Chapter 1

Fundamental of Global Warming and Climate Change

‘We, the people, still believe that our obligations as Americans are not just to ourselves, but to all posterity. We will respond to the threat of climate change, knowing that the failure to do so would betray our children and future generations. Some may still deny the over-whelming judgment of science, but none can avoid the devastating impact of raging fires and crippling drought, and more powerful storms.’

—Pres. Barack Obama,
Jan.21st, 2013

What is weather and climate?

Weather describes the short-term (usually few hours to few days) state of the atmosphere. Alternatively, weather is defined as the instantaneous state of the atmosphere at some place and locations. The weather of a place or region is normally expressed in terms of air temperature, pressure, wind speed and direction, precipitation, and cloudiness in addition to other humidity parameters like relative humidity, absolute humidity and vapors pressure etc.

Weather is what the forecasters on the TV news predict each day. They tell people about the temperature, cloudiness, humidity, and whether a storm is likely in the next few days. It is the mix of events that happens each day in our atmosphere. Weather is not the same everywhere. It may be hot in one place and cold in other place. It may be sunny or cloudy in one part of the world, but freezing and snowy in another.

On the other hands, the **climate** is defined as the average weather patterns throughout several years over a large portion of Earth's surface. Usually, climate is measured for a specific area or region based on weather patterns over a 30-35 years time period. But according to the World Meteorological Organization (WMO), climate is defined in terms of the average (mean) of weather elements (such as temperature and precipitation) over specified period of time of 30 years.

Climate therefore varies from weather because weather is concerned only with short-term events whereas climate is the average weather in a place over many years. While the weather can change in just a few hours, climate takes hundreds, thousands, even millions of years to change.

A simple way to remember the distinction between the two is the saying, "Climate is what you expect, but weather is what you get."

How does climate differ from weather?

Weather is the current atmospheric conditions, including temperature, rainfall, wind, and humidity at a given place. If you stand outside, you can see that it's raining or windy, or sunny or cloudy. You can tell how hot it is by taking a temperature reading. Weather is what's happening right now or is likely to happen tomorrow or in the very near future.

Climate, on the other hand, is the general weather conditions over a long period of time. For example, on any given day in January, we expect it to be rainy in Portland, Oregon and sunny and mild in Phoenix, Arizona. And in Buffalo, New York, we are not surprised to see January newscasts about sub-zero temperatures and huge snow drifts.

Some meteorologists say that "climate is what you expect and weather is what you get”. According to one middle school student, "climate tells you what clothes to buy, but weather tells you what clothes to wear.

Climate is sometimes referred to as "average" weather for a given area. The National Weather Service uses data such as temperature highs and lows and precipitation rates for the past thirty years to compile an area's "average" weather. However, some atmospheric scientists think that you need more than "average" weather to accurately portray an area's climatic character - variations, patterns, and extremes must also be included. Thus, climate is the sum of all statistical weather information that helps describe a place or region. The term also applies to large-scale weather patterns in time or space such as an 'Ice Age' climate or a 'tropical' climate.

As climate is the average weather conditions of a place or region, it varies / changes very slowly and steadily whereas weather varies rapidly from morning to day and day to night, season to season, place to place. It is more fluctuating, unstable and changes rapidly from time to time.

What are the climatic elements (climatic variables) and climatic factors?

The climate of a place or location varies from other locations or regions because it consists by the combined influences of many forces on the location or region. These forces are termed as “climatic factors”. The climate of place is determined by the location i.e. the distance from the north and south poles (latitude), wind direction (movement of air) and speed (how intensified the wind is), how far it is from seas (relief), height from the sea level (elevation) and presence of water vapour in the air (humidity) and distinct forms in the ground, such as mountains, hills, plains, and valleys--these can make local winds (landforms) and weight of the air (pressure). These forces or parameters are technically called the climatic elements. The climate of a place can be expressed through measuring certain atmospheric parameters, which are called “climatic elements”. The elements of climate are solar radiation, air temperature, rainfall, humidity, wind and evaporation. A brief description of the climatic elements is:

(i) Solar radiation and cloud cover: Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy. About half of the radiation is in the visible short-wave part of the electromagnetic spectrum. The other half is mostly in the near-infrared part, with some in the ultraviolet part of the spectrum. **Cloud cover** (also known as cloudiness, cloud-age or cloud amount) refers to the fraction of the sky obscured by clouds when observed from a particular location. Okta is the usual unit of measurement of the cloud cover.

(ii) Temperature: Temperature is a degree of hotness or coldness the can be measured using a thermometer. It's also a measure of how fast the atoms and molecules of a substance are moving. Temperature is measured in degrees on the Fahrenheit, Celsius, and Kelvin scales.

(iii) Wind and storms: Windstorm, a wind that is strong enough to cause at least light damage to trees and buildings and may or may not be accompanied by precipitation. Wind speeds during a windstorm typically exceed 55 km (34 miles) per hour. A storm is any disturbed state of an environment or astronomical body's atmosphere especially affecting its surface, and strongly implying severe weather. It may be marked by significant disruptions to normal conditions such as strong wind, hail, lightning (a thunderstorm), heavy precipitation (snowstorm, rainstorm), heavy freezing rain (ice storm), strong winds (tropical cyclone, windstorm), or wind transporting some substance through the atmosphere as in a dust storm, blizzard, sandstorm, etc.

(iv) Humidity and fog: Humidity is the amount of water vapour in the air. Water vapour is the gaseous state of water and is invisible. Humidity indicates the likelihood of precipitation, dew, or fog. Higher humidity reduces the effectiveness of sweating in cooling the body by reducing the rate of evaporation of moisture from the skin. This effect is calculated in a heat index table or humidex, used during summer weather.Fog consists of cloud water droplets or ice crystals suspended in the air at or near the Earth's surface. Fog can be considered a type of low-lying cloud, and is heavily influenced by nearby bodies of water, topography, wind conditions, and even human activities. In turn, fog has affected many human activities, such as shipping and transport, warfare, and culture.

(v) Precipitation: Precipitation is any form of liquid or solid water particles that fall from the atmosphere and reach the surface of the Earth. For the Gulf Coast area, precipitation includes drizzle, rain, hail, and on rare occasions, snow and sleet. Different seasons and geographic locations see varying amounts of precipitation in amount and intensity. Precipitation is caused when a mass of warm, moist air hits a mass of cold air. Condensation causes the moisture to form droplets that become rain or crystals that become snow or ice. When these droplets or crystals become too heavy to be suspended in the atmosphere, they fall to Earth as precipitation.

Climatic Factors: The climate of any particular place is influenced by a host of interacting factors. These include latitude, elevation, nearby water, ocean currents, topography, vegetation, and prevailing winds. The global climate system and any changes that occur within it also influence local climate. There are lots of factors that influence our climate:

(i) Elevation or Altitude effect climate

Normally, climatic conditions become colder as altitude increases. “Life zones” on a high mountain reflect the changes, plants at the base are the same as those in surrounding countryside, but no trees at all can grow above the timberline. Snow crowns the highest elevations.

(ii) Prevailing global wind patterns

There are 3 major wind patterns found in the Northern Hemisphere and also 3 in the Southern Hemisphere. These are average conditions and do not essentially reveal conditions on a particular day. As seasons change, the wind patterns shift north or south. So does the inter-tropical convergence zone(ITCZ), which moves back and forth across the Equator. Sailors called this zone the doldrums because its winds are normally weak.

(iii) Latitude and angles of the sun rays

As the Earth circles the sun, the tilt of its axis causes changes in the angle of which sun's rays contact the earth and hence changes the daylight hours at different latitudes. Polar regions experience the greatest variation, with long periods of limited or no sunlight in winter and up to 24 hours of daylight in the summer.

(iv) Topography

The Topography of an area can greatly influence our climate. Mountain ranges are natural barriers to air movement. In California, winds off the Pacific ocean carry moisture-laden air toward the coast. The Coastal Range allows for some condensation and light precipitation. Inland, the taller Sierra Nevada range rings more significant precipitation in the air. On the western slopes of the Sierra Nevada, sinking air warms from compression, clouds evaporate, and dry conditions prevail.

(v) Effects of Geography

The position of a town, city or place and its distance from mountains and substantial areas of water help determine its prevailing wind patterns and what types of air masses affect it. Coastal areas may enjoy refreshing breezes in summer, when cooler ocean air moves ashore. Places south and east of the Great Lakes can expect “lake effect” snow in winter, when cold air travels over relatively warmer waters.

(vi) Surface of the Earth

Just look at any globe or a world map showing land cover, and you will see another important factor which has a influence on climate: the surface of the Earth. The amount of sunlight that is absorbed or reflected by the surface determines how much atmospheric heating occurs. Darker areas, such as heavily vegetated regions, tend to be good absorbers; lighter areas, such as snow and ice-covered regions, tend to be good reflectors. The ocean absorbs and loses heat more slowly than land. Its waters gradually release heat into the atmosphere, which then distributes heat around the globe. The factor affecting climates are classified as: Physical – latitude, nearest to sea and physical barriers while vegetation and human interference are known as non-physical factors of climate.

What are the weather elements and weather factors?

