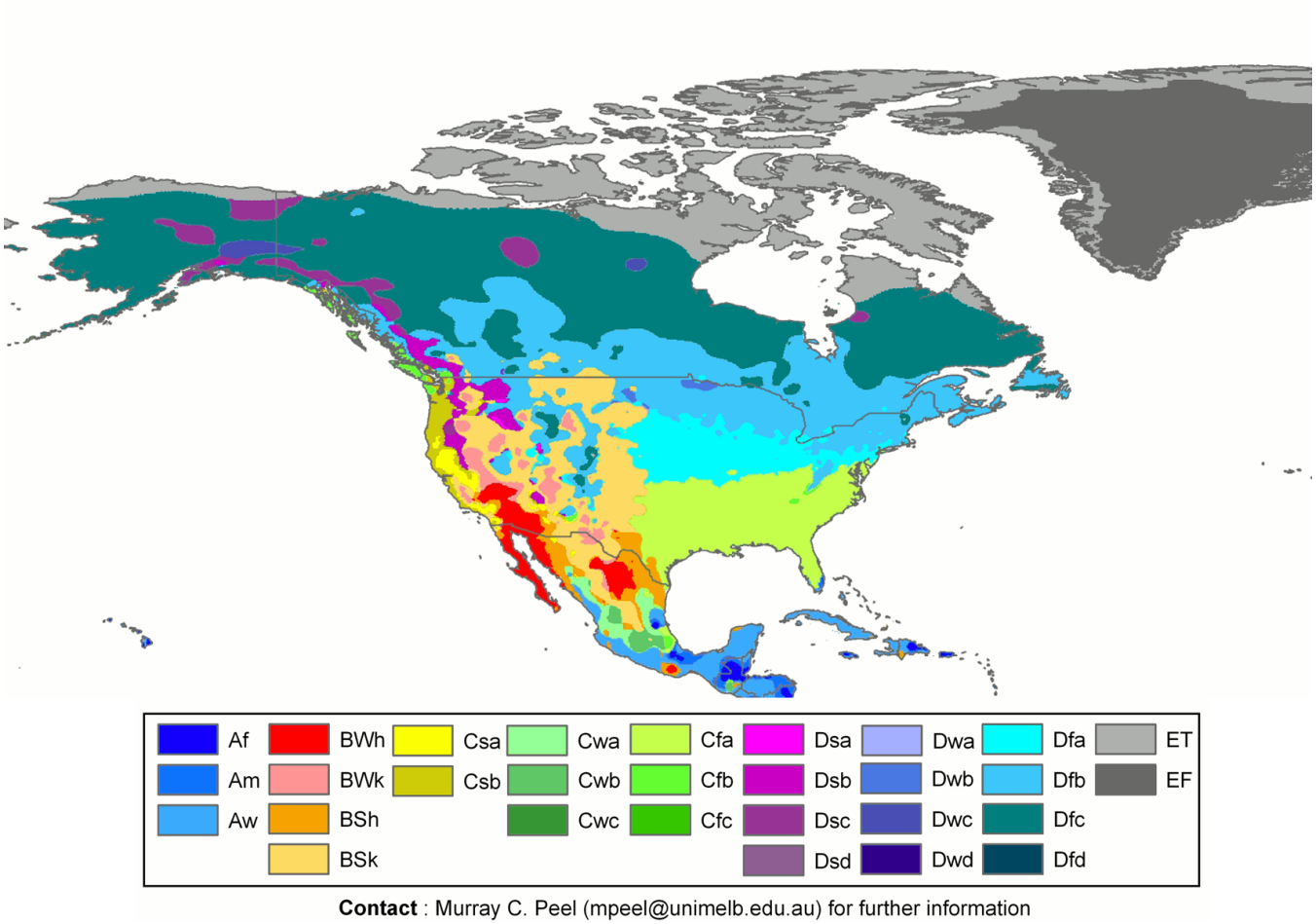
NORTH AMERICA MAP



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SOUTH AMERICA MAP

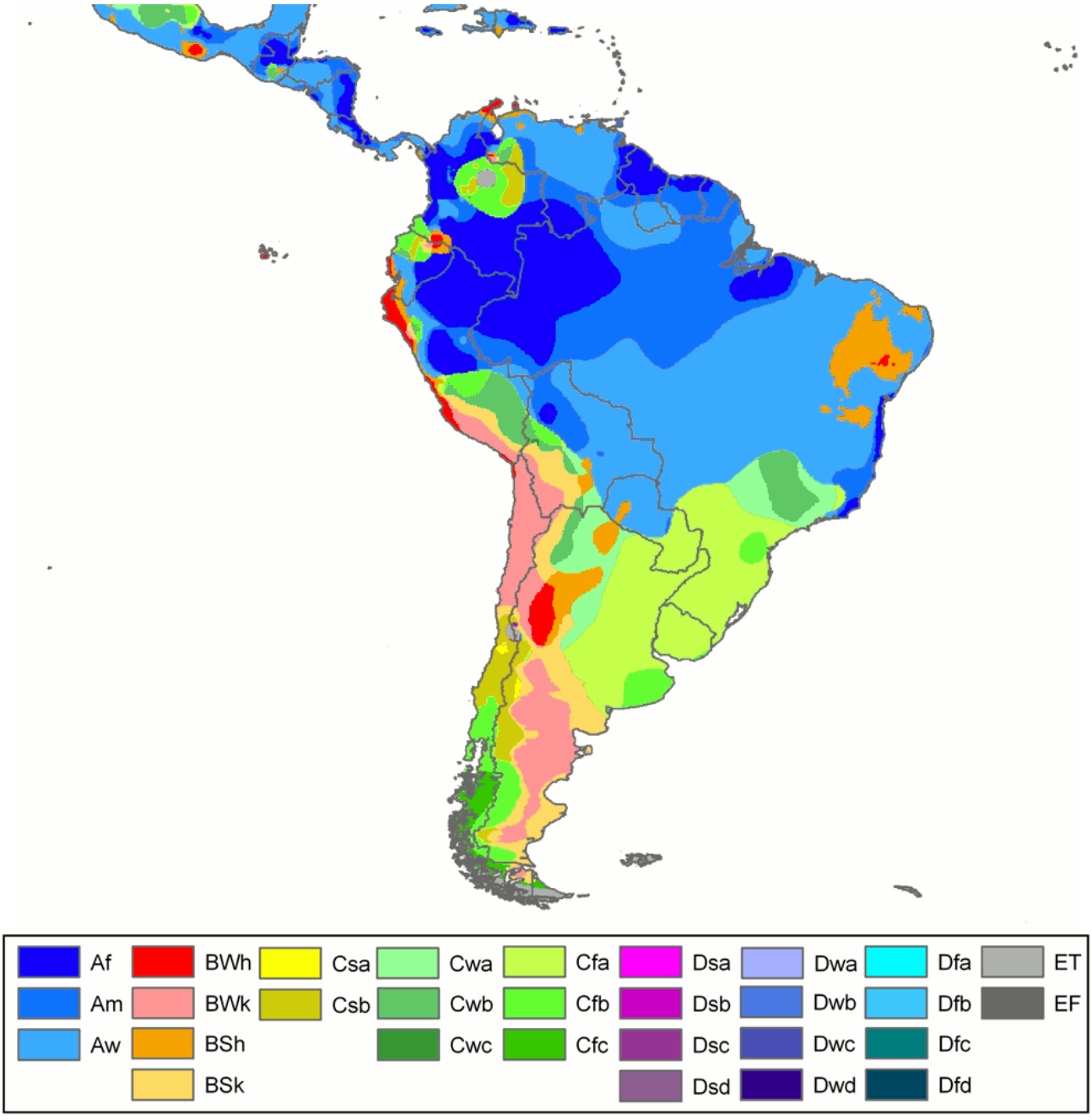
