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Lecture: 13

CLIMATOLOGY

Topics Covered: CLIMATOLOGY

Atmosphere

- **Composition:** Gases, Water Vapor, Dust Particles
- **Structure:** Exosphere, Thermosphere, Mesosphere, Stratosphere, Troposphere,
- **Temperature:** Altitude vs. Temperature, Inversion of Temperature
  - Factors controlling Temperature distribution
- Distribution of Temperature Month of January-July

Climatology

Climatology is the **scientific study** of **climate**. It is a branch of the **atmospheric sciences** concerned with the **description** of the climate, the **analysis** of the **causes** of climatic **differences** and **changes** and their **practical consequences.**

Climate vs Weather

Parameter	Climate	Weather
Definition	Describes the average conditions expected at a specific place at a given time. A region's climate is generated by the climate system, which has five components: atmosphere, hydrosphere, cryosphere, land surface, and biosphere.	Describes the atmospheric conditions at a specific place at a specific point in time. Weather generally refers to day-to-day temperature and precipitation activity
Components	Climate may include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail storms over a long period of time.	Weather includes sunshine, rain, cloud cover, winds, hail, snow, sleet, freezing rain, flooding, blizzards, ice storms, thunderstorms, steady rains from a cold front or warm front, excessive heat, heat waves and more
Forecast	By aggregates of weather statistics over periods of 30 years	By collecting meteorological data, like air temperature, pressure, humidity, solar radiation, wind speeds and direction etc.
Determining factors	Aggregating weather statistics over periods of 30 years ("climate normals").	Real-time measurements of atmospheric pressure, temperature, wind speed and direction, humidity, precipitation, cloud cover, and other variables

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Parameter	Climate	Weather
About	Climate is defined as statistical weather information that describes the variation of weather at a given place for a specified interval.	Weather is the day-to-day state of the atmosphere, and its short-term (minutes to weeks) variation
Time period	Measured over a long period	Measured for short term
Study	Climatology	Meteorology

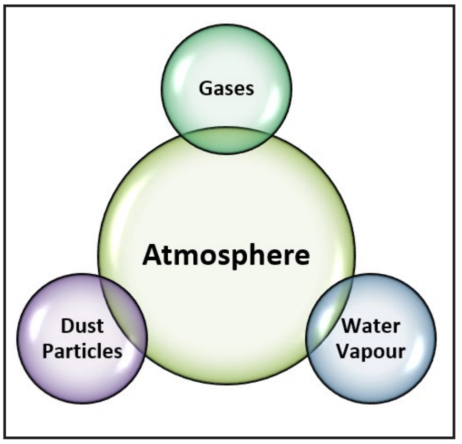
ATMOSPHERE

The atmosphere is the layer of gases that surrounds a celestial body, such as a planet or a moon.

- **Mars,** a neighboring planet to Earth, also has an atmosphere, although it is much thinner compared to Earth's. The Martian atmosphere is predominantly composed of **carbon dioxide (around 95.3%),** with **nitrogen, argon,** and trace amounts of other gases. The thin atmosphere on Mars cannot support human life as we know it, and it does not provide significant protection against harmful solar radiation.
- **Venus,** another neighboring planet, has an atmosphere that is mainly composed **of carbon dioxide (around 96.5%)** and thick clouds of **sulfuric acid.** The atmosphere on Venus is incredibly dense and generates a strong **greenhouse effect,** resulting in surface temperatures that can melt lead. This makes Venus the hottest planet in our solar system, despite being farther from the Sun than Mercury.
- On **Earth,** the atmosphere is crucial for supporting life and plays a vital role in regulating the planet's **climate.** The Earth's atmosphere is a dynamic and complex mixture of gases, water vapor, and dust particles. These components also play crucial roles in **shaping weather patterns.**
- The **earth** is enveloped entirely by **air,** creating a **spherical shape** that is flatter at the **poles** and bulging at the **Equator** due to the combined influence of **gravity** and the **Earth's rotation,** similar to an **egg's shape.**
- The atmosphere can be divided into several **layers** or **spheres,** each concentric with the **Earth,** exhibiting different **temperature** and **chemical characteristics.**
- The force of **gravity** is responsible for holding the atmosphere to the **planet**, and it also determines the composition of **gases** present within it.

Gases in the Atmosphere

- The **atmosphere** consists mainly of different **gases**, with **nitrogen** and **oxygen** being the most abundant. Other gases like **carbon dioxide, water vapor**, **methane, ozone,** and noble gases like **argon** are also present in smaller quantities.
- **Nitrogen (N_2):** It is the most abundant gas, making up approximately **78%** of the air we breathe. Plants and animals use nitrogen to build proteins and other organic molecules.



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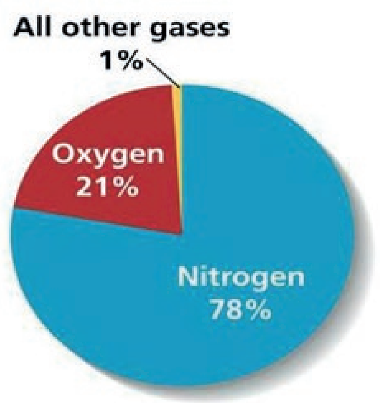
- **Oxygen (O_2):** Oxygen accounts for about **21%** of the atmosphere. It is essential for respiration, as organisms use it to extract energy from food through cellular respiration.
- **Carbon Dioxide (CO_2):** Though it constitutes a small fraction (around **0.04%**), carbon dioxide plays a crucial role in the greenhouse effect. It traps heat, keeping the Earth warm enough to support life. Increased human activities like burning fossil fuels have raised CO_2 levels, contributing to global warming.
- **Methane (CH_4):** Methane is a potent greenhouse gas, even though its concentration is relatively low. It is released from various sources, including natural wetlands, livestock, and fossil fuel extraction.
- **Ozone (O_3):** Ozone is a molecule with three oxygen atoms. It exists in two main layers of the atmosphere: the **stratosphere,** where it shields life on Earth from harmful ultraviolet (UV) radiation, and the **troposphere,** where it contributes to pollution and smog formation.



Gas	Percentage by Volume
Nitrogen (N_2)	78.084
Oxygen (O_2)	20.946
Argon (Ar)	0.934
Carbon dioxide (CO_2)	0.037
Neon (Ne)	0.00182
Helium (He)	0.00052
Methane (CH_4)	0.00015
Krypton (Kr)	0.00011

Water Vapor

Water vapor is the gaseous form of water in the atmosphere. It plays a crucial role in the **water cycle,** evaporating from water bodies, forming clouds, and eventually falling as rain or snow. Water vapor influences weather patterns, cloud formation, and precipitation.