Weather elements: Temperature is a very important factor in determining the weather, because it influences or controls other elements of the weather, such as precipitation, humidity, clouds and atmospheric pressure. Humidity is the amount of water vapour in the atmosphere. Therefore, temperature is called as a weather factor as it helps determine the weather elements. In addition to this it also useful parameter to express the atmospheric condition and called as useful weather element. The several weather elements are: temperature, inversion, wind, stability of the atmosphere, relative humidity, precipitation, cloud development etc.

Temperature

Temperature is a degree of hotness or coldness the can be measured using a thermometer. It's also a measure of how fast the atoms and molecules of a substance are moving. Temperature is measured in degrees on the Fahrenheit, Celsius, and Kelvin scales. Temperature is a measure of the average heat or thermal energy of the particles in a substance. Since it is an average measurement, it does not depend on the number of particles in an object. In that sense it does not depend on the size of it. In the lowest layer of the atmosphere, the troposphere, within which virtually all of Earth’s weather transpires, temperature generally declines with altitude. This is a function of decreasing air pressure as altitude increases; higher up, the molecules of atmospheric gas are more spread out and slower moving, producing less heat energy.

Inversions

A temperature inversion occurs when the normal cooling of air with altitude is reversed: cold air near the ground is overlain with a layer of warmer air, which prevents convection, or air-mass lifting, for the duration of the inversion. Basins enclosed by mountains are particularly susceptible to such inversions, which can concentrate pollutants in the lower atmosphere. During an inversion, a mountain rambler may enjoy sunny, warm conditions while a valley counterpart contends with chilly fog.

Wind

Wind has a strong effect on fire behavior due to the fanning effect on the fire. Wind can change direction and intensity throughout the day. This change can be very abrupt surprising the burner that is not alert. Abrupt changes generally occur during the afternoon when atmospheric conditions are most unstable. We will discuss stability later. Wind is important to the prescribed burners fire fighter because of three influences it has on fire behavior:

- Supplying oxygen for the combustion process.
- Reducing fuel moisture by increasing evaporation.
- Exerting pressure to physically move the fire and heat produced closer to fuel in the path of the fire increasing radiation including in some cases pitching burn embers, firebrands

Effect of Wind on Vegetation:

- Friction slows down speed next to the surface
- Causes turbulence and eddies
- Fire is more intense at edge of openings
- Increases evaporation by blowing away the moist air next to fuel

Different types of winds are described below:

Pressure or Gradient Winds: Air always moves as a result of temperature differences. It moves from high pressure areas to low pressure areas in an attempt to balance out the differences in temperature. Due to the movement of the earth, this is not a straight line. Wind from a "high" will spiral outward in a clockwise direction in the northern hemisphere. The wind flow toward a "low" will spiral in a counter clockwise direction toward the center. These highs and lows are generally shown on weather maps.

On a rotating earth with a uniform surface, the general circulation of the Northern Hemisphere would be composed of the northeast trade winds, prevailing westerlies, and polar easterlies.

Frontal Winds: A weather front is the boundary layer between two air masses of different temperatures. Fronts start from an area of low pressure. Winds will be the strongest at the frontal boundaries. Wind direction will also shift in a clockwise direction as the front passes.

Local types of Winds: General winds are winds that are included in the weather forecast. Local factors will also affect the wind in an area that is too small to be included in the forecast. These are known as "local winds". There are two that are important to fire behaviour in the southeast.

Land and Sea Breezes: As discussed earlier, land surfaces become warmer than water surfaces during the day. As a result, the air adjacent to the land surface, being warmer, begins to rise and the cooler air (thus heaver) flows inland to take its place. This local wind begins around 2 to 3 hours after sunrise and ends around sunset. At night, the reverse is true because the land surface cools more quickly than the water surface causing airflow from land to the water. This shift generally occurs around 2 am.

While these winds are normally strongest in coastal areas they may occur around large bodies of water.

Eddies: Eddy winds form around large objects and along tree lines. Eddie winds can strongly influence fire behavior at the edge of stands and open fields or along roads.

Slope Winds

Over large, flat areas, it is difficult for the air mass to mix even though the air next to the surface is warmer, thus lighter. However on a slope, the lighter air can rise along the slope with cooler air filling in from below. Local winds will flow upslope during the day and down-slope at night. This is true even on the slightest slope unless the general wind is strong enough to overcome this phenomenon.

Relative Humidity

Relative humidity (abbreviated RH) is the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at the same temperature. Relative humidity depends on temperature and the pressure of the system of interest. The relative humidity of an air-water mixture is defined as the ratio of the partial pressure of water vapor (H_2O) in the mixture to the equilibrium vapor pressure of water at a given temperature. The humidity of an air-water vapor mixture is determined through the use of psychrometric charts if both the dry bulb temperature (T) and the wet bulb temperature (T_w) of the mixture are known.

These quantities are readily estimated by using a sling psychrometer.

Precipitation

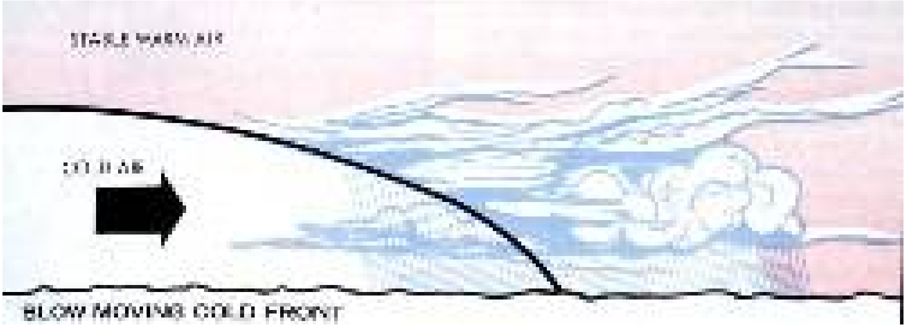
In meteorology, precipitation is any product of the condensation of atmospheric water vapour that falls under gravity. The main forms of precipitation include drizzle, rain, sleet, snow, graupel and hail. Precipitation occurs when a portion of the atmosphere becomes saturated with water vapour, so that the water condenses and "precipitates". Thus, fog and mist are not precipitation but suspensions because the water vapour does not condense sufficiently to precipitate. Two processes, possibly acting together, can lead to air becoming saturated: cooling the air or adding water vapors to the air. Generally, precipitation will fall to the surface; an exception is virga which evaporates before reaching the surface. Precipitation forms as smaller droplets coalesce via collision with other rain drops or ice crystals within a cloud. Rain drops range in size from oblate, pancake-like shapes for larger drops, to small spheres for smaller drops. The standard way of measuring rainfall or snowfall is the standard rain gauge, which can be found in 100 mm plastic and 200 mm metal varieties. The inner cylinder is filled by 25 mm of rain, with overflow flowing into the outer cylinder. Plastic gauges have markings on the inner cylinder down to 0.25 mm resolution, while metal gauges require use of a stick designed with the appropriate 0.25 mm markings. After the inner cylinder is filled, the amount inside it is discarded, then filled with the remaining rainfall in the outer cylinder until all the fluid in the outer cylinder is gone, adding to the overall total until the outer cylinder is empty. Other types of gauges include the popular wedge gauge (the cheapest rain gauge and most fragile), the tipping bucket rain gauge, and the weighing rain gauge. The wedge and tipping bucket gauges will have problems with snow.

Cloud Development and Fronts

When moisture is added to the atmosphere or the air temperature is lowered, the relative humidity increases. When it increases to the saturation point, the moisture begins to combine into droplets. As this process continues, the droplets become visible--as clouds. When the atmosphere is very dry, saturation may not be reached, and no clouds are formed.

Clouds are formed when there is a lot of surface heating from the sun and a lot of moisture is present. As the air close to the surface is heated, it rises to be replaced by cooler air. The heated air can rise until it is saturated and clouds form. As it rises the warmer air cools until it reaches the temperature of the surrounding air. At this altitude puffy type cumulus clouds will form. If they continue to build up, they become darker and rain may occur.

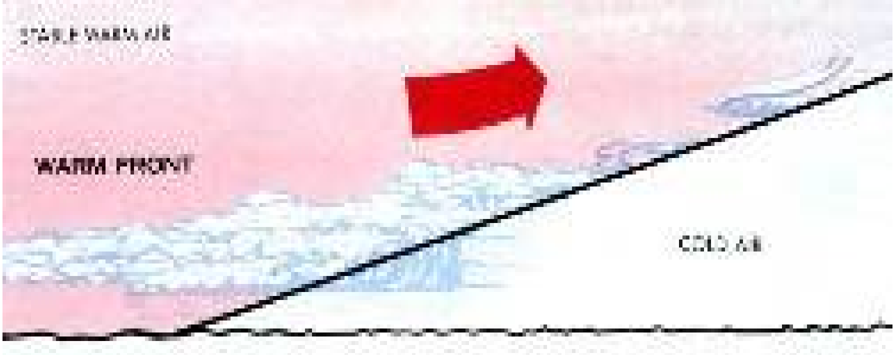
Clouds are also caused by fronts. Fronts and the associated clouds are important because fronts mean changing weather. Clouds are visible indicators of fronts and other weather phenomenon. Cumulus clouds indicate vertical movement in the atmosphere. Clouds are moisture. The more clouds available, the more moisture available and relative humidity will be higher. Overcast skies shade the surface of the earth and less radiant heat is received. Temperatures are lower and winds are more moderate.