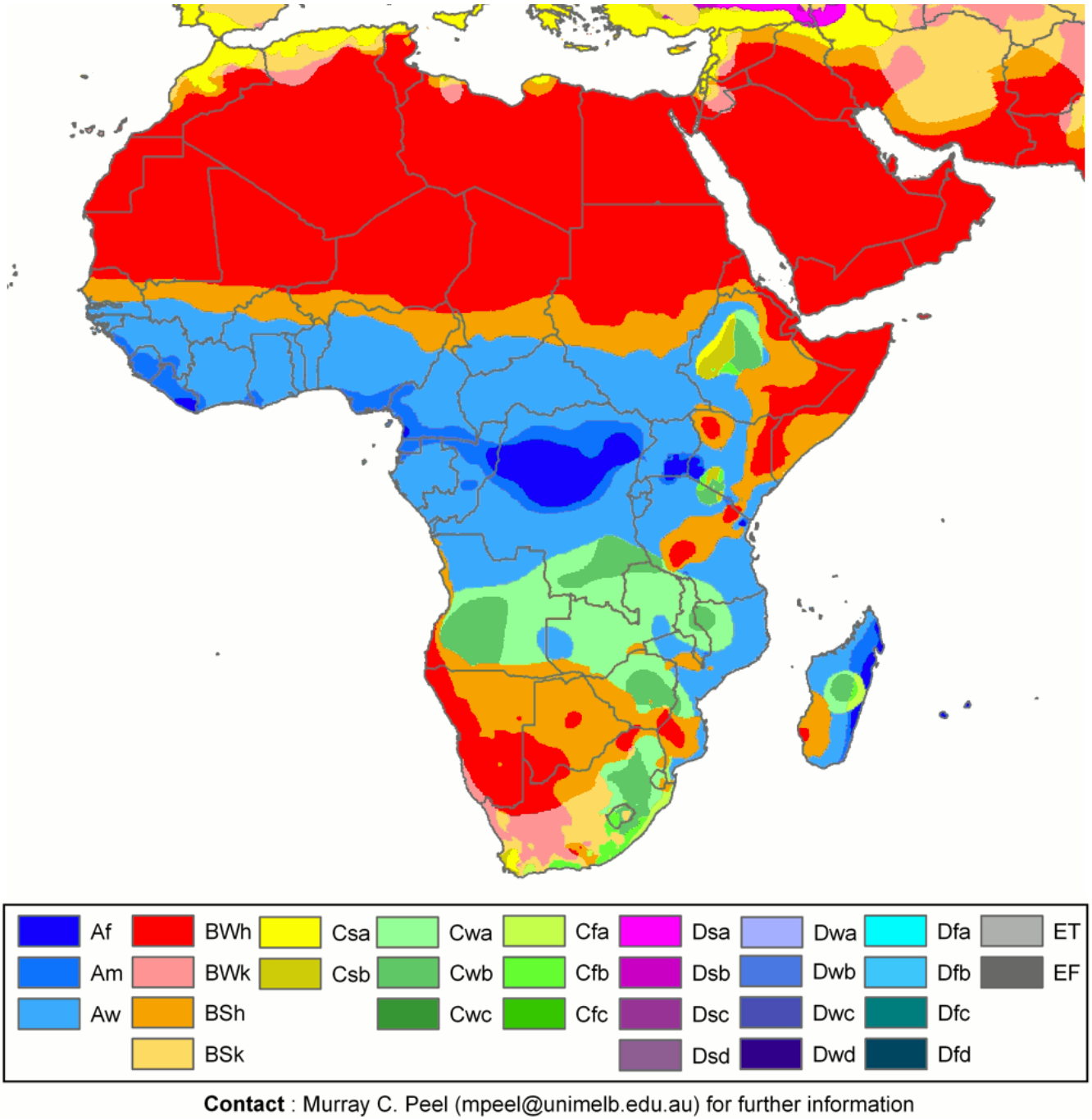


Image Source: Peel, M. C., Finlayson, B. L., and McMahon, T. A. (University of Melbourne) derivative work: Br-Sc-94 (World_Koppen_Map.png) [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons. http://commons.wikimedia.org/wiki/File%3AKoppen_World_Map_(retouched_version).png

AFRICA MAP



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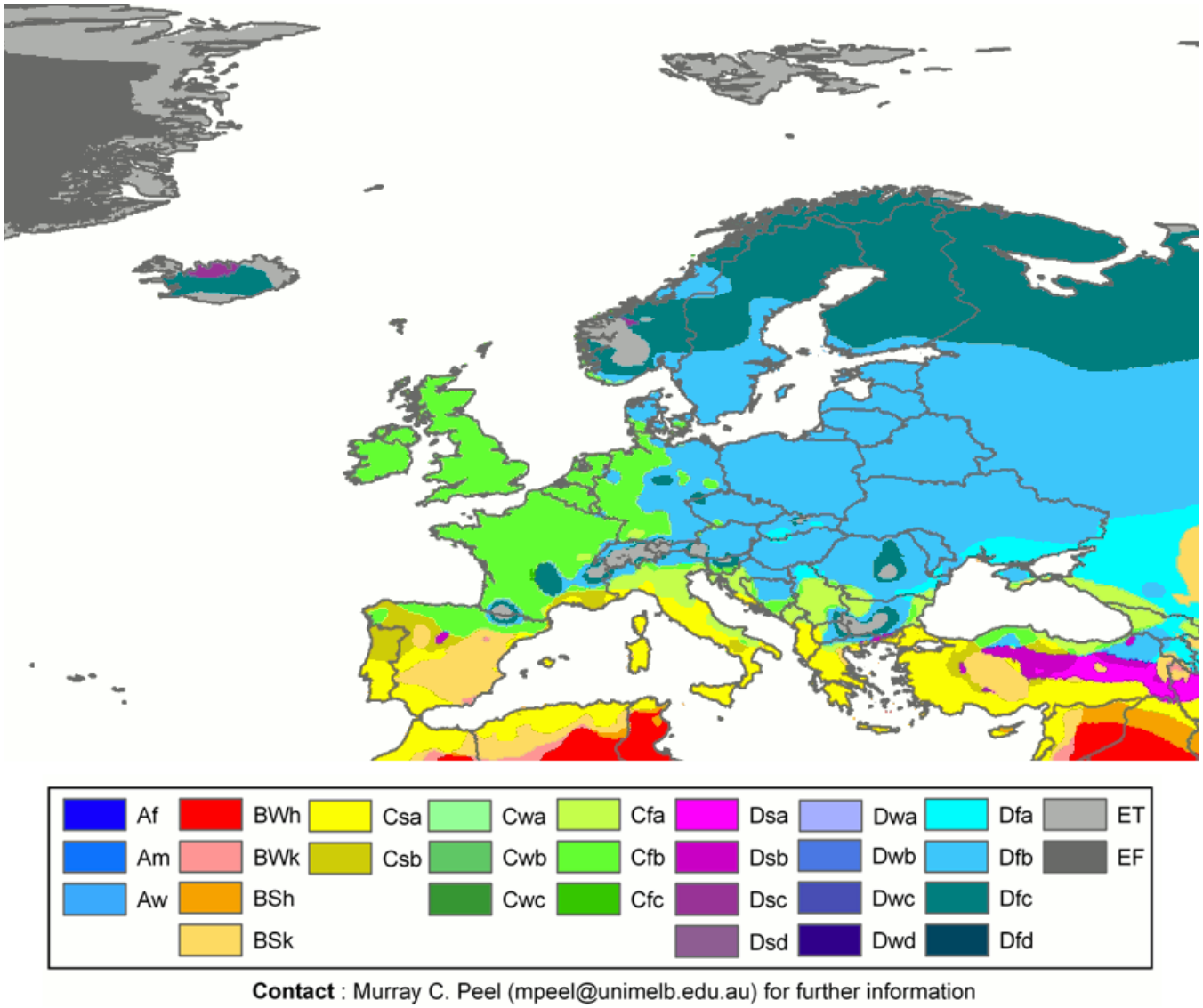
EUROPE MAP



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