M. Sc | Geography | Unit 1 to 5 | Climatology

Applied Climatology

Presentation By

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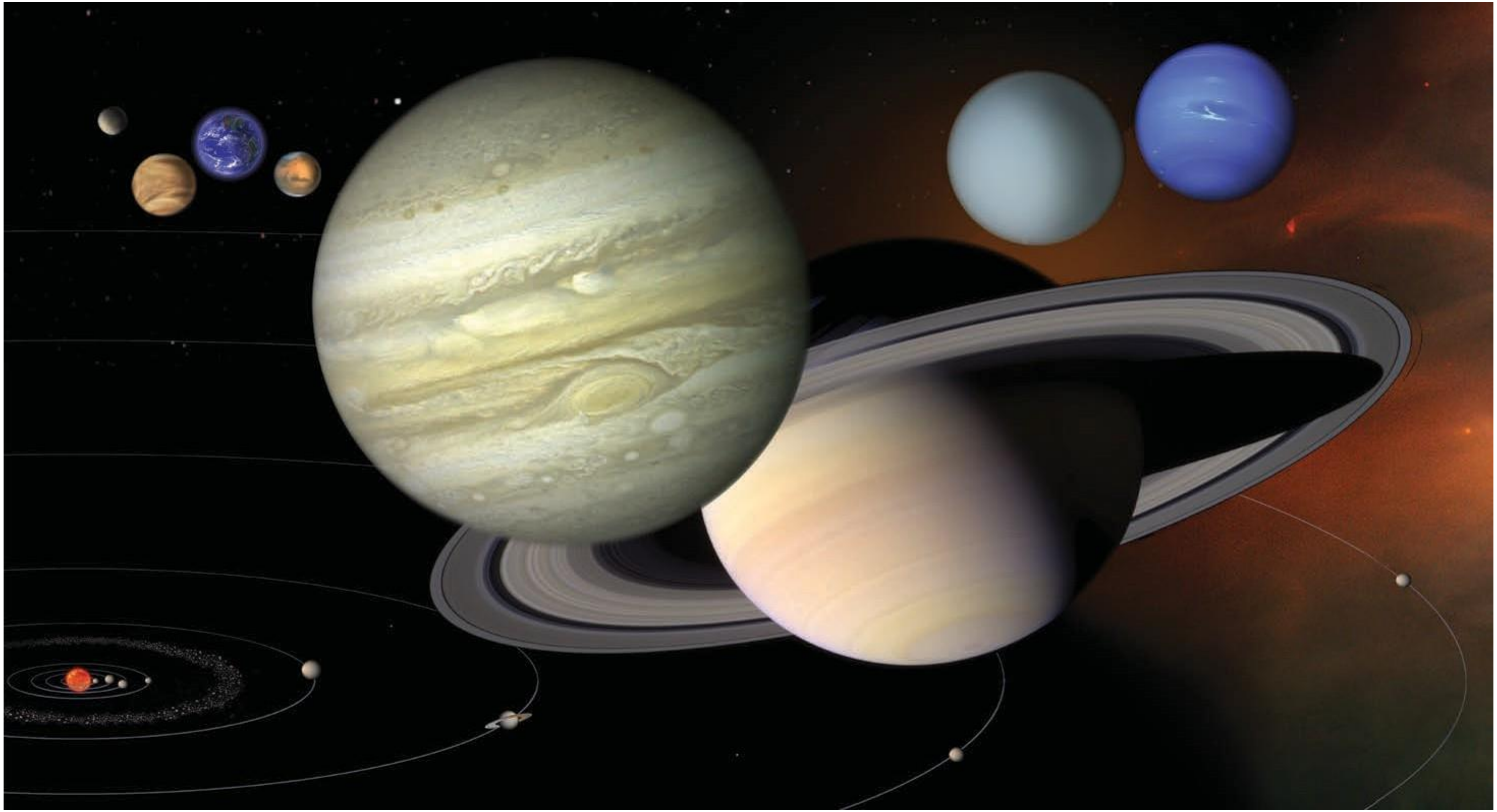
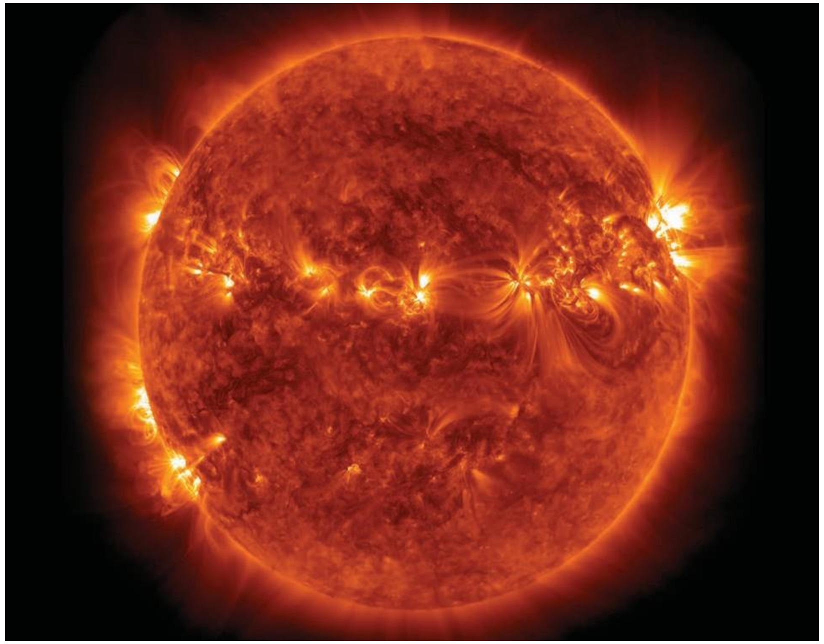
UNIT - I

Atmosphere Composition and Structure: Solar radiation – Temperature – factors controlling the distribution of temperature – horizontal, vertical distribution of temperature – heat balance of the earth – Atmospheric Pressure – distribution – General circulation of the atmosphere – wind – systems – planetary – seasonal and local winds.

Solar System



Our Star — The Sun

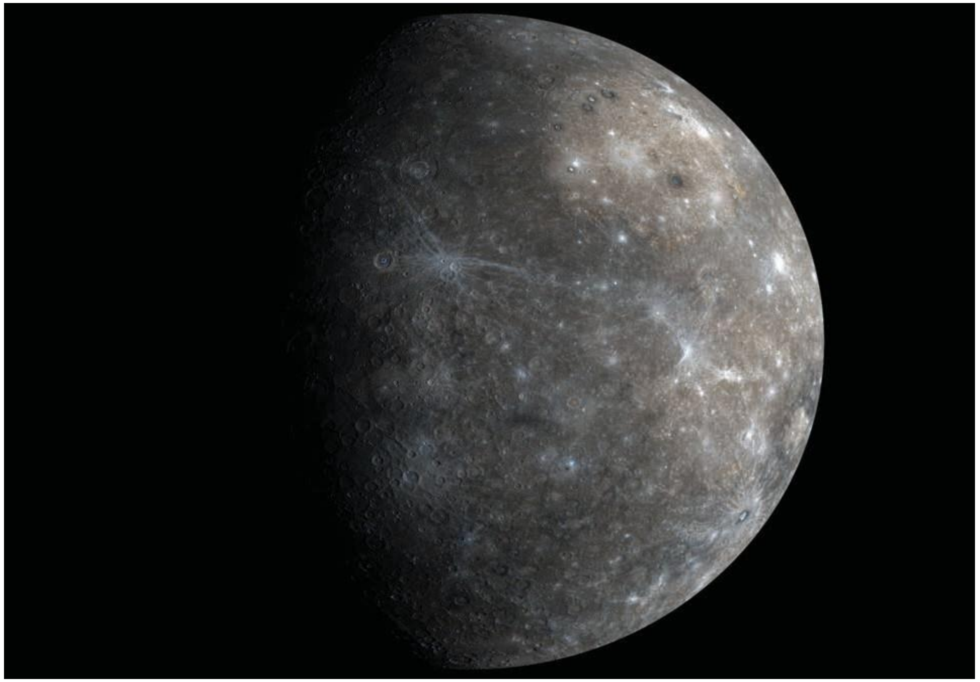


Spectral Type of Star	G2V
Age	4.6 billion years
Mean Distance to Earth	149.60 million km (92.96 million mi) (1 astronomical unit)
Rotation Period at Equator	26.8 days
Rotation Period at Poles	36 days
Equatorial Radius	695,500 km (432,200 mi)
Mass	1.989×10^{30} kg
Density	1.409 g/cm^3
Composition	92.1% hydrogen, 7.8% helium, 0.1% other elements
Surface Temperature (Photosphere)	5,500 deg C (10,000 deg F)
Luminosity*	3.83×10^{33} ergs/sec

SIGNIFICANT DATES

- 150 CE — Greek scholar Claudius Ptolemy writes the *Almagest*, formalizing the Earth-centered model of the solar system. The model was accepted until the 16th century.
- 1543 — Nicolaus Copernicus publishes *On the Revolutions of the Celestial Spheres* describing his heliocentric (Sun-centered) model of the solar system.
- 1610 — First observations of sunspots through a telescope made independently by Galileo Galilei and Thomas Harriot.
- 1645–1715 — Sunspot activity declines to almost zero, possibly causing a "Little Ice Age" on Earth.
- 1860 — Eclipse observers see a massive burst of material from the Sun; it is the first recorded coronal mass ejection.
- 1994 — The Ulysses spacecraft makes the first observations of the Sun's polar regions.
- 2004 — NASA's Genesis spacecraft returns samples of the solar wind to Earth for study.
- 2007 — NASA's double-spacecraft STEREO mission returns the first three-dimensional images of the Sun.
- 2009 — After more than 18 years, the Ulysses mission ends. 2010 — SDO is launched and begins observing the Sun in super-high definition.
- 2011 — The STEREO spacecraft, from their dual perspective, see the entire Sun for the first time.

Mercury



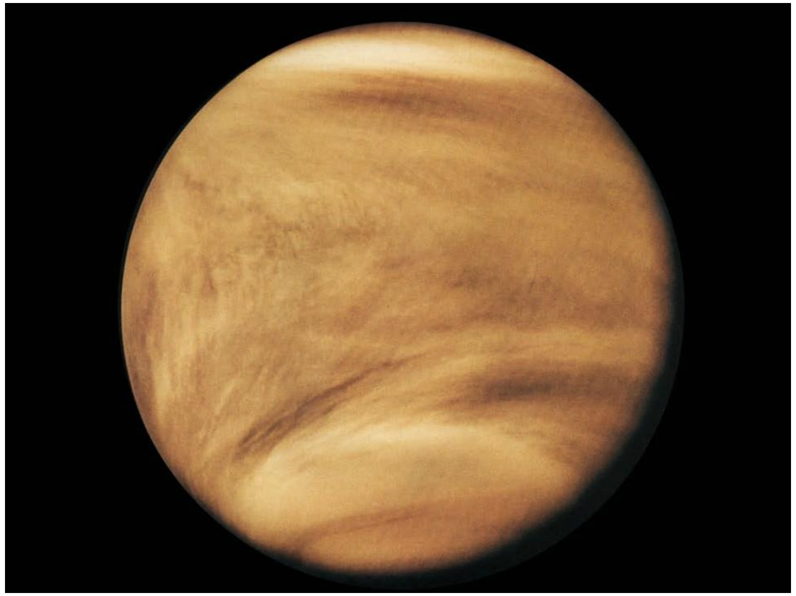
Namesake	Messenger of the Roman gods
Mean Distance from the Sun	57.91 million km (35.98 million mi)
Orbit Period	87.97 Earth days
Orbit Eccentricity (Circular Orbit = 0)	0.206
Orbit Inclination to Ecliptic	7 deg
Inclination of Equator to Orbit	0 deg
Rotation Period	58.65 Earth days
Successive Sunrises	175.97 days
Equatorial Radius	2,440 km (1,516 mi)
Mass	0.055 of Earth's
Density	5.43 g/cm^3 (0.98 of Earth's)
Gravity	0.38 of Earth's
Exosphere Components	hydrogen, helium, sodium, potassium, calcium, magnesium

Temperature Range	–180 to 430 deg C (–290 to 800 deg F)
Known Moons	0
Rings	0

SIGNIFICANT DATES

- 1609 — Thomas Harriott and Galileo Galilei observe Mercury with the newly invented telescope.
- 1631 — Pierre Gassendi uses a telescope to watch from Earth as Mercury crosses the face of the Sun.
- 1965 — Incorrectly believing for centuries that the same side of Mercury always faces the Sun, astronomers find that the planet rotates three times for every two orbits.
- 1974–1975 — Mariner 10 photographs roughly half of Mercury's surface in three flybys.
- 1991 — Scientists using Earth-based radar find signs of ice locked in permanently shadowed areas of craters in Mercury's polar regions.
- 2008–2009 — MESSENGER observes Mercury during three flybys.
- 2011 — MESSENGER begins its orbital mission of Mercury, yielding a treasure trove of images, compositional data, and scientific discoveries.

Venus



Namesake	Roman goddess of love and beauty
Mean Distance from the Sun	108.21 million km (67.24 million mi)
Orbit Period	224.70 Earth days
Orbit Eccentricity (Circular Orbit = 0)	0.0068
Orbit Inclination to Ecliptic	3.39 deg
Inclination of Equator to Orbit	177.3 deg
Rotation Period	243.02 Earth days (retrograde)
Successive Sunrises	116.75 days
Equatorial Radius	6,052 km (3,760 mi)
Mass	0.815 of Earth's
Density	5.24 g/cm³ (0.95 of Earth's)
Gravity	0.91 of Earth's
Atmosphere Primary Component	carbon dioxide
Temperature at Surface	470 deg C (880 deg F)
Known Moons	0
Rings	0

SIGNIFICANT DATES

- 1960 — NASA launches the Television Infrared Observation Satellite (TIROS), the first weather satellite.
- 1972 — The Earth Resources Technology Satellite 1 (renamed Landsat 1) is launched.
- 1987 — NASA's Airborne Antarctic Ozone Experiment helps determine the cause of the Antarctic ozone hole.
- 1992 — TOPEX/Poseidon, a U.S.–France mission, begins measuring sea-surface height. Jason 1 continues in 2001. 1997 — TOPEX/Poseidon captures the onset of one of the largest El Niño events of the 20th century.
- 1997 — The U.S.–Japan Tropical Rainfall Measuring Mission is launched to provide 3-D maps of storm structure.
- 1999 — Quick Scatterometer (QuikScat) launches in June to measure ocean surface wind velocity; in December the Active Cavity Irradiance Monitor Satellite launches to monitor the total amount of the Sun's energy reaching Earth.
- 1999–2006 — A series of satellites is launched to provide global observations of the Earth system: Terra (land, oceans, atmosphere), Aqua (water cycle), Aura (atmospheric chemistry) CloudSat (clouds), and the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observation mission (aerosols, clouds).
- 2002 — The Gravity Recovery and Climate Experiment launches to monitor mass variations associated with land features and water movement.
- 2006 — The Antarctic ozone hole was the largest yet observed. 2007 — Arctic sea ice reaches the all-time minimum since satel- lite records began.
- 2008 — The third U.S.–France mission to measure sea-level height, Ocean Surface Topography Mission/Jason 2, is launched, doubling global data coverage.
- 2009 — NASA and Japan release the most accurate topographic map of Earth.
- 2011 — NASA launches Aquarius, its first instrument to measure the salinity of the global oceans.

Earth

Mean Distance from the Sun	149.60 million km (92.96 million mi) (1 astronomical unit)
Orbit Period	365.26 days
Orbit Eccentricity (Circular Orbit = 0)	0.0167
Orbit Inclination to Ecliptic	0.00005 deg
Inclination of Equator to Orbit	23.45 deg
Rotation Period	23.93 hr
Successive Sunrises	24.00 hr
Equatorial Radius	6,378 km (3,963 mi)
Mass	5.9737×10^{24} kg
Density	5.515 g/cm^3
Gravity (Global Average)	9.8 m/sec^2 (32.15 ft/sec^2)
Atmosphere Primary Components	nitrogen, oxygen
Surface Temperature Range	–88 to 58 deg C (–126 to 136 deg F)
Known Moons	1
Rings	0

- **SIGNIFICANT DATES**
- 1610 — Galileo Galilei is the first to use a telescope to make scientific observations of the Moon.
- 1959–1976 — The U.S.S.R.'s Luna program of 17 robotic missions achieves many "firsts" and three sample returns. 1961–1968 — The U.S. Ranger, Lunar Orbiter, and Surveyor robotic missions pave the way for Apollo human lunar landings.
- 1969 — Astronaut Neil Armstrong is the first human to walk on the Moon's surface.
- 1994–1999 — Clementine and Lunar Prospector data suggest that water ice may exist at the lunar poles.
- 2003 — The European Space Agency's SMART-1 lunar orbiter inventories key chemical elements.
- 2007–2008 — Japan's second lunar spacecraft, Kaguya, and China's first lunar spacecraft, Chang'e 1, both begin one-year missions orbiting the Moon; India's Chandrayaan-1 soon follows in lunar orbit.
- 2008 — The NASA Lunar Science Institute is formed to help lead NASA's research activities related to lunar exploration goals.
- 2009 — NASA's LRO and LCROSS launch together, beginning the U.S. return to lunar exploration. In October, LCROSS was directed to impact a permanently shadowed region near the lunar south pole, resulting in the discovery of water ice.
- 2011 — Twin GRAIL spacecraft launch to map the interior of the Moon from crust to core, and NASA begins the ARTEMIS mission to study the Moon's interior and surface composition.

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Earth Moon

Mean Distance from Earth	384,400 km (238,855 mi)
Orbit Period	27.32 Earth days
Orbit Eccentricity (Circular Orbit = 0)	0.05490
Orbit Inclination to Ecliptic	5.145 deg
Inclination of Equator to Orbit	6.68 deg
Rotation Period	27.32 Earth days
Equatorial Radius	1,737.4 km (1,079.6 mi)
Mass	0.0123 of Earth's
Density	3.341 g/cm^3 (0.61 of Earth's)
Gravity	0.166 of Earth's
Temperature Range	–248 to 123 deg C (–414 to 253 deg F)

- **SIGNIFICANT DATES**
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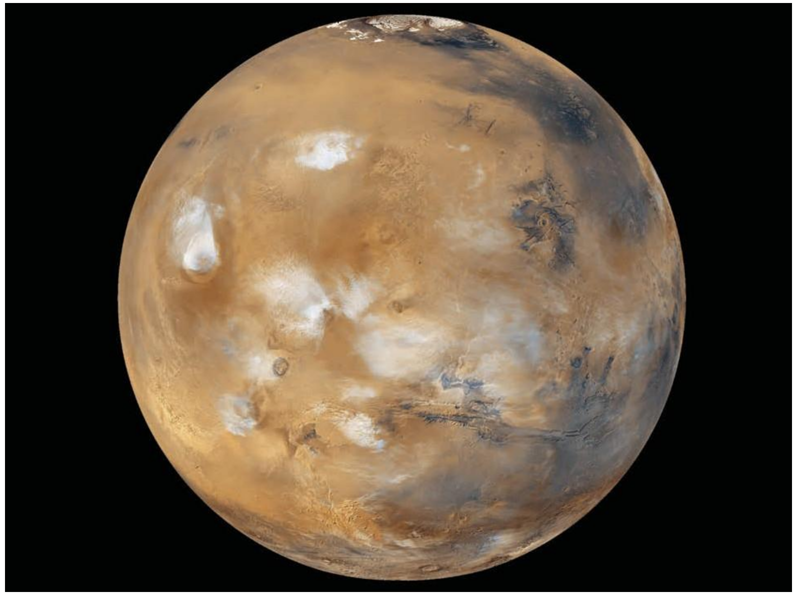
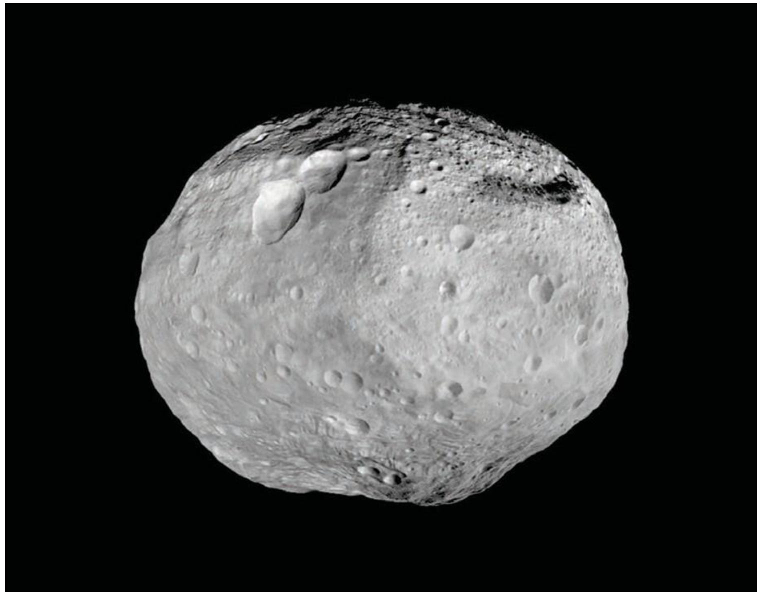
Mars



Namesake	Roman god of war
Mean Distance from the Sun	227.94 million km (141.63 million mi)
Orbit Period	1.8807 Earth years (686.98 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.0934
Orbit Inclination to Ecliptic	1.8 deg
Inclination of Equator to Orbit	25.19 deg
Rotation Period	24.62 hr
Successive Sunrises	24.660 hr
Equatorial Radius	3,397 km (2,111 mi)
Mass	0.10744 of Earth's
Density	3.934 g/cm^3 (0.714 of Earth's)
Surface Gravity	0.38 of Earth's
Atmosphere Primary Components	carbon dioxide, nitrogen, argon
Temperature Range	–87 to –5 deg C (–125 to 23 deg F)
Known Moons*	2
Rings	0

- **SIGNIFICANT DATES**
- 1877 — Asaph Hall discovers the two moons of Mars.
- 1965 — NASA's Mariner 4 sends back 22 photos of Mars, the world's first close-up photos of a planet beyond Earth.
- 1976 — Viking 1 and 2 land on the surface of Mars.
- 1997 — Mars Pathfinder lands and dispatches Sojourner, the first wheeled rover to explore the surface of another planet.
- 2002 — Mars Odyssey begins its mission to make global obser- vations and find buried water ice on Mars.
- 2004 — Twin Mars Exploration Rovers named Spirit and Opportunity find strong evidence that Mars once had long-term liquid water on the surface.
- 2006 — Mars Reconnaissance Orbiter begins returning high- resolution images as it studies the history of water on Mars and seasonal changes.
- 2008 — Phoenix finds signs of possible habitability, including the occasional presence of liquid water and potentially favorable soil chemistry.
- 2012 — NASA's Mars rover Curiosity lands in Gale Crater and finds conditions once suited for ancient microbial life on Mars.

Asteroids



- **SIGNIFICANT DATES**
- 1801 — Giuseppe Piazzi discovers the first and largest asteroid, Ceres, orbiting between Mars and Jupiter.
- 1898 — Gustav Witt discovers Eros, one of the largest near- Earth asteroids.
- 1991–1994 — The Galileo spacecraft takes the first close-up im- ages of an asteroid (Gaspra) and discovers the first moon (later named Dactyl) orbiting an asteroid (Ida).
- 1997–2000 — The NEAR spacecraft flies by Mathilde and orbits and lands on Eros.
- 1998 — NASA establishes the Near-Earth Object Program Office to detect, track, and characterize potentially hazardous asteroids and comets that could approach Earth.
- 2006 — Ceres attains a new classification, “dwarf planet,” but retains its distinction as the largest known asteroid.
- 2008 — The European spacecraft Rosetta, on its way to study a comet in 2014, flies by and photographs asteroid Steins, a rare type of asteroid composed of silicates and basalts.
- 2010 – Rosetta flies by asteroid Lutetia, revealing a primitive survivor from the violent birth of our solar system.
- 2011–2012 — Dawn studies Vesta. Dawn is the first spacecraft to orbit a main-belt asteroid and continues on to dwarf planet Ceres in 2015.

ASTEROID CLASSIFICATIONS

- Main asteroid belt — The majority of known asteroids orbit within the asteroid belt between Mars and Jupiter, generally with not very elongated orbits. The belt is estimated to contain between 1.1 and 1.9 million asteroids larger than 1 kilometer (0.6 mile) in diameter, and millions of small- er ones. Early in the history of the solar system, the gravity of newly formed Jupiter brought an end to the formation of planetary bodies in this region and caused the small bodies to collide with one another, fragmenting them into the asteroids we observe today.
- Trojans — These asteroids share an orbit with a larger planet, but do not collide with it because they gather around two special places in the orbit (called the L4 and L5 Lagrangian points). There, the gravitational pull from the Sun and the planet are balanced by a trojan’s tendency to otherwise fly out of the orbit. The Jupiter trojans form the most significant population of trojan asteroids. It is thought that they are as numerous as the asteroids in the asteroid belt. There are Mars and Neptune trojans, and NASA announced the discovery of an Earth trojan in 2011.
- Near-Earth asteroids — These objects have orbits that pass close by that of Earth. Asteroids that actually cross Earth’s orbital path are known as Earth-crossers. As of June 19, 2013, 10,003 near-Earth asteroids are known and the number over 1 kilometer in diameter is thought to be 861, with 1,409 classified as potentially hazardous asteroids — those that could pose a threat to Earth.

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SIGNIFICANT DATES

- 4.55 billion years ago — Formation age of most meteorites, taken to be the age of the solar system.
- 65 million years ago — Chicxulub impact leads to the death of 75 percent of the animals on Earth, including the dinosaurs. 50,000 years — Age of Barringer Meteorite Crater in Arizona. 1478 BCE — First recorded observation of meteors.
- 1794 — Ernst Friedrich Chladni publishes the first book on meteorites, in which he proposes that they have an extra- terrestrial origin.
- 1908 (Tunguska), 1947 (Sikote Alin), 1969 (Allende and Murchi- son), 1976 (Jilin) — Important 20th-century meteorite falls.
- 1969 — Discovery of meteorites in a small area of Antarctica leads to annual expeditions by U.S. and Japanese teams. 1982–1983 — Meteorites from the Moon and Mars are identified in Antarctic collections.
- 1996 — A team of NASA scientists suggests that martian mete- orite ALH84001 may contain evidence of microfossils from Mars, a still-controversial claim.
- 2005 — NASA's Mars Exploration Rover Opportunity finds a basketball-size iron–nickel meteorite on Mars.
- 2009 — Opportunity finds another iron–nickel meteorite on Mars.

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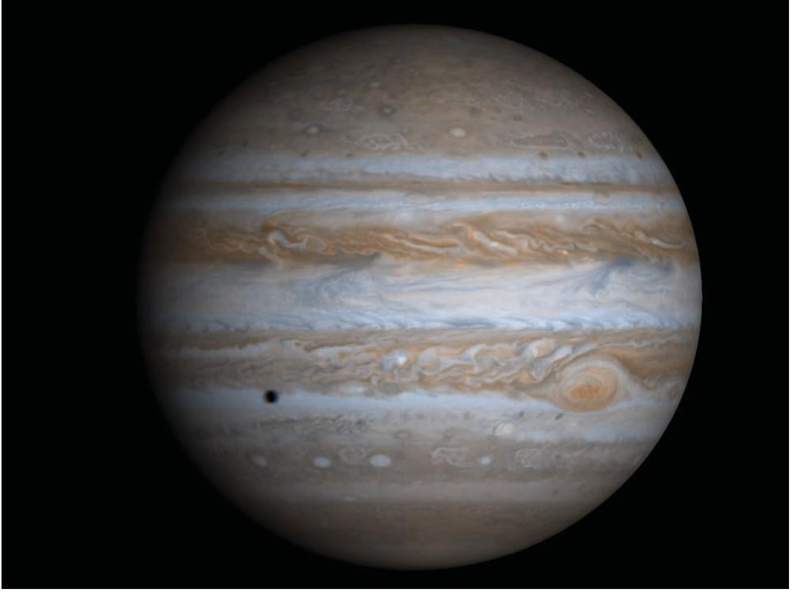
PLANETS AND SELECTED MOONS

Planet	Moon	Mean Radius (km)	Mean Radius (mi)
Earth	Moon	1,737.4	1,079.6
Mars	Phobos	11.1	6.9
Mars	Deimos	6.2	3.9
Jupiter	Io	1,821.6	1,131.9
Jupiter	Europa	1,560.8	969.8
Jupiter	Callisto	2,410	1,498
Jupiter	Ganymede	2,631	1,635
Saturn	Mimas	198.6	123.4
Saturn	Enceladus	249.4	154.9
Saturn	Tethys	529.9	329.3
Saturn	Dione	560	348
Saturn	Rhea	764	475
Saturn	Titan	2,575	1,600
Saturn	Iapetus	718	446
Uranus	Miranda	235.8	146.5
Uranus	Ariel	578.9	359.7
Uranus	Umbriel	584.7	363.3
Uranus	Titania	788.9	490.2
Uranus	Oberon	761.4	473.1
Neptune	Triton	1,353.4	841
Neptune	Nereid	170	106

❑ SIGNIFICANT DATES

- ❑ 1610 — Galileo Galilei and Simon Marius independently discover four moons orbiting Jupiter. Galileo is credited and the moons are called "Galilean." This discovery changed the way the solar system was perceived.
- ❑ 1877 — Asaph Hall discovers Mars' moons Phobos and Deimos. 1969 — Astronaut Neil Armstrong is the first of 12 humans to walk on the surface of Earth's Moon.
- ❑ 1979 — Voyager 1 photographs an erupting volcano on Jupiter's moon Io; the first ever seen anywhere other than Earth.
- ❑ 1980 — Voyager 1 instruments detect signs of surface features beneath the hazy atmosphere of Saturn's largest moon, Titan. 2005 — The Cassini spacecraft discovers jets or geysers of water ice particles venting from Saturn's moon Enceladus.
- ❑ 2000–present — Using improved ground-based telescopes, the Hubble Space Telescope, and spacecraft observations,
- ❑ scientists have found dozens of new moons in our solar system. Newly discovered moons (as well as other solar system objects) are given temporary designations until they are confirmed by subsequent observations and receive permanent names from the International Astronomical Union.

Jupiter



Namesake	King of the Roman gods
Mean Distance from the Sun	778.41 million km (483.68 million mi)
Orbit Period	11.8565 Earth years (4,330.6 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.04839
Orbit Inclination to Ecliptic	1.305 deg
Inclination of Equator to Orbit	3.12 deg
Rotation Period	9.92 hr
Equatorial Radius	71,492 km (44,423 mi)
Mass	317.82 of Earth's
Density	1.33 g/cm^3
Gravity	20.87 m/sec^2 (68.48 ft/sec^2)
Atmosphere Primary Components	hydrogen, helium
Effective Temperature at 1 bar	–108 deg C (–163 deg F)
Known Moons*	50
Rings	1 (three major components)

SIGNIFICANT DATES

- 1610 — Galileo Galilei makes the first detailed observations of Jupiter.
- 1973 — Pioneer 10 becomes the first spacecraft to cross the asteroid belt and fly past Jupiter.
- 1979 — Voyager 1 and 2 discover Jupiter's faint rings, several new moons, and volcanic activity on Io's surface.
- 1994 — Astronomers observe as pieces of comet Shoemaker– Levy 9 collide with Jupiter's southern hemisphere.
- 1995–2003 — The Galileo spacecraft drops a probe into Jupi- ter's atmosphere and conducts extended observations of Jupiter and its moons and rings.
- 2007 — Images taken by NASA's New Horizons spacecraft, on the way to Pluto, show new perspectives on Jupiter's atmospheric storms, the rings, volcanic Io, and icy Europa. 2009 — On July 20, almost exactly 15 years after fragments of
- comet Shoemaker–Levy slammed into Jupiter, a comet or aster- oid crashes into the giant planet's southern hemisphere, creating a dark scar.