Examples of Weather Phenomena Involving Water Vapor:

- **Evaporation and Condensation:** Water bodies exposed to sunlight undergo **evaporation,** converting water into water vapor in the air. When the air cools, water vapor **condenses** into clouds.
- **Humidity:** Humidity represents the amount of water vapor in the air relative to its maximum capacity. High humidity can make us feel uncomfortable.
- **Clouds:** Rising moist air cools and forms clouds as water vapor condenses into tiny droplets or ice crystals.
- **Precipitation:** Water droplets or ice crystals in clouds grow and fall to the Earth as rain, snow, sleet, or hail.
- **Greenhouse Effect:** Water vapor is a **potent greenhouse gas** that traps heat in the Earth's atmosphere, maintaining a habitable temperature range.

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Dust Particles

Dust particles in the atmosphere are tiny solid particles originating from natural sources like wind erosion, volcanic eruptions, and dust storms, as well as human activities like burning fossil fuels, agriculture, and construction.

Examples of Dust Particles:

- **Mineral Dust:** Commonly from deserts and dry regions, carried by wind.
- **Volcanic Ash:** Released during volcanic eruptions, affecting weather and posing hazards.
- **Soot and Black Carbon:** Resulting from incomplete combustion, contributing to air pollution and global warming.
- **Pollen:** Airborne during pollen season, causing allergies in some individuals.

Effects of Dust Particles in the Atmosphere:

- **Atmospheric Cooling:** Certain dust particles, like volcanic ash, reflect sunlight, causing temporary cooling.
- **Air Quality and Health:** Inhalation of dust particles can lead to respiratory problems.
- **Climate Impact:** Dust particles influence cloud formation and weather patterns.
- **Nutrient Transport:** Dust can carry essential nutrients like phosphorus and iron to other ecosystems.

Understanding atmospheric composition is vital for addressing environmental challenges and ensuring a sustainable future.

Structure of Atmosphere

Structure of Atmosphere

The Earth's atmosphere is divided into several distinct layers based on their temperature and composition. Each layer has its **unique characteristics** and plays a **crucial role** in the Earth's climate and **atmospheric processes.** Let's explore the **structure of the atmosphere** and the features of each layer:

Troposphere:

- **The troposphere** is the **lowest layer** of the atmosphere, extending from the Earth's surface up to an average altitude of about 7 to 17 kilometers (4 to 11 miles).
- **Features:**
  - **Weather:** The troposphere is where most of the **weather phenomena** occur. As air rises and cools, it can **condense** to form clouds and precipitation. Vertical air movements in the troposphere lead to the formation of **thunderstorms, hurricanes,** and other **weather events.**
  - **Jet Streams:** High-altitude, fast-moving air currents known as **jet streams** are found within the upper part of the troposphere, influencing weather patterns and air travel routes.
- **Boundary:** The upper boundary of the troposphere is called the **tropopause**. It acts as a stable boundary between the troposphere and the stratosphere and varies in height with latitude and season.
- **For Example:**
  - Rainfall occurs in the troposphere as warm, moist air rises and cools, leading to **condensation** and **cloud formation.**

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- Thunderstorms and hurricanes, driven by convective processes, are typical weather events that occur within the troposphere.

Stratosphere:

- **The stratosphere** lies above the troposphere and extends up to about 50 kilometers (31 miles) above the Earth's surface.
- **Features:**
  - **Ozone Layer:** The stratosphere contains a high concentration of **ozone (O_3)** in the ozone layer. Ozone absorbs most of the **Sun's harmful UV radiation,** protecting life on Earth from its damaging effects.
- **Boundary:** The upper boundary of the stratosphere is called the **stratopause**. It separates the stratosphere from the mesosphere and marks the region where the temperature starts to increase with altitude.
- **For Example:** Stratospheric **ozone** is crucial for protecting life on Earth from harmful UV radiation. Human activities, such as the release of **ozone-depleting substances,** can lead to thinning of the ozone layer, resulting in increased UV radiation reaching the Earth's surface.

Mesosphere:

- **The mesosphere** is located above the stratosphere and extends up to about 85 kilometers (53 miles) in altitude.
- **Features:**
  - **Shooting Stars:** The mesosphere is where most **meteoroids burn up** upon entering the Earth's atmosphere. The friction with the air causes them to heat up and produce streaks of light known as **shooting stars** or **meteors**.
- **Boundary:** The upper boundary of the mesosphere is called the **mesopause.** It separates the mesosphere from the thermosphere and is characterized by its extremely low temperatures.
- **For Example:** No specific human activities or technology are directly related to the mesosphere. However, it plays a role in **protecting the Earth's surface** from meteoroid impacts.

Thermosphere:

- **The thermosphere** lies above the mesosphere and extends up to about 600 kilometers (372 miles) above the Earth's surface.
- **Features:**
  - **Auroras:** The thermosphere is where the **auroras**, such as the Northern and Southern Lights, occur. Charged particles from the solar wind interact with gases in the thermosphere, producing the beautiful **light displays.**
- **Boundary:** The upper boundary of the thermosphere is not precisely defined, as the transition between the thermosphere and the exosphere is gradual. This region is called the **thermopause**.
- **Example:** The International Space Station (ISS) orbits within the lower thermosphere. Its relatively low atmospheric density allows it to stay in orbit while experiencing very little **drag.**

Ionosphere:

- **The ionosphere** is a region within the thermosphere and the upper mesosphere. It is characterized by the presence of ionized gases (ions) due to the absorption of solar ultraviolet and X-ray radiation.