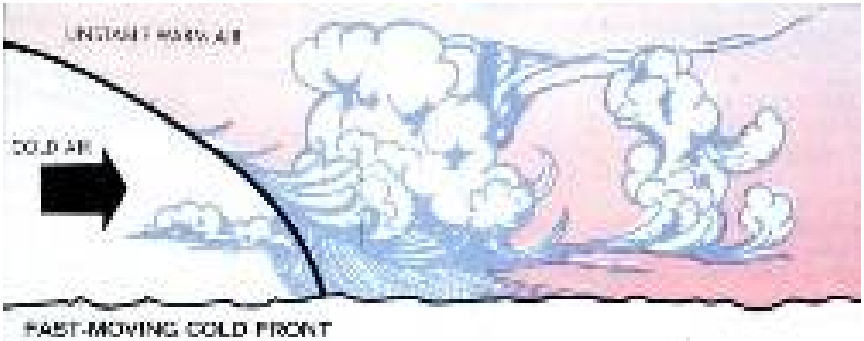
Clouds and precipitation cover a wide band and extend some distance behind slow-moving cold fronts. If the warm air is moist and stable, stratus-type clouds and steady rain occur. If the warm air is conditionally unstable, showers and thunderstorms are likely.

If the warm air above a warm front is moist and conditionally unstable, altocumulus and cumulonimbus clouds form. Often, thunderstorms will be embedded in the cloud masses.

Lifting of warm, moist air as it is forced up the slope of a warm front, produces widespread cloudiness and precipitation.



If the warm air above a warm front is moist and stable, clouds are of the stratus type. The sequence of cloud types is cirrus, cirrostratus, altostratus, and nimbostratus. Precipitation is steady and increases gradually with the approach of a front.



With rapidly moving cold fronts, the weather is more severe and occupies a narrower band. If the warm air is moist and conditionally unstable, as in this case, scattered showers and thunderstorms form just ahead of the cold front.

The steepness and speed of cold fronts result in a narrow band of cloudiness and precipitation as warm, moist air ahead of the front is lifted.

Thunderheads

One type of cloud can spell trouble even though of short duration. As cumulus clouds build higher, they become more turbulent. Such clouds are called thunderheads. Their towering, turbulent-appearing head can be easily recognized. In the later stage the towering top may become anvil-shaped with the point facing the direction the thunderhead is traveling. As they develop, air currents reach a critical height and precipitation begins. The falling rain or hail indicates a strong downdraft below the cloud. The strong downdraft strikes the ground and spreads in all directions producing strong, gusty winds of up to 70 mph in a few seconds. As the thunderhead moves, the wind shifts rapidly.

Radiation from the sun is at its maximum when the sun is directly overhead. Because of a delay in its effect, the peak of the burning period is generally around 1:00 to 2:00 in the afternoon depending on latitude and daylight savings time.

Drought

Days since the last rain and seasonal soil moisture deficit have an influence on fuel moisture and fire behaviour. The drier the soil, generally, the drier the litter, duff, and organic matter in the soil will be. It is generally inadvisable to burn the organic matter out of the soil.

Weather Factors: There are many factor that influence weather, many of which we cannot see.

Water Cycle

As the sun warms the surface of the Earth, water rises in the form of water vapor from lakes, rivers, oceans, plants, the ground, and other sources. This process is called evaporation. Water vapor provides the moisture that forms clouds; it eventually returns to Earth in the form of precipitation, and the cycle continues.

Air Masses

In meteorology, an air mass is a volume of air defined by its temperature and water vapour content. Air masses cover many hundreds or thousands of square miles, and adopt the characteristics of the surface below them. They are classified according to latitude and their continental or maritime source regions. Colder air masses are termed polar or arctic, while warmer air masses are deemed tropical. Continental and superior air masses are dry while maritime and monsoon air masses are moist. Weather fronts separate air masses with different density (temperature and/or moisture) characteristics

Jet Stream

A jet stream is the name given to the area of air above where two air masses of different temperature converge e.g. a cold front meeting a warm front. The greater the temperature difference between the air masses, the greater the air pressure difference, and the faster the wind blows in the jet stream. This river of air has wind speeds which often exceed 100 mph, and sometimes over 200 mph. Jet streams more commonly form in the winter, when there is a greater difference between the temperature of the cold continental air masses and warm oceanic air masses.

Weather Fronts

The transition zone between two air masses of different humidity and temperature is called a front. Along a cold front, cold air displaces warm air; along a warm front, warm air displaces cold air. When neither air mass displaces the other, a stationary front develops. Towering clouds and intense storms may form along cold fronts, while widespread clouds and rain, snow, sleet, or drizzle may accompany warm fronts.

What is climatic classification?

The combined effects of the climate elements resulting in a homogeneous set of conditions constitute a climate type. Different regions of same climate type constitute the area of "equal climate "or "iso- climate" regions.

The method of identifying some homogeneous regions having equal climate or iso- climate is called classification.

A system of classification suitable for one purpose is not necessary useful for another purpose. Classification based on temperature and moisture (rainfall) to characterize the place suitable for crop growth may be of interest to an agronomist but is of little interest to a weather forecaster who needs classification, storms, wind direction, velocity etc. No classification is static

The broad objectives of classification are:

a) To establish different types of climate found in the earth.
b) To establish relationship among the type climate.
c) To extend application of the classification to the whole world.
d) To provide a basic structure for further subdivision for specific purpose.

The approaches for classification of climate are: Empirical, Genetic and Applied.

Empirical classification: It is based on qualification of observable elements by statistics or experiments. Climate on the basis of temperature are referred as hot, warm, or cold. Climate on the basis of temperature moisture are known as wet, humid and dry. Climate on the basis of combined effect of temperature and rainfall are termed as hot-wet, hot-dry or hot-humid. Empirical method of classification is more reliable and stable because it is based on experimentation and mathematical coding.

Generic classification: It is based on the genesis of variation of climatic elements. It is made on the basis of causes on origin of climatic phenomena.

Applied classification: It known as technical or functional classification. It is a classification scheme for the solution of specialized problems involving more than one climatic factor. It establishes a systematic relationship between climatic factor and vegetation.

Köppen climate classification

The **Köppen climate classification** is one of the most widely used climate classification systems. It was first published by Crimea German climatologist Wladimir Köppenin 1884, with several later modifications by Köppen himself, notably in 1918 and 1936. The classification suggested by Koppen based on monthly averaged temperature and rainfall seems to be the 1st useful method for general practical purpose. The system is based on the concept that native vegetation is the best expression of climate. Thus, climate zone boundaries have been selected with vegetation distribution in mind. He divided world climate according to 5 major groups using five letters based on average annual precipitation, average monthly precipitation, and average monthly temperature as:

Type “A” classification known as **tropical rainy climate** or **tropical moist climates which** extend northward and southward from the equator to about 15 to 25 degrees of latitude. In these climates all months have average temperatures greater than 18 degrees Celsius. Annual precipitation is greater than 1500 mm. Three minor Köppen climate types exist in the A group and their designation is based on seasonal distribution of rainfall.

“Af” type is known as **tropical wet. It**is a tropical climate where precipitation occurs all year long. Monthly temperature variations in this climate are less than 3 degrees Celsius. Because of intense surface heating and high humidity cumulus and cumulonimbus clouds form early in the afternoons almost every day. Daily highs are about 32 degrees Celsius while night time temperatures average 22 degrees Celsius.

“Am” is a **tropical monsoon** climate. Annual rainfall is equal to or greater than “Af”, but falls in the 7 to 9 hottest months. During the dry season very little rainfall occurs.

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 millimetres and only during the summer season.

Type “B” is known as dry climate in which the annual evaporation is more than annual precipitation. The deficient precipitation is noticed during most of the years. The most obvious climatic feature of this climate is potential evaporation and transpiration exceeds precipitation. These climates extend from 20 - 35 degrees North and South of the equator and in large continental regions of the mid-latitudes often surrounded by mountains. Minor types of this climate include:

Bw- dry arid (desert) is a true desert climate. It covers 12 % of the earth's land surface and is dominated by xerophytic vegetation. **Bs- dry semiarid** (steppe) is a grassland climate that covers 14% of the earth's land surface. It receives more precipitation than the Bw either from the Intertropical convergence zone (ITCZ) or from mid-latitude cyclones.

Type "C" is known as Mid-Latitude rainy climate with mild winter (Average temperature of the coldest month is less than 18^{o}C but above -3^{o}C and averaged temperature of the warmest month is more than 10^{o}C). This climate generally has warm and humid summers with mild winters. Its extent is from 30 to 50 degrees of latitude mainly on the eastern and western borders of most continents. During the winter the main weather feature is the mid-latitude cyclone. Convective thunderstorms dominate summer months. Three minor types exist:

Sub type of "Cfa" known as humid subtropical; **Cs** is as **mediterranean**; and **Cfb** as **marine**. The humid subtropical climate (Cfa) has hot muggy summers and mainly thunderstorms. Winters are mild and precipitation during this season comes from mid-latitude cyclones. A good example of a

Cfa climate is the southeastern USA. Cfb, marine, climates are found on the western coasts of continents. They have a humid climate with short dry summer. Heavy precipitation occurs during the mild winters because of continuous presence of mid-latitude cyclones. Mediterranean climates (Cs) receive rain primarily during winter season from the mid-latitude cyclone. Extreme summer aridity is caused by the sinking air of the subtropical highs and may exist for up to 5 months. Locations in North America are from Portland, Oregon to all of California.