Galilean Moons of Jupiter

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Satellite	Mean Distance from Jupiter
Io	422,000 km (262,200 mi)
Europa	671,000 km (417,000 mi)
Ganymede	1,070,000 km (665,000 mi)
Callisto	1,883,000 km (1,170,000 mi)

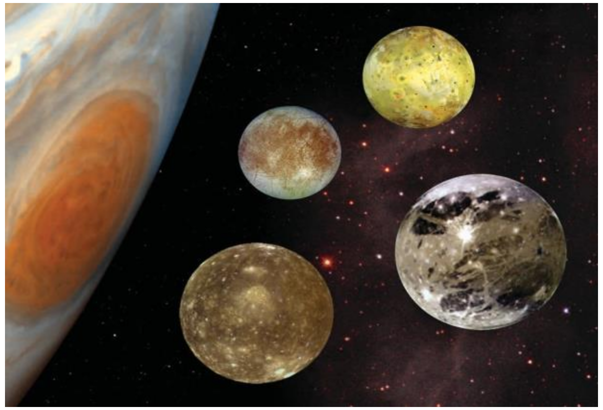
Satellite	Mean Radius
Io	1821.6 km (1,131.9 mi)
Europa	1,560.8 km (969.8 mi)
Ganymede	2,631 km (1,635 mi)
Callisto	2,410 km (1,498 mi)

Satellite	Orbital Period (Earth Days)
Io	1.769
Europa	3.551
Ganymede	7.155
Callisto	16.689

Satellite	Density (g/cm^3)
Io	3.528
Europa	3.013
Ganymede	1.942
Callisto	1.834

SIGNIFICANT DATES

- 1610 — Galileo Galilei and Simon Marius independently discover four moons orbiting Jupiter. This discovery, among others by Galileo, helped change the way people thought about the heav- ens. The prevailing idea of the time was that all heavenly bodies orbit Earth: a planet with its own small orbiting bodies did not conform to this geocentric model.
- 1979 — Voyager 1 photographs an erupting volcano on Io: the first ever seen anywhere other than Earth.
- 1979–2000 — Using data from the Voyager and Galileo space- craft, scientists gather strong evidence of an ocean beneath the icy crust of Europa; Galileo data indicate oceans within Gany- mede and Callisto as well.
- 2003 — The Galileo mission ends with the spacecraft deliber- ately descending into Jupiter's atmosphere and being vaporized. Mission controllers purposely put Galileo on a collision course with Jupiter to eliminate any chance that the spacecraft would crash into Europa and contaminate that moon with terrestrial microbes.



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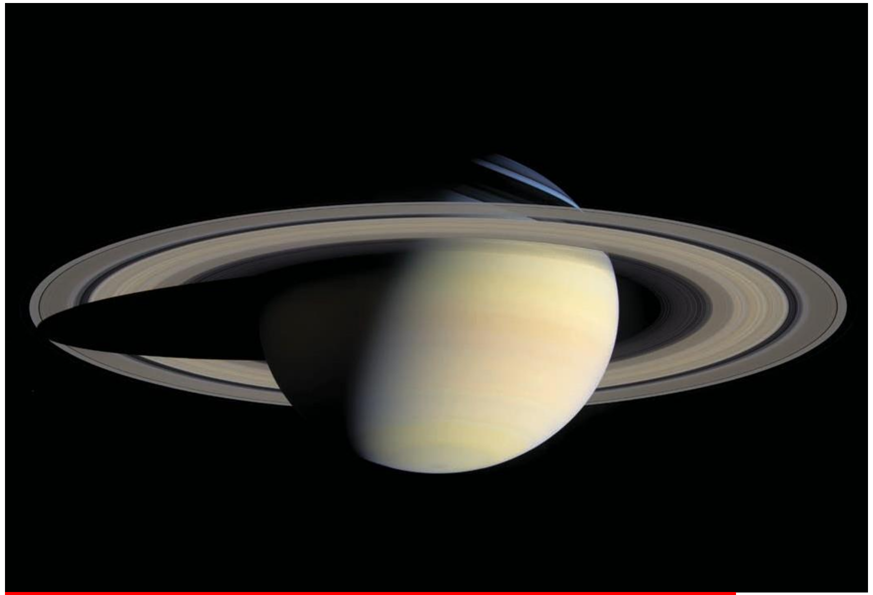
Saturn



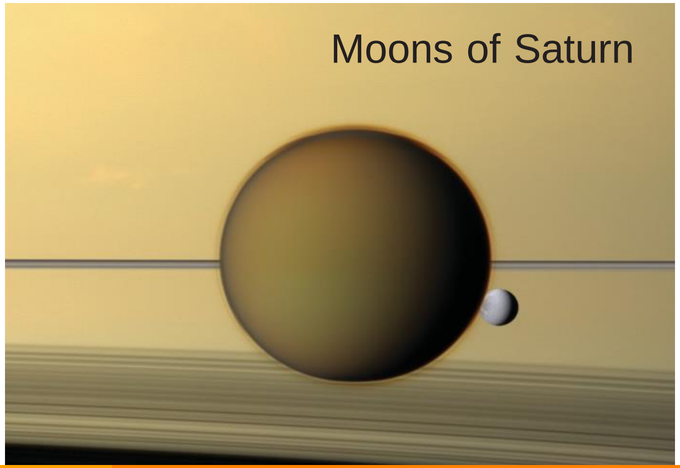
Namesake	Roman god of agriculture
Mean Distance from the Sun	1,426.666 million km (886,489 million mi)
Orbit Period	29.4 Earth years (10,755.7 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.05386179
Orbit Inclination to Ecliptic	2.486 deg
Inclination of Equator to Orbit	26.73 deg
Rotation Period	10.656 hours
Equatorial Radius	60,268 km (37,449 mi)
Mass	95.16 of Earth's
Density	0.70 g/cm^3
Gravity	7.207 m/sec^2 (23.64 ft/sec^2)
Atmosphere Primary Components	hydrogen, helium
Effective Temperature	–178 deg C (–288 deg F)
Known Moons*	53
Rings	7 main rings (C, B, A, D, F, G, E)

SIGNIFICANT DATES

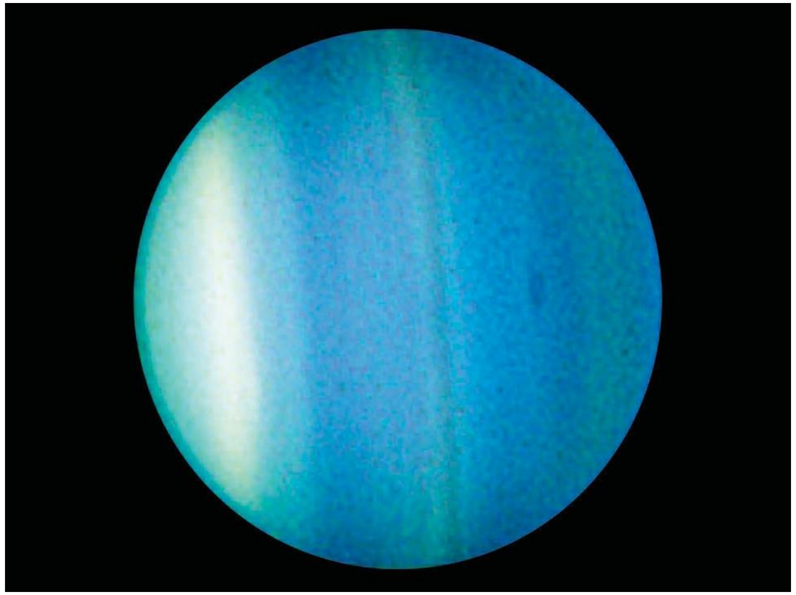
- 1610 — Galileo Galilei reports seeing odd appendages on either side of Saturn; he did not realize he was viewing Saturn's rings. 1979 — Pioneer 11 is the first spacecraft to reach Saturn, flying within 22,000 kilometers (13,700 miles) of the cloud tops.
- 1981 — Using Saturn's powerful gravity as an interplanetary "slingshot," Voyager 2 is placed on a path toward Uranus, then Neptune, then out of the solar system.
- 1994 — The Hubble Space Telescope finds evidence of surface features beneath the hazy atmosphere of Titan.
- 2004 — After a seven-year journey, Cassini–Huygens becomes the first spacecraft to orbit Saturn.
- 2005 — The Huygens probe successfully lands on Titan, return- ing images of the complex surface.
- 2005–2008 — The Cassini spacecraft continues to return high- resolution images of the Saturn system. Mission discoveries include evidence for liquid hydrocarbon lakes of methane and ethane on Titan, a new radiation belt around Saturn, new rings and moons, and icy jets and geysers at the south polar region of the moon Enceladus.
- 2008–2010 — Cassini's mission is extended for two years and designated the Cassini Equinox Mission.
- 2010–2017 — Cassini's mission is extended for seven years and designated the Cassini Solstice Mission.

• Largest Moon of Saturn	Titan
Titan's Diameter	5,150 km (3,200 mi)
• Closest Moon to Saturn	Pan
Pan's Distance from Saturn	133,583 km (83,022 mi)

• Fastest Orbit	Pan
Pan's Orbit Around Saturn	13.8 hours
• Number of Moons Discovered by Voyager (Atlas, Prometheus, Pandora, and Pan)	4
• Number of Moons Discovered by Cassini (Methone, Pallene, Polydeuces, Daphnis, Anthe, and Aegaeon)	6



Uranus



Namesake	Greek god of the heavens ("Ouranos")
Mean Distance from the Sun	2,870.97 million km (1,783.94 million mi)
Orbit Period	84.02 Earth years (30,687.2 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.047168
Orbit Inclination to Ecliptic	0.770 deg
Inclination of Equator to Orbit	97.86 deg
Rotation Period	17.24 hours (retrograde)
Equatorial Radius	25,559 km (15,882 mi)
Mass	14.371 of Earth's
Density	1.32 g/cm^3
Gravity	8.43 m/sec^2 (27.7 ft/sec^2)
Atmosphere Primary Components	hydrogen, helium
Effective Temperature	−216 deg C (−357 deg F)
Known Moons*	27

Known Rings	13 (Zeta, Six, Five, Four, Alpha, Beta, Eta, Gamma, Delta, Lambda, Epsilon, Nu, Mu)

SIGNIFICANT DATES

- 1781 — Astronomer William Herschel discovers Uranus. 1787–1851 — Four Uranian moons are discovered and named Titania, Oberon, Ariel, and Umbriel.
- 1948 — Another moon, Miranda, is discovered.
- 1977 — Scientists discover nine faint rings of Uranus while observing a distant star pass behind the planet.
- 1986 — Voyager 2 discovers 10 moons and two additional rings during its historic flyby.
- 1997–2005 — Astronomers discover more tiny moons. 2003–2005 — The Hubble Space Telescope images two delicate rings far from the planet, and two new moons.
- 2007 — Uranus reaches equinox.

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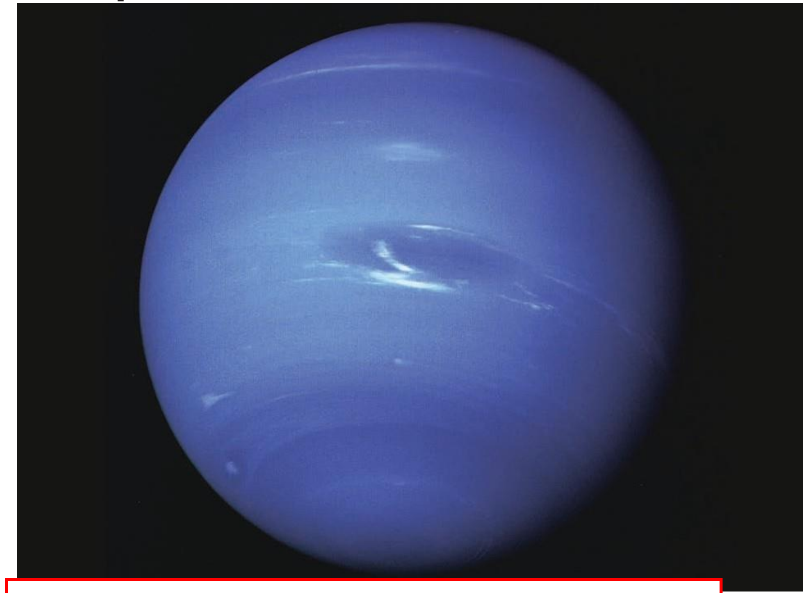
Neptune



Namesake	Roman god of the sea
Mean Distance from the Sun	4,498.25 million km (2,795.08 million mi)
Orbit Period	164.79 Earth years (60,190 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.00859
Orbit Inclination to Ecliptic	1.769 deg
Inclination of Equator to Orbit	29.58 deg
Rotation Period	16.11 hours
Equatorial Radius	24,764 km (15,388 mi)
Mass	17.147 of Earth's
Density	1.64 g/cm^3
Gravity	10.71 m/sec^2 (35.14 ft/sec^2)
Atmosphere Primary Components	hydrogen, helium
Effective Temperature	–214 deg C (–353 deg F)
Known Moons*	13
Known Rings	6 (Galle, Arago, Lassell, Le Verrier, unnamed ring co-orbital with the moon Galatea, Adams)

SIGNIFICANT DATES

- 1846 — Using mathematical calculations, astronomers discover Neptune, increasing the number of known planets to eight. Neptune's largest moon, Triton, is found the same year.
- 1984 — Astronomers find evidence for the existence of a ring system around Neptune.
- 1989 — Voyager 2 becomes the first and only spacecraft to visit Neptune, passing about 4,800 kilometers (2,983 miles) above the planet's north pole.
- 1998 — Scientists using telescopes on Earth and in space image Neptune's rings and ring arcs for the first time.
- 2003 — Using improved observing techniques, astronomers discover five new moons orbiting Neptune.
- 2005 — Scientists using the Keck Observatory image the outer rings and find that some of the ring arcs have deteriorated.
- 2011 — Neptune completes its first 165-year orbit of the Sun since its discovery in 1846.
- 2013 — A scientist studying Neptune's ring arcs in archival Hubble Space Telescope images finds a previously unknown 14th moon of Neptune, provisionally designated S/2004 N 1.

Pluto and Charon

Namesake	Roman god of the underworld
Mean Distance from the Sun	5,906.38 million km (3,670.05 million mi)
Orbit Period	247.92 Earth years (90,553 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.2488
Orbit Inclination to Ecliptic	17.14 deg
Inclination of Equator to Orbit	119.61 deg
Rotation Period	6.387 Earth days (retrograde)
Equatorial Radius (Pluto)	1,180 km (733 mi)
Equatorial Radius (Charon)	600 km (373 mi)
Mass	0.0022 of Earth's

SIGNIFICANT DATES

- 1930 — Clyde Tombaugh discovers Pluto.
- 1977–1999 — Pluto's lopsided orbit brings it slightly closer to the Sun than Neptune. It will be at least 230 years before Pluto moves inward of Neptune's orbit for 20 years.
- 1978 — American astronomers James Christy and Robert Harrington discover Pluto's unusually large moon, Charon.
- 1988 — Astronomers discover that Pluto has an atmosphere. 2005 — Scientists using the Hubble Space Telescope announce the discovery of two additional moons of Pluto.
- 2006 — NASA's New Horizons mission launches to explore Pluto and the Kuiper Belt region.
- 2011–2012 — Three more small moons are found, bringing the total of known moons to five.

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Climatology is the science that seeks to describe and explain the nature of climate, how it differs from place to place, and how it is related to man's activities. In his opinion "**Climatology broadens the findings of meteorology in space and in time to cover the whole earth and periods of time as long as observations and indirect evidence will permit".**

(**Critchfield, H.J. 1975**).

- **(Thornthwaite C.W. 1961)** ***broadens the scope of climatology when he suggests that the study of the atmosphere as well as that of the earth's surface form the core of this discipline. This is so because each and every characteristic of climate is determined by the exchange of heat, moisture and momentum between the earth's surface and the atmosphere.***

The term climatology is correctly applied to the study of the following five growing fields:
(i) climatological record, (ii) theory of climate, (iii) energy and moisture balances of the earth, (iv) study of climate as the environment of living organisms and (v) study of climate as the direct environment of man.

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Climatology, according to **F. Kenneth Hare**, is an integral part of physical geography, perhaps closer to the centre than any other. At the same time, it has also been described as a major aspect of meteorology from which it must draw its fundamental principles.

- The geographer is interested in **the study of climate simply because there are climatic regions found on the earth's surface, and each climatic region, despite its different geographical setting, is characterized** by certain degree of uniformity.
- The boundaries of these climatic regions are so **well-marked that they can be easily recognised on the basis of soil-groups, different types of land forms, and various plant communities**. They can be easily defined on the basis of climatic numerical data.
- Since climate is said to be the key to regional variations, **the geographer is, therefore, naturally interested in the science of climatology. Similarities or differences found in different landscapes are the resultant effects of diversities in climate. A particular type of climatic condition gives rise to a specific landscape**.

Sub-Divisions of Climatology

There are three basic sub-divisions of the science of climatology:

(A) Physical Climatology (B) Regional (or Descriptive) Climatology

(C) Applied Climatology

Physical Climatology

- This branch of climatology seeks to explain **the factors responsible for bringing about the temporal and spatial variations in heat exchange, moisture exchange and air movement.**
- Observations of such **climatic elements as insolation, duration of sunshine, temperature, air pressure, precipitation, winds, cloudiness and fog, and visibility, etc.** In fact, **physical climatology is directly concerned with the discussion of all those factors and all those weather processes that cause regional differentiation of climate**.
- Thus, physical climatology is closely related to **meteorology which includes not only the physics, chemistry and dynamics of the atmosphere, but also many of its direct effects upon the earth's surface, the oceans and life in Usual. Physical climatology is a major aspect of meteorology from which most of its basic principles** are drawn.

Regional climatology

This branch of climatology seeks to **determine and describe the various types of climates. It is also labelled as descriptive climatology, for it is concerned with the identification of important climatic characteristics and analyses the interaction of the weather and climatic elements upon the life, health, and economics of peoples and areas.**

It may be pointed out that the very basis of the classification of climatic types is the statistical analysis of the climatic data. Moreover, while discussing the spatial distribution of climatic elements regional climatology encompasses the concept of scale as well.

Based on **spatial scale M.M. Yoshino** identified the following four groups of climates to be included in regional climatology : **1. micro-climate, 2. local climate, 3. meso-climate, and 4. macro-climate**

Microclimate

The climatic condition of **the smallest areal unit having a horizontal extent from less than one meter to 100 meters and vertical extent from the ground surface to 100 meters** (e.g. single crop field or a single household or the area around a single tree) is termed as microclimate. It may be mentioned that **data of climatic variables** (e.g. temperature, air pressure, humidity, evaporation, precipitation, air circulation etc.) **are not available in published climatological data records and hence such data are always obtained through fieldwork (measurement of these data by suitable instruments) by the individual** (investigator).

Local Climate:

The local climate comprises a **few microclimatic areas and hence its dimension in terms of areal coverage is larger than microclimate. The areal unit of local climate has the horizontal extent from 100 meters to 1000 meters and vertically, the area extends from ground surface upto 1000 meters**. It may be mentioned that in the study of local climate of an area (having different characteristics, namely a forest cover, an orchard, a village, an urban area etc.) the horizontal differences in climatic conditions are given roove importance than the vertical differences. Local climate varies even **in forest covers depending upon the nature of forest canopy, density of trees, ground cover, vertical structure, seasonality** etc.

Mesoclimate:

The mesoclimate incorporates **several local climatic areas which has horizontal extent from 100 meters to 20 km and vertical extent from the ground surface to 6 km in the atmosphere.** It may be mentioned that topographically **the mesoclimatic area is homogeneous which is characterized by similar physical controls of climate** e.g. the Ganga Delta, Konkan coastal plain, middle Ganga plain, Sundarban, Rewa plateau, Tarai region of Uttar Pradesh, Godavari Delta, Sardar Sarovar area etc.

Macroclimate:

Macroclimate also known as **geoclimate or geographical climate covers largest area of all the other three types of regional climate as referred** to above**. The horizontal distance is more than 20 km, it may be several hundred kilometers and vertical extent from ground surface may be more than 6 km**.

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This branch of climatology is concerned with **the application of the climatological knowledge to specific practical problems**. It analyses the relationship of climatology to other sciences.

In applied climatology **the main purpose is to find out ways and means to make use of our knowledge of climatic elements for the betterment of human life on the earth.**

The practical application of the discoveries and techniques to various types of human activities is growing day by day. Knowledge of **weather and climate is being applied to the solution of such problems as plant and animal production, transportation, communication and industry, structural designs and construction activities, atmospheric pollution and many other activities of** man.

Because of the rapidly growing literature of **climatology and the experience of persons working in the field, there have emerged, in recent decades, many specialized branches of the science of climatology**. They are labelled as agricultural or agro climatology, medical climatology, urban climatology, bio-climatology, architectural climatology, etc.

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Meteorology, **the physics of the lower atmosphere, studies the individual phenomenon of the atmosphere**.

Climatology, on the other hand, is concerned with the discussion of the component elements of climate as well as the factors which determine and control its distribution.

The function of climatology is two-fold. **First**, the meteorological aspect of this discipline examines the process of gain and loss of heat energy by the air layer near the ground, keeping in view the fact that the basic principles apply at any place on the globe.

Second, climatological aspect of the discipline examines the global pattern of thermal environment as it is expressed by characteristic values of air temperatures. The same is true in case of other climatic elements. Thus, climatology recognizes global climatic types and regions in terms of various combinations of the basic environmental ingredients such as air, temperature, and availability of water to plants in terms of precipitation and evaporation.

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Critchfield has clearly stated that climatology broadens the findings of meteorology in space and time. Meteorology is the atmosphere and the phenomena that occur within it, whereas climatology is the study of the weather conditions over a longer period.

Meteorology combines physics and geography. It draws its fundamental principles from physics and applies them to the behaviour of the atmosphere which is a mixture of different kinds of gases. It also studies the whole atmosphere and its movements as they are largely controlled by the geographic factors such as topography, distribution of continents and oceans, altitude, and latitude.

Although climatology aims at **a systematic study of climate and its distribution on the earth's surface, a knowledge of the individual weather or climatic element is equally essential. It is in this respect that climatology comes closer to meteorology.**

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In order to appreciate the changes occurring in "**the weather of a particular place or area, and in order to describe the atmospheric conditions at a particular point of time, at a particular place, the observation and measurement of individual weather aspects is necessary**".

Following are some of the most important elements of weather which in different combinations make up the climate of a particular place of area: solar radiation, air temperature, air pressure, wind velocity and wind direction, humidity and precipitation and amount of cloudiness

A Composition of The Atmosphere

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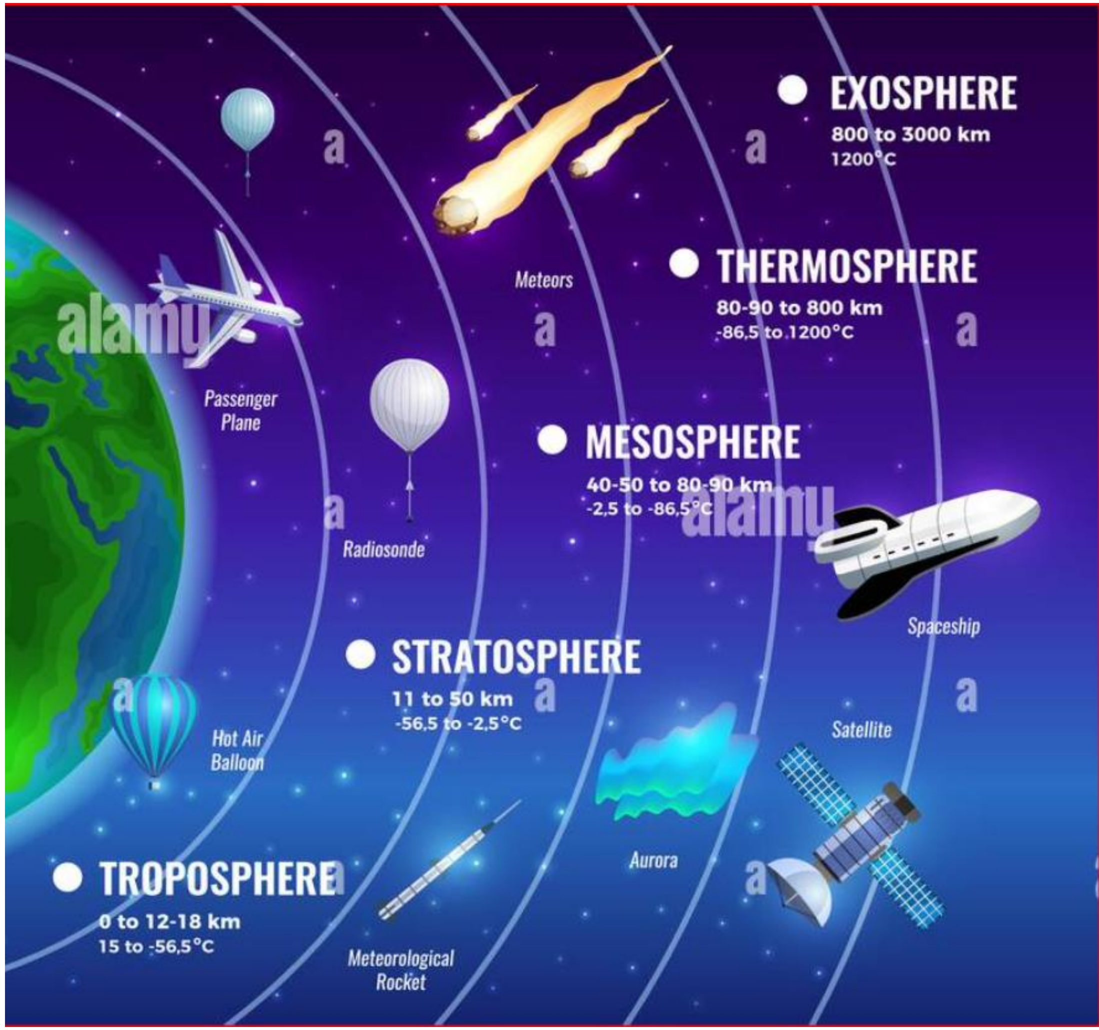
The eleven most abundant gases found in the Earth's lower atmosphere by volume. Of the gases listed, nitrogen, oxygen, water vapor, carbon dioxide, methane, nitrous oxide, and ozone are extremely important to the health of the Earth's biosphere.

Gas Name	Chemical Formula	Percent Volume
Nitrogen	**N_2**	**78.08%**
Oxygen	O_2	**20.95%**
***Water**	H_2O	**0 to 4%**
Argon	Ar	**0.93%**
***Carbon Dioxide**	CO_2	**0.0360%**
Neon	Ne	**0.0018%**
Helium	He	**0.0005%**
***Methane**	CH_4	**0.00017%**
Hydrogen	H_2	**0.00005%**
***Nitrous Oxide**	N_2O	**0.00003%**
***Ozone**	O_3	**0.000004%**

Principal gases comprising dry air in the lower atmosphere.



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Homosphere

This is **the lower part of atmosphere which extends up to a height of about 88 kilometres**. It is characterized by uniformity in composition. In other words, **the proportion of the component gases of this sphere are uniform at different levels. In fact, the term "homosphere" means the zone of homogeneous composition**. The homosphere has been subdivided into three sub-layers:

(a) troposphere
(b) stratosphere and
(c) mesosphere.

Each sub-layer is separated from the adjoining one by a very shallow transition zone. **Tropopause, stratopause and mesopause represent such transition zones**.

Heterosphere

The atmosphere above the homosphere is not uniform in composition. **It has a heterogeneous composition, hence the name “heterosphere”.** Different layers of the atmosphere in this part differ from one another in their chemical and physical properties.

The heterosphere is also referred to as **the thermosphere, for in this layer temperature goes on rising upto the outermost boundary of the atmosphere.** It may be remembered that in the upper parts of **the atmosphere where the gases are so rarefied, the high temperatures are caused exclusively by the photochemical actions of the ultraviolet solar radiation.**

COMPOSITION OF THE ATMOSPHERE

Air is a mechanical mixture of gases, not a chemical compound. Dry air, by volume, is more than 99 per cent composed of nitrogen and oxygen. Rocket observations show that these gases are mixed in remarkably constant proportions up to about 100 km altitude. Yet, despite their predominance, these gases are of little climatic importance.

Component	*Symbol*	*Volume % (dry air)*	*Molecular weight*
Nitrogen	N_2	78.08	28.02
Oxygen	O_2	20.95	32.00
*‡Argon	Ar	0.93	39.88
Carbon dioxide	CO_2	0.037	44.00
‡Neon	Ne	0.0018	20.18
*‡Helium	He	0.0005	4.00
†Ozone	O_3	0.00006	48.00
Hydrogen	H	0.00005	2.02
‡Krypton	Kr	0.0011	
‡Xenon	Xe	0.00009	
§Methane	CH_4	0.00017	

Average composition of the dry atmosphere below 25 km.

Greenhouse gases

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In spite of their relative scarcity, the so-called greenhouse gases play a crucial role in the thermodynamics of the atmosphere. They trap radiation emitted by the earth, thereby producing the greenhouse effect Moreover, the concentrations of these trace gases are strongly affected by human (i.e. anthropogenic) activities:

1. Carbon dioxide (CO_2) is involved in a complex global cycle. It is released from the earth's interior and produced by respiration of biota, soil microbia, fuel combustion and oceanic evaporation. Conversely, it is dissolved in the oceans and consumed by plant photosynthesis. The imbalance between emissions and uptake by the oceans and terrestrial biosphere leads to the net increase in the atmosphere.
2. Methane (CH_4) is produced primarily through anaerobic (i.e. oxygen-deficient) processes by natural wetlands and rice paddies (together about 40 per cent of the total), as well as by enteric fermentation in animals, by termites, through coal and oil extraction, biomass burning, and from landfills.

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H^2O$$

Almost two-thirds of the total production is related to anthropogenic activity.

Methane is oxidized to CO 2 and H_2O by a complex photochemical reaction system.

$CH_4 + O_2 + 2x \rightarrow CO_2 + 2x\ H_2$

where x denotes any specific methane destroying species (e.g. H, OH, NO, Cl or Br).

3. Nitrous oxide (N_2O) is produced primarily by nitrogen fertilizers (50–75 per cent) and industrial processes. Other sources are transportation, biomass burning, cattle feed lots and biological mechanisms in the oceans and soils. It is destroyed by photochemical reactions in the stratosphere involving the production of nitrogen oxides (NO_x) Ozone (O_3) is produced through the breakup of oxygen molecules in the upper atmosphere by solar ultraviolet radiation and is destroyed by reactions involving nitrogen oxides (NO_x) and chlorine (Cl) (the latter generated by CFCs, volcanic eruptions and vegetation burning) in the middle and upper stratosphere.

4. Chlorofluorocarbons (CFCs: chiefly $CFCl_3$ (F–12) and $CF_2 Cl_2$ (F–12)) are entirely anthropogenically produced by aerosol propellants, refrigerator coolants (e.g. 'freon'), cleansers and air-conditioners, and were not present in the atmosphere until the 1930s. CFC molecules rise slowly into the stratosphere and then move poleward, being decomposed by photochemical processes into chlorine after an estimated average lifetime of some 65 to 130 years.