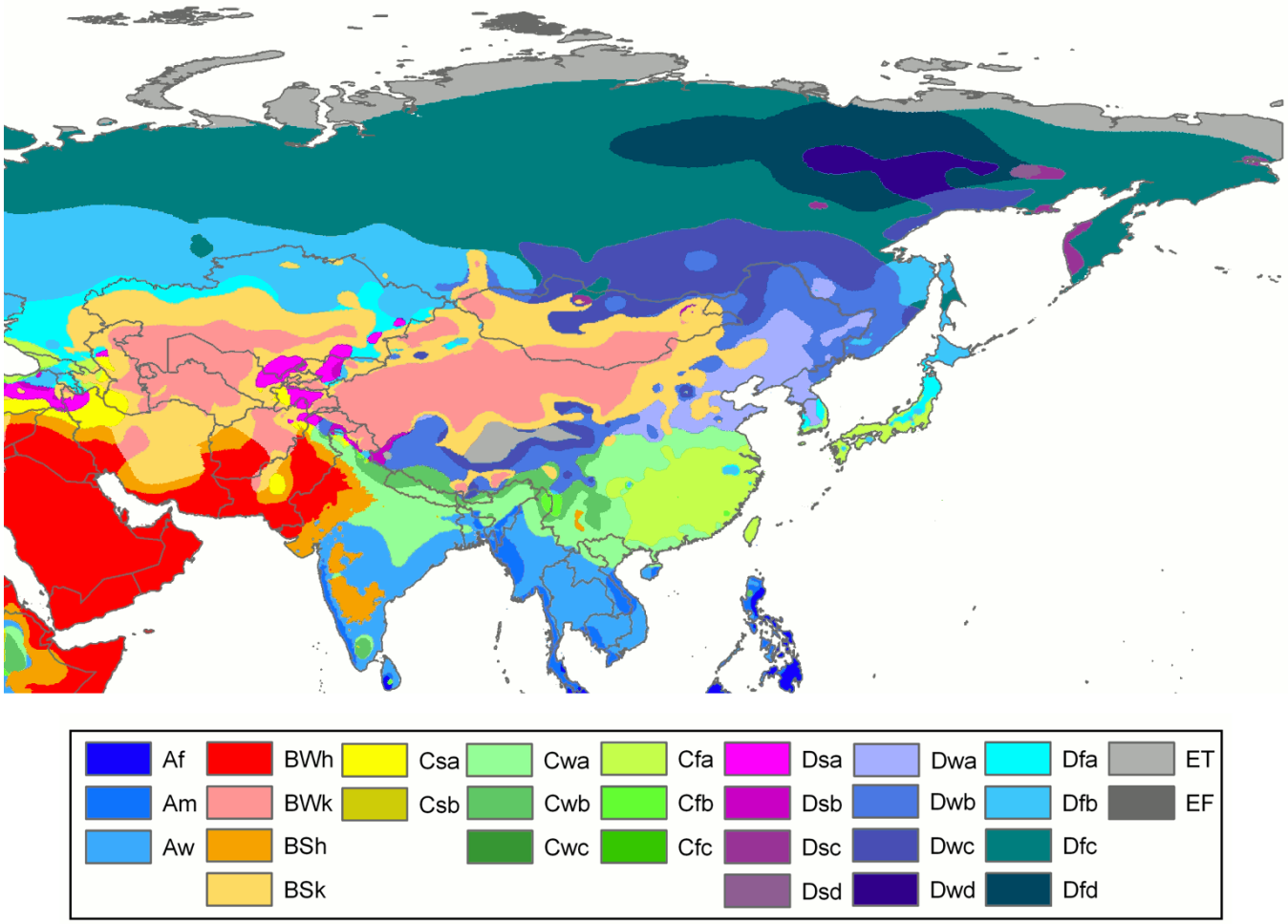
ASIA MAP



Contact : Murray C. Peel (mpeel@unimelb.edu.au) for further information