The type "**<u>D" is denoted as Mid-Latitude</u> rainy climate with severe winter** in which lowest temperature will be less than -3°C. Moist continental mid-latitude climates have warm to cool summers and cold winters. The location of these climates is pole ward of the C climates. The warmest month is greater than 10 degrees Celsius, while the coldest month is less than -30 degrees Celsius. Winters are severe with snowstorms, strong winds, bitter cold from Continental Polar or Arctic air masses. Like the C climates, there are three minor types: **Dw** is known as **dry winters**; **Ds** is **dry summers**; and **Df** is denoted as **wet all seasons**.

The last climatic type of the world climate is written as "**<u>E" called as Polar</u> Climate**. The average temperature of the warmest month is less than 10°C and average temperature of the entire region is less than 0°C. Polar climates have year-round cold temperatures with warmest month less than 10 degrees Celsius. Polar climates are found on the northern coastal areas of North

America and 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 caps has a surface that is permanently covered with snow and ice.

Advantages of Koppen Classification

It had advantage of statistical manipulation and interpretation between heat and moisture is well established in depicting the vegetation types. The climatic group and sub-groups and further sub-division are easy to follow through the use of letters. While the Koppen system doesn't take such things as temperature extremes, average cloud cover, number of days with sunshine, or wind into account, it's a good representation of our earth's climate. Another limitation of widely used Koppen classification is the lack of rational basis of selecting temperature and precipitation values for different climatic zone.

Salient features of C.W. Thornthwaite (1931) classification. - This classification is almost similar to Koppen's classification in so far as it defines climatic boundaries quantitatively, and it is also based on vegetation. Like Koppen's scheme it also makes use of letter combinations to designate climatic types. However, it differs from Koppen's classification on two scores: first, he introduced an expression for precipitation efficiency, and second, he made use of an index of thermal efficiency.

a) The precipitation effectiveness (PI) is defined as

$$PI = \sum_{n=1}^{n} {}^{P}\!/_{E}\, x10$$

Where P is total monthly precipitation and E is the total monthly evaporation. The ration is summed over 12 months of the year and multiplied by 10 to avoid fractions. If evaporation is not available, then it can be calculated by using temp data. As

$$\underline{\sum_{n=1}^{12} 115(\frac{P}{T-10})^{(10/9)}}$$

Where P is the precipitation in inch and T is temperature in ^{o}F.

Thornthwaite makes moisture the primary classificatory factor. Since Thornthwaite adopted the precipitation effectiveness and temperature efficiency indices for his climate' classification, the delimitation of the climatic boundaries becomes difficult and vague. On the basis of P/E indices, he recognized 5 humidity provinces with associated vegetation.

Humidity provinces	P/E index	Vegetation
A (Wet)	>127	Rainforest
B(Humid)	64–127	Forest
C (Sub-humid)	32-63	Grassland
D(semi-arid)	16-31	Steppe(A wide tree less plain)
E (Arid)	<16	Desert

2. Temperature efficiency/ Thermal efficiency: It is defined as potential evapotranspiration in cm. It is an index of energy in terms of water depth. It is derived from thermal data. On the basis of temperature efficiency he recognized 6 types of vegetations.

a. Tropical rain forest
b. Temperature rain forest
c. Micro-thermal rain forest
d. Taiga
e. Tundra
f. Perpetual forest(No vegetation)

Combination of 5 humidity and 6 thermal zones results 5x6=30 climatic regions. Again he recognized 4 climatic types on the basis of seasonal distributions of rainfall. These are

r- type- abundant precipitation in all seasons
s- type---scanty (small amount) rainfall in summer and abundant in winter
w- type--- scanty (small amount) rainfall in winter and abundant in summer
d- type--- scanty (small amount) rainfall in all seasons.

Hence combination of precipitation effectiveness, thermal efficiency and distribution of precipitation in different seasons, there exist total 5x6x4=120 types of climate- vegetations. But actually only 32 types of climate exists and other combinations meteorologically do not possible or do not exist.

The point to be remembered is that in Thornthwaite's classification the letter symbols used are relatively less in number than those in Koppen's classification. Lastly, it may be pointed out that the climatic classifications as devised by Koppen and Thornthwaite are more useful and appealing to zoologists, botanists, and geographers. But these schemes of classification are not so useful for meteorologists and climatologists because the interplay between the weather elements and other climatic factors is not clearly shown.

Thornthwaite's 1948 Classification - In 1948 Thornthwaite proposed a new classification of climate which is his most important contribution. His second classification is based on the concept of potential evapotranspiration, which represents the amount of moisture that would be transferred to the atmosphere by evaporation of liquid or solid water plus transpiration from living tissues, principally plants if it (the moisture) were available. The potential evapotranspiration (PE) is calculated from the mean monthly temperature (in °C), with corrections for day length. For a 30-day month (12-hour days):

PE (in cm) = $1.6\ (10t/I)^{a}$

Where, t is the mean monthly temperature in ^{o}C and I is the annual heat index which is the sum of 12 monthly indices i which is

$i = (t/5)^{I.514}$ and

$$I = \sum_{i=1}^{12} i$$

a is the place specific exponential cubic function of I

$a = 6.67 \times 10^{-7} I^{3} - 7.71 \times 10^{-5} I^{2} + 1.792 \times 10^{-2} I + 0.49239$

The monthly water surplus (S) or deficit (D) is calculated from a moisture budget assessment including stored soil moisture. A **moisture index** (I_m) is given by the following formula:

$$I_m = (100S-60D)/PE$$

On the basis of moisture index the following 9 climatic types were delineated by Thornthwaite as per criteria indicated against each.

1. On the basis of moisture index (I_m), there are 9 types of climates namely Perhumid(A), Humid(B1-B4), Sub humid (C_1-C_2) , semiarid (D) and arid which is shown in details in Table bellow

Humidity Province	Moisture index (I_m)
A per humid	>100
B_4 humid	80-90
B_3 humid	60-80
B_2 humid	40-60
B_1 humid	20-40
C_2 Moist sub-humid	0-20
C_1 Dry sub-humid	-20 to 0
D Semiarid	-40 to -20
E Arid	-60 to -40

In general, Thornthwaite developed four indices to determine boundaries of different climatic type's e.g.

1. Moisture index 2. Thermal efficiency(PE), 3. Aridity and Humidity indices,

4. Index of summer concentration of thermal efficiency

The moisture index is already defined above, the other indices are define as

Thermal efficiency(PE): Thermal efficiency is the potential evapotranspiration in cm. It is an index of energy in term of water depth. It is derived from thermal data. It is represented as T/E, where T= monthly average temperature and E= monthly evaporation.

Similarly, on the basis of thermal efficiency and its summer efficiency, there are nine climatic types, there are nine climatic types

Type of classification	Symbol	Thermal index (PET in cm)
Megathermal	A'	114 and above
Mesothermal	B_4'	99.7 to 114.0
Mesothermal	B_3'	85.5 to 99.7
Mesothermal	B_2'	71.2 to 85.5
Mesothermal	B_1'	57.0 to 71.2
Microthermal	C_2'	42.7 to 57.0
Microthermal	C_1'	28.5 to 42.7
Tundra	D'	14.2 to 28.5
Frost	E'	Below 14.2

Index of summer concentration of thermal efficiency: The percentage of mean annual PE that accumulates in the three summer months is the summer concentration of thermal efficiency.

Climatic Type	Index (cm)
a’ Megathermal	<48.0
b’ Mesothermal	48.0 to 51.9
b'_3Mesothermal	51.9 to 56.3
b'_2Mesothermal	56.3 to 61.6
b'_1Mesothermal	61.6 to 68.0
c_2Microthermal	68.0 to 76.3
c_1Microthermal	76.3 to 88.0
d’ Tundra	> 88.0

Aridity index: In the moist climate the aridity index is the annual water deficit takes as a percentage of annual PET i.e.

$$I_a = \frac{d}{PET} x100$$

For moist climate (moisture provinces of A, B and C_2) the sub division on basis of aridity index

Water deficiency	Aridity index (I_a)
r (little or no water deficiency)	0 to 16.7
s (moderate summer water deficiency)	16.7 to 33.3
w (moderate winter water deficiency)	16.7 to 33.3
s_2 (large summer water deficiency)	>33.3
w_2(large winter water deficiency)	>33.3

Humidity index: In dry climate water surplus as a percentage of annual PET gives the humidity index i.e.,

$$I_h = \frac{S}{PET} x100 ´$$

For dry climate (moisture provinces C_1, D, E) the sub division on basis of humidity index

Water surplus	Humidity index (I_h)
d (little or no water surplus)	0 to 10
s (moderate winter water surplus)	10 to 20
w (moderate summer water surplus)	10 to 20
s_2 (large winter water surplus)	>20
w_2(large summer water surplus)	>20

What is climate change and climate variability?

Any change is perceived and estimated by following a pattern or a shift in term of some references like baseline or benchmarks. This is why a change is rather easy to estimate because of its frame of reference. The climate change is kind of change which can be estimated over time and space by technically elucidating a frame of reference, here, it can be base temperature (background temperature) of the earth surface just before or at the beginning of industrialization. To estimate the change, we need to have methodological approach to make the analysis a kin to reality and the prediction, the closest to possibilities. To do that we follow, analyzing of long-term history data, pattern analysis and identification of critical dents on evolutionary pathways and ultimately based on it, we simulate the broader climate change scenarios, having both short–term (contingent) and long-term (protractile).