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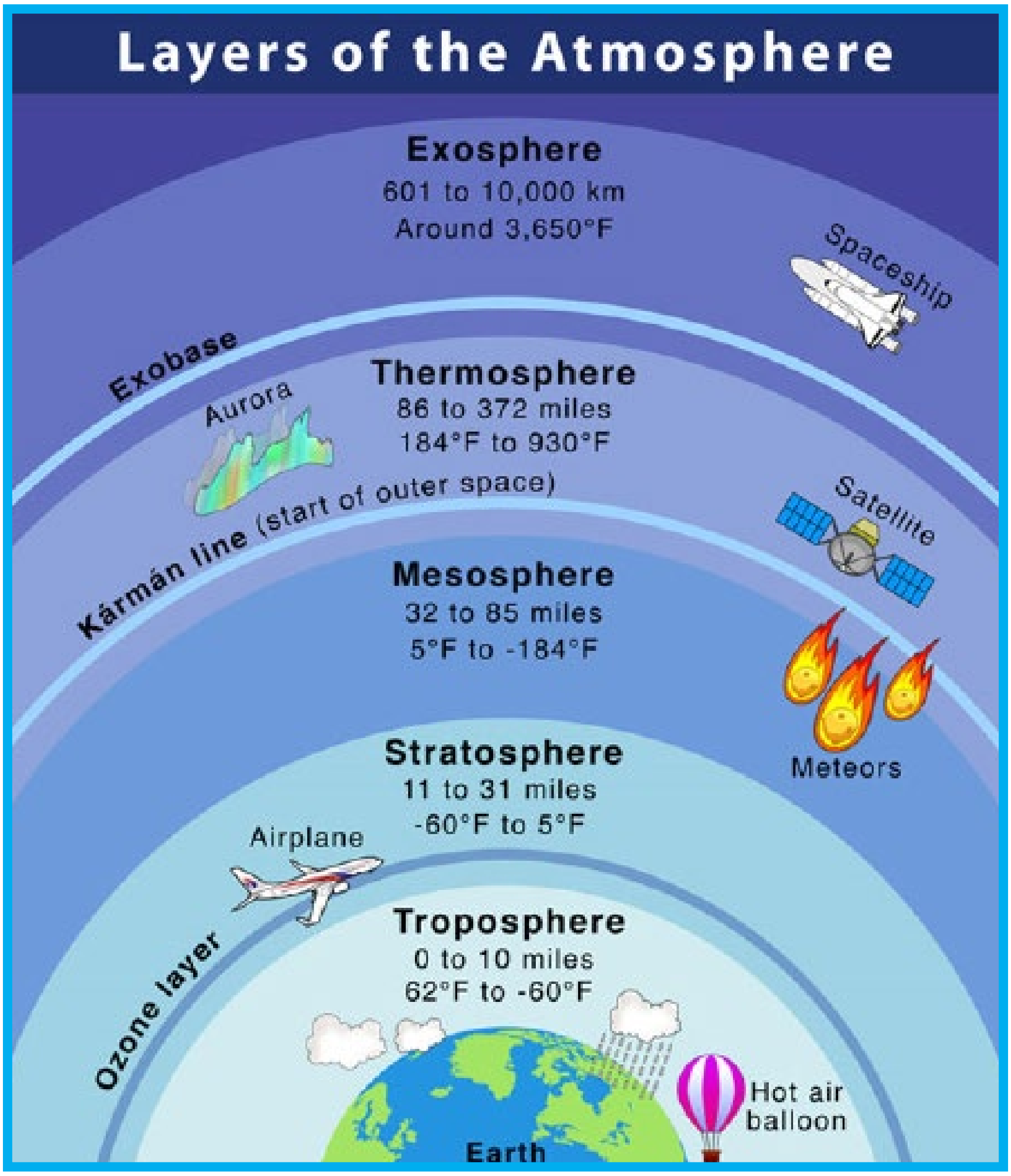
- **Features:**
  - **Ionization:** Solar radiation in the ionosphere is energetic enough to **strip electrons** from atoms, creating free ions. This ionization affects the behavior of **radio waves**, allowing long-distance radio communication via reflection and refraction of signals back to the Earth's surface.
  - **Different Layers:** The ionosphere consists of several layers named **D, E, F1,** and **F2**. The presence and characteristics of these layers vary with solar activity and time of day.
  - **Radio signals**, such as AM, FM, and shortwave broadcasts, can bounce off the ionosphere and return to the Earth's surface, enabling **long-range communication.**



Exosphere:

- **The exosphere** is the **outermost layer** of the Earth's atmosphere, transitioning into outer space. It extends beyond the thermosphere and has a very low density of gas molecules.

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- **Features:**
  - **Low Density:** The exosphere contains very few air molecules, and **collisions between molecules are rare.**
  - **Transition to Space:** In the exosphere, atmospheric gases become extremely sparse, and individual gas particles can travel great distances before colliding with another particle. Eventually, these particles **escape the Earth's gravitational pull** and enter space.
  - **No Well-Defined Boundary:** The exosphere gradually fades into the emptiness of space, and there is **no clear boundary** between the Earth's atmosphere and space.
  - **For Example:** Satellites and space probes operate within the exosphere and beyond, **orbiting the Earth** or exploring other celestial bodies.

In summary, the Earth's atmosphere consists of several layers, each with its **distinct characteristics** and **functions**. These layers interact and play a **crucial role** in shaping the planet's **climate, weather patterns,** and protecting life from **harmful radiation**. Understanding the **structure and dynamics** of the atmosphere is essential for various scientific disciplines, including **meteorology, climatology,** and **space exploration.**

TEMPERATURE

- **Temperature** is a **relative measure** or indication of **hotness** or **coldness.**
- A **hot** utensil is said to have a **high temperature**, and an **ice cube** to have a **low temperature.**
- An object with a **higher temperature** than another is said to be **hotter.**
- Temperature is a measure of how fast the atoms in a material are **vibrating.**
- **High-temperature** particles **vibrate faster** than **low temperature particles.**
- Rapidly vibrating atoms **smash together**, which generates **heat**.
- As a material **cools down**, the atoms vibrate more slowly and **collide less frequently**. As a result, they emit **less heat**.

What is the difference between heat and temperature?

- Heat is a form of energy while temperature denotes the intensity of hotness or coldness of any substance.
- Heat denotes the quantity of energy present in any substance while temperature refers to the degree of hotness of that substance.

Which has higher heat, and which has a higher temperature: a candle flame or a bathtub full of hot water?

- The flame has a higher temperature, but less heat, because the hot region is very small.
- The bathtub has a lower temperature but contains much more heat because it has many more vibrating atoms. The bathtub has greater total energy.