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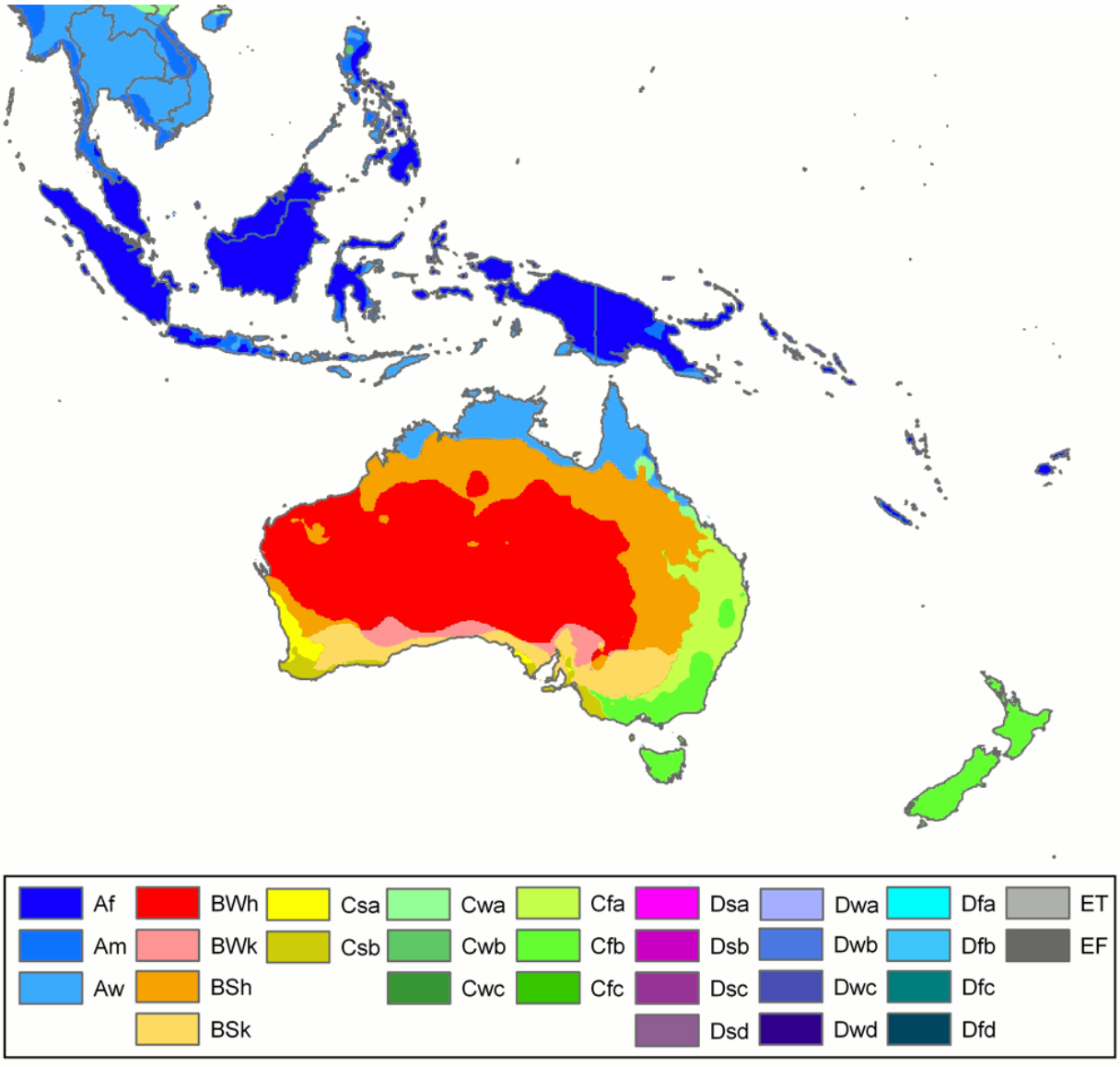
AUSTRALIA / NEW ZEALAND MAP



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