5. Hydrogenated halocarbons (HFCs and HCFCs) are also entirely anthropogenic gases. They have increased sharply in the atmosphere over the past few decades, following their use as substitutes for CFCs. Trichloroethane ($C_2H_3Cl_3$), for example, which is used in dry-cleaning and degreasing agents, increased fourfold in the 1980s and has a seven-year residence time in the atmosphere. They generally have lifetimes of a few years, but still have substantial greenhouse effects. The role of halogens of carbon (CFCs and HCFCs) in the destruction of ozone in the stratosphere is described below.

6. Water vapour (H_2O), the primary greenhouse gas, is a vital atmospheric constituent. It averages about 1 per cent by volume but is very variable both in space and time, being involved in a complex global hydrological cycle.

INSOLATION (Solar Radiation)

The sun is the primary source of energy on the earth. This energy is radiated in all directions into space through short waves. This is known as solar radiation. Only two billionths or (two units of energy out of 1,00,00,00,000 units of energy radiated by the sun) of the total solar radiation reaches the earth's surface. This small proportion of solar radiation is of great importance, as it is the only major source of energy on the earth for most of the physical and biological phenomena. **Incoming solar radiation through short waves is termed as insolation. The amount of insolation received on the earth's surface is far less than that is radiated from the sun because of the small size of the earth and its distance from the sun. Moreover water vapour, dust particles, ozone and other gases present in the atmosphere absorb a small amount of insolation.**

Factors influencing Insolation

The amount of insolation received on the earth's surface is not uniform everywhere. It varies from place to place and from time to time. The tropical zone receive the maximum annual insolation. It gradually decreases towards the poles. Insolation is more in summers and less in winters. The following factors influence the amount of insolation received.

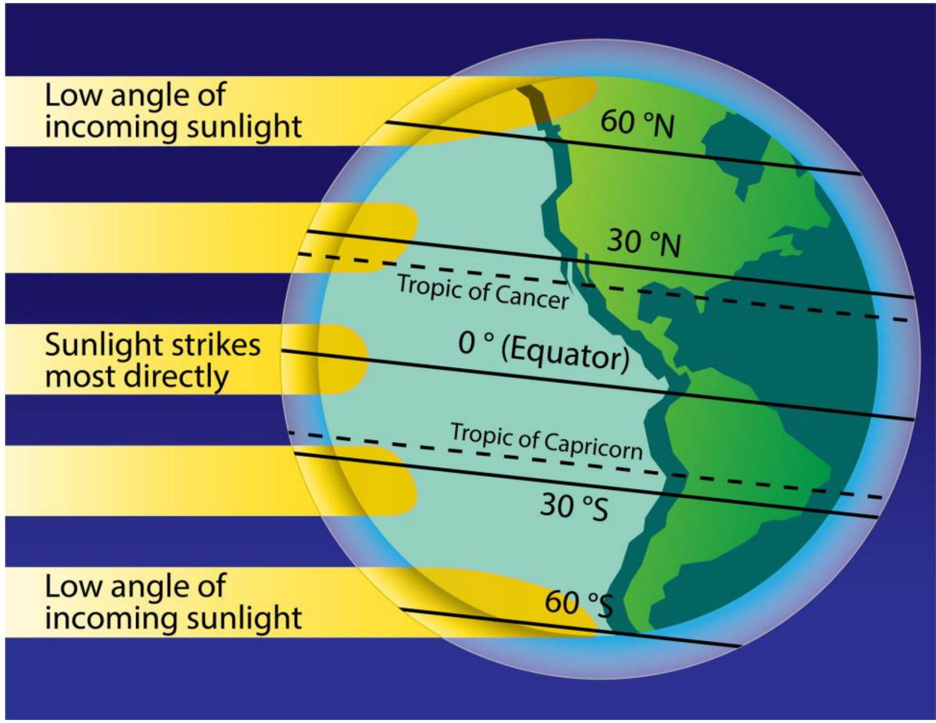
(i) The angle of incidence. (ii) Duration of the day. (daily sunlight period) (iii) Transparency of the atmosphere.

The Angle of Incidence

Since the earth is round, the sun's rays strike the surface at different angles at different places. The angle formed by the sun's ray with the tangent of the earth's circle at a point is called angle of **incidence**. It influences the insolation in two ways.

First, when the sun is almost overhead, the rays of the sun are vertical. The angle of incidence is large hence, they are concentrated in a smaller area, giving more amount of insolation at that place. If the sun's rays are oblique, angle of incidence is small and sun's rays have to heat up a greater area, resulting in less amount of insolation received there.

Secondly, the sun's rays with small angle, traverse more of the atmosphere, than rays striking at a large angle. Longer the path of sun's rays, greater is the amount of reflection and absorption of heat by atmosphere. As a result the intensity of insolation at a place is less.



(ii) Duration of the day :

Duration of the day varies from place to place and season to season. It decides the amount of insolation received on earth's surface. The longer the duration of the day, the greater is the amount of insolation received. Conversely shorter the duration of the day leads to receipt of less insolation.

(iii) Transparency of the atmosphere:

Transparency of the atmosphere also determines the amount of insolation reaching the earth's surface. The transparency depends upon cloud cover, its thickness, dust particles and water vapour, as they reflect, absorb or transmit insolation. Thick clouds hinder the insolation to reach the earth while clear sky helps it to reach the surface. Water vapour absorb insolation, resulting in less amount of insolation reaching the surface.

Heating and cooling of the Atmosphere

Sun is the ultimate source of atmospheric heat and energy, but its effect is not direct. For example, as we climb a mountain or ascend in the atmosphere, temperature become steadily lower, rather than higher, as we might expect. This is because the mechanism of heating the atmosphere in not simple. There are four heating processes directly responsible for heating the atmosphere.

They are : **(i) Radiation (ii) Conduction (iii) Convection and (iv) Advection**

Radiation :

Radiation is the process by which solar energy reaches the earth and the earth loses energy to outer space. When the source of heat transmits heat directly to an object through heat waves, it is known as radiation process. In this process, heat travels through the empty space. The vast amount of heat energy coming to and leaving the earth is in the form of radiation. The following facts about radiation are worth noting.

(i) All objects whether hot or cold emit radiant energy continuously.
(ii) Hotter objects radiate more energy per unit area than colder objects.
(iii) Temperature of an object determines the waves length of radiation. Temperature and wave length are inversely related. Hotter the object shorter is the length of the wave.
(iv) Insolation reaches the earth's surface in short waves and heat is radiated from the earth in long waves.

You will be amused to know that atmosphere is transparent to short waves and opaque to long waves. Hence energy leaving the earth's surface i.e. terrestrial radiation heats up the atmosphere more than the incoming solar radiation i.e. insolation.

Conduction

When **two objects of unequal temperature come in contact with each other, heat energy flow from the warmer object to the cooler object and this process of heat transfer is known as conduction.** The flow continues till temperature of both the objects becomes equal or the contact is broken. The conduction in the atmosphere occurs at zone of contact between the atmosphere and the earth's surface. However, this is a minor method of heat transfer in terms of warming the atmosphere since it only affects the air close to the earth's surface.

Convection

Transfer of heat by movement of a mass or substance from one place to another, generally vertical, is called convection. The air of the lower layers of the atmosphere get heated either by the earth's radiation or by conduction. The heating of the air leads to its expansion. Its density decreases and it moves upwards. Continuous ascent of heated air creates vacuum in the lower layers of the atmosphere. As a consequence, cooler air comes down to fill the vacuum, leading to convection. The cyclic movement associated with the convectional process in the atmosphere transfer .

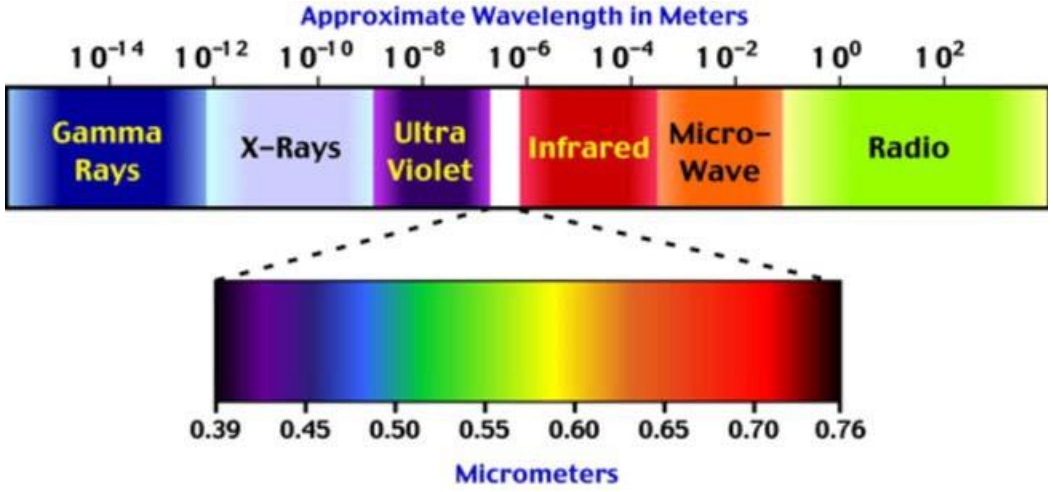
Advection

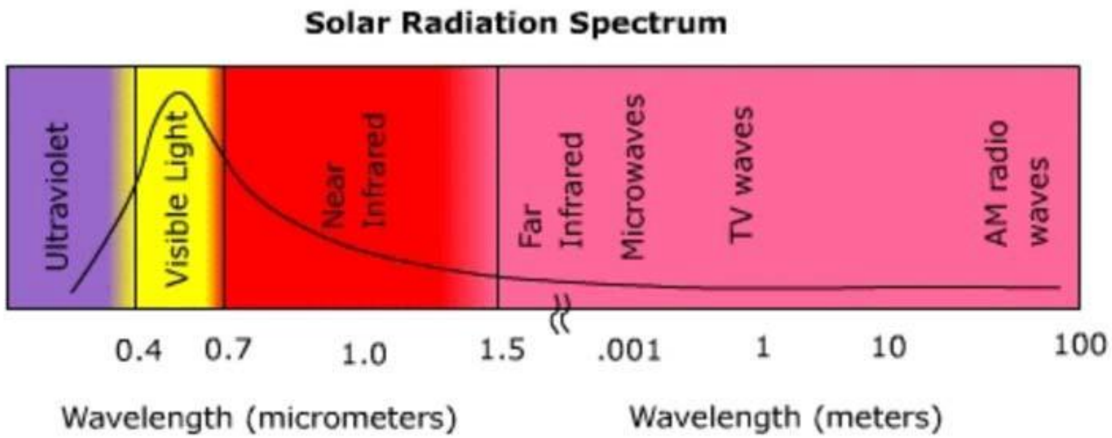
Winds carry the temperature of one place to another. The temperature of a place will rise if it lies on the path of winds coming from warmer regions. The temperature will fall if the place lies on the path of the winds blowing from cold regions. This process of horizontal transport of heat by winds is known as advection.

Energy and Radiation

The transfer of energy via electromagnetic waves that travel at the speed of light. The velocity of light in a vacuum is approximately 3 x 10^8 m/s. The time it takes light from the sun to reach the Earth is 8 minutes and 20 seconds. Heat transfer by electromagnetic radiation can travel through empty space. Any body above the temperature of absolute zero (-273.15º C) radiate energy to their surrounding environment.

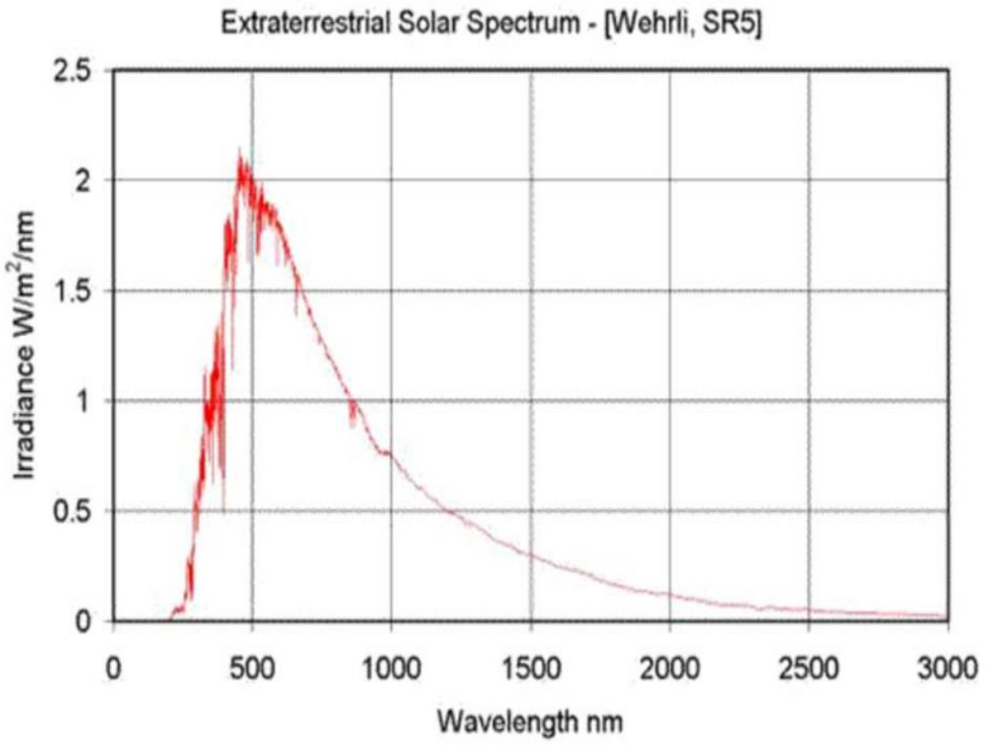
The many different types of radiation is defined by its wavelength. The electromagnetic radiation can vary widely.





Sun Radiation Spectrum

Visible light has a wavelength of between 0.40 to 0.71 micrometers (µm). The sun emits only a portion (44%) of its radiation in this range. Solar radiation spans a spectrum from approximately 0.1 to 4.0 micrometers. About 7% of the sun's emission is in 0.1 to 0.4 micrometers wavelength band (UV). About 48% of the sun's radiation falls in the region between 0.71 to 4.0 micrometers (near infrared : 0.71 to 1.5 micrometers; far infrared: 1.5 to 4.0 micrometers).



Solar radiation incident outside the earth's atmosphere is called extraterrestrial radiation. On average the extraterrestrial irradiance is 1367 W/m^2. This value varies by ±3% as the earth orbits the sun.

Stephan-Boltzmann Law

The amount of electromagnetic radiation emitted by a body is directly related to its temperature. If the body is a perfect emitter (black body), the amount of radiation given off is proportional to the 4th power of its temperature as measured in degrees **Kelvin**. This natural phenomenon is described by the Stephan-Boltzmann law:

$$E = \sigma T^4$$

Where $\sigma = 5.67 \times 10^{-8}$ $Wm^{-2}k^{-4}$ and T is in K

In general, good emitters of radiation are also good absorbers of radiation at specific wavelength bands. This is especially true of greenhouse gases. Some objects in nature have almost completely perfect abilities to absorb and emit radiation. We call these objects black bodies. The radiation characteristics of the sun and the Earth are very close to being black bodies.

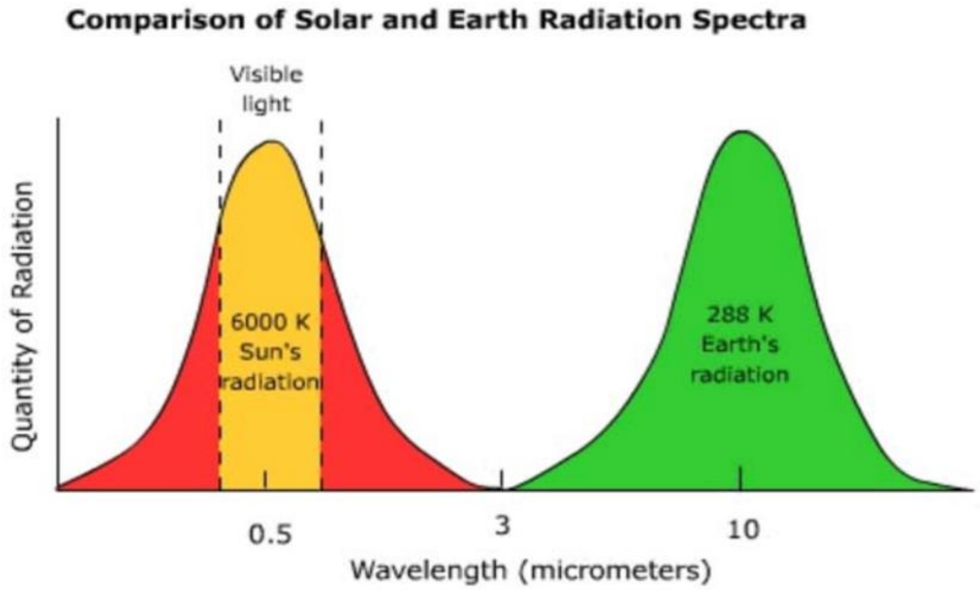
Wien's Law

The wavelength of **maximum emission** of any body is inversely proportional to its absolute temperature. Thus, the higher the temperature, the shorter the wavelength of maximum emission. This phenomenon is often called Wien's law:

$$\lambda \text{Max} = \frac{C}{T}$$

$$C = 2897$$

where T is in Kelvin. According to the above equation the wavelength of maximum emission for the sun (5800 K) is about 0.5 μm, while the wavelength of maximum emission for the Earth (288 K) is approximately 10.0 μm.



The gases of the atmosphere are relatively good absorbers of long wave radiation and thus absorb the energy emitted by the Earth's surface. The absorbed radiation is emitted downward toward the surface as ***long wave atmospheric counter-radiation*** keeping near surfaces temperatures warmer than they would be without this blanket of gases. This is known as the "greenhouse effect".

Inverse Square Law

The amount of radiation passing through a specific area is inversely proportional to the square of the distance of that area from the energy source. This phenomenon is called the inverse square law. Using this law we can model the effect that distance traveled has on the intensity of emitted radiation from a body like the sun.

$$Intensity = \frac{I}{d_2}$$

Where I is the intensity of radiation at one d *and* d *is the distance traveled*

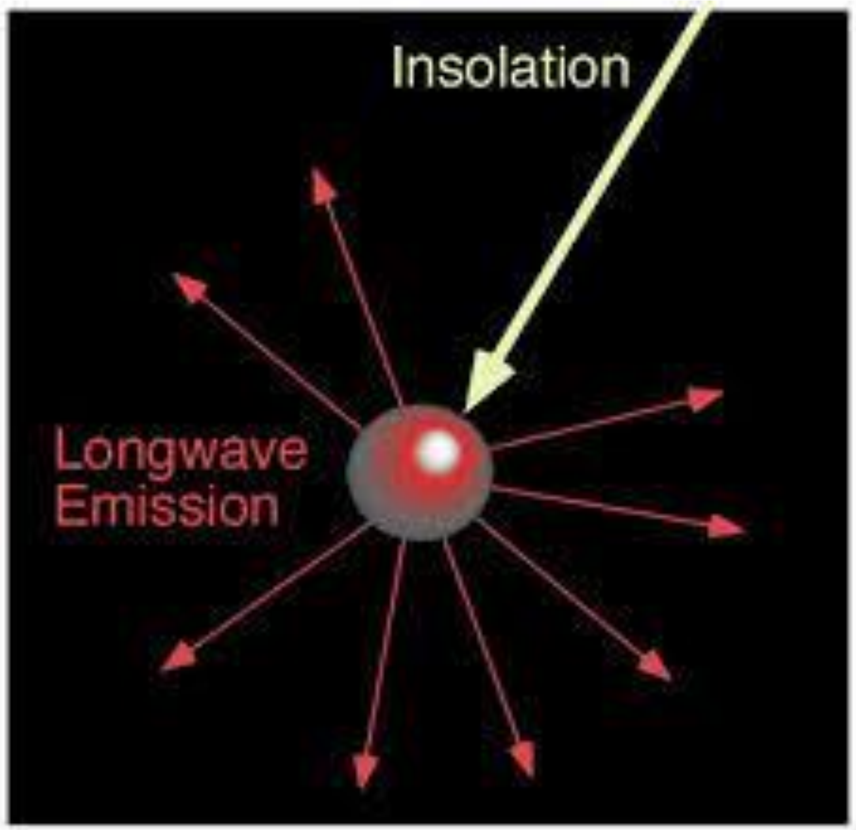
Radiation from the Sun is lessened by the inverse square law as it reaches further and further away from the Sun. So the further away that a planet is from the Sun then the less radiation it receives. What happens to that radiation depends on whether the planet has an atmosphere, whether the atmosphere contains clouds and how the clouds, or the surface, reflect the radiation.

For planets with no atmosphere all the Sun's radiation will strike the surface. Some of this will be reflected away from the planet but the rest will be absorbed. The temperature of the surface will be raised until there is equilibrium between the energy radiated by the warm surface of the planet and the received solar radiation. For planets like Mercury, this results in a very hot surface where the Sun is shining (more than 400°C) but very cold on the night side, where the radiation from the surface rapidly cools it to -180°C.

Atmospheric Effects on Incoming Solar Radiation

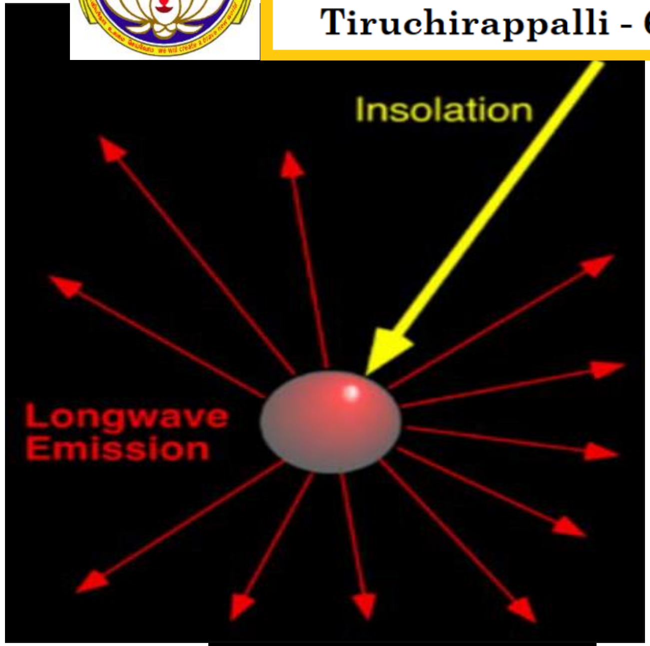
The Earth is a planet with an atmosphere and is largely transparent to the incoming solar radiation. There are constituents in the atmosphere which prevent some kinds of radiation from reaching the surface, such as ozone which stops the **ultraviolet**. A fair proportion of the Earth is covered by clouds which reflect a lot of the Sun's radiation and thus affecting the surface temperature.

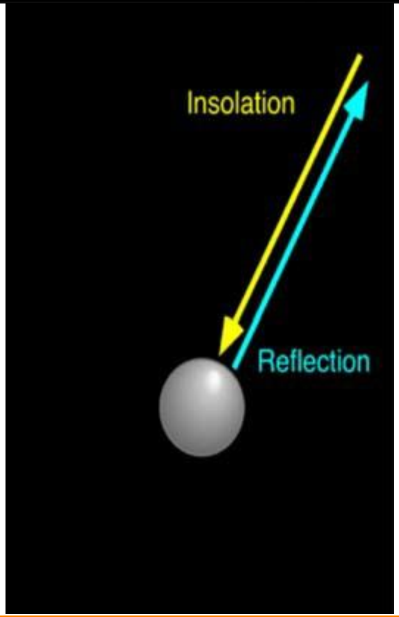
- The process of scattering occurs when small particles and gas molecules diffuse part of the incoming solar radiation in random directions without any alteration to the λ of the electromagnetic energy.
- Scattering does, however, reduce the amount of incoming radiation reaching the Earth's surface. A significant proportion of scattered shortwave solar radiation is redirected back to space.
- The amount of scattering that takes place is dependent on two factors: λ of the incoming radiation and the size of the scattering particle or gas molecule.
- In the Earth's atmosphere, the presence of a large number of particles with a size of about 0.5 μm results in shorter wavelengths being preferentially scattered.
- This factor also causes our sky to look blue because this color corresponds to those wavelengths that are best diffused. If scattering did not occur in our atmosphere the daylight sky would be black.



Atmospheric Effects on Incoming Solar Radiation

- If intercepted, some gases and particles in the atmosphere have the ability to absorb incoming insolation. Absorption is defined as a process in which solar radiation is retained by a substance and converted into heat.
- The creation of heat also causes the substance to emit its own radiation. In general, the absorption of solar radiation by substances in the Earth's atmosphere results in temperatures that get no higher than 1800° C.
- Bodies with temperatures at this level or lower would emit their radiation in the longwave band. Further, this emission of radiation is in all directions so a sizable proportion of this energy is lost to space.
- The third process in the atmosphere that modifies incoming solar radiation is reflection. Reflection is a process where sunlight is redirect by 180° after it strikes an atmospheric particle. This redirection causes a 100 % loss of the insolation. Most of the reflection in our atmosphere occurs in clouds when light is intercepted by particles of liquid and frozen water. The reflectivity (albedo) of a cloud can range from 40 to 90 %.

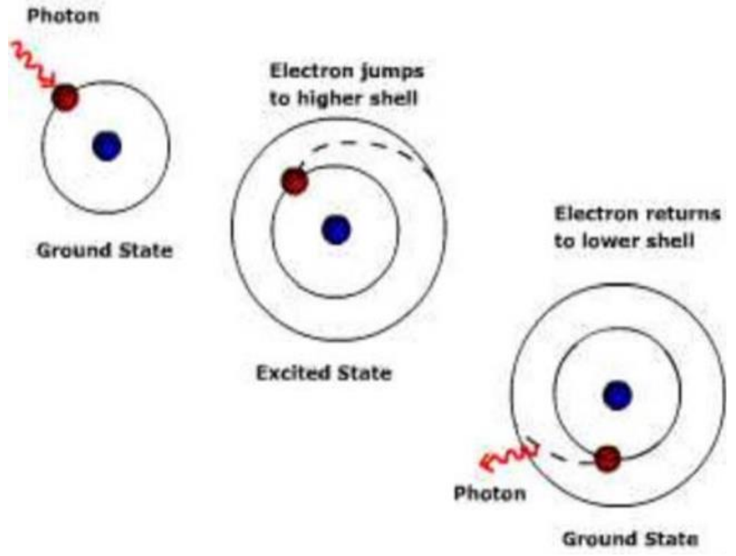




Selective Absorption of the Atmosphere

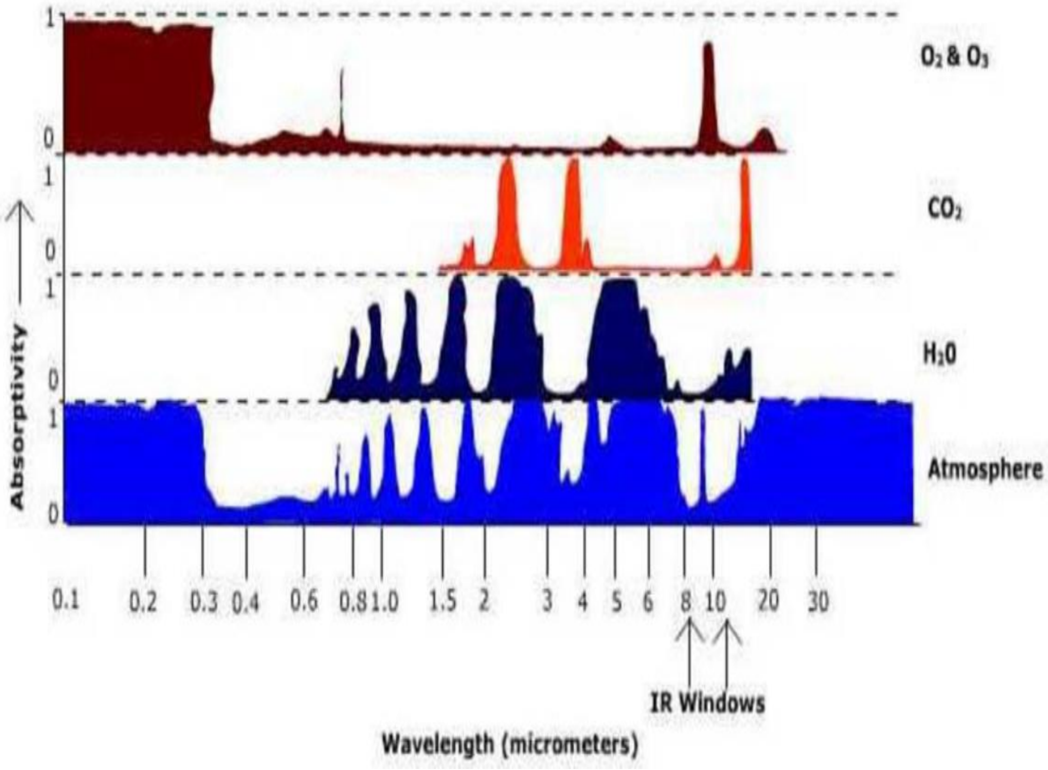
At the smallest scale the electromagnetic radiation behaves as a particle, like when light is emitted by a single atom or molecule. When energy is given off there is a change in the orbital pattern of the electrons that surround the nucleus of an atom. As the orbit changes, a bundle of energy called a "**photon**" is released. However, particles of light differ from particles of matter: they have no mass, occupy no space, and travel at the speed of light. The amount of energy carried by a photon varies inversely with wavelength, the shorter the wavelength the more energetic is the photon. Normally, light is formed from a large number of photons, with the intensity related to the number of them.

The gasses that comprise our atmosphere absorbs only particular wavelengths of light. Electronsorbit the nucleus of an atom at fixed orbital distances called orbital shells. The orbital shell for each atom is different and discrete. That is, for a given atom like hydrogen, its electrons can only orbit at particular distances and are different than those for atoms of other gases.



Selective Absorption of the Atmosphere

The amount of energy carried by a photon depends on the wavelength. Thus the atoms that comprise a gas can only absorb, or emit, particular wavelengths of energy (i.e. photons of energy). We can see this selective absorption by examining Figure below. The graph shows very little absorption for atmosphere as a whole in the shortwave end of the spectrum, especially in the visible light band (the band of maximum emission for the Sun). The atmosphere absorbs far better in the long wave end of the electromagnetic spectrum which is the region of maximum emission (10μm) for the Earth.