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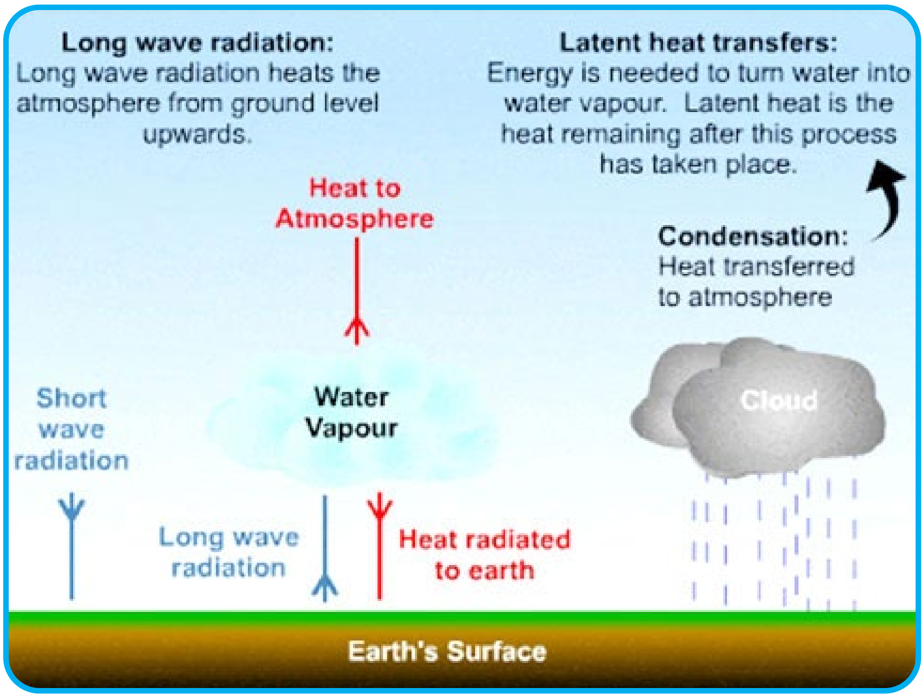
HEAT

- **Heat is the form of energy transferred between two (or more) systems or a system and its surroundings by virtue of temperature difference.**
- Heat is taken in or released when an object changes state, or changes from a gas to a liquid, or a liquid to a solid.
- **This heat is called latent heat.** When a substance changes state, latent heat is released or absorbed.
- A substance that is changing its state of matter does not change temperature.
- All of the energy that is released or absorbed goes toward changing the material's state.

Example:

Imagine a pot of boiling water on a stove burner: That water is at 100° C (212° F). If you increase the temperature of the burner, more heat enters the water. The water remains at its boiling temperature, but the additional energy goes into changing the water from liquid to gas. With more heat, the water evaporates more rapidly. When water changes from a liquid to a gas it takes in heat. Since evaporation takes in heat, this is called evaporative cooling. Evaporative cooling is an inexpensive way to cool homes in hot, dry areas.

The SI unit of heat energy transferred is expressed in joule (J) while the SI unit of temperature is Kelvin (K), and °C is a commonly used temperature unit.



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LAPSE RATE

- ***The atmospheric lapse rate refers to the change of an atmospheric variable with a change of altitude***, the variable being temperature unless specified otherwise (such as pressure, density or humidity).
- While usually applied to Earth's atmosphere, the concept of lapse rate can be extended to atmospheres (if any) that exist on other planets.
- Lapse rates are usually expressed as the amount of temperature change associated with a specified amount of altitude change, such as 9.8 °Kelvin (K) per kilometer, 0.0098 °K per meter or the equivalent 5.4 °F per 1000 feet.

If the atmospheric air cools with increasing altitude, the lapse rate may be expressed as a negative number. If the air heats with increasing altitude, the lapse rate may be expressed as a positive number.

Types of lapse rates

- There are ***three types*** of lapse rates that are used to express the rate of temperature change with a change in altitude, ***namely-***

  1. The dry adiabatic lapse rate
  2. The wet adiabatic lapse rate
  3. The environmental lapse rate

1. Dry adiabatic lapse rate

- **Atmospheric pressure** decreases with altitude, causing the **volume** of an air parcel to **expand** as it rises.
- Conversely, a sinking air parcel from a higher to a lower altitude experiences **compression** due to the higher pressure at the lower altitude.
- **Adiabatic lapse rate** is the rate at which the **temperature** of an air parcel changes in response to expansion or compression during changes in altitude, assuming **no heat exchange** occurs during the process.
- **Saturated air:** Earth's atmospheric air usually contains some **water vapor.** When it contains as much water vapor as it can hold, it's referred to as **saturated air** (relative humidity of **100%**).
- **Dry adiabatic lapse rate:** The lapse rate of **unsaturated air** (relative humidity less than **100%**).
- Also known as d**ry adiabatic, DALR,** or **unsaturated lapse rate**.
- The term "dry" indicates **no liquid water** (moisture) is present in the air, but water vapor may still be present.
- **Troposphere:** The **lowest layer** of the Earth's atmosphere where almost all **human activity** takes place.
- **Dry adiabatic lapse rate** is **approximately constant** in the troposphere due to **little variation** in **gravity (g)** and **specific heat capacity of dry air (cpd)** with altitude.

2. Wet adiabatic lapse rate

- An **unsaturated parcel of air** will rise from Earth's surface and **cool** at the **dry adiabatic rate** of – 9.8 K / kilometer until it reaches the **atmospheric dew point.**
- At the **dew point temperature,** the air parcel becomes **saturated**, and the rate of cooling will **decrease** to the **wet adiabatic lapse rate** (SALR or MALR).

- The **wet adiabatic lapse rate** is not constant and depends on the amount of **water vapor** the air contained when it started to rise, resulting in variable heat release.
- In the **troposphere**, the rate can vary from about **4 K / kilometer** (2.2 °F / 1000 ft) at **25 °C** (77 °F) to about **7 K / kilometer** (3.8 °F / 1000 ft) at **– 10 °C** (14 °F).
- After reaching the **dew point** and cooling at the **wet adiabatic lapse rate,** the air parcel will continue to rise until all of its **water vapor** has condensed, and its cooling rate will revert back to the **dry adiabatic lapse rate**.