Definition of global warming and climate change: Global warming and climate change can both refer to the observed century-scale rise in the average temperature of the Earth's climate system and its related effects. Due to diverse activities on the Earth surface by the name of civilization through industrialization and urbanization, there is a permanent increase of back ground temperature of the Earth surface compared to its pre-industrial period is known as global warming and climate change. As for example, the global averaged earth surface temperature was ~15^{o}C during the period of pre-industrialization (1750-1850); Pre-industrial society refers to social attributes and forms of political and cultural organization that were prevalent before the advent of the Industrial Revolution, which occurred from 1750 to 1850. IPCC different assessment reports published in different times reported that earth's surface has warmed more than 1^{o}C after the preindustrial period. Now the present background temperature of the Earth surface is 15^{o}C +1^{o}C= 16^{o}C. This is the permanent rise of the Earth surface averaged temperature, which is called the global warming. Global warming does not mean the warmer weather in future. As the planet gets heats gradually, climate patterns change to hotter and some wetter, others drier. We know the planet has warmed by an average of nearly 1°C in the past century. That might not sound much, but on a global scale it's a huge increase and it's creating big problems for people and wildlife.

Difference between Global warming and Climate change: Global warming is a more specific term. It refers to describe the current increase in the Earth's average temperature because of greenhouse gas build up in the atmosphere. On the other hands, climate change is a broader term that refers not only to global changes (increases or decreases)

in temperature but also to changes in wind, precipitation, the length of seasons as well as the strength and frequency of extreme weather events like droughts and floods. It is to be mentioned that due to increase of earth surface averaged temperature, which is termed as “global warming”, the climatic pattern as mentioned is changing rapidly and drastically. Therefore, global warming is one of the major causes of the climate change and climate change is manifested as its effect. Human greenhouse gas emissions are causing global warming, which in turn is causing climate change. However, because the terms are causally related, they are often used interchangeably A warmer Earth, from global warming, will lead to changes in rainfall patterns, a rise in sea level, and a wide range of impacts on plants, wildlife, and humans. When scientists talk about the issue of climate change, their concern is about global warming caused by human activities.

Climatic Variability versus Change

Longer period of time series data is a mixture of signal and noise. It has its own year to year fluctuations or oscillations from its long-term means which are known as noise or “variability” in climate science. If we able to filter out the noise of long-term data through any statistical approaches namely the 10 points moving average or the auto regressive integration of moving average(ARIMA, etc., we will get a significant change (increasing/decreasing) of the time series, which is called a climate change signal.

Climate is typically defined in terms of 30 year means, and higher-order moments about those means. This implicitly assumes stationarity of a given climate state. In practice, climate varies on time-scales both longer and shorter. On the shortest time scale, we enter the realm of weather. Variability on time scales of a few years to a few decades (i.e., shorter than a climatic averaging period) is usually referred to as climatic variability. Variability on time scales longer than a few decades (longer than a standard climatic averaging period) is usually referred to as climatic change. Though meaningful, the distinction is arbitrary, and ultimately depends on context (the question at hand)

Global Climate Change: Evidence and Causes

For most folks, global climate change is one of those issues we hear about constantly in the news but have a hard time really understanding because the scientific concepts are complex and information presented is often contradictory. One article might say climate change absolutely the result of human activity and the next may argue that it a natural process that has occurred many times throughout Earth's long history. But scientists are in agreement, the global climate is rapidly warming and the causes are rooted in human activity. Some of clearest evidence that global climate change is indeed occurrin today and is being caused by human activity comes from carbon dioxide levels in the atmosphere. Atmospheric carbon dioxide does naturally fluctuate, but it's never been has high as it is today. Carbon dioxide levels are much higher than they would naturally be if we were not burning so much fossil fuel (like oil, gas and coal). And what scientists have shown by studying hundreds of thousands of years of geological data is that temperature increases in when carbon dioxide increases, so the current spike in carbon dioxide is sure to result in a rapid increase in global temperature

What is the greenhouse effect?

The greenhouse effect is a natural process that warms the Earth’s surface. When the sun’s energy reaches the Earth’s atmosphere, some of it is reflected back to space and the rest is absorbed and re-radiated by greenhouse gases. Greenhouse gases include water vapour, carbon dioxide, methane, nitrous oxide, ozone and some artificial chemicals such as chlorofluorocarbons (CFCs).The absorbed energy warms the atmosphere and the surface of the Earth. This process maintains the Earth’s temperature at around 33 degrees Celsius warmer than it would otherwise be, allowing life on Earth to exist.The recent rapid increase in greenhouse gases has resulted in a thickening of the atmosphere. The thicker atmosphere traps more solar radiation and in turn, raises the global temperature.

More scientifically, the Sun is source of energy on the Earth’s climate. It emits radiant energy at very short wavelengths, predominately in the visible or near-visible (e.g., ultraviolet) part of the spectrum. One-third of the solar energy that reaches the top of Earth’s atmosphere is reflected directly back to space. Remaining two-thirds is absorbed by the surface and, to a lesser extent, by the atmosphere. To balance the absorbed incoming energy, the Earth must, on average, radiate the same amount of energy back to space. Because the Earth is much colder than the Sun, it radiates at much longer wavelengths, primarily in the infrared part of the spectrum. Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and reradiated back to Earth. This is called the greenhouse effect.

The glass walls in a greenhouse reduce airflow outwards and increase the temperature of the air inside. Analogously, but through a different physical process, the Earth’s greenhouse effect warms the surface of the planet. Without the natural greenhouse effect, the average temperature at Earth’s surface would be below the freezing point of water. Thus, Earth’s natural greenhouse effect makes life as we know it possible. However, human activities, primarily the burning of fossil fuels and clearing and burning of forests, have greatly intensified the natural greenhouse effect, causing global warming. Averaged over all land and ocean surfaces, temperatures have warmed roughly 0.74ºC over the last century, according to the Intergovernmental Panel on Climate Change Synthesis Report Summary for Policymaker.

If climate changes naturally over time, why isn't the current warming just another natural cycle?

The industrial activities that our modern civilization depends upon have raised atmospheric concentrations of carbon dioxide and methane to higher levels than at any point during the last 650,000 years. Scientists agree it is very likely that most of the global average warming since the mid-20th century is due to the human-induced increases in greenhouse gases, rather than to natural causes. While natural variations have altered the climate significantly in the past, it is very unlikely that the changes in climate observed since the mid-20th century can be explained by natural processes alone.

Are greenhouse gases increasing?

Human activity has been increasing the concentration of greenhouse gases in the atmosphere (mostly carbon dioxide from combustion of coal, oil, and gas; plus a few other trace gases). There is no scientific debate on this point. Pre-industrial levels of carbon dioxide (prior to the start of the Industrial Revolution) were about 280 parts per million by volume (ppmv), and current levels are greater than 380 ppmv and increasing at a rate of 1.9 ppm yr-1 since 2000. The global concentration of CO_2 in our atmosphere today far exceeds the natural range over the last

650,000 years of 180 to 300 ppmv. According to the IPCC Special Report on Emission Scenarios (SRES), by the end of the 21st century, we could expect to see carbon dioxide concentrations of anywhere from 490 to 1260 ppm (75-350% above the pre-industrial concentration).

Hasn't the amount of carbon dioxide in the atmosphere decreased recently?

People don’t always produce more CO_2 from one year to the next. When the global economy weakens, emissions from human activities can actually drop slightly for a year or two. Yet the accumulation of CO_2 in the atmosphere continues to rise, as shown in the graph to the right. It’s a bit like a savings account: even if your contributions get smaller in a tight budget year, the total in your account still goes up.

Vegetation also makes a difference, because growing plants absorb CO_2. Large-scale atmospheric patterns such as El Niño and La Niña bring varying amounts of flooding, drought, and fires to different regions at different times, which affect global plant growth. Thus, the amount of human-produced CO2 emissions absorbed by plants varies from as little as 30% to as much as 80% from year to year. Over the long term, just over half of the CO2 we add to the atmosphere remains there for as long as a century or more. About 25% is absorbed by oceans and the rest by plants. This "balance sheet" is known as the global carbon budget.

How much carbon dioxide is already in the atmosphere?

One of the strongest pieces of evidence for human-induced climate change is the consistent rise in carbon dioxide (CO2) in modern times, as measured at the Mauna Loa Observatory in Hawaii, where CO2 has been observed since 1958. As of December 2008, the concentration of CO2 in Earth's atmosphere was about 386 parts per million (ppm), with a steady recent growth rate of about 2 ppm per year.

Current atmospheric concentrations of CO_2 are about 30% higher than they were about 150 years ago at the dawn of the industrial revolution. According to the Scripps Institution of Oceanography, ice core reconstructions going back over 400,000 years show concentrations of around 200 ppm during the ice ages and about 280 ppm during the warm interglacial periods. In other words, our current CO_2 levels are higher than they've been in at least the last 400 millennia.

Almost a quarter of the carbon dioxide emitted by human activities is absorbed by land areas; another quarter is absorbed by the ocean. The remainder stays in the atmosphere for a century or longer.

Isn't there still a lot of debate among scientists?