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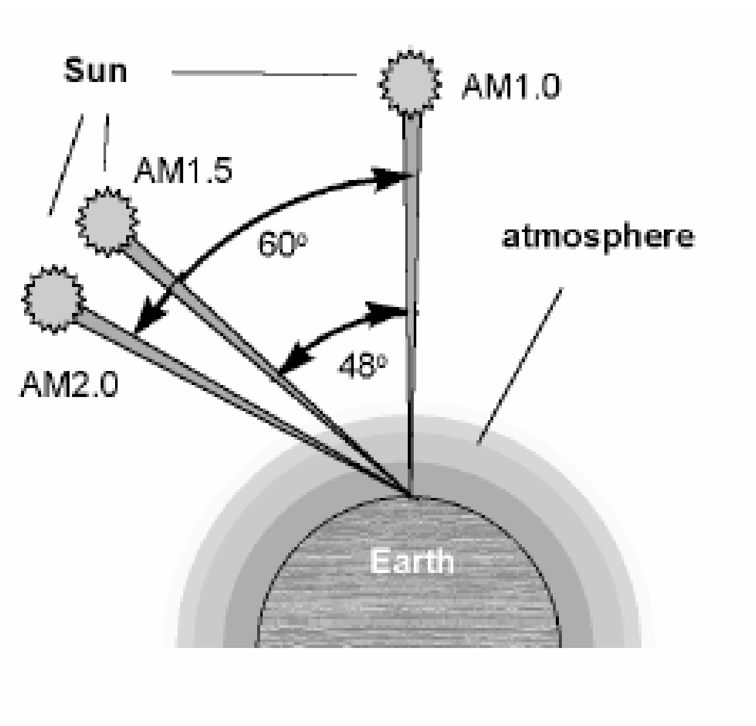
Irradiance & Irradiation

- Irradiance is given in *W/m^2 and is represented by the symbol G.*
- The rate at which radiant energy is incident on a surface per unit area of surface.
- Irradiation is given in *J/m^2* and is the incident energy per unit area on a surface - determined by integration of irradiance over a specified time, usually an hour or a day.
- Insolation is a term used to solar energy irradiation
- Radiosity is the rate at which radiant energy leaves a surface, per unit area, by combined emission, reflection and transmission.



Air Mass

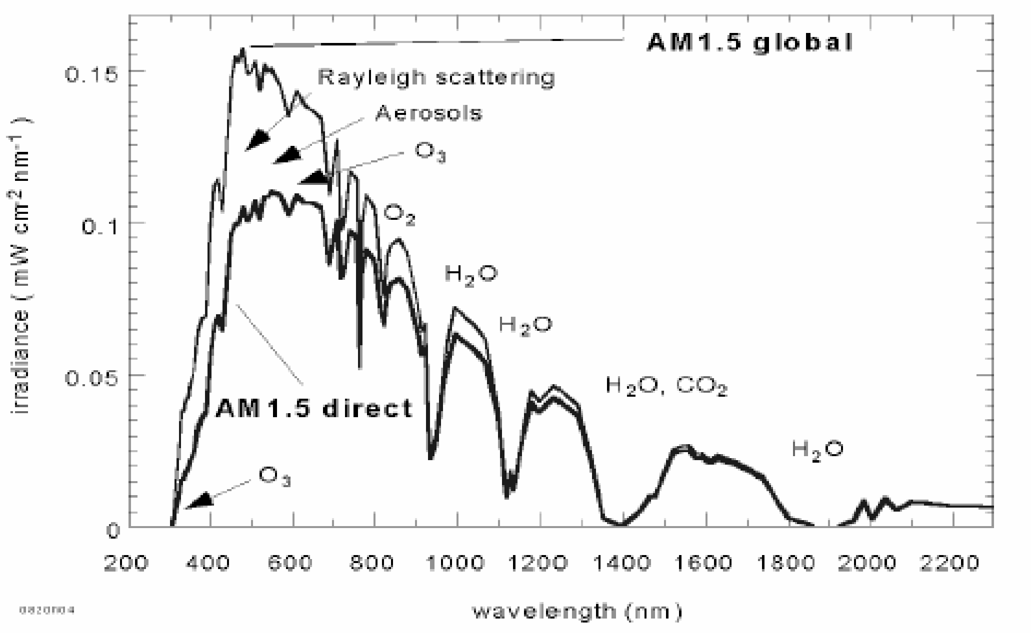
The path length of the solar radiation through the Earth's atmosphere in units of Air Mass (*AM*) increases with the angle from the zenith. The AM 1.5 spectrum is the preferred standard spectrum for solar cell efficiency measurements.

The easiest way to estimate the air mass in practice is to measure the length of the shadow *s* cast by a vertical structure of height *h* using

$$AM = \sqrt{1 + \left(\frac{s}{h}\right)^2}$$

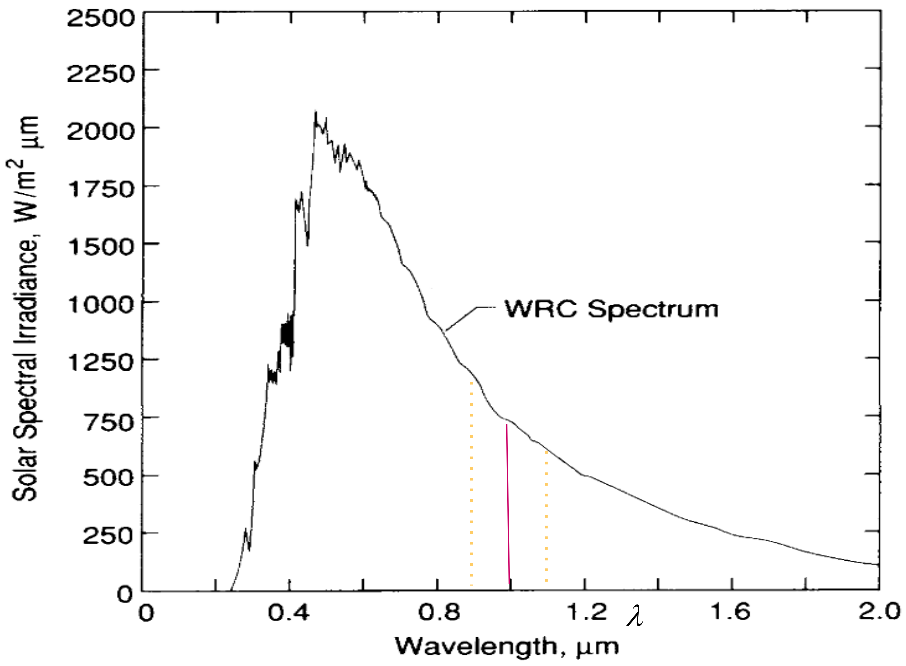
Air Mass *AM* : The ratio of the mass of atmosphere through which beam radiation passes to the mass it would pass through if the sun were at zenith (directly overhead).
At sea level, AM =1 when the sun is at zenith; *AM* = 2 for a zenith angle θ_z of 60º. For $0 < \theta_z < 70^o$ AM= 1/cos θ_z

Global Radiation



The global spectrum comprises the direct plus the diffused light.

Spectral Distribution of Extraterrestrial Radiation



$G_{SC,\lambda}$: The average energy over small bandwidths centered at wavelength λ; $F_{0-\lambda}$: The fraction of the total energy in the spectrum that is between wavelengths 0 and λ.

**The radiation that would be received in the absence of the atmosphere at mean-earth- sun distance* (World Radiation Center (WRC) standard)

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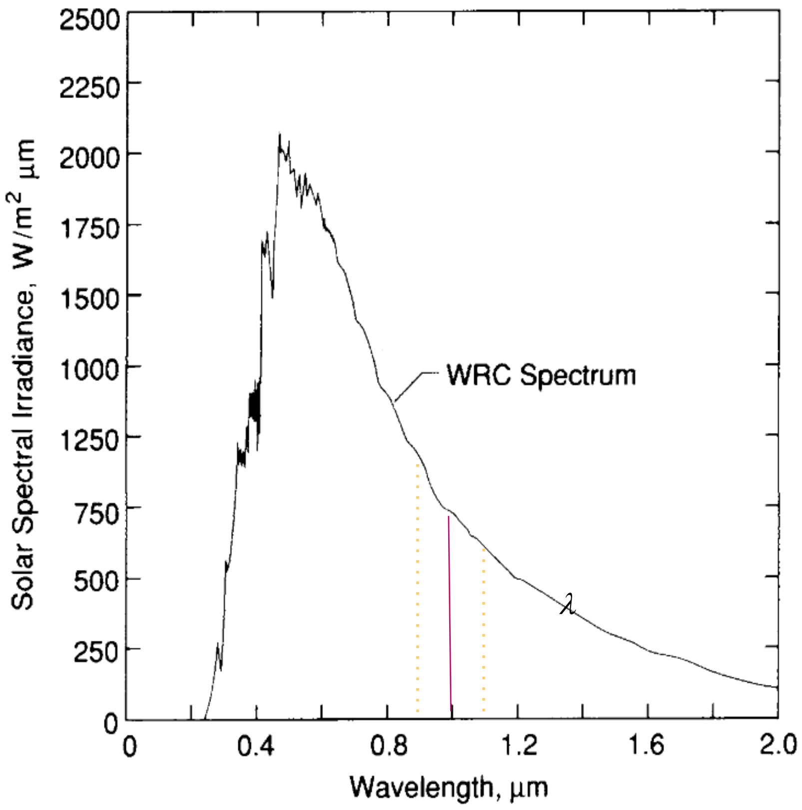
***The radiation that would be received in the absence of the atmosphere at mean-earth- sun distance** (World Radiation Center (WRC) standard)

AM 1.5d Spectrum Energy Distribution

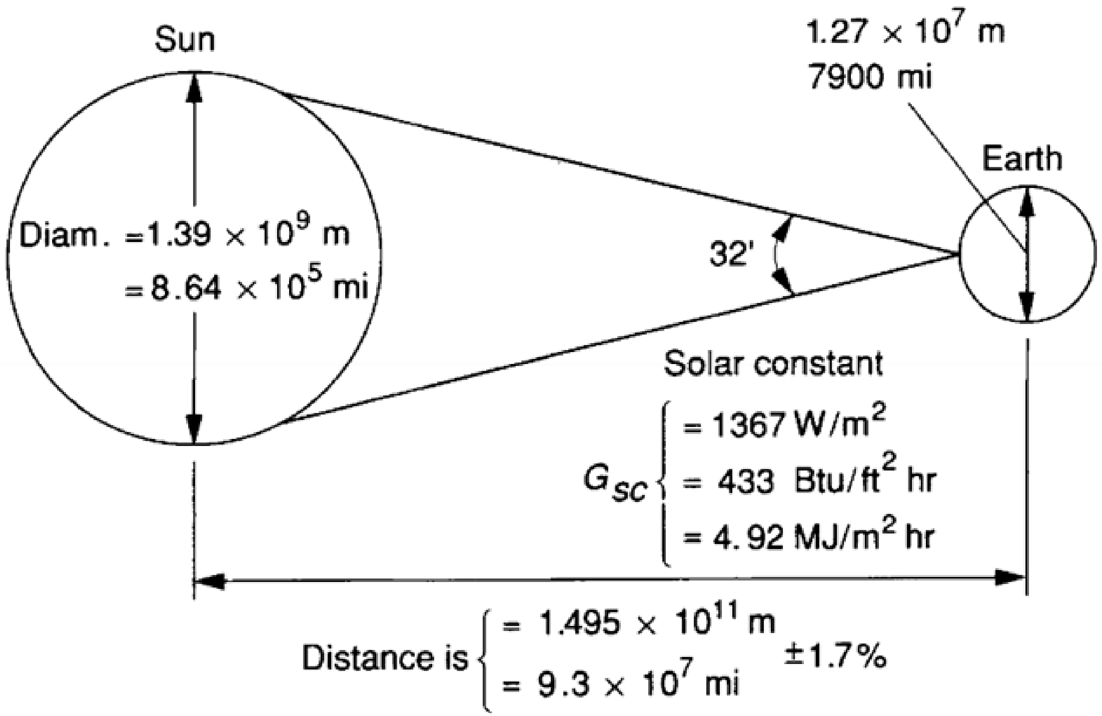
(eV) :	4.1	3.5	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.24	1.18	1.13	1.08	1.03	0.99	0.95	0.69	0.62	0.5
(nm):	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1800	2000	2500
300	0	0.7	2.9	7.6	14	21	28	35	42	48	54	59	64	67	70	74	77	79	81	84	86	96	96	100
350		0	2.2	6.9	14	21	28	35	41	47	53	58	63	66	69	73	77	78	80	83	85	95	96	99
400			0	4.7	11	18	25	33	39	45	51	56	61	64	67	71	74	76	78	81	83	93	93	97
450				0	6.7	14	21	28	34	40	46	51	56	59	62	66	70	71	73	76	78	88	89	92
500					0	7.0	14	21	28	34	39	44	50	52	56	60	63	64	67	69	72	81	82	86
550						0	7.1	14	21	27	32	37	42	45	49	53	56	57	60	62	65	74	75	79
600							0	7.1	14	20	25	30	35	38	42	46	49	50	52	55	58	67	68	72
650								0	6.5	13	18	23	28	31	35	39	42	43	45	48	51	60	61	65
700									0	6.1	12	17	22	25	28	32	35	37	39	42	44	54	54	58
750										0	5.6	11	16	19	22	26	29	30	33	35	38	48	48	52
800											0	5.1	10	13	16	20	24	25	27	30	32	42	43	46
850												0	5.1	8.0	11	15	19	20	22	25	27	37	37	41
900													0	2.9	6.3	10	13	15	17	20	22	32	32	36
950														0	3.3	7.3	11	12	14	17	19	29	29	33
1000															0	3.9	7.2	8.4	11	13	16	26	26	30
1050																0	3.2	4.5	6.8	9.5	12	22	22	26
1100																	0	1.2	3.5	6.2	8.7	18	19	23
1150																		0	2.3	5.0	7.5	17	18	21
1200																			0	2.7	5.2	15	15	19
1250																				0	2.5	12	13	16
1300																					0	10	10	14
1800																						0	0.5	4.3
2000																							0	3.8
2500																								0



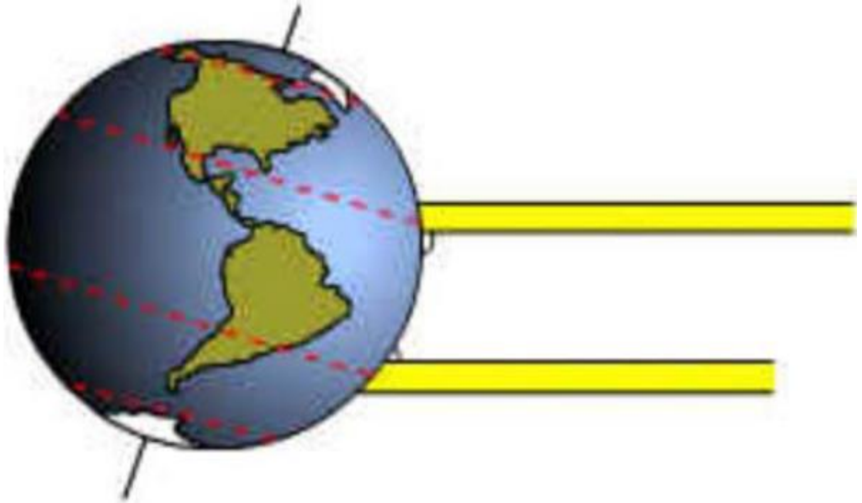
Silicon solar cells with a bandgap of 1.13ev can maximally absorb 77% of the terrestrial solar energy.

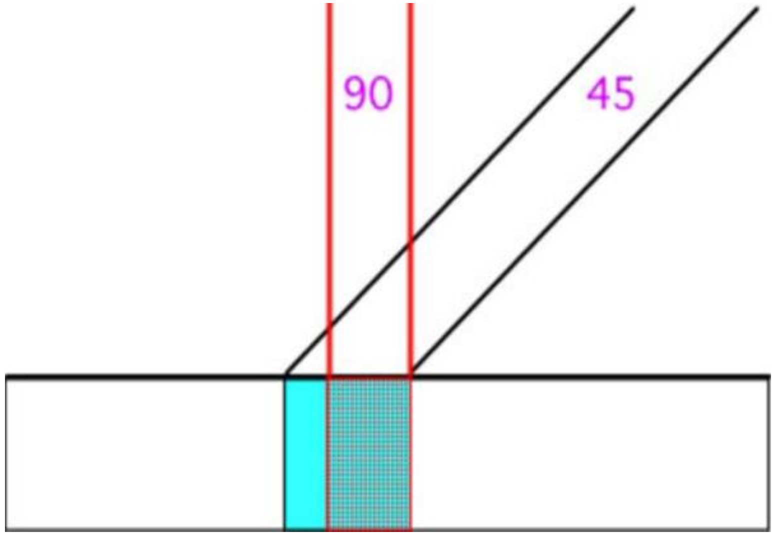
Sun-Earth Relationships

The solar constant, G_{SC} is the energy from the sun, per unit time, received on a unit area of surface perpendicular to the direction of propagation of the radiation, at mean earth-sun distance, outside of the atmosphere.

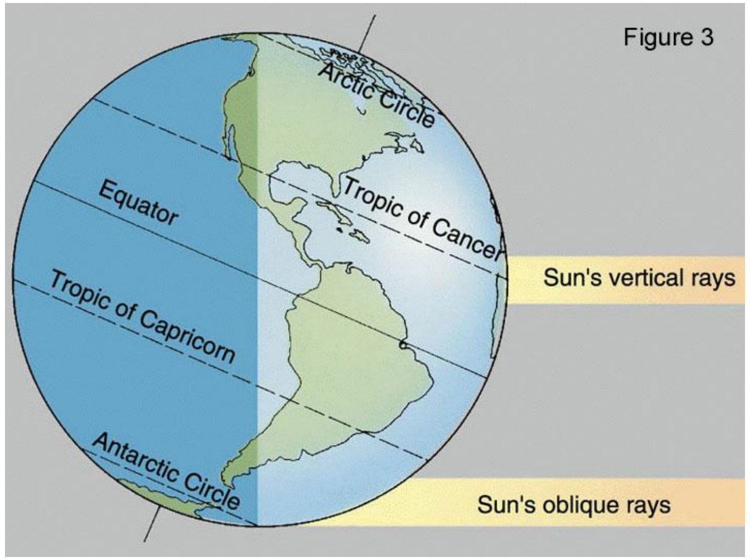


The Earth's axis is tilted 23 1/2 degrees from being perpendicular to the plane of the ecliptic. The axis of rotation remains pointing in the same direction as it revolves around the Sun, pointing toward the star Polaris. The constant tilt and parallelism causes changes in the angle that a beam of light makes with respect to a point on Earth during the year, called the "***sun angle***". The most intense incoming solar radiation occurs where the sun's rays strike the Earth at the highest angle. As the sun angle decreases, the beam of light is spread over a larger area and decreases in intensity. During the summer months the Earth is inclined toward the Sun yielding high sun angles. During the winter, the Earth is oriented away from the Sun creating low sun angles.





Sun angle determines the intensity of energy.



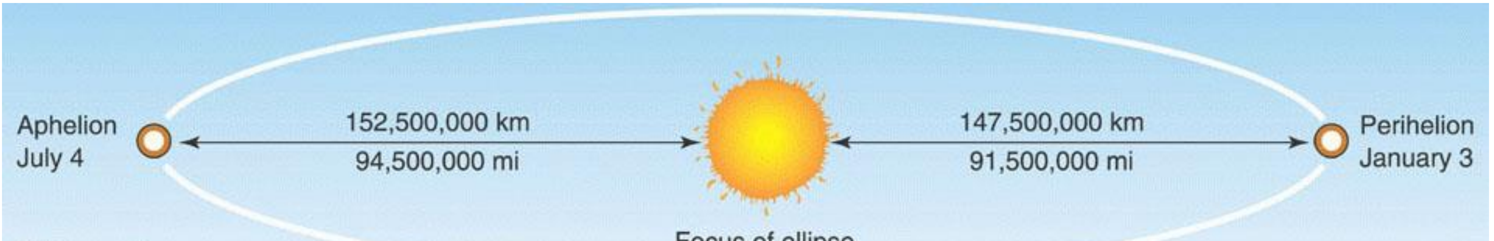
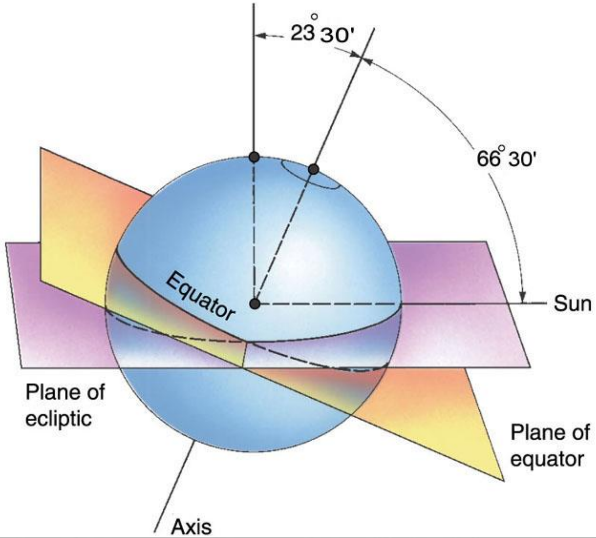


Figure 1

Figure 2



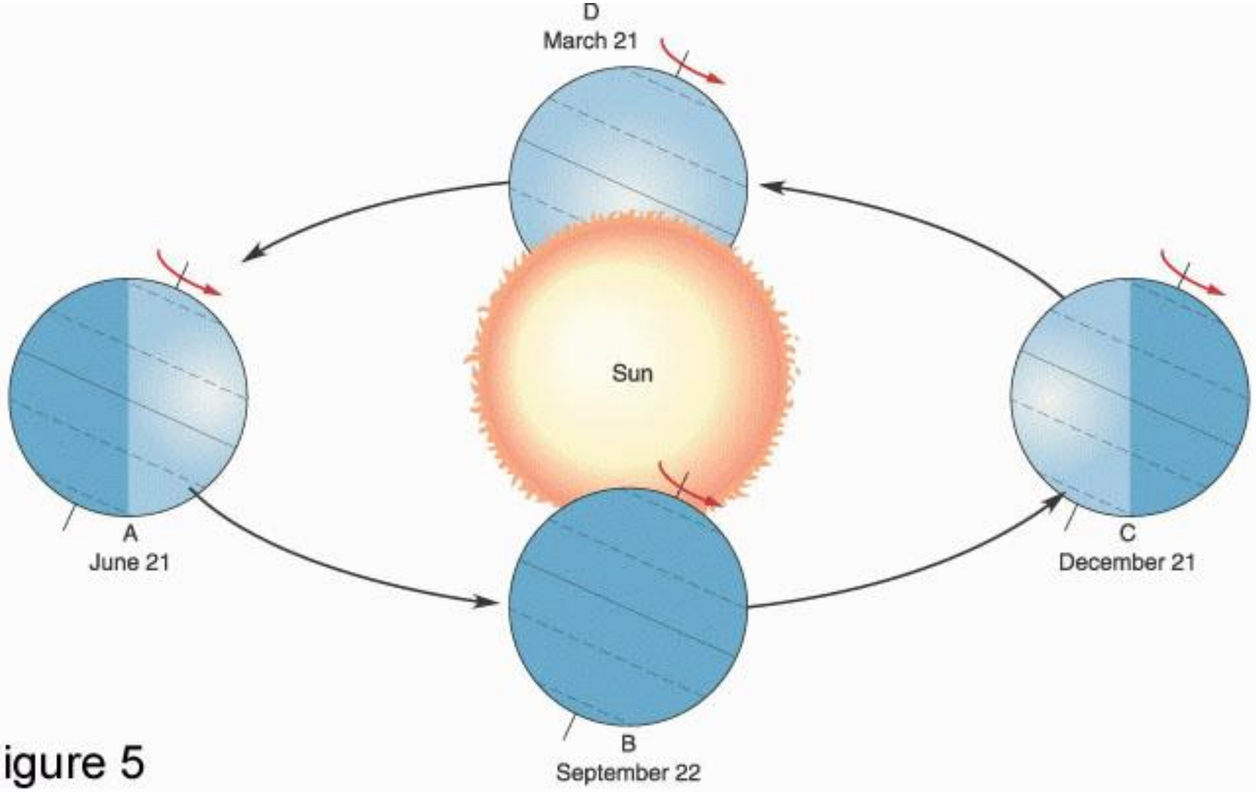


Figure 5

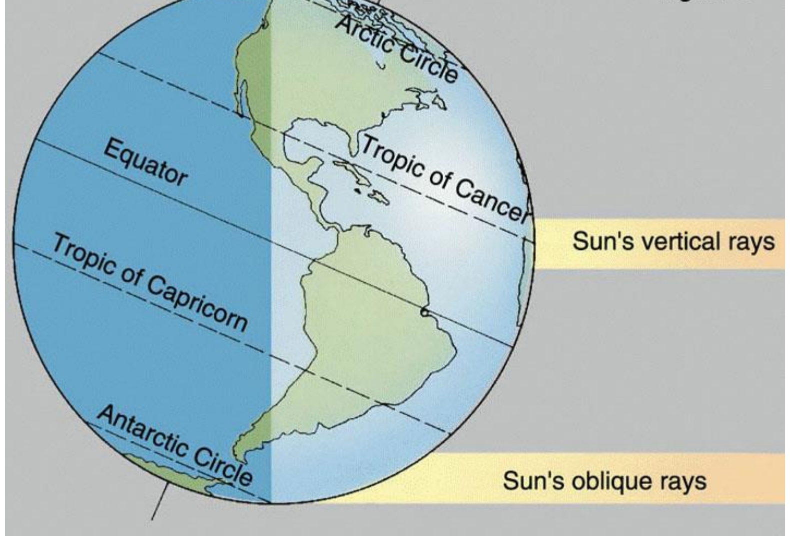
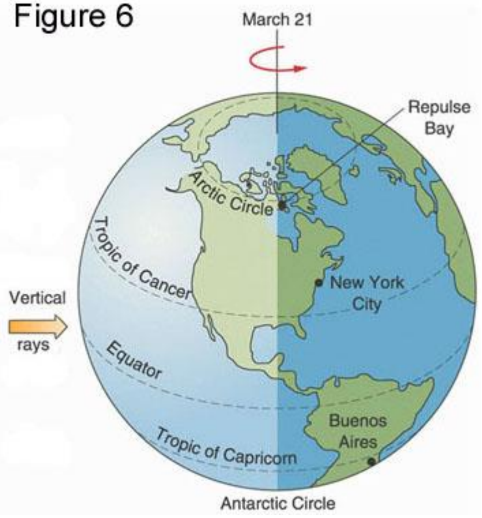


Figure 3

Figure 6



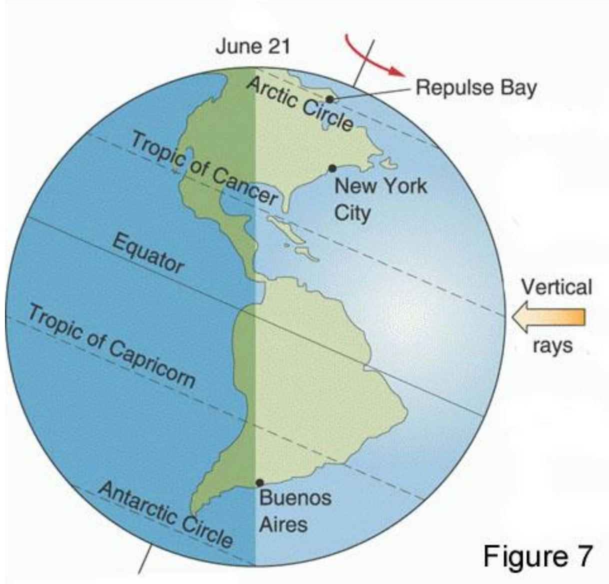


Figure 7

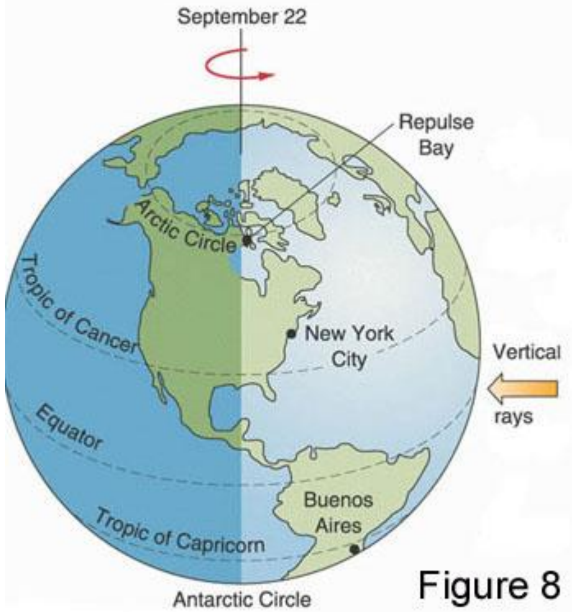
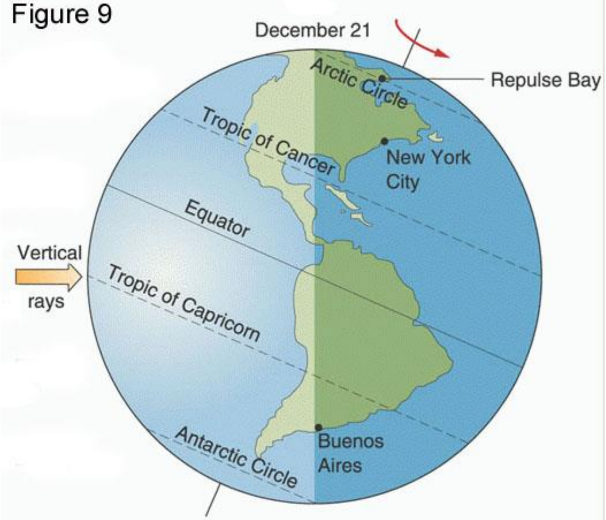


Figure 8

Figure 9



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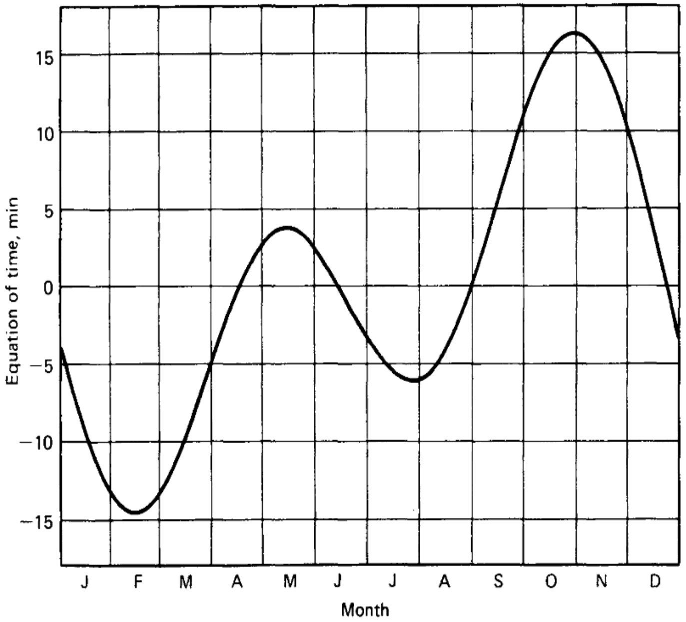
Solar Time

Solar time is used in all sun-angle relationships. It is based on the apparent angular motion of the sun across the sky, with solar noon the time the sun crosses the meridian of the observer. Two corrections are needed to convert from standard time. 1) Correction for difference in longitude between observer's meridian and the meridian at which local standard time is based. 2) Correction from the equation of time which accounts for perturbations in the earth's rate of rotation.

$$Solar\ Time - standard\ time = 4(L_{st} - L_{loc}) + E$$

Where L_{st} is the standard meridian for local time zone. L_{loc} is the longitude of the location in question and E is the equation of time in minutes



Tallahassee, FL Latitude: 30.438N
Longitude: 84.28W
Time zone: Eastern Daylight Saving

$$E = 229.2(0.000075 + 0.001868\cos B - 0.032077\sin B - 0.014615\cos 2B - 0.04089\sin 2B)$$