3. Environmental lapse rate

- The dry adiabatic lapse rate and the wet adiabatic lapse rate are both theoretical rates.
- ***The actual real-world profile of temperature versus altitude that exists at any given time and in any given geographical location is called the environmental lapse rate, also often referred to as the ELR, prevailing lapse rate or ambient lapse rate.***

Altitude v/s Temperature

- **In Troposphere:** The **temperature** in the troposphere generally **decreases** with altitude at an average rate of about **6.5°C per kilometer** (3.6°F per 1,000 feet), known as the **environmental lapse rate.**
  - Cooling occurs because the troposphere is primarily **heated from below.** The Earth's surface is heated by the **Sun**, warming the air in contact with it.
  - Moving higher, the air encounters **lower pressure**, expanding and cooling, resulting in **cooler temperatures** at higher altitudes.
- **In Stratosphere:** The **temperature trend** is different. The lower part of the stratosphere has a slight **increase in temperature** with altitude, while the upper part experiences a **warming effect** known as the **stratopause**.
  - Warming is primarily due to the presence of the **ozone layer,** where ozone (O3) molecules **absorb and scatter** the Sun's **ultraviolet (UV) radiation.** This absorbed energy heats the surrounding air, causing the temperature to rise with increasing altitude.
- **In Mesosphere:** Above the stratosphere is the **mesosphere**, where temperatures start to decrease again with altitude. The temperature reaches its **coldest point** at the **mesopause**, as low as **-90°C** (-130°F).
  - Cooling occurs because there is **less heat-absorbing gas** compared to the stratosphere, and the **density of air molecules decreases** with altitude, resulting in a temperature decrease with height.
- **Thermosphere and Exosphere:** In the thermosphere and exosphere, the relationship between altitude and temperature becomes more complex due to the presence of highly energetic particles from the Sun.
  - The thermosphere experiences **a rapid increase** in temperature due to the **absorption of intense solar radiation.**
  - The exosphere has very high temperatures for individual molecules despite an **overall low density.**
- **Overall,** the altitude vs. temperature relationship in the Earth's atmosphere is crucial for understanding weather patterns, climate dynamics, and the behavior of various atmospheric layers. It influences many atmospheric processes, from the formation of clouds and precipitation in the troposphere to the absorption of harmful UV radiation by the ozone layer in the stratosphere.

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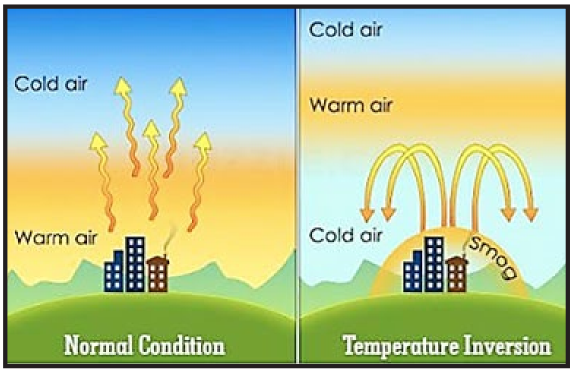
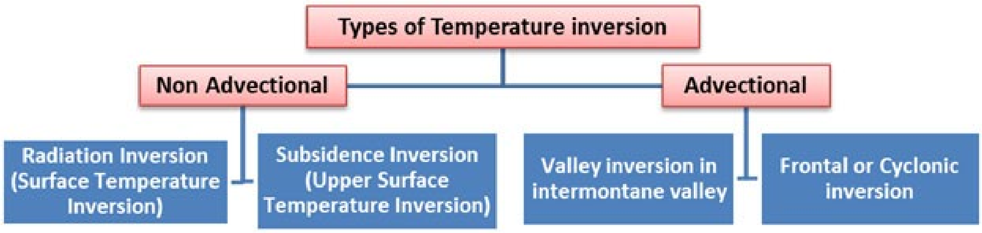
Inversion of temperature

- **Under normal conditions, temperature** usually **decreases** with an **increase in altitude** in the troposphere at a rate of **1 degree** for every **165 meters.** This is called **normal lapse rate.**
- **Inversion of temperature** in the atmosphere refers to a situation where the **normal decrease** in temperature with increasing altitude is **reversed**, leading to **warmer air above cooler air.**
- **Inversions** occur when a **layer of warm air** is **trapped above** a **layer of cooler air,** preventing the usual vertical mixing of the atmosphere. They can have significant effects on **weather and air quality.**



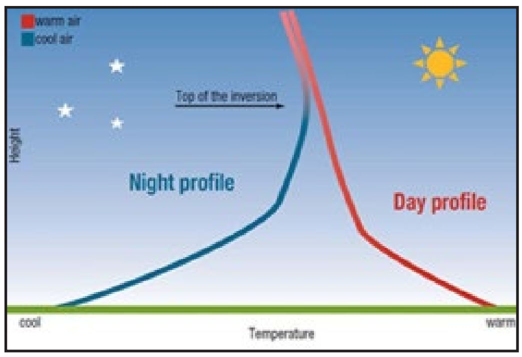
Favorable Conditions for Temperature Inversion:

- **Long winter nights:** Loss of heat by **terrestrial radiation** from the ground surface during the night may exceed the amount of incoming solar radiation.
- **Cloudless and clear sky:** Loss of heat through terrestrial radiation proceeds more rapidly without any obstruction.
- **Dry air** near the ground surface: It limits the absorption of the radiated heat from the Earth's surface.
- **Slow movement of air:** It results in no transfer or mixing of heat in the lower layers of the atmosphere.
- **Snow-covered ground surface:** It results in the maximum loss of heat through reflection of incoming solar radiation.



Non-Advectional Temperature Inversion:

- **Advection** refers to the horizontal movement of air masses, which can influence the temperature profile of a region.
- A **non-advectional temperature inversion** occurs without the influence of horizontal air movement or advection.
- Other **atmospheric processes** are responsible for the formation and maintenance of the inversion layer.



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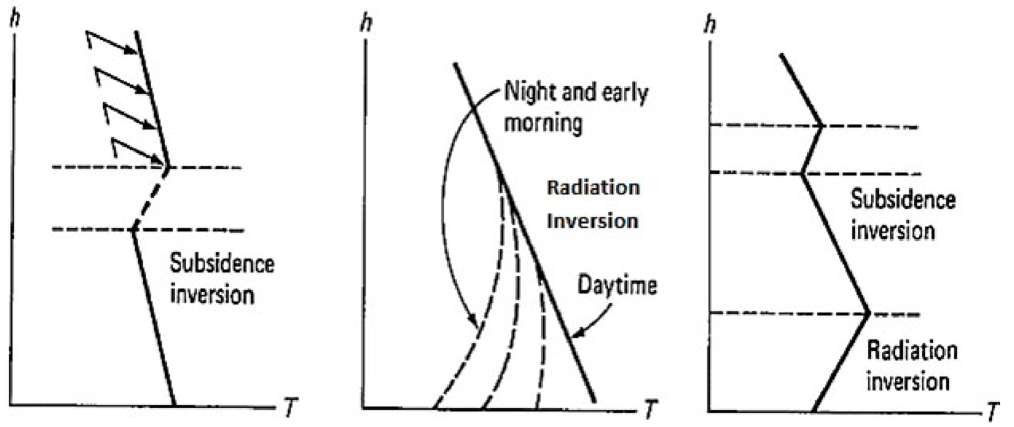
Types of Non-Advectional Temperature Inversion:

1. Radiation Inversion:

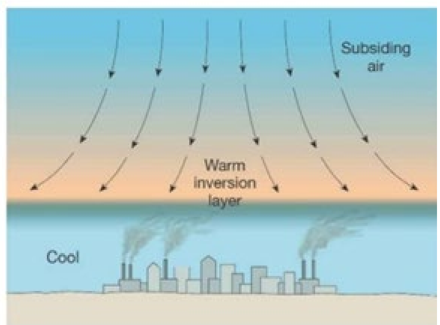
- **Radiation inversions** occur during clear, calm nights when the Earth's surface cools rapidly through **radiation**.
- The ground cools the air in direct contact with it, making the cooler air near the surface denser and causing it to stay close to the ground.
- Above this cool layer, there may be a layer of warmer air that acts as a cap, preventing further vertical mixing of the atmosphere and resulting in a **temperature inversion**.