The scientific method is built on debate among scientists. Scientists test a question, or hypothesis, and then submit their results to the scrutiny of other experts in their field. That scrutiny, known as "peer review," includes examining the data, experimental and/or analytical methods and findings. The spirited debate around remaining uncertainties in climate science is a healthy indicator that the scientific method is alive and well, but the fundamental elements of climate change are not in disputed.

Is sea level rising?

Global mean sea level has been rising at an average rate of 1.7 mm/year (plus or minus 0.5mm) over the past 100 years, which is significantly larger than the rate averaged over the last several thousand years. Depending on which greenhouse gas increase scenario is used (high or low) projected sea-level rise is projected to be anywhere from 0.18 (low greenhouse gas increase) to 0.59 meters for the highest greenhouse gas increase scenario. However, this increase is due mainly to thermal expansion and contributions from melting alpine glaciers, and does not include any potential contributions from melting ice sheets in Greenland or Antarctica. Larger increases cannot be excluded but our current understanding of ice sheet dynamics renders uncertainties too large to be able to assess the likelihood of large-scale melting of these ice sheets.

How do the sun and solar cycles affect climate change and global warming?

Since 1750, the average amount of energy coming from the sun either remained constant or increased slightly. Estimates of the amount of energy the sun has sent to Earth are based on sunspot records dating back more than two centuries, and other proxy indicators, such as the amount of carbon in tree rings. More recently, satellite observation of solar activity from space suggest a slight increase in solar activity, but the change can't account for more than 10 percent of the warming trend seen during the past century.

Why doesn’t the temperature rise at the same rate that CO2 increases?

The amount of CO_2 is increasing from 280 ppm before the industrial revolution to a landmark of 400 ppm which is `~42.8%. A tiny amount of CO_2 and other greenhouse gases, like methane and water vapour, keep the Earth’s surface 30°Celsius (54°F) warmer than it would be without them. We have added 42% more CO_2 but that doesn't mean the temperature will go up by 42% too. There are several reasons why. Doubling the amount of CO_2 does not double the greenhouse effect. The way the climate reacts is also complex, and it is difficult to separate the effects of natural changes from man-made ones over short periods of time.

As the amount of man-made CO_2 goes up, temperatures do not rise at the same rate. In fact, although estimates vary - climate sensitivity is a hot topic in climate science, if you’ll forgive the pun - the last IPCC report (AR4) described the likely range as between 2 and 4.5 degrees C, for double the amount of CO_2 compared to pre-industrial levels. So far, the average global temperature has gone up by about 0.8 degrees C. According to an ongoing temperature analysis conducted by scientists at NASA’s Goddard Institute for Space Studies (GISS), the average global temperature on Earth has increased by about 0.8°C since 1880. Two-thirds of the warming has occurred since 1975, at a rate of roughly 0.15-0.20°C per decade. The speed of the increase is worth noting too. Unfortunately, as this quote from NASA demonstrates, anthropogenic climate change is happening very quickly compared to changes that occurred in the past. As the Earth moved out of ice ages over the past million years, the global temperature rose a total of 4 to 7 degrees Celsius over about 5,000 years. In the past century alone, the temperature has climbed 0.7 degrees Celsius, **roughly ten times faster than the average rate of ice-age-recovery warming.** Small increases in temperature can be hard to measure over short periods, because they can be masked by natural variation. For example, cycles of warming and cooling in the oceans cause temperature changes, but they are hard to separate from small changes in temperature caused by CO_2 emissions which occur at the same time.

Tiny particle emissions from burning coal or wood are also being researched, because they may be having a cooling effect. Scientists like to measure changes over long periods so that the effects of short natural variations can be distinguished from the effects of man-made CO_2.The rate of surface warming has slowed in the past decade. Yet the physical properties of CO_2 and other greenhouse gases cannot change. The same energy they were re-radiating back to Earth during previous decades must be evident now, subject only to changes in the amount of energy arriving from the sun - and we know that has changed very little. But if that's true, where is this heat going?

Climatologists prefer to combine short-term weather records into long-term periods when they analyze climate, including global averages. According to the World Meteorological Organization (WMO) the annual average temperature for the globe was **around 14.0°C during the period of** 1961 to 1990.

Rice and climate change

Global rice production has steadily increased, but there are still 852 million people who are suffering from hunger and malnutrition. There is an always question that is there any link between rice production, food security and Global climate change?

Emission

Flooded rice fields emit methane (or CH_4), which is second in importance to CO_2 as a greenhouse gas. Under anaerobic condition of submerged soils of flooded rice fields, methane is produced and much of it escapes from the soil into the atmosphere via gas spaces in the rice roots and stems, and the remainder CH_4 bubbles up from the soil and/or diffuses slowly through the soil and overlying flood water.

Sequestration

Rice cultivation is both an important sequester of carbon dioxide from the atmosphere and an important source of greenhouse gases (e.g. methane and nitrite oxide) emission. In 2004, for example, the global paddy rice output was 607.3 million tons at 14% moisture content. At the grain/straw ratio of 0.9 for most currently planted rice varieties, the global rice straw output in 2004 was about 676 million tonnes at 14% moisture content. This means that in 2004, rice sequestered about 1.74 billion tones of CO_2 from the atmosphere to produce about 1.16 billion tones of biomass at 0% moisture content.

Sustainable

Capable of being supported or upheld, as by having its weight borne from below or able to maintained or kept going, as an action or process: a sustainable negotiation between the two countries or Pertaining to a system that maintains its own viability by using techniques that allow for continual reuse: sustainable agriculture. Aquaculture is a sustainable alternative to overfishing.

Livelihood

A livelihood is a means of making a living. It encompasses people's capabilities, assets, income and activities required to secure the necessities of life. A livelihood is sustainable when it enables people to cope with and recover from shocks and stresses (such as natural disasters and economic or social upheavals) and enhance their well-being and that of future generations without undermining the natural environment or resource base.

In social sciences, the concept of livelihood extends to include social and cultural means, i.e. “the command an individual, family, or other social group has over an income and/or bundles of resources that can be used or exchanged to satisfy its needs.’’ This may involve information, cultural knowledge, social networks and legal rights as well as tools, land and other physical resources.

Sustainable livelihood

The sustainable livelihoods idea was first introduced by the Brundtland Commission on Environment and Development as a way of linking socioeconomic and ecological considerations in a cohesive, policy-relevant structure. The 1992 United Nations Conference on Environment and Development (UNCED) expanded the concept, especially in the context of Agenda 21, and advocated for the achievement of sustainable livelihoods as a broad goal for poverty eradication. It stated that sustainable livelihoods could serve as ‘an integrating factor that allows policies to address ‘development, sustainable resource management, and poverty eradication simultaneously’

Most of the discussion on SL so far as focused on rural areas and situations where people are farmers or make a living from some kind of primary self managed production. In a classic 1992 paper, Sustainable Rural Livelihood: practical concepts for the 21st century, Robert chambers and Gordon Conway proposed the following composite definition of a sustainable rural livelihood: A livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living: a livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels and in the short and long term.(UNDP,1997)

Impact of climate change on disaster

India is among the ten top disaster prone countries of the world and is vastly susceptible to floods, droughts and other disasters. Different parts of the country are prone to specific disasters. While the Himalayan region and the plains adjoining it are prone to disasters like earthquakes, landslides and floods, Peninsular India is known to be more stable. Floods and droughts owing to extreme weather conditions are common though. They are closely associated with the nature of Indian monsoon and its inter-annual fluctuations lead to devastating floods and droughts.

The recession of the glaciers, decrease of rainfall is likely to have adverse impact on water availability. At the same time, there will be increased flooding in certain areas owing to climate change. This will threaten food security and have adverse impacts on natural ecosystems and biodiversity that sustain the livelihoods of rural households.

Developing countries like India would be adversely affected; within this, the poor vulnerable communities that are not resilient to disasters will have to bear the brunt. It is well known that poverty and disaster risk are linked and poorer people are the worst sufferers during disasters. Poor are compelled to occupy marginalized spaces because of inadequate land reforms and encroachment of commons by powerful sections. Even when they try to conserve natural resources around them they are pushed further by all kind of ‘development’ activities. They are compelled to ‘encroach’ or ‘exploit’ vulnerable spaces such as steep slopes or flood plains, where they are made to live an insecure life, finding it difficult to eke out the bare minimum necessities. They have to often migrate out leaving their families on unsafe locations/ shelters during disasters. Climate change induced disasters will disrupt community livelihoods, health, education and damage housing and infrastructure of the vulnerable sections.

It is, therefore, important to look at the legislative and regulatory framework at national level related to climate change. The section below provides an overview of the institutional set-up related to disaster risk reduction as well as climate change adaptation and the need for convergence.

Impact of climate change on agriculture

India with its fifteen agro-climatic zones, diverse crop seasons and farming systems is very prone to climate change. Agriculture will on the one hand contribute to climate change and on the other will be impacted by it. As against global average of 13.5 per cent, the agriculture sector in India contributes 28 per cent to the total GHG emissions from the country.

Increased uncertainties in climatic variability have become a major challenge for sustaining agriculture as well assists allied sectors in the face of already declining natural resource base. Agriculture is the main livelihoods system of most of our people and along with allied sectors like livestock and fisheries, contributes to twenty five per cent of the country's Gross Domestic Product. India's food production is likely to be affected by the climate sensitivity of its agriculture. This in turn will impact on poverty and livelihoods.