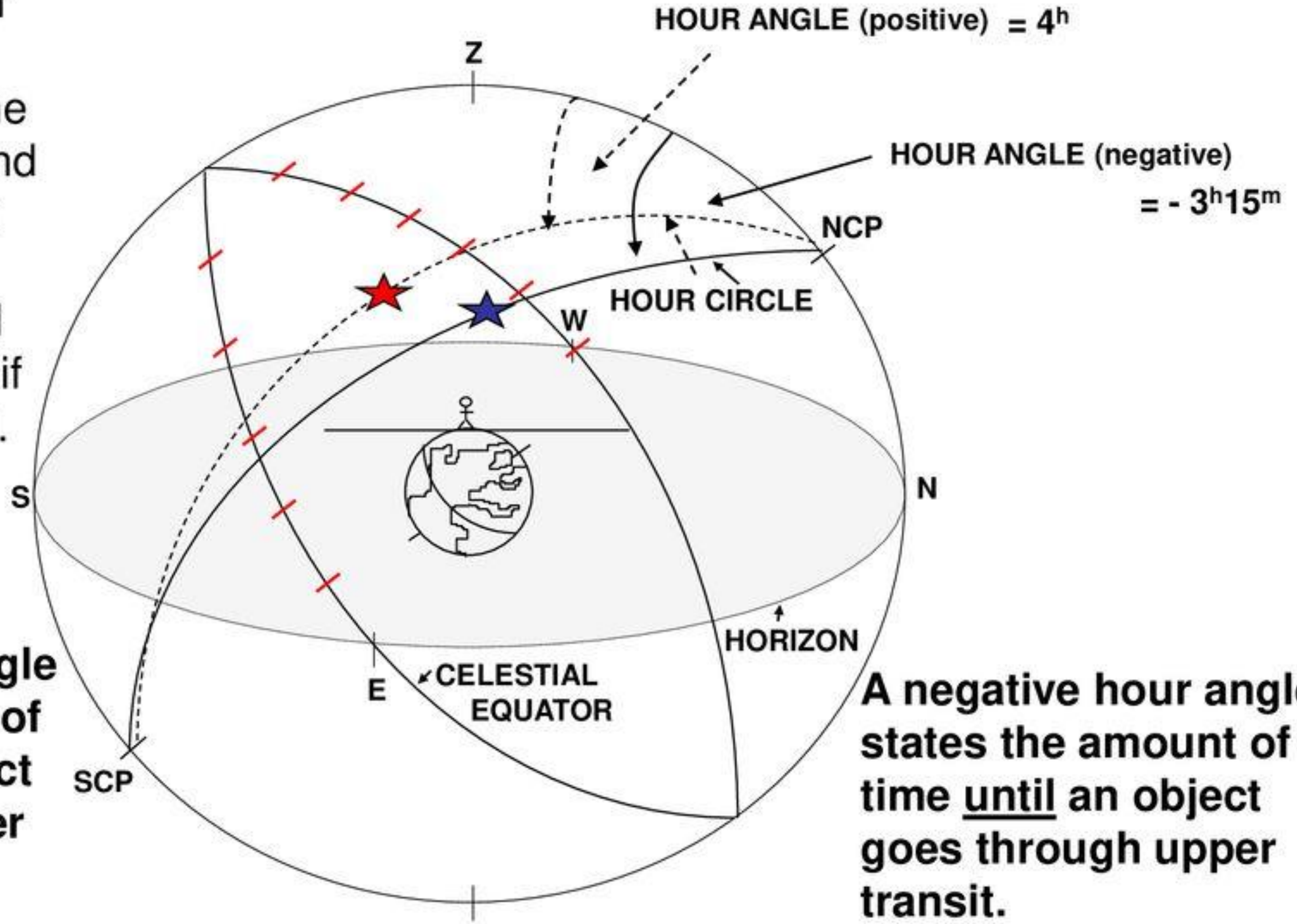
$$B = (n-1)\frac{360}{365} \quad 1 \le n \le 365$$

Where n is the day of the year

	Angles	Formulas
1	Zenith angle (θ_Z)	$\cos\theta_Z = \cos\phi\ \cos\delta\ \cos\omega + \sin\phi\sin\delta$
2	Solar Altitude angle (α_s)	$\alpha_s = 90 - \theta_Z$ $\cos\alpha_s = \cos(90-\theta_Z) = \sin\theta_Z$ $\sin\alpha_s = \sin(90-\theta_Z) = \cos\theta_Z$
3	Solar Azimuthal Angle (γ_s)	$\sin\gamma_s = \frac{\cos\delta\ \sin\omega}{\sin\theta_Z}$ $\cos\gamma_s = \mathrm{sign}(\omega)\left[\cos^{-1}\left(\frac{\cos\theta_Z\sin\phi - \sin\delta}{\sin\theta_Z\cos\phi}\right)\right]$
4	Hour Angle (ω)	Sunset hour angle: $\cos\omega_s = -\tan\phi\tan\delta$ $\omega_s(\text{Sunrise}) = -\omega_s(\text{Sunset})$

Hour Angle

The angle in units of hours, minutes and seconds between the celestial meridian and the hour circle of an object. The angle is positive if measured westward, negative if measured eastward.

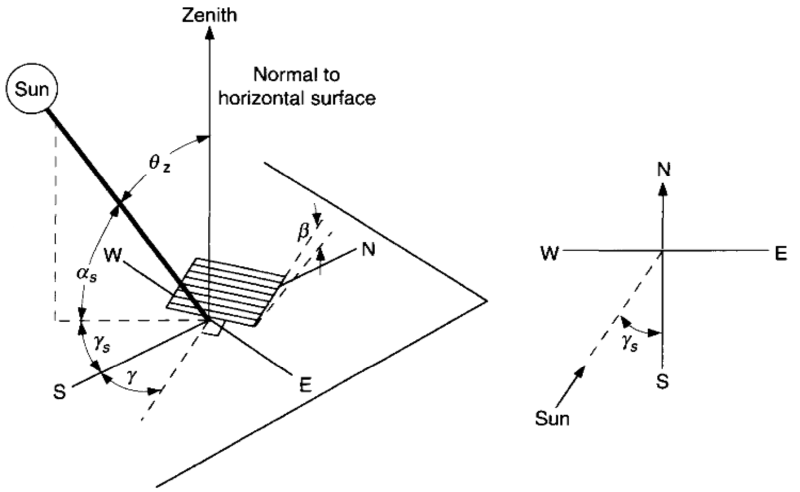


A positive hour angle states the amount of time <u>since</u> an object went through upper transit.

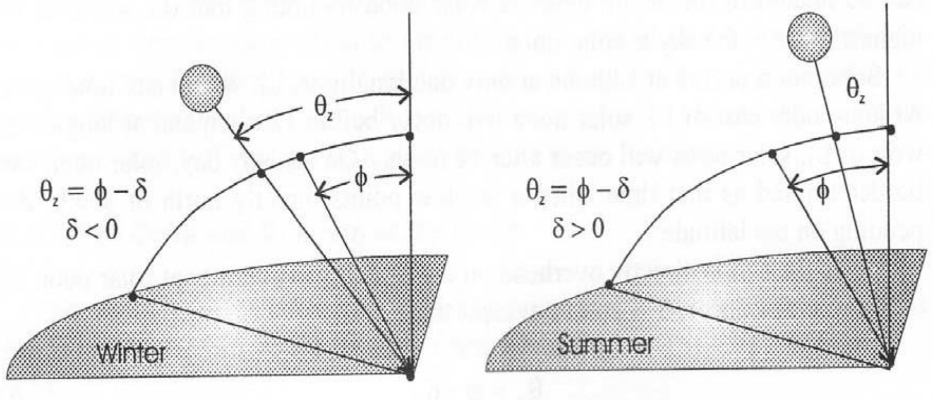
A negative hour angle states the amount of time <u>until</u> an object goes through upper transit.

Observer-Sun Angles

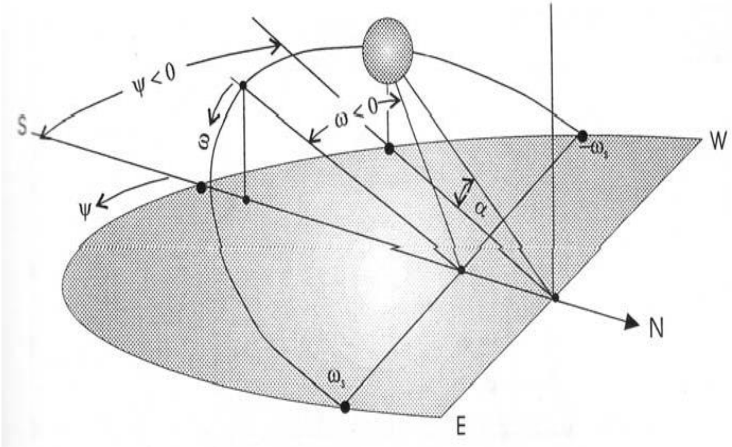
Direction of Beam Radiation: The geometric relationships between a plane of any particular orientation relative to the earth at any time and the incoming beam solar radiation can be described in terms of several angles (Latitude(φ), Declination(δ), Slope(β), Surface azimuth angle(γ), Hour angle(ω), Angle of incidence(θ), Zenith angle(θ_z), Solar altitude angle (α_s) and solar azimuth angle (γ_s)).



(a) Zenith angle, slope, surface azimuth angle, and solar azimuth angle for a tilted surface. (b) Plan view showing solar azimuth angle.



Relationships among θ_z, ϕ and δ at solar noon in winter and summer.



Sun angles, showing altitude, azimuth and hour angle.

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Collector Angle

There is a set of useful relationships among these angles. Equations relating the angle of incidence of beam radiation on a surface, θ, to the other angles are:

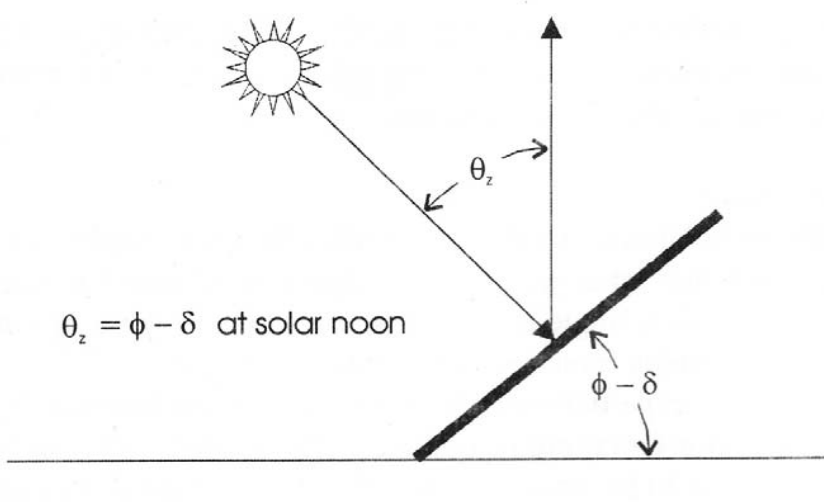
$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right)$$

$$\begin{aligned}\cos\theta &= \sin\delta \sin\varphi \cos\beta \\ &- \sin\delta \cos\varphi \sin\beta \cos\gamma \\ &+ \cos\delta \cos\varphi \cos\beta \cos\omega \\ &+ \cos\delta \sin\varphi \sin\beta \cos\gamma \cos\omega \\ &+ \cos\delta \sin\beta \sin\gamma \sin\omega\end{aligned}$$

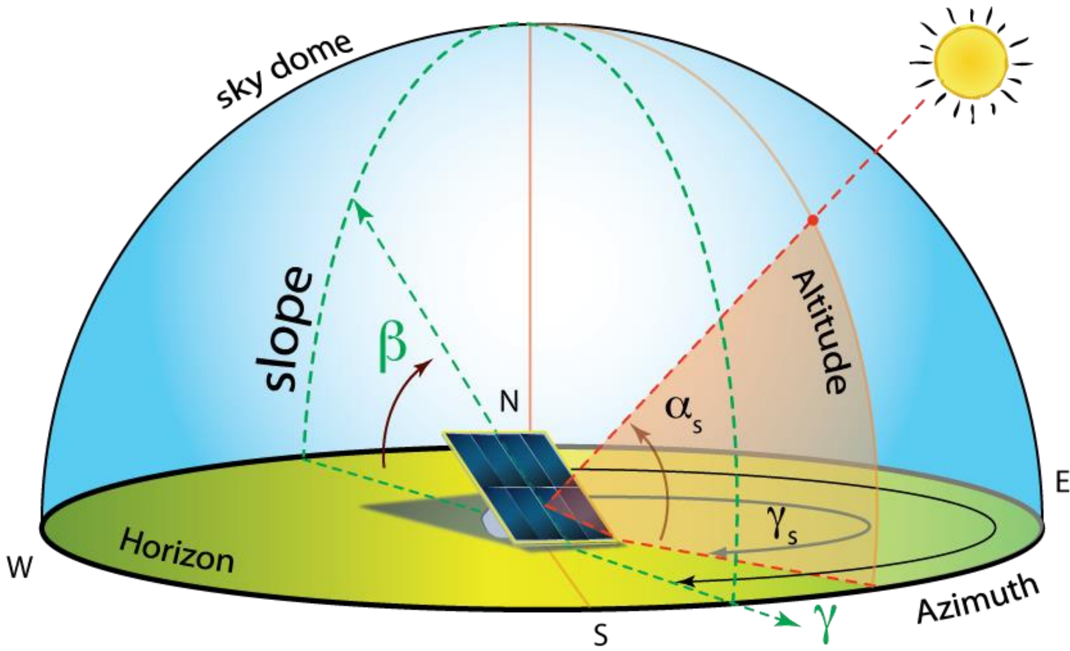
and

$$\cos\theta = \cos\theta_z \cos\beta + \sin\theta_z \sin\beta \cos(\gamma_s - \gamma)$$

Mounting Angle of a Fixed Collector

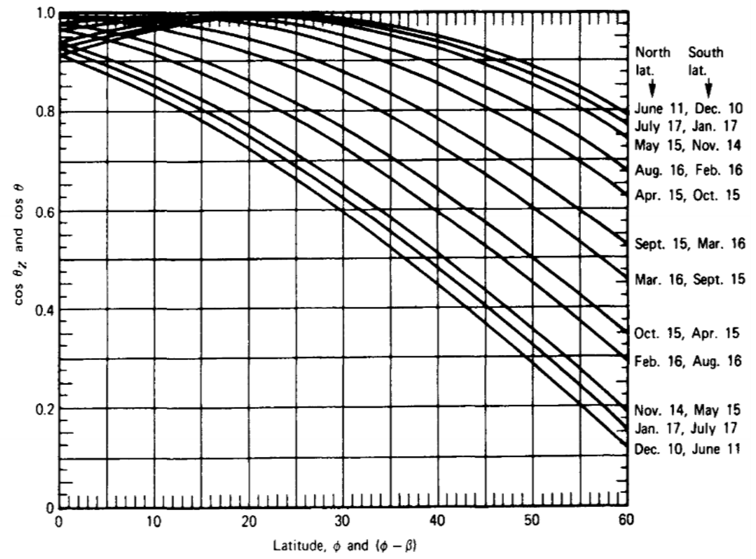


Optimizing the mounting angle of a fixed collector.



Zenith Angle

Determination of Zenith angle (θ_z) for tilted surfaces: The zenith angle for tilted surfaces is determined from Whillier's curves.



Cos θ vs. ($\phi - \beta$) and cos θ_z vs. ϕ for hours 11 to 12 and 12 to 1 for surfaces tilted toward the equator. The columns on the right show dates for the curves for north and south latitudes. In south latitudes, use $|\phi|$. Adapted from Whillier (1975).

Tracking Surface Angles

For a plane rotated about a horizontal east-west axis with single daily adjustment of beam radiation being normal to the surface at noon each day:

$$\cos\theta = \sin^2\delta + \cos^2\delta\cos\omega$$

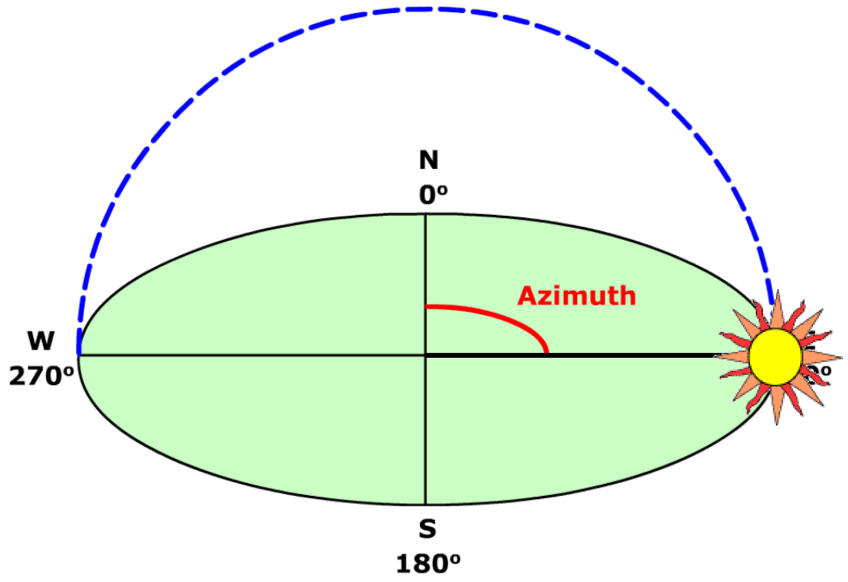
The slope of the surface is fixed for each day: $\beta = \varphi - \delta$

If (φ - δ) >0, γ = 0°; (φ - δ) < 0, γ = 180°

At solar noon φ_z = φ - δ

Azimuth Angle

- The azimuth angle is the compass direction from which the sunlight is coming.
- At solar noon, the sun is always directly south in the northern hemisphere and directly north in the southern hemisphere. The azimuth angle varies throughout the day as shown in the animation below.
- At the equinoxes, the sun rises directly east and sets directly west regardless of the latitude, thus making the azimuth angles 90° at sunrise and 270° at sunset.
- In general however, the azimuth angle varies with the latitude and time of year and the full equations to calculate the sun's position throughout the day are given on the following page.



The azimuth is calculated from the above parameters:

$$Azimuth = cos^{-1}\left[\frac{sin\delta cos\varphi - cos\delta sin\varphi cos(HRA)}{cos\alpha}\right]$$

where α is the elevation, Φ is the latitude, and δ is the declination. The above equation only gives the correct azimuth in the solar morning so that:

Azimuth = A_{zi}, for LST <12 or HRA < 0

Azimuth = 360° - A_{zi}, for LST > 12 or HRA >0

Incoming Solar Radiation

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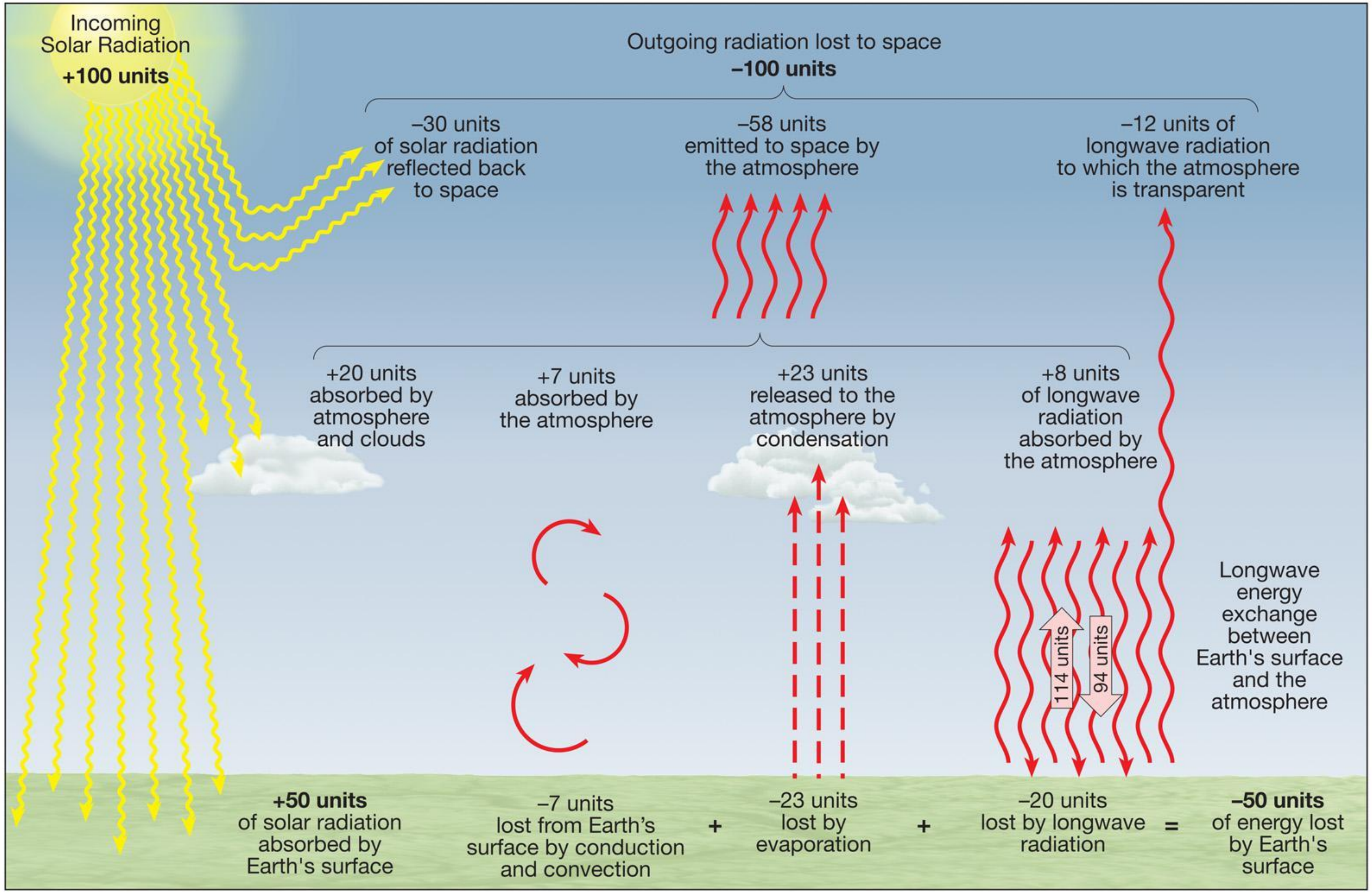


DISTRIBUTION OF TEMPERATURE

Temperature Measurements:

Fahrenheit:

- Daniel Gabriel Fahrenheit (1686-1736) was a German physicist who is credited with the invention of the alcohol thermometer in 1709 and the mercury thermometer in 1714. The Fahrenheit temperature scale was developed in 1724.
- Fahrenheit originally established a scale in which the temperature of an ice-water-salt mixture was set at 0 degrees. The temperature of an ice-water (no salt) mixture was set at 30 degrees and the temperature of the human body was set at 96 degrees.
- Using this scale, Fahrenheit measured the temperature of boiling water as 212°F on his scale. He later adjusted the freezing point of water from 30°F to 32°F, thus making the interval between the freezing and boiling points of water an even 180 degrees (and making body temperature the familiar 98.6°F). The Fahrenheit scale is still commonly used in the United States

Celsius

Anders Celsius (1701-1744) was a Swedish astronomer credited with the invention of the centigrade scale in 1742.

Celsius chose the melting point of ice and the boiling point of water as his two reference temperatures to provide for a simple and consistent method of thermometer calibration.

Celsius divided the difference in temperature between the freezing and boiling points of water into 100 degrees (thus the name centi, meaning one hundred, and grade, meaning degrees).

After Celsius's death, the centigrade scale was renamed the Celsius scale and the freezing point of water was set at 0°C and the boiling point of water at 100°C.

Kelvin

Lord William Kelvin (1824-1907) was a Scottish physicist who devised the Kelvin (K) Scale in 1854. The Kelvin scale is based on the idea of absolute zero, the theoretical temperature at which all molecular motion stops and no discernible energy can be detected.

In theory, the zero point on the Kelvin scale is the lowest possible temperature that exists in the universe: -273.15ºC. The Kelvin scale uses the same unit of division as the Celsius scale; however, it resets the zero point to absolute zero: -273.15ºC.

The freezing point of water is therefore 273.15 Kelvins, and 373.15 K is the boiling point of water. The Kelvin scale, like the Celsius scale, is a standard SI unit of measurement used commonly in scientific measurements. Since there are no negative numbers on the Kelvin scale (because theoretically nothing can be colder than absolute zero), it is very convenient to use Kelvins when measuring extremely low temperatures in scientific research.

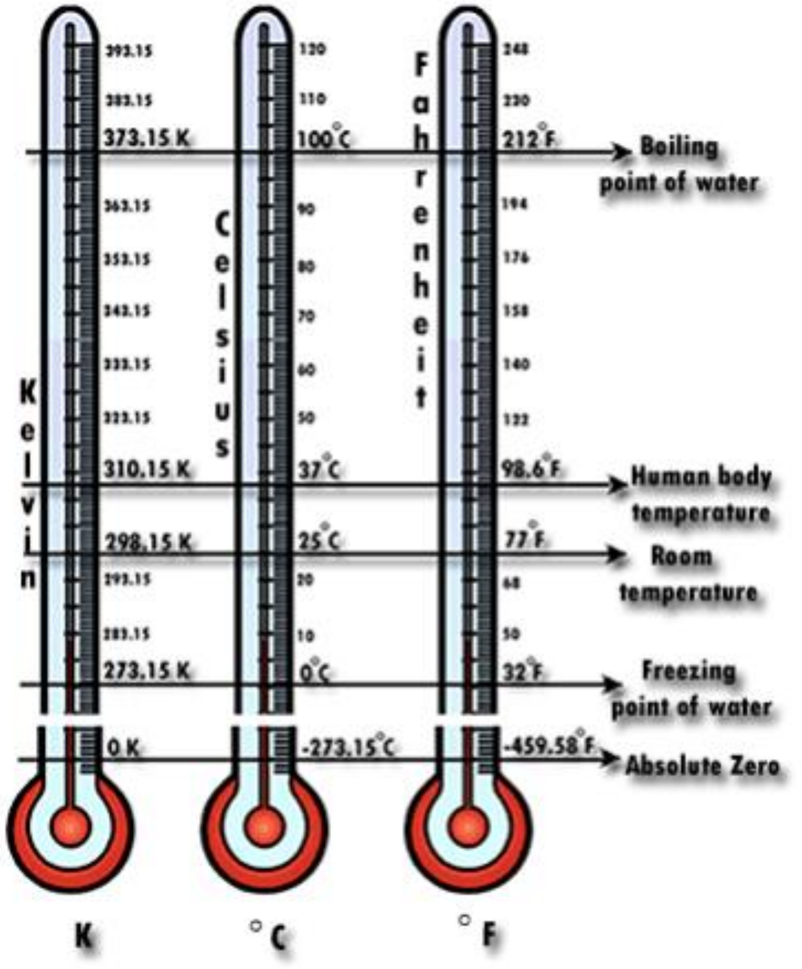
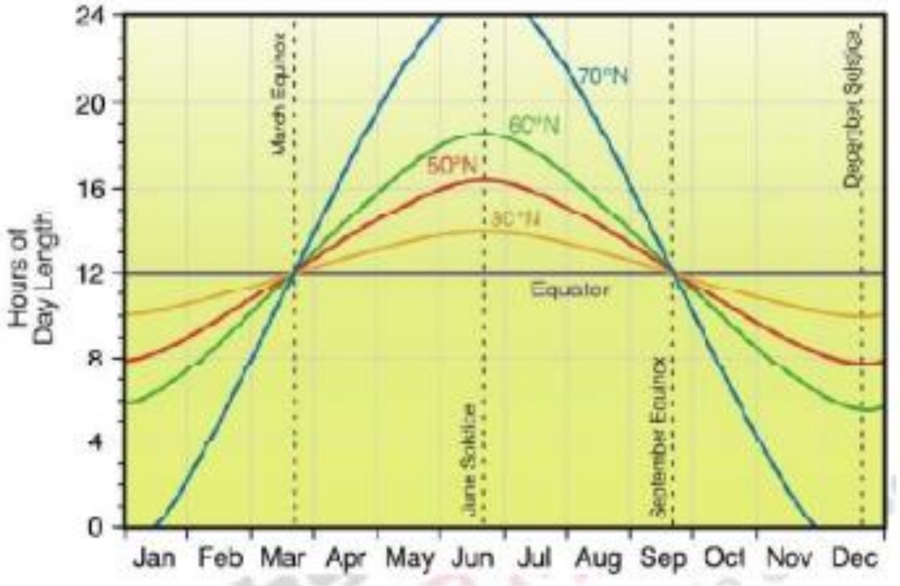


Figure 1: Comparison of three different temperature scales.

Global Temperature Distribution

The global temperature distribution is explained in two ways horizontal and vertical. The temperature on the earth surfac and in its atmosphere is not alike, but it varies significantly. The variation is controlled by various factors. Important amo them are:



- Latitude
- Altitude
- Length of the day
- Continentality (maritime influence)
- Wind and ocean currents
- Aspect: Southern facing slope in the north hemisphere gets direct and almost vertical sun’s rays. In southern hemisphere, northern facing slope gets bright and effective sun’s energy and the temperature is high on the sun facing slopes.
- Topography and vegetation

Latitude :

- You have already studied under “insolation” that the angle of incidence goes on decreasing from equator towards poles.
- Higher the angle of incidence, higher is the temperature.
- Lower angle of incidence leads to the lowering of temperature.
- It is because of this that higher temperatures are found in tropical regions and they generally decrease at a considerable rate towards the poles.
- Temperature is below freezing point near the poles almost throughout the year

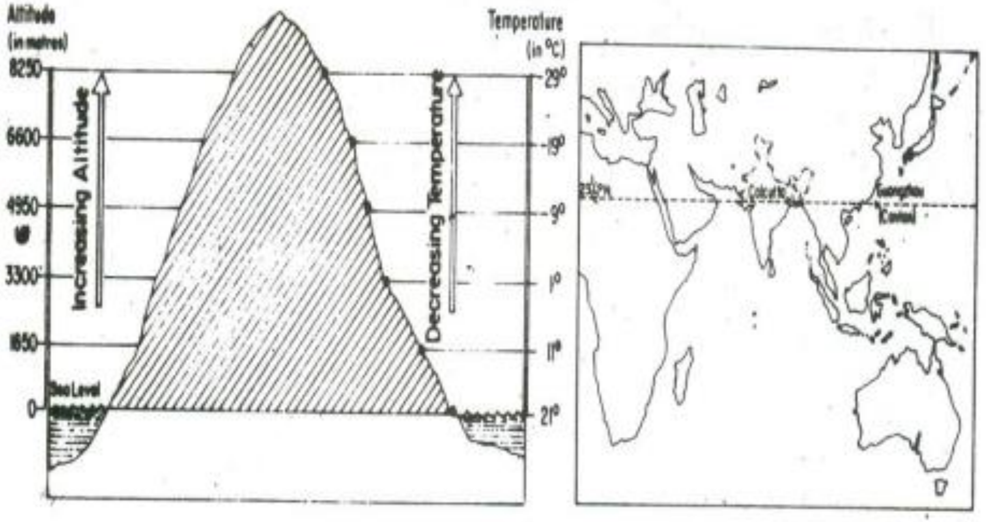
Land and Sea Contrast:

Land and sea contrast affects temperature to a great extent. Land gets heated more rapidly and to a greater degree than water during sunshine. It also cools down more rapidly than water during night. Hence, temperature is relatively higher on land during day time and it is higher in water during night. In the same way there are seasonal contrasts in temperature. During summer the air above land has higher temperature than the oceans. But the air above oceans gets higher temperature than landmasses in winter. Not withstanding the great contrast between land and water surfaces, there are differences in the rate of heating of different land surfaces. A snow covered land as in polar areas warms very slowly because of the large amount of reflection of solar energy. A vegetation covered land does not get excessively heated because a great amount of insolation is used in evaporating water from the plants.