Example: Formation of **fog** during a clear, calm night due to the cooling of the ground and air near the surface. The inversion layer traps the fog close to the ground, reducing visibility and creating potentially hazardous driving conditions.



2. Subsidence Inversion:

- **Subsidence inversions** occur when a large-scale sinking of air in the atmosphere leads to **compressional heating.**
- This typically happens in high-pressure systems when air descends from upper levels of the atmosphere to the surface.
- The sinking air gets compressed, causing its temperature to increase. This warmer air forms a stable layer above the cooler air near the surface, creating a **subsidence inversion**.



- ***Example:*** Common in some desert regions during high-pressure systems, where the sinking warm air creates a stable layer, trapping pollutants and dust near the surface. This can lead to the accumulation of smog and reduced air quality in these areas.

Impacts of Inversions:

- Inversions can have **positive** and **negative** impacts.
- **Positive**: They can protect crops from frost damage by trapping warm air near the surface on cold nights.
- **Negative:** When inversions trap pollutants close to the ground, they lead to poor air quality and increased health risks.

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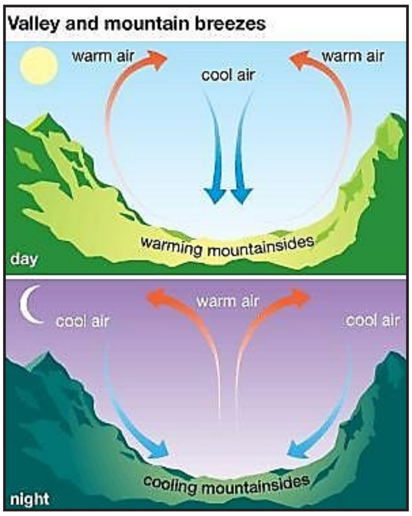
Advectional Temperature Inversion:



- An **advectional temperature** inversion occurs due to the horizontal movement (**advection**) of warm air over a cooler surface or vice versa.
- Unlike radiation or subsidence inversions, which are primarily caused by vertical processes, advectional inversions result from **horizontal temperature differences**.

1. Valley Inversion in Intermontane Valley:

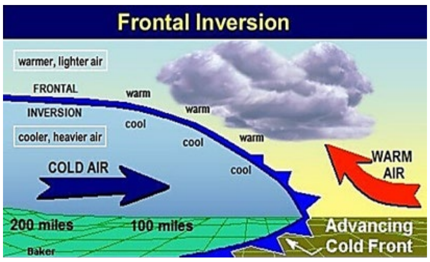
- Valley inversions typically occur during clear, calm nights when the Earth's surface cools rapidly through **radiation**.
- The air near the surface cools, becoming colder than the air at higher elevations in the valley.
- **Colder air** near the surface is denser and settles into the valley due to its higher density compared to the warmer air above, creating a stable layer known as the **valley inversion**.

Features and Impacts:

1. **Temperature Gradient**: The valley inversion creates a noticeable **temperature gradient** within the valley, with the air near the valley floor significantly colder than at higher elevations.
2. **Trapping of Air Pollutants**: Stable conditions trap pollutants and particulate matter near the surface, leading to **poor air quality**, especially in urbanized valleys with significant sources of air pollution.
3. **Fog Formation**: Colder air near the valley floor may reach its dew point during colder months, causing **water vapor** to condense into fog or low-lying clouds.
4. **Impact on Local Weather:** Valley inversions influence weather patterns in the valley, affecting **temperature, humidity, and cloud cover.** Trapped cold air can delay or inhibit the heating of the valley floor during the day, leading to cooler daytime temperatures compared to surrounding mountain slopes.

Valley inversions are common in regions with **clear skies, light winds, and long nights**, making them prevalent in many intermontane valleys worldwide.

2. Frontal or Cyclonic Inversion:



- Fronts are boundaries where different air masses meet, and they can be **warm fronts** (warm air advancing over colder air) or **cold fronts** (cold air advancing over warmer air).
- As a front approaches, warm, less dense air is forced to rise over the cooler, denser air mass. As the warm air ascends, it cools and condenses, leading to cloud formation and often precipitation. This rising warm air can create an area of **low pressure**, associated with cyclones.
- During the rising and cooling process, the air may become colder than the surrounding air aloft, forming a **temperature inversion** that traps the cooler air below the warmer air mass associated with the front or cyclone.

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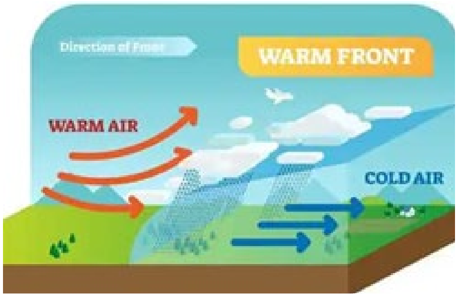
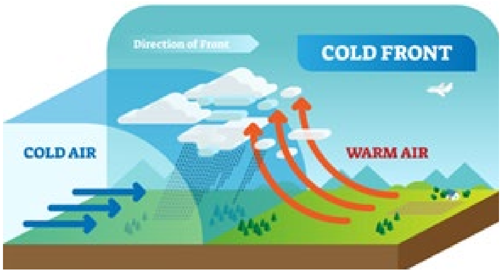
Features and Impacts:

1. **Stability**: Frontal or cyclonic inversions create **stable atmospheric conditions**, preventing further vertical mixing of the air, resulting in calm and relatively wind-free conditions.
2. **Weather Conditions**: Frontal or cyclonic inversions influence the **weather associated with the front or cyclone**, enhancing cloud development and precipitation, leading to potentially heavy rain or snowfall.
3. **Impact on Air Quality**: Like other temperature inversions, frontal or cyclonic inversions **trap pollutants near the surface**, leading to degraded air quality, especially in urban areas.
4. **Dissipation:** Frontal or cyclonic inversions may dissipate as the front or cyclone moves through the region and the air masses mix, allowing the inversion to break down and the air to disperse.