Climate change is likely to destabilize the agricultural production in India. According to Ninan *et al.* "agricultural productivity is sensitive to two broad classes of climate-induced effects - (1) direct effects from changes in temperature, precipitation, and carbon dioxide concentrations (2) indirect effects through changes in soil moisture and the distribution and frequency of infestation by pests and diseases."

With climate change droughts and floods are becoming more frequent and intense leading to crop failures. Various studies in India, observe an increasing trend in temperature. All this showed that yield would increase if temperature remained unchanged and CO_2 levels increased. However, with increase in temperature, the CO_2 effects nullified for increase in temperature as low as 0.90 degree Celsius.

The Indian Meteorological Department (IMD) and Indian Institute of Tropical Meteorology (IITM) estimate that rainfall will increase by 15 to 40 per cent while mean annual temperature will increase by 3 to 6 degree Celsius by 2100.

Hot spots of key future climatic impacts

The IPCC (2007) report provides the hot spots of key future climate impacts and vulnerabilities as given below (p.481, WGII, Ch.10, IPCC, 2007)

- Forest production in North Asia is likely to benefit from carbon fertilization. But the Combined effects of climate change, extreme weather events and human activities are likely to increase the forest fire frequency.
- Net primary productivity of grassland in colder regions of Asia is projected to decline and shift northward due to climate change. The limited herbaceous production, heat stress from higher temperature and poor water intake due to declining rainfall could lead to reduced milk yields and increased incidence of diseases in animals.
- Cereal yields could decrease up to 30% by 2050 even in South Asia. In West Asia, climate change is likely to cause severe water stress in 21st century.
- In East Asia, for 1^oC rise in surface air temperature expected by 2020s, water demand for Agricultural irrigation would increase 6 – 10% or more.
- The gross per capita water availability in India will decline from ~1820 m3/yr in 2001 to as low as ~1140 m3 /yr in 2050

- Rice yield is projected to decrease up to 40% in irrigated lowland areas of central and southern Japan under doubled atmospheric CO_2.
- Increase in coastal water temperatures would exacerbate the abundance and/or toxity of cholera in South Asia.
- The projected relative sea level rise, including that due to thermal expansion, tectonic movement, ground subsidence and the trends of rising river water level are 70-90, 50-70and 40-60 cm in the Huanghe, Changjiang and in the Zhujiang Deltas respectively by the Year 2050.
- Around 30% of Asia‘s coral reefs are likely to be lost in the next 30 years due to multiple stresses and climate change.

Impact of climate change on migration

Climate change may lead to migration of people in different countries of the region. There has been significant attention to climate-induced migration which has grown considerably in recent years, reinforced by storms and flooding that have stimulated temporary or longer term dislocation of millions of people in countries such as Pakistan, the People‘s Republic of China, the Philippines, and Sri Lanka. Over time, climate migrants have come to incarnate the human face of climate change, though very little is yet known about the way populations will react to changes in the environment and weather (ADB, 2011). Migration depends on many factors including climate change. It is difficult to isolate climate change induced migration.

Rice and food security in a changing climate

When measured against the total greenhouse gas emissions of a country, the amount of methane emitted from rice fields ranges from only 0.1% as in USA in 2005 to about 9.8% as in India in 2006. The burning of rice residues such as straw and husks also contributes to greenhouse gas emission. Similarly the inefficient application of nitrogen fertilizers in rice production systems promotes the release of nitrous oxide, a potent greenhouse gas, into the atmosphere.

The immediate impacts of climate change on rice production systems and food security will be felt in the form of adverse effects of extreme weather events on rice production. Floods also cause indirect damage to rice production by destroying the properties and production means of farmers, and infrastructures supporting rice production such as dams, dikes, roads, etc. Less immediate but possibly even more significant impacts are anticipated due to changes in mean temperatures, increasing weather variability, and sea level rising.

Rice is the most important crop of India contributing about 43% of total food grain production which is the most important source of livelihood for the farmers in the selected Bhandara district of Maharashtra and non adoption of improvements package of practices is important constrained noticed. Considering the large yield gap in past years so there is a wide scope for decreasing the rice production due to the climate change. Bhandara is one of the district of Maharashtra and is the district of lakes and also called as the "rice bowl of Maharashtra" which is situated under the Nagpur division. There are 7 talukas under this division namely as Bhandara, Mohadi, Tumsar, Sakoli, Lakhani, Lakhandur and Pavani.

Keeping in mind the above discussion, the present study mainly focuses on the agro-economic, socio-psychological, extension communication factors and climatic factors which influences livelihood through the rice production management in the light of climate change.

Table 1.1: Methane gas emissions from rice fields in selected countries.

Country & year	**Total amount of emitted CH_4 (Gg CH4)**	**Contribution of rice methane to total methane emission (%)**	**Contribution of rice methane to total greenhouse gases emission (%)**
USA in 2005	328	1.3	0.1
Italy in 2005	70	3.7	0.3
Japan in 2004	274	24.0	0.4
China in 1994	10182	30.0	5.9
India in 2006	6600	35.0	9.8

Source: Leip, Bocchi, 2007

Table 1.1, it showed that the contribution of rice methane to total greenhouse gases emission (%) was low (0.1) in USA during 2005 and the contribution of rice methane to total greenhouse gases emission (%) was high (9.8) in India during 2006.The contribution of rice methane to total methane emission (%) was low (1.3) in USA during 2005 and contribution of rice methane to total methane emission (%) was highest (35.0) in India during 2006. The total amount of emitted CH_4 was low (70) in Italy during 2005 and total amount of emitted CH_4 was highest (10182) in China during 1994.

Table 1.2: Local coping strategies as adaptation tools to mitigate the impacts of climate change in agriculture.

Sub region / country	Local area	Natural disaster	Impacts	Adaptation action	Local coping strategies
Maharashtra	Drought and /aridity	Water shortage/soil erosion	Rainwater harvesting	Building ground barriers and shallow excavations through various barriers	Diversification, Using stored water efficiency
Nepal	-	Extreme cold	Loss of crops	Post-harvest management	Processing green and leafy vegetables
Gujarat	Drought/ aridity	Water shortage	Desalting, cleaning, and deepening of ponds to collect rain water	Rainwater harvesting	-

Bhutan	Wangling, jangbi,phumzur, villages in trongsa district	Erratic rainfall	Loss of crops	Diet diversification	Harvesting wild vegetables, fruits and tubers from the forest by the Monpas, a Bhutaneses ethnic group
Rajasthan	Drought/ aridity	Water shortage	Rain water harvesting	Harvesting water and recharging ground water with earthen check dams	-
Pakistan	Sindh	Droughts and aridity	water shortage	Sustainable water management	Building laths at different levels to irrigate fields

Source: Adapted from ADB and IFPRI (2009)

Table 1.2, it showed that the local coping strategies used for climate change in the state of Maharashtra- Diversification and using stored water efficiency under the local area drought and aridity. For Nepal-processing green and leafy vegetables under extreme cold condition. For Bhutan-Harvesting wild vegetables, fruits and tubers from the forest by the monpas, a Bhutanese ethnic group in villages in trongsa district and for Pakistan-building laths at different levels to irrigate fields under drought/aridity condition.

Table 1.3: Climate data for Maharashtra

Climate data for Maharashtra							
Month	**Jan**	**Feb**	**Mar**	**April**	**May**	**Jun**	**Year**
Average high °C (°F)	29.9 (85.8)	31.9 (89.4)	35.4 (95.7)	37.7 (99.9)	28.4 (98.4)	31.7 (89.1	31.59 (88.86)
Average low °C (°F)	11.0 (51.8)	12.1 (53.8)	15.8 (60.4)	19.9 (67.8)	22.4 (72.3)	22.9 (73.2)	17.76 (63.96)
Precipitation (inches)	0 (0)	3 (0.12)	2 (0.08)	11 (0.43)	40 (1.57)	138 (5.43)	741 (29.17)
Avg. precipitation days	0.1	0.3	0.3	1.1	3.3	10.9	67.8

Month	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Average high °C (°F)	28.4 (83.1)	27.4 (81.3)	29.4 (84.9)	31.4 (88.5)	30.1 (86.2)	28.9 (84)	31.59 (88.86)
Average low °C (°F)	22.2 (72)	21.6 (70.9)	20.8 (69.4)	18.5 (65.3)	14.4 (57.9)	11.5 (52.7)	17.76 (63.96)
Precipitation mm (inches)	163 (6.42)	129 (5.08)	155 (6.1)	68 (2.68)	28 (1.1)	4 (0.16)	741 (29.17)
Avg. precipitation days	17.0	16.2	10.9	5.0	2.4	0.3	67.8

Source: **Local Weather Report** . Local Weather Report and Forecast Department. 21 May 2012**. Retrieved 18 July 2012.**

Table 1.3, it showed that the minimum average high ^{o}C (^{0}F) was 27.4 (81.3) during the month of august and maximum average high ^{o}C (^{0}F) was 37.7 (99.9) during the month of april. The minimum average low ^{o}C (^{0}F) was 11.0 (51.8) during the month of january and maximum average low ^{o}C (^{0}F) was 22.9 (73.2) during the month of june. The minimum precipitation mm (inches) was 0 (0) during the month of january and maximum precipitation mm (inches) was 163 (6.42) during the month of july.