Relief and Altitude:

- Relief features such as mountains, plateaus and plains control the temperature by way of modifying its distribution Mountains act as barriers against the movement of winds.
- The Himalayan ranges prevent cold winds of Central Asia from entering India, during winter. Because of this Kolkata is not as cold as Guangzhou (Canton) in winter though both are situated almost on the same latitude.
- As we move upwards from sea level, we experience gradual decrease in temperature. Temperature decreases at an average rate of 60C per 1000 m. altitude. It is known as normal lapse rate. The air at lower elevations is warmer than that of higher elevations because it is closest to the heated surface of the earth.
- As a result mountains are cooler than the plains even during summers. It is worth remembering that the rate of decrease of temperature with altitude varies with time of day, season and location.

- Quito and Guayaquil are two cities of Ecuador (South America) situated near the equator and relatively close to each other. Quito is at 2800 metres. high from mean sea level while Guayaquil is just at 12 metres altitude. However because of difference in altitude. Quito experiences annual mean temperature of 13.3°C while in Guayaquil it is 25.5°C.



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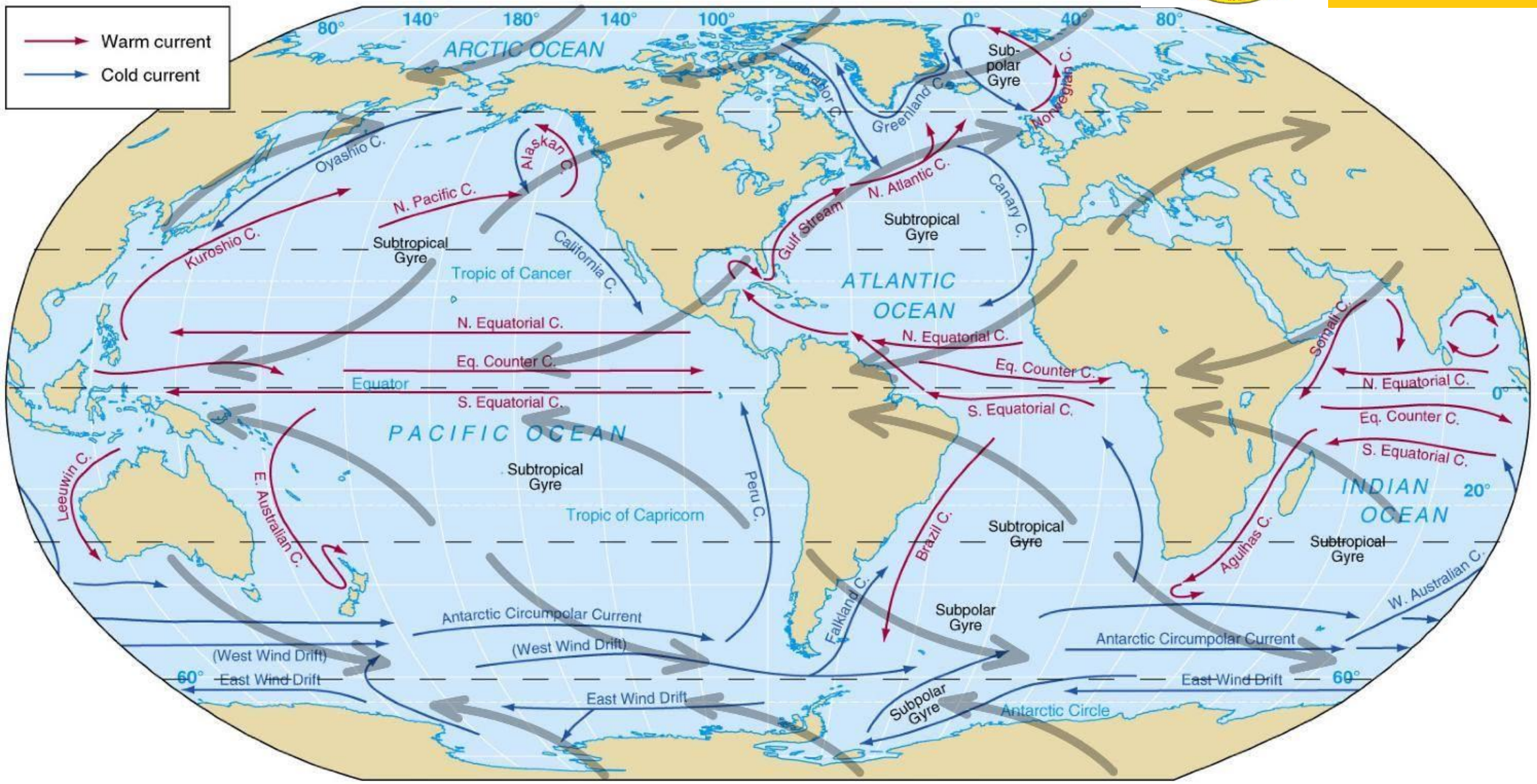
Ocean Currents:



Effect of Warm and Cold Ocean Current

Ocean currents are of two types - warm and cold. Warm currents make the coasts along which they flow warmer, while cold currents reduce the tempeeture of the coasts along which they flow. The North-Western European.Coasts do not freeze in winter due to the effect of North Atlantic Drift (a warm current), while the Quebec on the coast of Canada is frozen due to the Cold Labrador Current flowing along it, though the Quebec is situated in lower latitudes than the North-West European Coast.

(iii) Winds : Winds also affect temperature because they transport heat from one region to the other, about which you have already studied under advection.

Vegetation Cover:

Soil devoid of vegetation cover receives heat more rapidly than the soil under vegetation cover. Because vegetation cover absorbs much of sun's heat and then prevents quick radiation from the earth whereas the former radiates it more rapidly. Hence the temperature variations in dense forested areas are lower than those in desert areas. For example annual range of temperature in equatorial regions is about 5°C while in hot deserts, it is as high as 38°C.

Nature of the Soil: Colour, texture and structure of soils modify temperature to a great degree. Black, yellow and clayey soils absorb more heat than sandy soils. Likewise heat radiates more rapidly from sandy soils than from black, yellow and clayey soils. Hence temperature contrasts are relatively less in black soil areas than those of sandy soils.

Slope and Aspect :

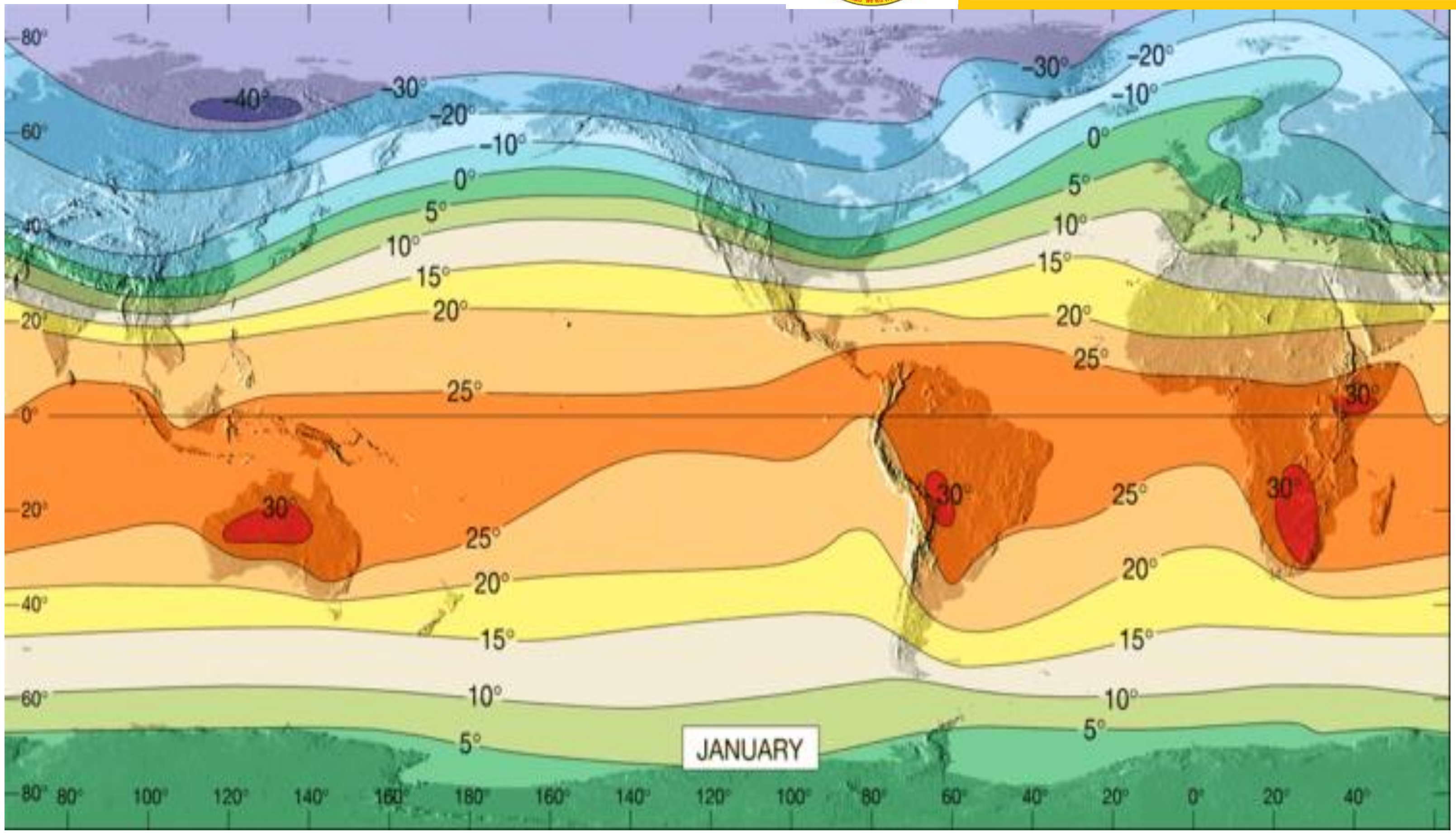
Angle of the. slope and its direction control the receipt of insolation. The angle of incidence of sun's rays is greater along a gentler slope and smaller along a steeper slope. The ray in both the cases carry an equal amount of solar energy. Greater concentration of solar energy per unit area along gentler slope raises the temperature while its lesser concentration along steeper slopes lowers the temperature. For such reasons, the southern slopes of the Himalaya are warmer than the northern ones. At the same time the slopes, in terms of aspect, exposed to the sun receive more insolation and are warmer than those which are away from the direct rays of the sun. The northern slopes of the Himalaya for example, not facing the sun are exposed to cold northernly winds are obviously colder. On the other hand the southern slopes of the Himalaya are sun-facing and are also shelter from the northernly cold winds are warmer. Hence we observe settlements and cultivation largely on the southern slopes of the Himalaya while the northern slopes are more under forest area.

Horizontal Temperature Distribution

In general, equatorial region is hot and its temperature is high throughout the year. Generally, from equator to polewards, temperature keeps on declining. The lowest temperature is at and near the pole. Sun is almost vertical in the tropical zone, the annual average temperature varies between 220 C to 260 C. The 220 C is at Tropic of Capricorn, laying in the southern hemisphere. Along Tropics of Cancer, the annual average temperature is 240 C. The reason behind the difference is that, southern hemisphere has more water bodies while northern hemisphere has relatively more continental areas.Isotherm is an imaginary line joining the places with same temperature are used to represent distribution of temperature

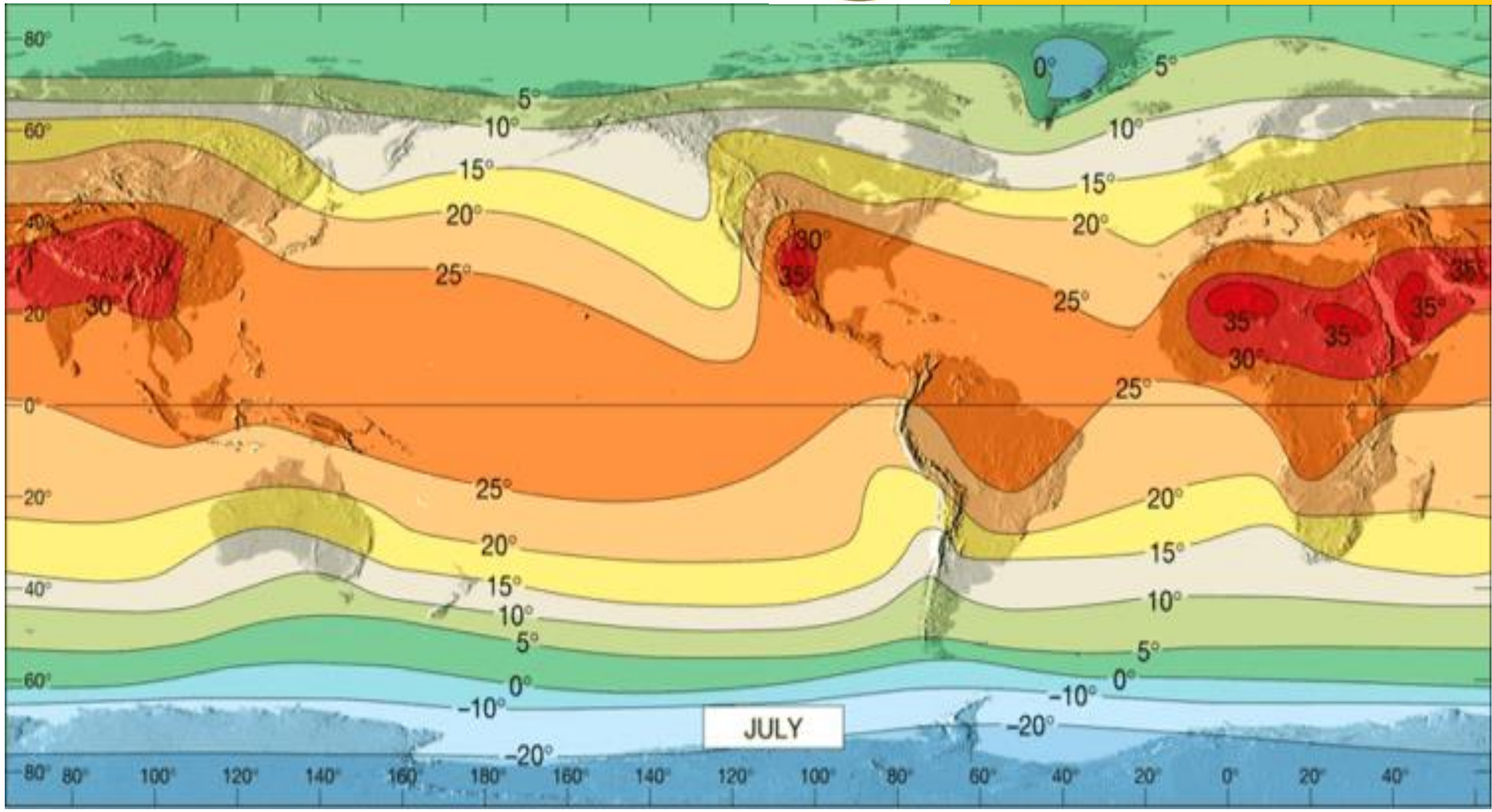
Horizontal Distribution of Temperature in January

In January, the sun shines vertically overhead near the Tropic of Capricorn. Hence it is summer in southern hemisphere and winter in northern hemisphere. High temperature is found over the landmasses mainly in three regions of the southern hemisphere. These regions are North-west Argentina, East, Central Africa, and, Central Australia. Isotherm of 30°C closes them. In northern hemisphere landmass arc cooler than oceans. During this time Northeast Asia experiences lowest temperatures.



As the air is warmer over oceans than over landmasses in the northern hemisphere, the Isotherms bend towards poles when they cross the oceans. In southern hemisphere, the position of the isotherms is just reverse. They bend towards poles when they cross the landmasses and towards equator when they cross oceans. Large expanse of water exists in southern hemisphere. Hence, isotherms are regular and widely spaced in the southern hemisphere. While they are irregular and closely spaced in northern hemisphere due to large expanse of landmasses. For these reasons no extreme seasonal contrasts between land and water are found in middle and higher latitudes in the southern hemisphere as they exist north of equator.

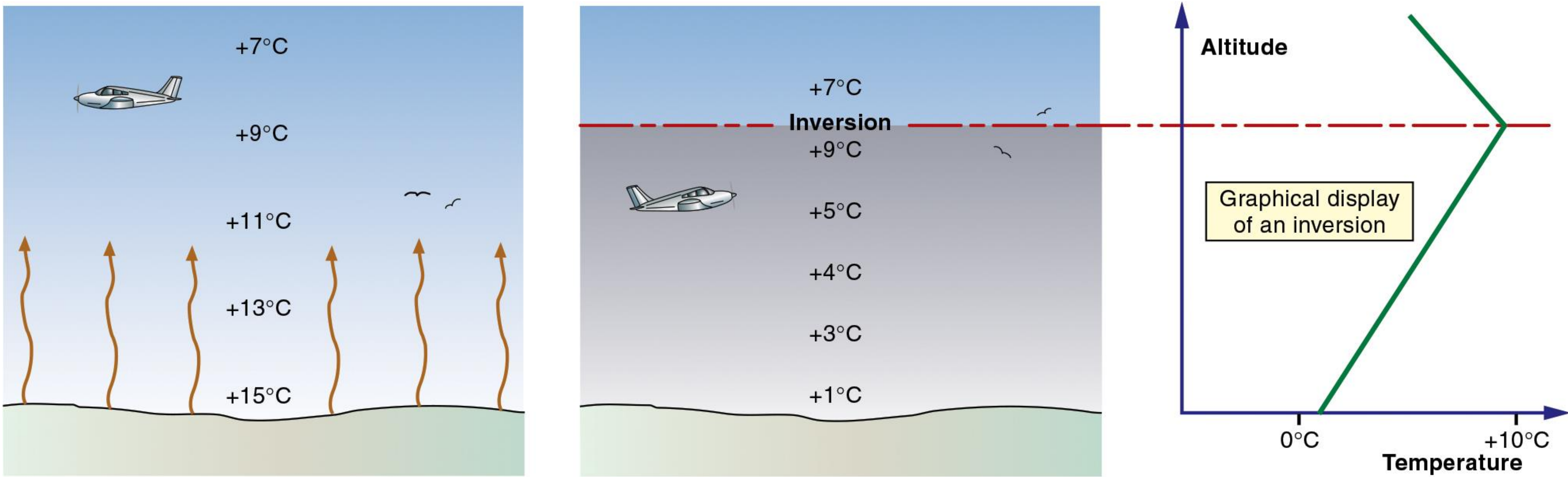
Horizontal Distribution of Temperature in July



- During this period the sun shines vertically overhead near the Tropic of Cancer. Hence, high temperatures are found in the entire northern hemisphere. Isotherm of 30°C passes between 10° N and 40° N latitudes.
- The regions having this temperature include South Western USA, the Sahara, the Arabia, Iraq, Iran, Afghanistan, desert region of India and China. However, lowest temperature of 0°C is also noticed in the Northern Hemisphere during summer in the central part of Greenland.
- During summer in the northern hemisphere, isotherms bend equatorward while crossing oceans and polewards while crossing landmasses. In southern Hemisphere the position of isotherms is just opposite.

- Isotherms are wide spaced over oceans while they are closely spaced over landmasses. A comparison between the January and July isotherm maps reveals the following important characteristics. The latitudinal shifting of highest temperature as a result of migration of the vertical rays of the sun.

- The occurance of highest values in the low latitudes and the lowest value in the high latitudes is due to the decreasing insolation from equator to the poles. In northern hemisphere the isotherms on leaving the land usually bend rather sharply towards poles in winter and towards the equator in the summer. This behaviour of the isotherms is due to the differential heating and cooling of landmasses. The continents are hotter in the summer and colder in the winter than the oceans.



- ✓ Under normal conditions, temperature usually decreases with increase in altitude in the troposphere at a rate of 6.5 degree centigrade for every 1 Kilometer. This is called **normal lapse rate**.

- ✓ But on some occasions, the situations get reversed and temperature starts increasing with height rather than decreasing. This is called **temperature inversion**.

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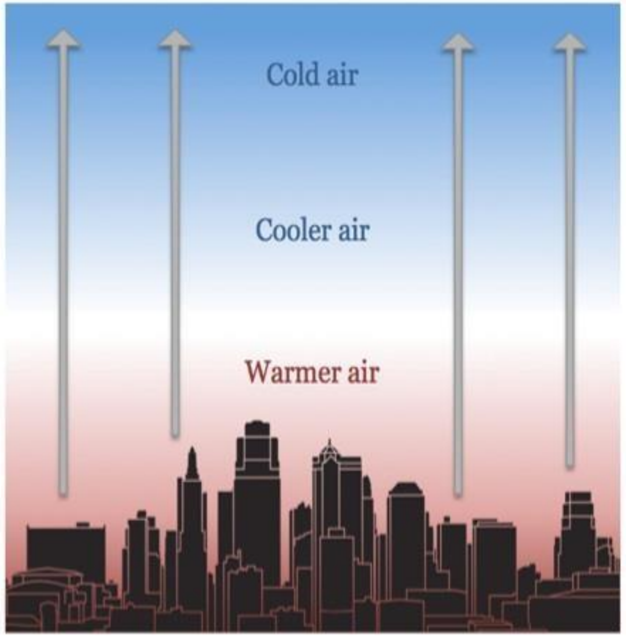
Concept of Temperature inversion

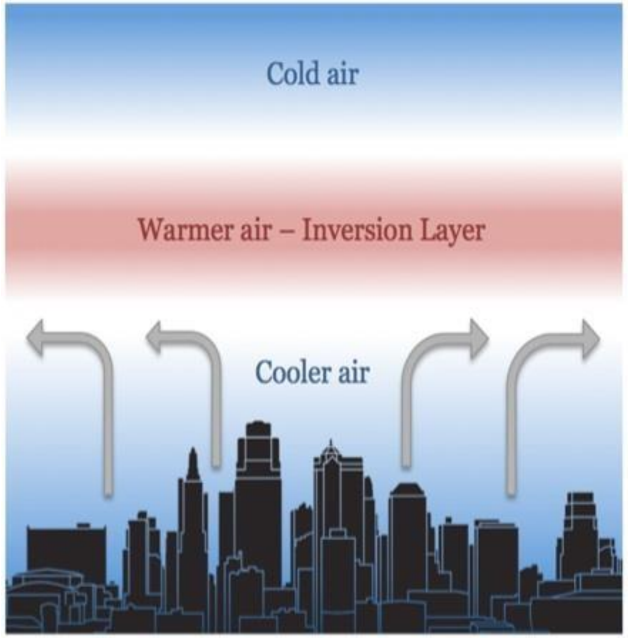
It is a reversal of the normal behavior of temperature in the troposphere. Under this meteorological phenomenon a layer of warm air lies over the cold air layer.

- Thus, warm air layer lies over cold air layer. This phenomenon may occur near the earth's surface or at greater height in the troposphere.
- The inversion of temperature near the earth's surface is of very short duration because the radiation of heat from the earth's surface during daytime warms up the cold air layer which soon disappears and temperature inversion also disappears.
- On the other hand, upper air temperature inversion lasts for longer duration because the warming of cold air layer aloft through terrestrial radiation takes relatively longer period of hours.

Normal Conditions



Temperature Inversion



Favorable Conditions for Temperature Inversion

Long winter nights

Loss of heat by terrestrial radiation from the ground surface during 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 maximum loss of heat through reflection of incoming solar radiation.

Types of Temperature Inversion

Temperature inversion is classified into the following types on the basis of **relative heights from the earth's surface** at which it occurs and the **type of air circulation**:

(1) Non-advectional Inversion

(i) Ground / surface inversion / radiation inversion

(ii) Upper air inversion

(2) Advectional Inversion

(i) Frontal inversion or cyclonic inversion

(ii) Valley inversion due to vertical air movement

(iii) Surface inversion due to horizontal air movement

(3) Mechanical Inversion

(i) Subsidence inversion

(ii) Turbulence and convective inversion

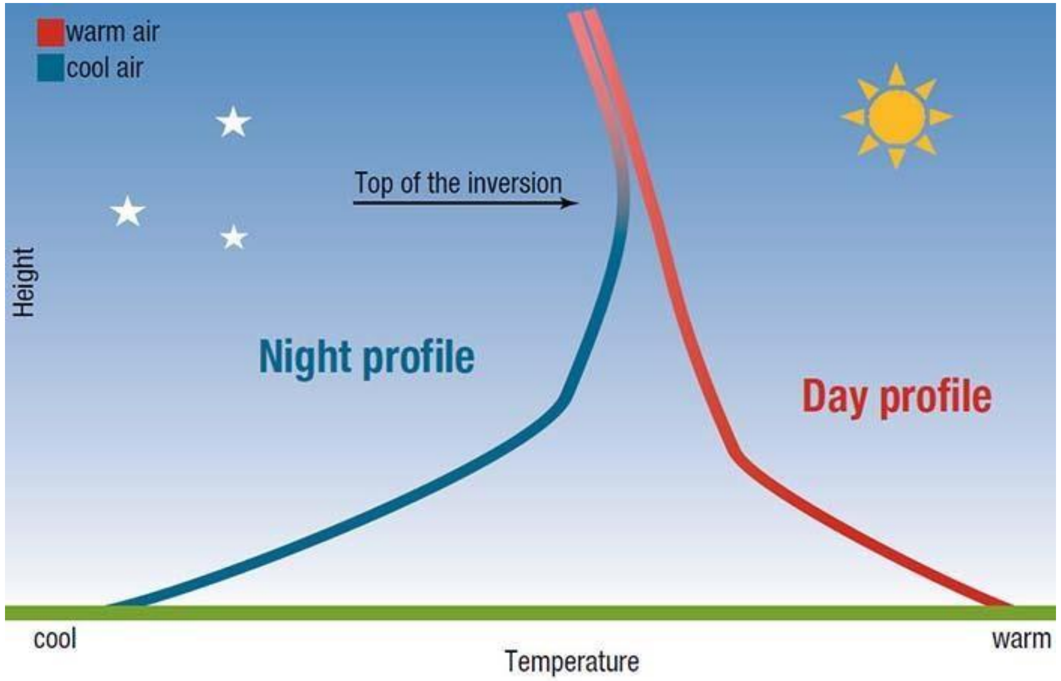
Ground / Surface Inversion

- **Ground or surface inversion, also called as radiation inversion, occurs near the earth's surface due to radiation mechanism. This is also called as non-advectional inversion because it occurs in stable atmospheric condition characterized by almost no movement of horizontal or vertical air.**
- Such inversion normally occurs during the long cold winter nights in the snow-covered regions of the middle and high latitudes. In the low latitude areas (tropical and subtropical areas) it occurs during winter nights only and the inversion generally disappears with sunrise but sometimes it persists up to noon.
- The duration and height of surface inversion increase pole-ward. The inversion occurs up to the height of 30-40 feet in the low latitudes, a few hundred feet in the middle latitudes and half a mile in the high latitudes.

Mechanism

a) Surface inversion is caused due to excessive nocturnal cooling of the ground surface due to rapid rate of loss of heat from the ground through outgoing long-wave terrestrial radiation.

b) The air coming in contact with the cool ground surface also becomes cold while the air layer lying above is relatively warm. Consequently, temperature inversion develops because of cold air layer below and warm air layer above.



Suitable Conditions

The ground or surface inversion occurs under the following conditions -

1.**Long winter nights** - so that the loss of heat by terrestrial radiation from the ground surface during night may exceed the amount of insolation received from the sun through incoming shortwave electromagnetic radiation waves and thus the ground surface becomes too cold.

2.**Cloudless and clear sky** - so that the loss of heat through terrestrial radiation proceeds more rapidly without any obstruction. Clouds absorb terrestrial radiation and hence retard loss of heat from the earth's surface.

3.**Presence of dry air near the ground surface** - so that it may not absorb much heat radiated from the earth's surface as moist air is capable of absorbing much of the radiant heat from the earth's surface.

4.**Slow movement of air** - so that there is no transfer and mixing of heat in the lower layers of the atmosphere.

5.**Snow-covered ground surface** - so that there is maximum reflection of incoming solar radiation. Snow is a bad conductor of heat which retards the flow of heat from the ground surface lying below the snow- layers to the lower atmosphere.

As this inversion of temperature occurs in the calm atmospheric condition (very little movement of air) and hence it is also called static or non-advectional inversion.

Upper Air Inversion

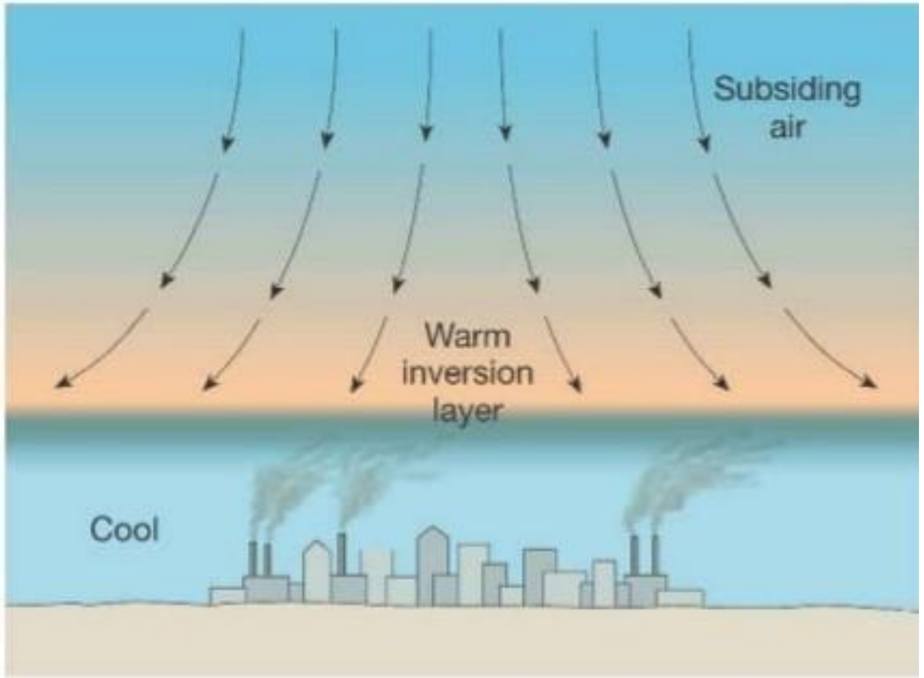
Upper air inversion is of two types -(i) thermal upper air inversion and (ii) mechanical upper air inversion.

Thermal upper air inversion is caused by the presence of ozone layer lying between the height of 15 to 35 km (even up to 80km) in the stratosphere. The ozone layer absorbs most of the ultraviolet rays radiated from the sun and thus the temperature of this layer becomes much higher than the air layers lying above and below ozone layer.

Mechanical inversion of temperature is caused at higher heights in the atmosphere due to subsidence of air and turbulence and convective mechanism. It may occurs in a number of ways -

a) Sometimes, warm air is suddenly transported upward (due to eddies formed by frictional forces) to the zone of cold air and thus cold air being denser lies under the warm air and inversion of temperature is formed.

b) When a parcel of air descends, it is warmed at the dry adiabatic rate of 10°C per 1000m because of compression. Thus, a zone of warm air formed above the cold layer of air and inversion is happened. Such mechanical inversion is generally associated with the **anticyclonic conditions.** So, it is very commonly occurred in the middle latitudes where high pressures are characterized by sinking air.