WARM FRONTS VS COLD FRONTS

Aspect	Warm Front	Cold Front
Air Masses	Warm air mass advancing and rising over a retreating cold air mass	Cold air mass advancing and displacing a warm air mass
Weather Transition	Gradual and slow weather change	Rapid and abrupt weather change
Weather Conditions	Often associated with long-lasting, steady precipitation	Intense and short-lived precipitation, followed by clearing skies
Cloud Types	Often brings stratus and nimbostratus clouds	Often brings cumulonimbus clouds
Temperature Change	Temperature increases as the warm air replaces the cold air	Temperature drops as the cold air replaces the warm air
Pressure Change	Gradual decrease in atmospheric pressure	Rapid decrease in atmospheric pressure
Wind Shift	Winds shift from southerly to southwesterly ahead of the front	Winds shift from southerly to northwesterly behind the front
Visibility	Generally reduces due to prolonged precipitation	Briefly reduces due to heavy rain and thunderstorms
Examples	Rainy and overcast days with moderate temperatures	Thunderstorms and heavy rain, followed by cooler and drier conditions





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Distribution of Temperature in the Earth's Atmosphere:

- The interaction of **insolation** (incoming solar radiation) with the atmosphere and the earth's surface creates **heat**, measured in terms of **temperature**.
- **Heat** represents the molecular movement of particles comprising a substance, while **temperature** measures the intensity of **heat**.

Heat and Temperature:

- **Temperature** indicates the relative degree of **heat** of a substance.
- **Heat** is the **energy** that makes things or objects hot, while **temperature** measures the average kinetic energy of the atoms in a substance.
- **Heat** (energy) is the total kinetic energy of all the atoms in a substance; the more atoms present, the greater the **heat**.
- **Temperature** represents the average kinetic energy of the atoms in a substance; a few atoms with rapid motion will have a higher **temperature** than many atoms with slow motion.
- Although distinct from each other, **heat** and **temperature** are closely related because gain or loss of **heat** is necessary to raise or lower the **temperature**.
- The movement of **heat** depends upon the **temperature** difference between two bodies.
- **Heat** always moves from a body of higher **temperature** to that of lower **temperature**.
- **Temperature** is primarily measured in the **kelvin (K)** unit in the study of physical sciences and most commonly measured in **Celsius (C)** or **Fahrenheit (F)** in day-to-day uses (denoted as °C, °F, and °K).

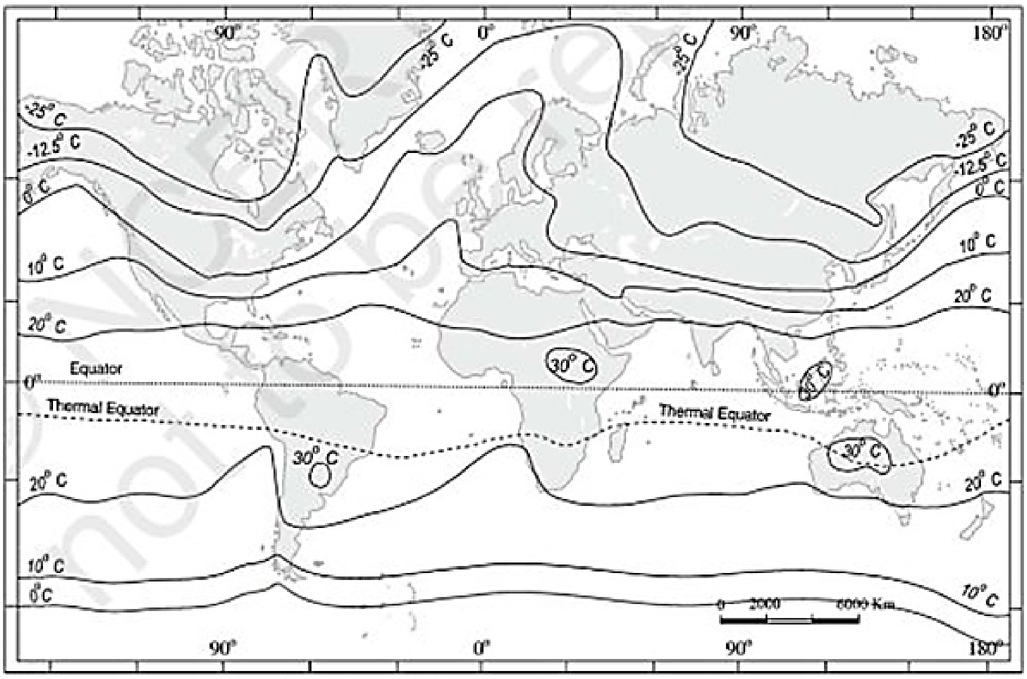
Factors Affecting the Temperature Distribution: The **temperature** of the air at any place is influenced by the following factors:

- The **latitude** of the place.
- The **altitude** of the place.
- Distance from the **sea**, the **air-mass circulation**.
- The presence of warm and cold **ocean currents**.
- **Local aspects**.

Global Temperature Distribution:

- The global distribution of **temperature** can be understood by studying the **temperature** distribution in **January** and **July**.
- The **temperature** distribution is generally shown on the map with the help of **isotherms**. Isotherms are lines joining places having equal **temperature**.
- The effect of the **latitude** on **temperature** is well pronounced on the map, as the **isotherms** are generally parallel to the **latitude**.
- The deviation from this general trend is more pronounced in **January** than in **July**, especially in the northern hemisphere.
- In the northern hemisphere, the **land surface** area is much larger than in the southern hemisphere, leading to more pronounced effects of **land mass** and **ocean currents**.

Seasonal Temperature Distribution – January



- During **January**, it is winter in the **northern hemisphere** and summer in the **southern hemisphere**.
- The **western margins** of continents are warmer than their eastern counterparts, since the **Westerlies** are able to carry high temperature into the landmasses.
- The temperature gradient is close to the **eastern margins** of continents. The isotherms exhibit a more regular behavior in the **southern hemisphere**.