Table 1.4: Climate data for Bhandara district

Climate data For Bhandara							
Month	**Jan**	**Feb**	**Mar**	**April**	**May**	**Jun**	**Year**
Average high ^{o}C (^{0}F)	27.6 (81.7)	31.1 (88)	35.2 (95.4)	39.0 (102.2)	42.1. (107.8)	38.1 (100.6)	32.71 (90.88)
Average low ^{o}C (^{0}F)	13.3 (55.9)	15.4 (59.7)	19.6 (67.3)	24.6 (76.3)	28.9 (84)	27.4 (81.3)	20.9 (69.62)
Precipitation mm (inches)	11.9 (0.469)	34.8 (1.37)	17.0 (0.669)	17.3 (0.681)	15.5 (0.61)	215.1 (8.469)	1388.2 (54,654)
Avg. precipitation days	1	1.2	1.4	1.1	1.4	8.7	57.9

Month	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Average high ^{o}C (^{0}F)	30.5 (86.9)	29.9 (85.8)	30.8 (87.4)	31.0 (87.8)	29.3 (84.7)	27.9 (82.2)	32.71 (90.88)
Average low ^{o}C (^{0}F)	24.3 (75.7)	24.1 (75.4)	23.9 (75)	21.2 (70.2)	15.2 (59.4)	12.9 (55.2)	20.9 (69.62)

Precipitation mm (inches)	413.3 (16.272)	387.9 (15.272)	207.3 (8.161)	44.5 (1.752)	15.5 (0.61)	8.1 (0.319)	1388.2 (54,654)
Avg. precipitation days	15.5	13.8	9	2.9	1.1	0.9	57.9

Source: **Local Weather Report** . Local Weather Report and Forecast Department. 21 May 2012**. Retrieved 18 July 2012.**

Table 1.4, it showed that the minimum average high ^{o}c (^{0}f) was 27.6 (81.7) during the month of january and maximum average high ^{o}c (^{0}f) was 42.1 (107.8) during the month of may. The minimum average low ^{o}c (^{0}f) was 13.3 (55.9) during the month of january and maximum average low ^{o}c (^{0}f) was 28.9 (84) during the month of may. The minimum precipitation mm (inches) was 8.1 (0.319) during the month of december and maximum precipitation mm (inches) was 413.3 (16.272) during the month of july.

Table 1.5: Means of area, production and productivity of rice during the decades of Maharashtra.

Particulars

	1960-61 to 1969-70	1970-71 to 1979-80	1980-81 to 1989-90	1990-91 to 1999-2009
Area (‘000’ ha	1334.70	1358.0	1490.50	1534.33
Production (‘000’ mt	1314.70	1533.50	2173.40	2424.00
Productivity (t\ha)	0.99	1.13	1.46	1.94

Source-Maharashtra State Statistics Dept, Pune. (2008-09).

Table 1.5, it showed that the total rice area during 1960-61 to 1969-70 was 1334.70 ha, during 1970-71 to 1979-80 was

1358.0 ha, during 1980-81 to 1989-90 was 1490.50 ha and during 1990-91 to 1999-2009 was 1534.33ha. The total production of rice during 1960-61 to 1969-70 was 1314.70 mt, during 1970-71 to 1979-80 was 1533.50 mt, during 1980-81 to 1989-90 was 2173.40 mt and during 1990-91 to 1999-2009 was 2424.00 mt. The total Productivity of rice during 1960-61 to 1969-70 was 0.99(t\ha), during 1970-71 to 1979-80 was 1.13(t\ha), during 1980-81 to 1989-90 was 1.46(t\ha), and during 1990-91 to 1999-2009 was 1.94 (t\ha).

Table 1.6: Total rice production year wise in Bhandara district

Year	Area in hectare	Average production kg/h
2001-02	161591	1373
2002-03	177146	800
2003-04	179046	1554
2004-05	179046	743
2005-06	181591	1724
2006-07	179046	1451
2007-08	179046	1788
2008-09	179046	721
2009-10	181591	1132
2010-11	181591	1459
2011-12	179046	1733
2012-13	179046	641
2013-14	179046	1661

Source: Divisional kharip progress report, State agriculture Dept. (2014-15),

Govt. Of Maharashtra.

Table 1.6, it showed that average highest rice production of Bhandara district was 1788 kg/h in179046 hectare area during the year 2007-08 and average lowest rice production of Bhandara district was 641 kg/h in 179046 hectare area during the year 2012-13.

Table 1.7: Classifications of high yielding varieties in Bhandara district

Variety type	Name of variety	Size	Crop period in days	Average yield q/h
Early variety	Sakoli-6	Medium	115-120 days	40-45
	Sindewahi-1	Medium	115-120 days	40-45
	Sindewahi-2001	Medium	125-130 days	45-50
	PKV Ganesh	Medium	126-128 days	40-45
Medium variety	PKV.HMT.selection	Fine	135-140 days	40-45
	Jayshriram	Fine size	135-140 days	35-40
	1001	Bold	135-140 days	35-40
	Suvarna	Medium	135-140 days	40-45
	HMT	Fine	135-140 days	40-45
	IR-36	Medium	135-140 days	40-45
	Jaya	Medium	135-140 days	40-45
	PNR-381	Medium	135-140 days	40-45
	JGL-384	Medium	135-140 days	40-45
Late variety	MTU-2001	Medium	140-145 days	40-45

	Sakoli-8	Fine	140-145 days	45-55
	Sindewahi-5	Bold	145-150 days	45-55
Scented variety	Sakoli-7	Fine	135-140 days	45-50
	Chinnor	Fine	145-150 days	45-55
	Dubrat	Medium	145-150 days	45-55
	PKV makarand	Medium	145-150 days	45-55
	PKV khamang	Fine	145-150 days	40-45
	Basmati	Fine	145-150 days	45-55
Hybrid variety	Sahyadri	Fine	135-140 days	45-50

Source: Rice cultivation bulletin, Dr. P. D .K .V. Akola.

Table 1.7, it showed that the high yielding varieties are classified in to four groups ie. **Early variety** including, Sakoli-6, Sindewahi-1, Sindewahi-2001, PKV Ganesh having their crop period minimum 115 to maximum 130 days with their average yield 40-45 q/h. **Medium variety** including PKV.HMT.selection, Jayshriram, 1001, Suvarna, HMT, IR-36, Jaya, PNR-381, JGL-384 are having their crop period minimum 135 to maximum 140 days with their average yield 40-45 q/h. **Late variety** including, MTU-2001, Sakoli-8 and Sindewahi-5 are having their crop period minimum 140to maximum 150 days with their average yield 40-55 q/h. **Scented variety** including, Sakoli-7,Chinnor, dubrat PKV Makarand , PKV Khamang, and Basmati are having their crop period minimum 135 to maximum 150 days with their average yield 40-55 q/h. **Hybrid variety** including, Sahyadri is having crop period minimum 135 to maximum 150 days with average yield 40-55 q/h.

General objective:

To study the impact of climate change on sustainable livelihood generation through rice production management in some selected area of Bhandara district in Maharashtra.

Specific objectives:

- To study the agro-economic, socio-psychological and extension communication characteristics of rice growers.
- To study the rice management practices both in Conventional and System of intensification farming situation in terms of livelihood.
- To identify the climatic factors having impact on the production behavior of rice as well as the health.
- To study the constraints in the rice management practices in the light of climate change.
- To derive some suggested intervention to combat the challenge of climate change.

Need for the study

It is increasingly argued that many climate change studies, whilst effective in alerting policymakers to the possible effect of climate change, have had limited usefulness in providing local-scale guidance on adaptation, and that the rice farming community under climate change situation should learn from experiences gained in food security and natural hazard studies.

Climate change is impacting on health, rice production, pests and diseases, weed pattern and on sustainable livelihood generation. Rice production-the mainstay of rural food and economy suffers a lot from erratic weather pattern such as heat stress, longer dry season and uncertain rainfall pattern. Declined yield due to unfavorable weather and climate will lead to vulnerability in the form of food insecurity, hunger and shorter life expectancies.

Management of rice production in the area where every aspect associated with rice can be dealt efficiently viz technology, adoption and marketing in the light of climate change. There is a also need to highlight the farmer perception about climate change for rice yield fluctuation and their operational strategy as to mitigate the blunt of climate change for sustainable livelihood.

In order to understand, the present study based on to explore and assess the impacts of climate changes on the sustainability of livelihood generation through the management of rice production technologies in particular, of the selected areas.

Limitations of the study

The study was undertaken in a limited area i.e. Bhandara and Sakoli block under the district of Bhandara district in Maharashtra. Being a time bond research programme, it was very difficult to cover the larger sample from wider operational area with more dissemination of the study. More over the correctness of the responses, which were based on primary recall, in spite of the investigator leave margin for error to creep in. There was also the problem of inadequate resources, while collecting the data. However, every effort and thought was exercised in making the study objectively and systematically in an orderly manner.

Organization of the thesis

The thesis has been divided into seven chapters. The second chapter, following the first of Introduction deals with the Theoretical orientation of the study. The third chapter deals with the Review of literature related with the study. The fourth chapter deals with Research setting. The fifth chapter Research methodology includes methodological framework adopted to achieve the various objectives of the present study. The sixth chapter contains the Results and discussion. The Summary, Conclusion, and Future scope of research have been presented in the seventh chapter. Lastly the Appendices, including the Interview schedule have been presented.