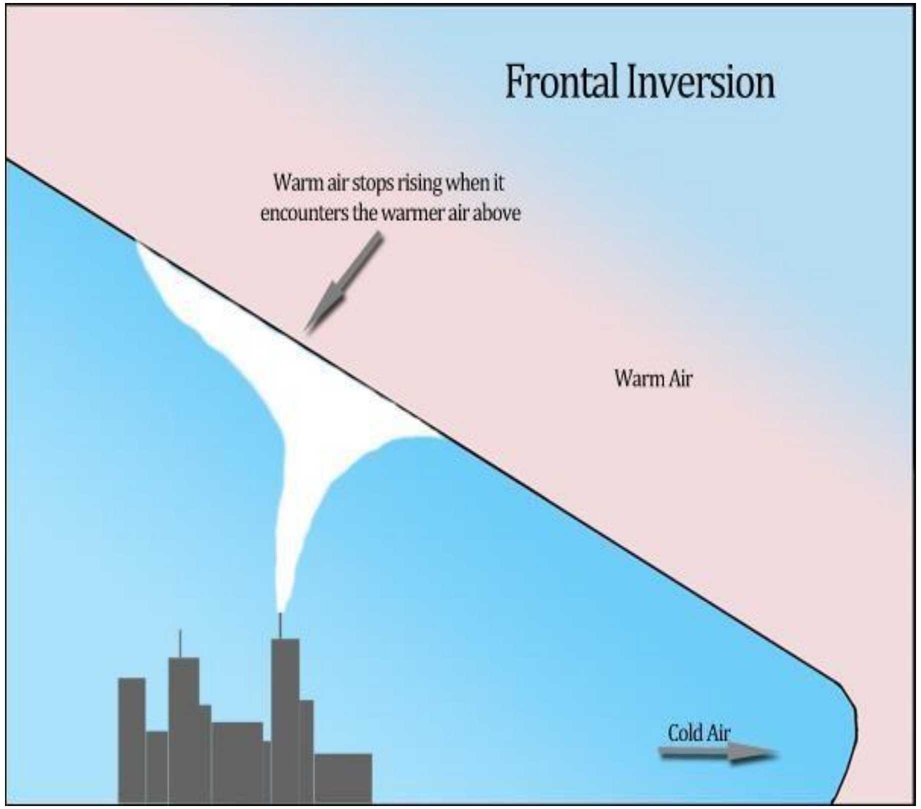


Advectional Inversion

Advectional inversion of temperature is also called as dynamic inversion because it is always caused due to either horizontal or vertical movements of air. Strong wind movement and unstable conditions of the atmosphere are prerequisite conditions for advectional inversion of temperature. This is further divided into 3 sub-types on the basis of the nature of air movements -

Frontal or cyclonic inversion

Frontal or cyclonic inversion is caused in the temperate zones due to temperate cyclones which are formed due to the convergence of warm westerlies and cold polar winds in the northern hemisphere. The warm air is pushed up by the cold polar air and thus the warm air overlies the cold air because it is lighter than the cold air. Thus, the existence of warm air above and cold air below reverses the normal lapse rate (decrease of temperature with increasing height) and inversion of temperature occurs.

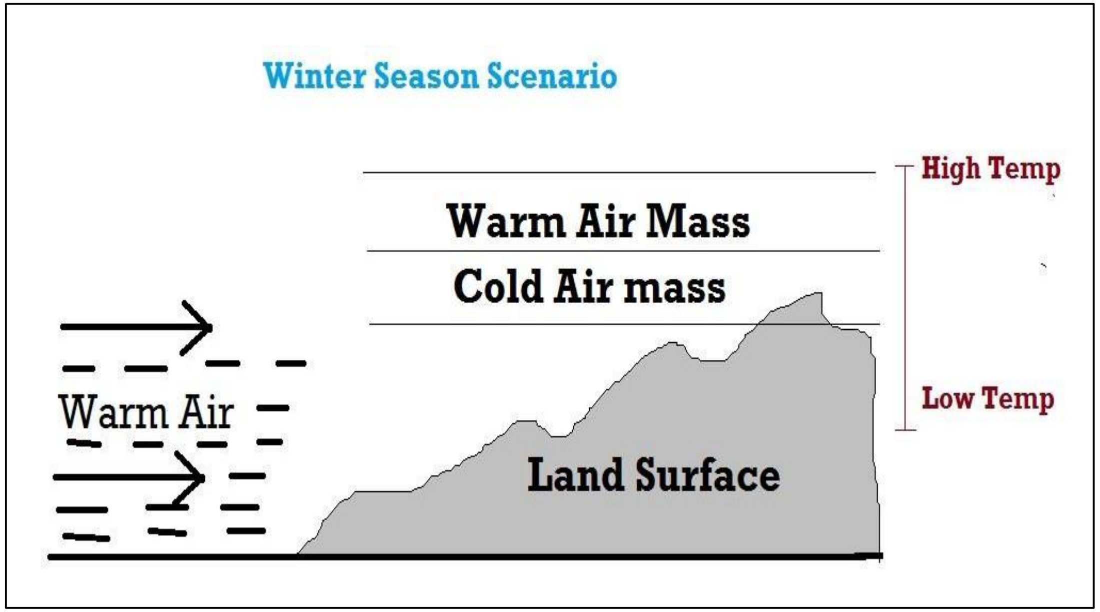


The inversion layer associated with frontal or cyclonic inversion is always sloping because the boundary zone (front) between the warm westerlies and cold polar air masses become slopy. It is also interesting to note that air moisture increases upward in frontal inversion of temperature while it decreases upward in other types of temperature inversion.

Surface inversion

Surface inversion of temperature caused by horizontal movement of air occurs in several situations. Such inversion is caused when warm air moves to the area of cold air or cold air moves into the area of warm air. As warm air being lighter is pushed upward by relatively denser cold air and inversion takes place.

Surface inversion occurs generally in the low latitudes. When the warm air moves, such inversion is caused over the continents during winter and over the oceans during summer but when the cold air becomes active and invades the areas of warm air, such inversion occurs over the continents during summer and over the oceans during winter.



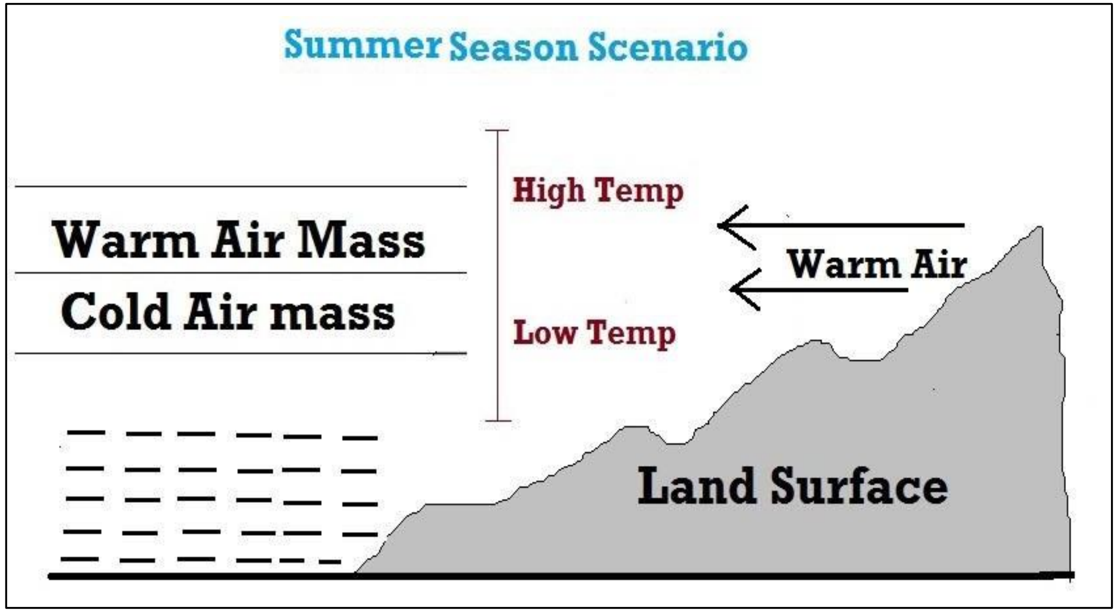


Fig: Surface inversion scenarios in low latitudes

Valley inversion

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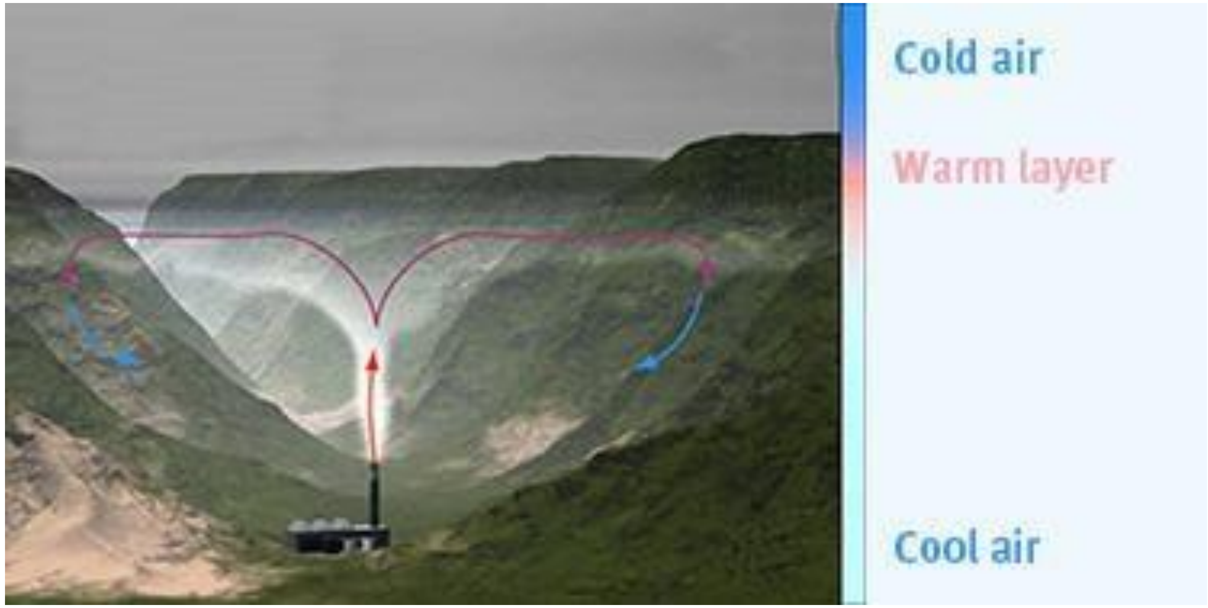
Valley inversion generally occurs in the mountainous valleys due to radiation and vertical movement of air. The temperature of the upper parts of the valleys in mountainous areas becomes exceedingly low during winter nights because of rapid rate of loss of heat from the surface through terrestrial radiation. Consequently, the air coming in contact with the cool surface also becomes cool. On the other hand, the temperature of the valley floor does not fall considerably because of comparatively low rate of loss of heat through terrestrial radiation. Thus, the air remains warmer than the air aloft and hence the warm and light air of the valley floor is pushed upward by the descending cold and heavier air of the upper part of the valley. Thus, there is warm air aloft and cold air in the valley floor and inversion of temperature is caused.

This situation is responsible for severe frost in the valley floors causing great damage to fruit orchards and vegetables and agricultural crops whereas the upper parts of the valleys are free from frost. This is why the valley floors are avoided for human settlements while the upper parts are inhabited in the mountainous valleys of middle latitudes.



Significance of Temperature Inversion

Though inversion of temperature denotes local and temporary conditions of the atmosphere but there are several climatic effects of inversion which are of great significance to man and his economic activities. Temperature inversion determines the precipitation, forms of clouds, and also causes frost due to condensation of warm air due to its cooling.

- **Dust particles hanging in the air:** Due to inversion of temperature, air pollutants such as dust particles and smoke do not disperse on the surface.

- **Stops the movement of air:** It causes the stability of the atmosphere that stops the downward and upward movement of air.

- **Less rainfall:** Convection clouds can not move high upwards so there is less rainfall and no showers. So, it causes a problem for agricultural productivity.

- **Lower visibility:** Fog is formed due to the situation of warm air above and cold air below, and hence visibility is reduced which causes disturbance in transportation.

- **Thunderstorms and tornadoes:** Intense thunderstorms and tornadoes are also associated with inversion of temperature because of the intense energy that is released after an inversion blocks an area's normal convention patterns.

- Diurnal variations in temperature tend to be very **small.**

Atmospheric Pressure

The weight of a column of air contained in a unit area from the mean sea level to the top of the atmosphere is called as the **atmospheric pressure**. The atmospheric pressure is expressed in units of **milibar**. At sea-level the average atmospheric pressure is **1,013.2 milibar**.

Due to the gravity, the air at the surface is denser and hence has a higher pressure. Air pressure is measured with the help of a **mercury barometer** or the aneroid barometer. The pressure decreases with height. **At any elevation it varies from place to place and its variation is the primary cause of air motion**, i.e., wind which moves from high pressure areas to low pressure areas.

Vertical Distribution of Pressure

- Air is a mixture of various gases. It is highly compressible. As it compresses, its density increases.
- The higher the density of air, the greater is the air pressure and vice versa. The mass of air above in the column of air compresses the air under it, hence its lower layers are more denser than the upper layers.
- As a result, **the lower layers of the atmosphere have higher density, thus, exert more pressure**.
- Conversely**, the higher layers are less compressed and, hence, they have low density and low pressure.** The columnar distribution of atmospheric pressure is known as vertical distribution of pressure.

Horizontal Distribution of Pressure

- The distribution of atmospheric pressure over the globe is known as horizontal distribution of pressure. It is shown on maps with the help of isobars. **An isobar is a line connecting points that have equal values of pressure. Isobars are analogous to the contour lines on a relief map. The spacing of isobars expresses the rate and direction of change in air pressure**.
- This change in air pressure is referred to as the pressure gradient. Pressure gradient is the ratio between pressure difference and the actual horizontal distance between two points. Close spacing of isobars expresses steep pressure gradient while wide spacing indicates gentle pressure gradient.
- **The horizontal distribution of atmospheric pressure is not uniform in the world. It varies from time to time at a given place; it varies from place to place over short distances**.

The factors responsible for variation in the horizontal distribution of pressure are as:

Air Temperature:

- As we know that t**he earth is not heated uniformly because of unequal distribution of insolation, differential heating and cooling of land and water surfaces**.
- Generally there is an **inverse relationship between air temperature and air pressure**.
- The **higher the air temperature, the lower is the air pressure**. Along **the equator lies a belt of low pressure known as the "equatorial low or doldrums".**
- Low air pressure in equatorial regions is due to the fact that hot air ascends there with gradual decrease in temperature causing thinness of air on the surface. In polar region, cold air is very dense hence it descends and pressure increases.

The Earth's Rotation:

- The earth's rotation generates **a centrifugal force**. This results in **the deflection of air from its original place, causing decrease of pressure.**
- It is believed that **the low pressure belts of the sub-polar Regions and the high pressure belts of the sub- tropical regions are created as a result of the earth's rotation**.
- The earth's rotation also causes convergence and divergence of moving air.
- Areas of convergence experience low pressure while those of divergence have high pressure.

Pressure of Water Vapour:

- Air with higher quantity of water vapour has lower pressure and that with lower quantity of water vapour has higher pressure.
- In winter the continents are relatively cool and tend to develop high pressure centres; in summer they stay warmer than the oceans and tend to be dominated by low pressure, conversely, the oceans are associated with low pressure in winter and high pressure in summer.

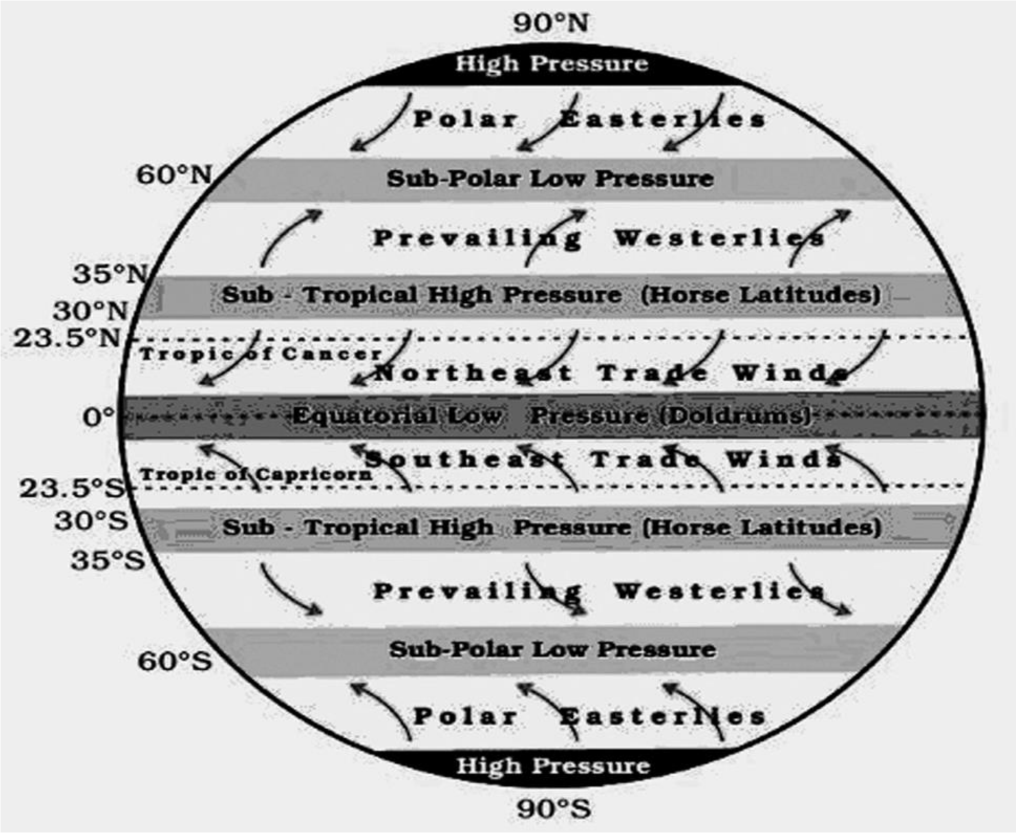
Pressure Belts

The horizontal distribution of air pressure across the latitudes is characterized by high or low pressure belts. This is however, **a theoretical model because pressure belts are not always found as such on the earth**. They migrate with the march of the sun northwards and southwards. The pressure belts are divided as:

(a) The Equatorial Low Pressure Belt

- The sun shines almost vertically on the equator throughout the year. As a result**, the air gets warm and rises over the equatorial region and produces the equatorial low pressure. This belt extends from equator to 10°N and 10°S latitudes.**
- Due to excessive heating horizontal movement of air is absent here and only conventional currents are there. Therefore, this belt is called doldrums (the zone of calm) due to virtual absence of surface winds. These are the regions of convergence because the winds flowing from sub-tropical high pressure belts converge here. This belt is also known as-**Inter Tropical Convergence Zone (ITCZ).**

- This belt is characterized by extremely low pressure with calm conditions. This is because of the absence of Surface winds since winds approaching this belt begin to rise near its margin.
- Thus, only vertical currents are found. As the larger part of the low pressure belt passes along the oceans, the winds obtain huge amount of moisture. Vertical winds (convection) carry the moisture form cumulonimbus clouds and lead to thunderstorms (convectional rainfall).
- In spite of high temperatures, cyclones are not formed at the equator because of 'zero' Coriolis force.



Major Pressure Belts and Wind System

(a) The Sub-tropical High Pressure Belts

- The sub-tropical high pressure belts extend from the tropics to about 35° latitudes in both the Hemispheres. In the northern hemisphere it is called as **the North sub-tropical high pressure belt and in the southern hemisphere it is known as the South sub-tropical high pressure belt**. The existence of these pressure belts is due to the fact that the uprising air of the equatorial region is deflected towards poles due to the earth's rotation. After becoming cold and heavy, it descends in these regions and gets piled up. This results in a high pressure.
- Calm conditions with feeble and variable winds are found here. In olden days vessels with cargo of horses passing through these belts found difficulty in sailing under these calm conditions. They used to throw the horses in the sea in order to make the vessels lighter. Henceforth, these belts or latitudes are also called '**horse latitudes**'. These are the regions of divergence because winds from these areas blow towards equatorial and subpolar low pressure belts.
- . The **subsiding air is warm and dry**; therefore, **most of the deserts are present along this belt, in both the hemispheres**. A calm condition (anticyclonic), with feeble winds, **is created in this high pressure belts**. Hence most of **the deserts are present in this belt.**

The Sub-Polar Low Pressure Belts

- The sub-polar low pressure belts extend between 45°N and the Arctic Circle in the northern hemisphere and between 45°S and the Antarctic Circle in the southern hemisphere. They are known as the **North sub-polar low and the South sub-polar low pressure belts**, respectively.
- Winds coming from **the sub-tropical and the polar high belts converge here to produce cyclonic storms or low pressure conditions**.
- This zone of convergence is also known as **polar front**. This pressure belt is dynamically induced. **The surface air spreads outwards from this zone due to the rotation of the earth thus, produce low pressure**.
- During winter, because of a high contrast between land and sea, this belt is broken into two distinct low centres – one in the vicinity of the Aleutian Islands (equatorial low pressure belt), and the other between Iceland and Greenland (the Circum – Polar low pressure belt). This zone is marked by ascent of warm Sub–tropical air over cold polar air blowing from poles. During summer, a lesser contrast results in a more developed and regular belt.
- The area of **contrast between cold and warm air masses produces polar jet streams which encircles the earth at 60 degrees latitudes and is focused in these low pressure areas**. Due to a great contrast between **the temperatures of the winds from sub-tropical and polar source regions**, **extra tropical cyclonic storms or lows' (temperate cyclones or frontal cyclones) are produced in this region.**

d) The Polar High Pressure Belts

In Polar Regions, the Sun never shines vertically. Sun rays are always slanting here, resulting in low temperatures. Because of low temperature, air compresses and its density increases. Hence, **high pressure is found here. In northern hemisphere the belt is called the North polar high pressure belt while it is known as the South polar high pressure belt in the southern hemisphere**. Winds from these belts blow towards sub-polar low pressure belts.

Winds, Monsoon and Jet-Streams

Wind is defined as air moving horizontally over the Earth's surface. Air motions can also be vertical, but these are known by other terms, such as updrafts or downdrafts. Wind direction is identified by the direction from which the wind comes.

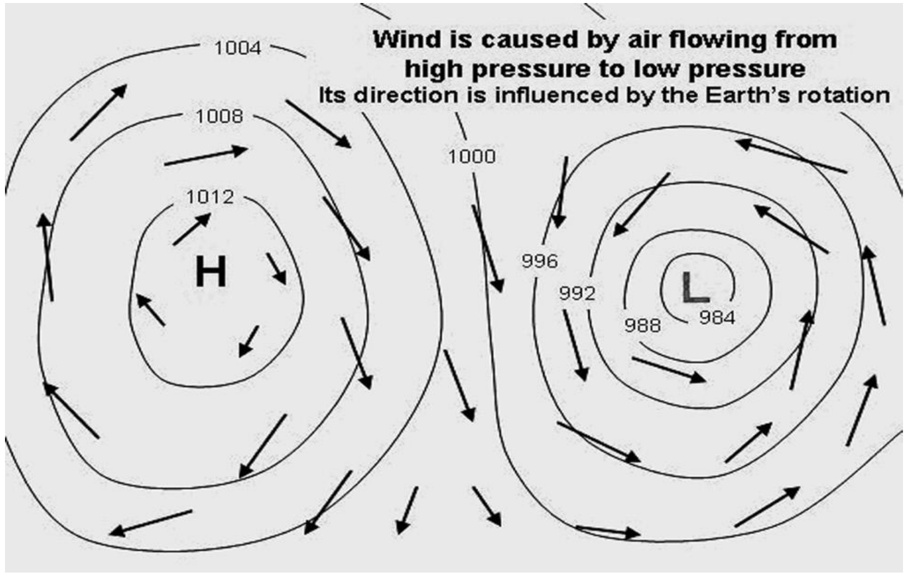
Factors Affecting Wind Strength and Direction

Pressure Gradients:

Which are usually associated with air temperature differences, act to push air from high- to low-pressure areas. The pressure gradient is strong where the isobars are close to each other and is weak where the isobars are apart. It affects the speed of the wind. It is greatest at the surface and its influence generally extends up to an elevation of 1-3 km. The vertical pressure gradient force is much larger than that of the horizontal pressure gradient. But, it is generally balanced by a nearly equal but opposite gravitational force. Hence, we do not experience strong upward winds. The wind direction follows the direction of change of pressure, i.e. perpendicular to the isobars.

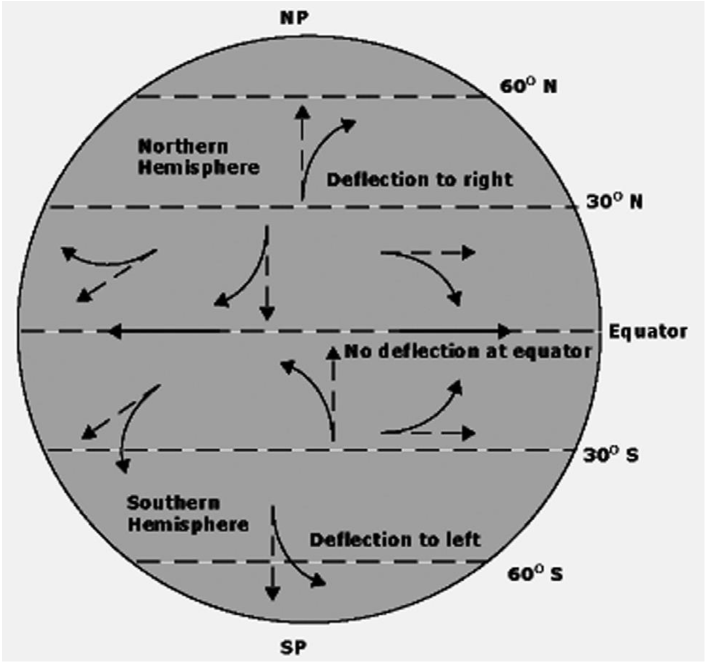
The Coriolis Effect:

Generated by the Earth's rotation, it turns the path of moving air sideways, changing the direction of flow. This deviation is the result of the earth's rotation and is called the Coriolis Effect or Coriolis force. Due to this effect, winds in the northern hemisphere get deflected to the right of their path and those in the southern hemisphere to their left, following Ferrell's Law (the law that wind is deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, derived from the application of the Coriolis effect to air Masses). The deflection is more when the wind velocity is high. This deflection force does not seem to exist until the air is set in motion and increases with wind velocity, air mass and an increase in latitude. The Coriolis force acts perpendicular to the pressure gradient force (pressure gradient force is perpendicular to an isobar). As a result of these two forces operating perpendicular to each other, in the low-pressure areas the wind blows around it.



The Effect of Earth's Rotation on Wind Direction

Due to the absence of Coriolis force there is absence of cyclones around the equator, since at the equator (Coriolis force is zero) wind blows perpendicular to the isobars. The low pressure gets filled instead of getting intensified i.e., there is no spiraling of air due to zero Coriolis Effect. The wind directly gets uplifted vertically to form thunderstorms.



Deflection of Winds with Latitude

Friction:

Surface slows the wind in the lower atmosphere and acts in a direction opposite to air motion. The irregularities of the earth's surface offer resistance to the wind movement in the form of friction. It affects the speed of the wind. It is greatest at the surface and its influence generally extends up to an elevation of 1 - 3 km. Over the sea surface the friction is minimal. Over uneven terrain, however, due to high friction, the wind direction makes high angles with isobars and the speed gets retarded.

Centripetal Acceleration:

Centripetal acceleration creates a force directed at right angles to the wind movement and inwards towards the centres of rotation (e.g., low and high pressure centres). This force produces a circular pattern of flow around centres of high and low pressure. Centripetal acceleration is more important for circulations smaller than the mid-latitude cyclone.

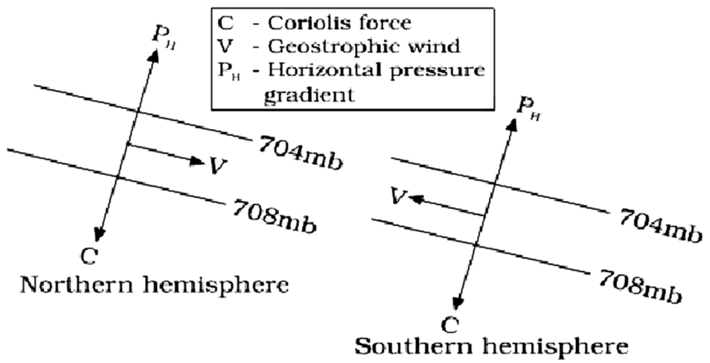
Types of Winds

Permanent or PlanetaryWinds

- Considering the fact that the location of high and low pressure belts remains stationary on the globe, consequently, the winds blow from high pressure to low pressure belts. Winds blow at the same direction throughout the year, remain little affected by the seasonal cycle.
- These cover large areas and distance over the earth. They are guided by the Horizontal movement, the pressure belt systems provide pressure gradient for movement of the winds. Their direction is affected by the Coriolis force.

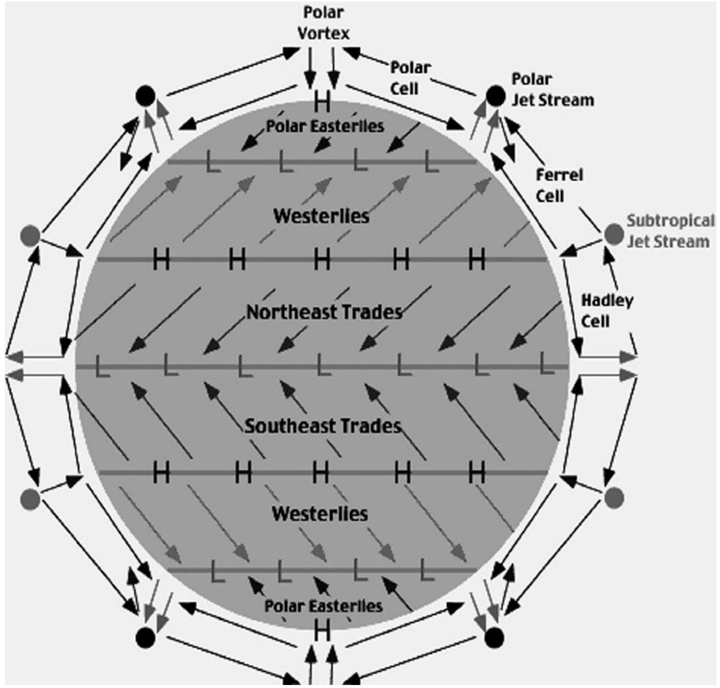
Geostrophic Wind

Air under the influence of both the pressure gradient force and Coriolis force tends to move parallel to isobars in conditions where friction is low (1000 meters above the surface of the Earth) and isobars are straight. Winds of this type are usually called Geostrophic winds. Geostrophic winds come about because pressure gradient force and Coriolis force come into balance after the air begins to move. A Geostrophic wind flows parallel to the isobars.