Northern Hemisphere

- The isotherms deviate to the north over the ocean and to the south over the continent. This can be seen on the **North Atlantic Ocean**.
- The presence of warm ocean currents, **Gulf Stream** and **North Atlantic drift**, make the Northern Atlantic Ocean warmer, and the isotherms show a poleward shift indicating that the oceans are warmer and can carry high temperatures poleward.
- An equatorward bend of the isotherms over the northern continents shows that the landmasses are overcooled and that polar cold winds are able to penetrate southwards, even in the interiors. It is much pronounced in the **Siberian plain**.
- **Lowest temperatures** are recorded over northern Siberia and Greenland.

Southern Hemisphere

- The effect of the ocean is well pronounced in the southern hemisphere. Here the isotherms are more or less **parallel to the latitudes** and the variation in temperature is more gradual than in the northern hemisphere.
- The **high-temperature belt** runs in the southern hemisphere, somewhere along **30°S latitude**.
- The thermal equator lies to the south of the geographical equator (because the **Intertropical Convergence Zone or ITCZ** has shifted southwards with the apparent southward movement of the sun).

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Seasonal Temperature Distribution – July

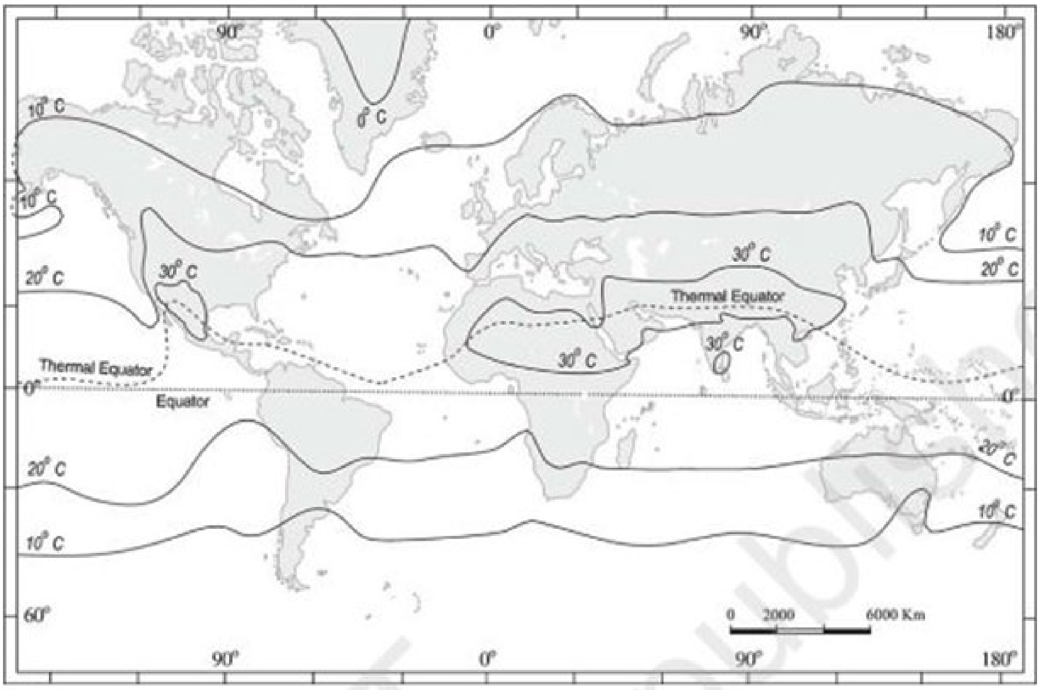
- During **July**, it is summer in the **northern hemisphere** and winter in the **southern hemisphere**. The isothermal behavior is the opposite of what it is in January.
- In July, the isotherms generally run parallel to the latitudes. The equatorial oceans record warmer temperature, more than **27°C**. Over the land, more than **30°C** is noticed in the subtropical continental region of Asia, along the **30° N latitude**.

Northern Hemisphere

- The highest range of temperature is more than **60°C** over the northeastern part of Eurasian continent. This is due to **continentality**. The least range of temperature, **3°C**, is found between **20° S and 15° N**.
- Over the northern continents, a poleward bend of the isotherms indicates that the landmasses are overheated and the hot tropical winds are able to go far into the northern interiors.
- The isotherms over the northern oceans show an equatorward shift indicating that the oceans are cooler and are able to carry the moderating effect into tropical interiors. The **lowest temperatures** are experienced over **Greenland**.
- The **highest temperature** belt runs through **northern Africa, west Asia, northwest India, arid southeastern USA**. The temperature gradient is irregular and follows a zig-zag path over the northern hemisphere.

Southern Hemisphere

- The gradient becomes regular over the southern hemisphere but shows a slight bend towards the equator at the edges of continents. **Thermal equator** now lies to the north of the geographical equator.



The distribution of surface air temperature in the month of July

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CLIMATE CHANGE AND ATMOSPHERE

The interaction between the **lower and middle atmospheres** impacts the **upper atmosphere** primarily through the upward propagation of **atmospheric waves**. As these waves move upward, their magnitude increases due to the **exponential decrease** in **atmospheric density** with altitude.

Impacts of Climate Change on the Atmosphere:

- **Heat Waves**: Climate change will lead to the enlargement of stalled high-pressure weather systems known as "**blocking events**," which have already caused some of the deadliest **heat waves** of the 21st century.
- **Contraction of the Upper Atmosphere**: The rise in atmospheric **CO2 concentration** is causing **cooling** and **compression** of the **upper atmosphere**, resulting in **lower densities** at higher altitudes and consequently, a prolonged lifespan of **space debris**.
  - Additionally, there might be indirect consequences of climate change in the **lower/middle atmosphere** that influence long-term trends in **upper atmosphere density**.
- **Formation of Surface-Level Ozone**: Climate changes can affect local air quality by increasing **ground-level ozone** in many regions due to **atmospheric warming**.
- **Uneven Warming and Cooling**: **Ozone** in the atmosphere contributes to **warming** the climate, while different components of particulate matter (**PM**) can have **warming** or **cooling effects** on the climate.
  - For example, **black carbon**, a particulate pollutant from combustion, contributes to Earth's **warming**, whereas **particulate sulfates cool** the atmosphere.
- **Drastic Climatic Changes**: Climate models (IPCC, 2007) have been utilized to forecast the evolution of **mean temperature** and **precipitation rate** in the coming centuries.
  - Under a "business-as-usual" scenario, the projected global surface mean temperature increase by the end of the 21st century is **2.8°C,** with an average warming of **3.5°C** on land and potentially up to **7°C** in the **Arctic region.**