Winds in the Tropics

- The trade winds are those blowing from the sub-tropical high pressure areas towards the equatorial low pressure belt. Therefore, these are confined to a region between 5°N-30°N and 5°S-30°S throughout the earth's surface. They flow as the north-eastern trades in the northern hemisphere and the south-eastern trades in the southern hemisphere.



The Tropical Wind System

- This deflection in their ideally expected north-south direction is explained on the basis of Coriolis force and Farrell's law.
- Trade winds are descending and stable in areas of their origin (sub-tropical high pressure belt), and as they reach the equator, they become humid and warmer after picking up moisture on their way. The trade winds from two hemispheres meet at the equator, and due to convergence they rise and cause heavy rainfall. The eastern parts of the trade winds associated with the cool ocean currents are drier and more stable than the western parts of the ocean.
- In the Southern hemisphere winds originating from the Sub-tropical high pressure and blowing towards the Equatorial low pressure are similarly deflected westward to become the prevailing South-east trades.
- Trade winds are noted for their consistency, both in force and direction in many areas especially over open seas and derive their name from the nautical expression 'to blow trade' meaning 'to blow along a regular track'.
- Zones of sub-tropical highs in latitudes about 30°-35°N and 30°-35°S are areas of descending air and are characterize **by calms light variable winds, comparatively dry air and quiet, stable weather conditions.**

The Westerlies

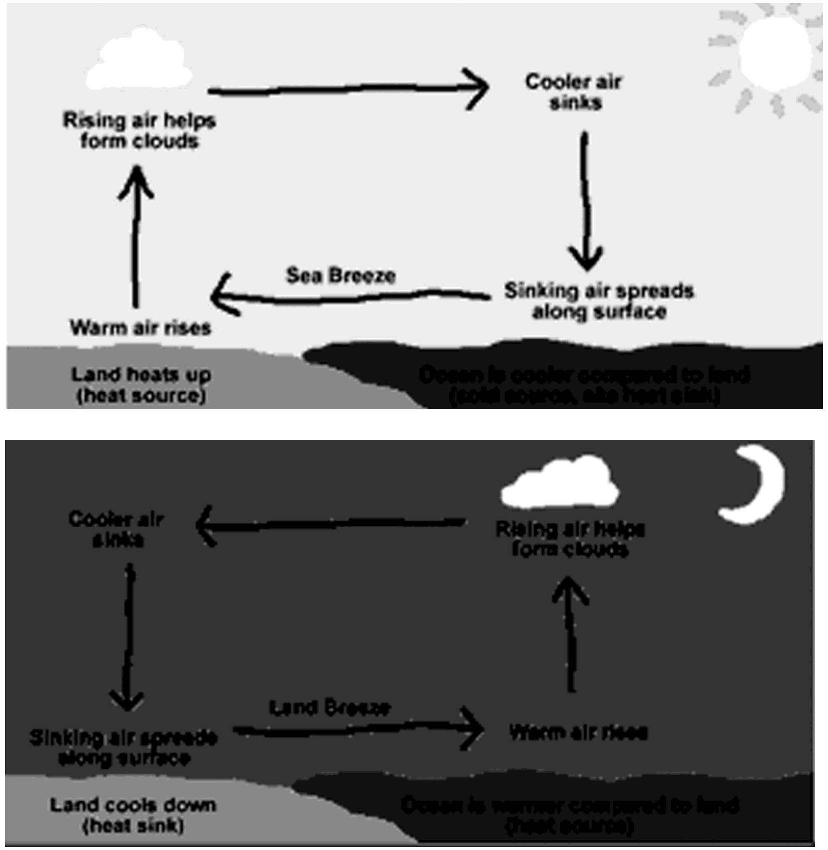
- The Westerly Winds blow across latitudes 35°-60° of both the hemispheres. The air streams flowing polewards from the Sub- tropical high pressure areas deflects eastward in the Northern hemisphere to form South- Westerlies.
- Similar winds in the Southern hemisphere are known as North-Westerlies. Unlike the trade winds, the Westerlies are very variable in force and direction, especially in the Northern hemisphere. In the Southern hemisphere, on the other hand, the Westerlies blow with great strength and regularity throughout the year over the almost uninterrupted expanse of ocean and have given the name **Roaring forties, Furious fifties** and **Shrieking Sixties** to the region specially between latitudes 40°S and 60°S. Sometimes the name is applied to the winds themselves as they give a roaring sound on account of high speed. The poleward boundary of the Westerlies is highly fluctuating. There are many seasonal and short-term fluctuations. These winds produce wet spells and variability in weather.

The Polar Easterlies

- The Polar easterlies blow from the Polar high pressure area to the Temperate low pressure area. On their equatorward journey they are deflected westwards to become North easterlies in the Northern hemisphere and South easterlies in the Southern hemisphere.
- The Polar easterlies are dry, cold prevailing winds blowing from north-east to south-west direction in Northern Hemisphere and south- east to north-west in Southern Hemisphere. They blow from the polar high-pressure areas of the sub-polar lows.

Local Winds

Winds, caused by local factors and confined to a limited area compared to planetary winds, are called as local winds. Some well-known examples of local winds are:



Land & Sea Breeze

Land Breeze:

It is a common local wind that affects only the Coastal areas. During the night the land becomes very much cooler than the sea as land is quickly chilled than the sea. The air adjacent to the surface is also chilled with the result that there is a marked high pressure over land. Thus the cooler, heavier, denser air over the land flows towards the sea and *land breeze* occurs.

See Breeze:

Unlike land breeze, it blows the opposite way from the sea to the land. During the day the land becomes quickly heated compared to sea with the result there is a marked low pressure over the land. Thus air is drawn into the land from the comparatively high pressure area of the adjacent seas or oceans. The southerly sea breeze in summer is highly welcome in Kolkata.

Fohn:

Fohn is a warm dry wind that blows down the valleys of the north facing **slopes of the Alps** and is most common in spring and autumn. It occurs when a depression to the north of the Alps draws air from the south over the mountains.

Famous 'Winds' of the World & their Regions		
Names	**Nature**	**Region**
Fohn	Warm	Alps
Chinook (Snow eater)	Warm	Rockies
Kalbaisakhi	Warm	North India
Berg	Warm	S Africa
Zonda	Warm	Andes
Loo	Warm	Indian subcontinent
Santa Ana	Warm	Coastal Southern California
Southerly	Cold	New South Wales Burster
Khamsin	Warm	Egypt
Harmattan (Doctor)	Warm	Guinea Coast
Mistral	Cold	S E France
Samun	Warm	Iran

Chinook: Chinook is a warm dry southwesterly wind, similar to the Fohn in origin and character. Chinook or the Fohn is relatively much warmer than the air into which it is invading, but in the absolute sense, it may be even colder at times below freezing point of water.

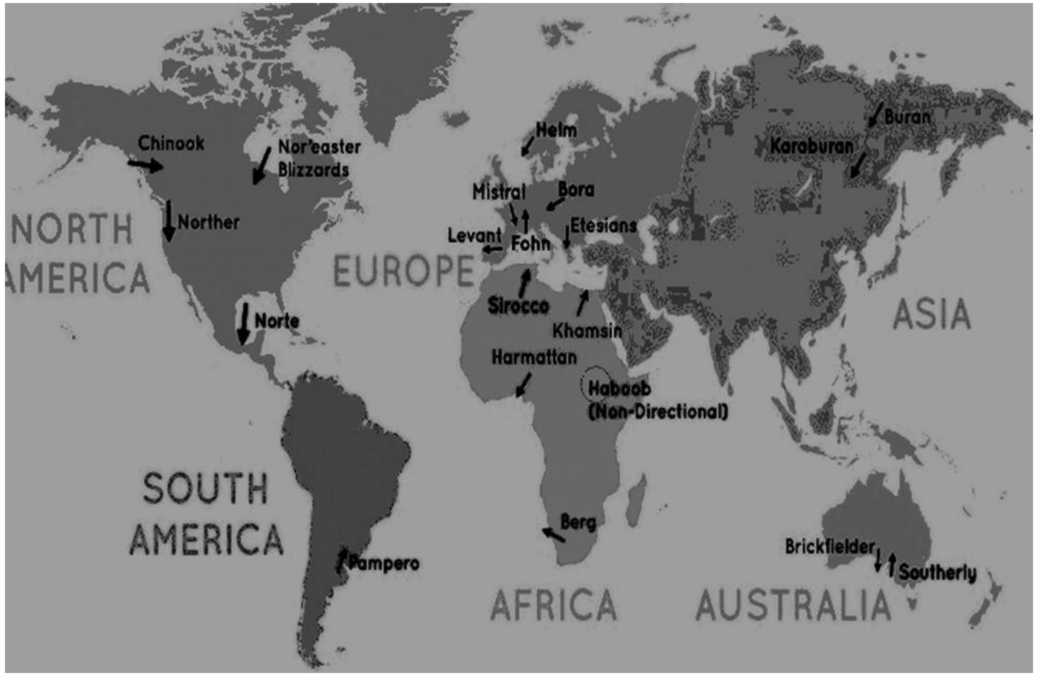
Mistral: It is one of the local names given to such winds that blow from the Alps over France towards the Mediterranean Sea. It is channeled through the Rhine valley. It is very cold and dry with a high speed. It brings blizzards into southern France.

Sirocco: It is a Mediterranean wind that comes from the Sahara and reaches hurricane speeds in North Africa and Southern Europe. It arises from a warm, dry, tropical air mass that is pulled northwards by low-pressure cells moving eastward across the Mediterranean Sea, with the wind originating in the Arabian or Sahara deserts. The hotter, drier continental air mixes with the cooler, wetter air of the maritime cyclone, and the counter-clockwise circulation of the low propels the mixed air across the southern coasts of Europe. The Sirocco causes dusty dry conditions along the northern coast of Africa, storms in the Mediterranean Sea, and cool wet weather in Europe.

Loo: In the plains of northern India and Pakistan, sometimes a very hot and dry wind blows from the west in the months of May and June, usually in the afternoons. It is known as loo. Its temperature invariably ranges between 45°C and 50°C. It may cause sunstroke to people.

Local Winds : Fact Sheet

1. **Harmattan** is a very dry and dust-laden West African wind that blows south-east from the Sahara to the coast especially between Octobers to February. Its incursion into the coast of Gulf of Guinea gives relief to stifling humidity.
2. The **Sirocco**, a hot dry south wind blowing from the Sahara to the Mediterranean, is most unpleasant. In Egypt this wind is called **Khamsin**.
3. The **Mistral** and **Bora** are cold north winter winds. Mistral is experienced in southern France, especially in the Rhone delta and *Bora* blows down the mountains to the east coast of Adriatic Sea and North Italy.
4. **Norwester** is a squall occurring during hot season (April-June) in North India and may bring rain or hail.
5. The Loos are hot and dry summer westerly winds that sweep the Upper and Middle Ganga Plains.



The "Location of Region' of Famous Wind Systems on the Globe

Tricellular Meridional Circulation of Atmosphere

- The Tricellular model is made up of three different air masses, these control atmospheric movements and the redistribution of heat energy. The three air masses, starting from the equator, are called the **Hadley cell, Ferrell cell** and the **Polar cell**.
- The Tricellular model also contains the ITCZ (Inter-Tropical Convergence Zone), this is the meeting place of the trade winds from both the northern hemisphere and the southern hemisphere. The ITCZ is a low pressure area where the trade winds, which have picked up latent heat as they crossed oceans, are now forced to rise by convection currents. These rising convection currents are then cooled adiabatically to form massive cumulonimbus clouds. It is believed that there is cellular circulation of air at each meridian (longitude). Surface winds blow from high pressure areas to low pressure areas but in the upper atmosphere, the general direction of air circulation is opposite to the direction of surface winds.

Cells of Tri-Cellular Meridional Circulation

Tropical Cell or Hadley Cell

Tropical cell is also called as Hadley cell because G Hadley first identified this thermally induced cell in both the hemispheres in the year 1735. The winds after being heated due to very high temperature at the equator ascend upwards. These ascending warm and moist winds release latent heat after condensation which causes further ascent of the winds which after reaching the height of 8 to 12 kilometres in the troposphere over the equator diverge northwards and southwards or sky polewards.

The surface winds in the name of trade winds blow from subtropical high pressure belts to equatorial low pressure belts in order to replace the ascending air at the equator. The upper air moving in opposite direction to surface winds (trade winds) is called the *antitrade*. These upper air antitrades descend near 30°-35° latitudes to cause a subtropical high pressure belt.

These antitrades after descending near a 30°- 35° latitudes again blow towards the equator where they are again heated and ascend. Thus, one complete meridional cell of air circulation is formed. This is called **tropical meridional cell** which is located between the equator and 30° latitudes. It may be pointed out that the regularity and continuity of the antitrade wind systems in the upper air has been refuted by a host of meteorologists on the basis of more upper air data being available during and after Second World War.

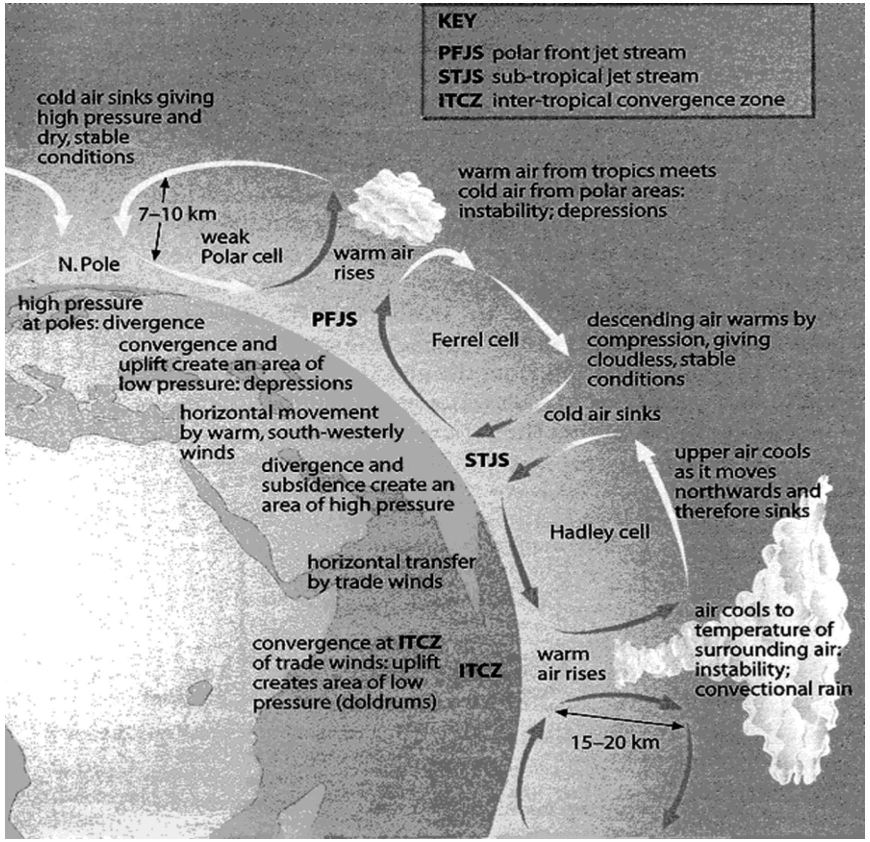
Polar Front Cell or Mid-Latitude Cell or Ferrel Cell

- Polar front cell or mid-latitude cell, according to old concept surface winds, known as Westerlies, blow from the subtropical high pressure belt to sub polar low pressure belt (60°-65°). The winds ascend near 60°-65° latitudes because of the rotation of the earth and after reaching the upper troposphere diverge in opposite directions (poleward and equator-ward).
- These winds (which diverge equator-ward) again descend near horse latitudes (30°- 35° latitudes) to reinforce subtropical high pressure belt. After descending, these winds again blow polewards as surface Westerlies and thus a complete cell is formed.
- Winds blow from subtropical high pressure belt to subpolar low pressure belt but the winds become almost westerly due to Coriolis force. It may be mentioned that the regularity and continuity of Westerlies are frequently disturbed by temperate cyclones, migratory extra-tropical cyclones and anticyclones.
- Contrary to the existing view of upper air tropospheric easterly winds in the zones extending between 30°-60° latitudes Rossby observed the existence of upper air Westerlies in the middle latitudes due to poleward decrease of air temperature.According to G.T. Trewartha the middle and upper tropospheric Westerlies are associated with long waves and jet streams. Warm air ascends along the polar front which is more regular and continuous in the middle troposphere. It may be pointed out that this new concept does not explain the cellular meridional circulation in the middle latitudes.

Polar or Sub Polar Cell

Polar cell involves the atmospheric circulation prevailing between 60° and poles. Cold winds, known as polar easterlies, blow from polar high pressure areas to sub-polar or mid-latitude low pressure belts. The general direction of surface polar winds becomes easterly (east to west) due to Coriolis force.These polar cold winds converge with warm Westerlies near 60°-65° latitudes and form polar front or mid- latitude front which becomes the centres for the origin of temperate cyclones. The winds ascend upward due to the rotation of the earth at the sub-polar low pressure belt and after reaching middle troposphere they turn poleward and equator-ward. The poleward upper air descends at the poles and reinforces the polar high pressure. Thus, a complete polar cell is formed.

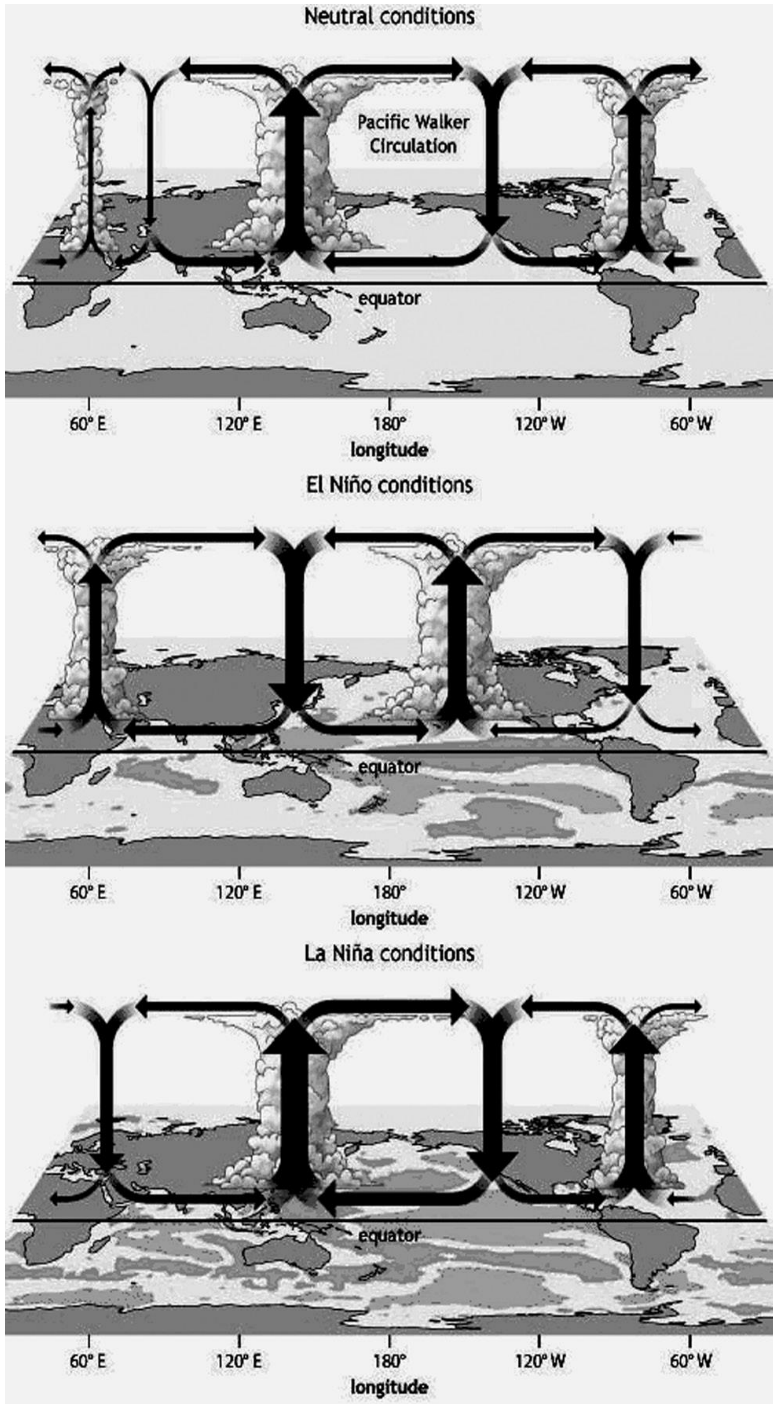
The subtropical high pressure and sub-polar low pressure belts are dynamically induced due to subsidence and spreading of air caused by the rotation of the earth respectively. Upper air anti-trades are not uniformly found over all the meridians. If the trade winds are exclusively of thermal origin, then the thermal gradient must be present boldly throughout the tropics but this is not true. At the height of 500 to 1000 m, in the atmosphere, the winds become almost parallel to the isobars which are generally parallel to the latitude. If this is so, the meridional cell of air circulation may not be possible.



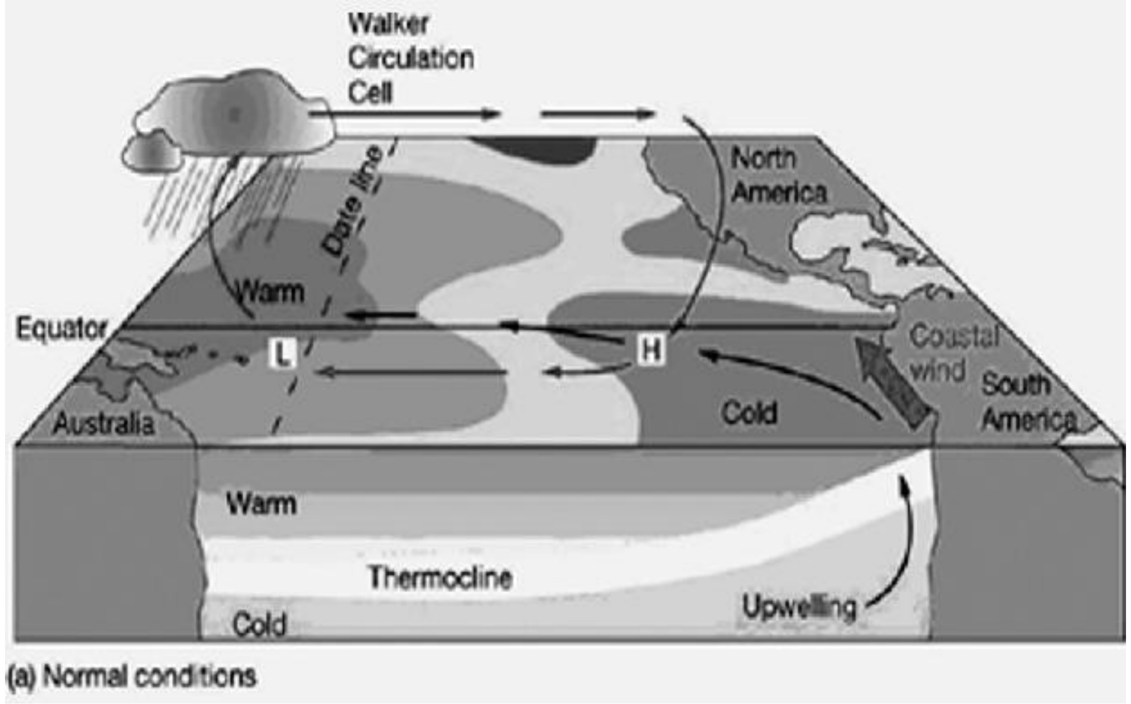
Tri-cellular Meridional Circulation

Walker Circulations

- The Walker circulation is an ocean-based system of air circulation that influences weather on the Earth.
- The Walker circulation is the result of a difference in surface pressure and temperature over the western and eastern tropical Pacific Ocean. Normally, the tropical western Pacific is warm and wet with a low pressure system, and the cool and dry eastern Pacific lie under a high pressure system. This creates a pressure gradient from east to west and causes surface air to move east to west, from high pressure in the eastern Pacific to low pressure in the western Pacific. Higher up in the atmosphere, west-to-east winds complete the circulation.
- The warm waters of the western Pacific Ocean in East Asia heat the air above it and supply it with moisture. On average, the air rises, forms clouds, and then flows to the east across the Pacific, losing moisture to rainfall. The air then sinks off the west coast of South America and returns to the west along the surface of the ocean, back to the western Pacific Ocean. The Walker circulation contributes to normal weather conditions in the tropical Pacific Ocean: warm, wet weather in the western Pacific and cool, dry weather in the eastern Pacific.



- **The Walker circulation reverses every few years, as part of a phenomenon called the El Nino – Southern Oscillation (ENSO).** When the Walker circulation weakens, the winds also weaken and the warm water of the western Pacific spreads to the east. These conditions are called **El Nino**. During times when the Walker circulation is particularly strong, called **La Niña**, the winds are stronger across the Pacific. These strong winds cause cooler ocean temperatures because of upwelling in the eastern Pacific. El Nino and La Nina impact the weather in North and South America, Australia, and Southeast Africa, and can cause flooding, droughts, and increases or decreases in hurricane activity.



The El Nino and La Nino Impacts

Monsoon in India Origin and Mechanism of Monsoon

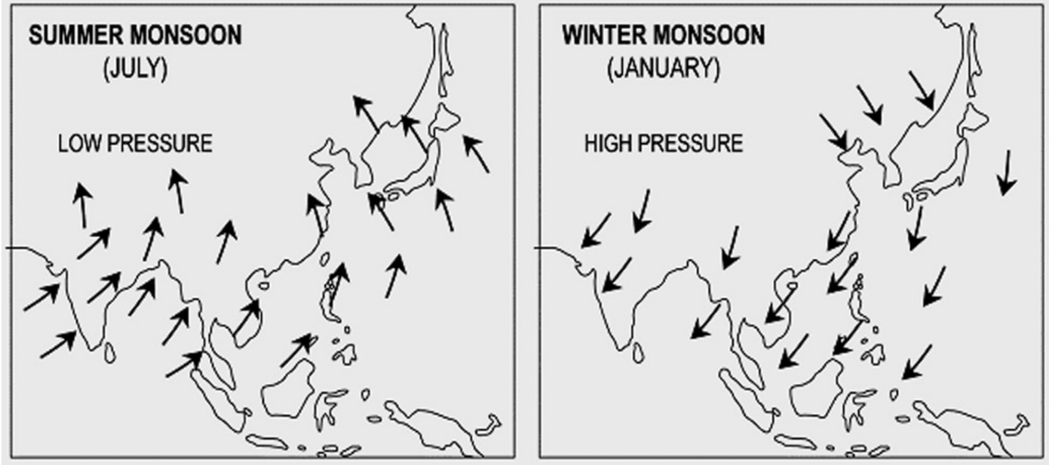
The term monsoon has been derived from the Arabic word **mousim** or the Malayan word **monsin**, both of which mean **season**. Monsoon is characterized by a seasonal reversal of wind direction. They flow from sea to land during the summer and from land to sea during the winter. The Asiatic seasonal wind reversal is notable for its immense extent and the penetration of its influence. C S Ramage (1971) has identified the **four main features of monsoon winds**.

1. The prevailing wind direction should shift by at least 120 ° between January and July.
2. The average frequency of prevailing wind directions in January and July should exceed 40 per cent.
3. The mean resultant wind velocity in at least one of the months should exceed 3 m/s.
4. There should be less than one cyclone anticyclone alternation every two years, in either month, over a five degree latitude/longitude grid.

On the basis of above four criteria, the area of the monsoon region is as a rectangle roughly extending from 35° N to 25° S latitudes and 30° W to 173° E longitudes.

The Thermal Concept of Monsoon

- According to this view monsoon is a result of differential rates of heating and cooling of land and sea. The sun is vertical over the Tropic of Cancer in summer season of northern hemisphere and the Indian landmass at this time gets heated to a greater extent than the neighboring sea. This leads to formation of low pressure conditions over the Indian subcontinent in comparison to that over Indian Ocean. Therefore, thermally induced pressure gradient is produced from ocean towards Indian sub-continent leading to the onset of southwesterly winds blowing from Indian Ocean towards India. These winds, called southwest monsoon, blowing from sea towards land, carry a large amount of moisture and cause copious rainfall over the landmass.
- The land not only gets heated faster, it also cools faster to a greater extent in summer than the ocean. Hence, the Indian Ocean is warmer than the Indian subcontinent in winter. This causes the pressure gradient to be reversed towards sea. This altered pressure gradient leads to the onset of winds blowing from northeast to southwest, i.e., winds blowing from Indian subcontinent towards Indian Ocean. This wind system is called the northeast monsoon. Since the winds are at this time blowing from land towards sea, they carry little moisture. The winter season over the Indian landmass thus remains largely dry.



The Summer and Winter Monsoon in India

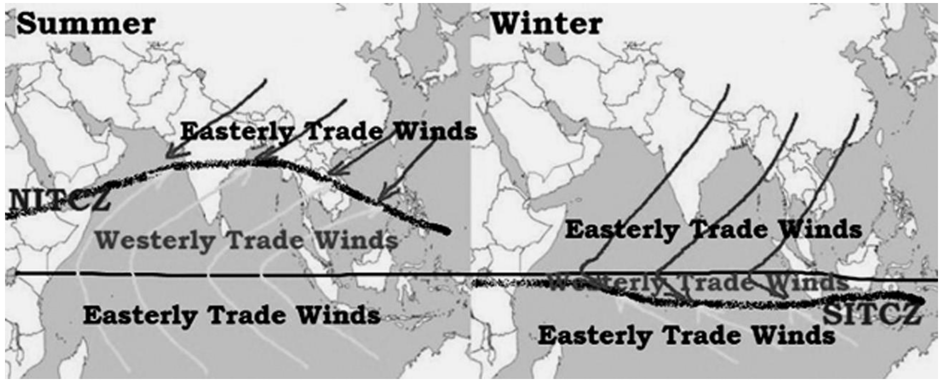
Criticism of the Thermal Concept

This concept visualizes monsoon winds as regional surface winds only. It fails to explain the inherent uncertain and irregular character of dynamic monsoon. Modern climatologists express doubt about the thermal origin of low (summer) and high (winter) pressure areas over the land (the Indian sub-continent). According to them, the position of low and high pressure areas change suddenly. These sudden changes are not exclusively related to thermal conditions rather than to dynamic factors. Another criticism is about the low pressure areas which are not stationary as stated in the thermal concept. The rainfall is not only convectional, but a mix of orographic, cyclonic and convectional rainfall.

Dynamic Concept: Shifting ofInter-Tropical Convergence Zone (ITCZ)

- This concept was propounded by H. Flohn of German Weather Bureau in 1951. He has suggested that monsoon system experienced in tropical Asia is a result of the seasonal changes in the planetary wind system resulting from the seasonal swing of temperature and pressure belts in this region in association with the changes in overhead position of sun.
- The planetary winds of tropics are trade winds. In the months of March and September, when sun is overhead in equatorial area, low pressure belt is created near equator and north-east trade winds of northern hemisphere and south-east trade winds of southern hemisphere converge in this belt of low pressure. This zone is known as Inter-tropical Convergence Zone or ITCZ. The ITCZ is associated with the zone of highest temperature and the lowest pressure. It is due to the low pressure here that the Trade Winds of the northern and the southern hemispheres converge here. When ITCZ is situated close to the equator, the Trade Winds converge near the equator. It is also known as the ‘doldrums’ or calm area. In this equatorial zone, the planetary winds are equatorial Westerlies.

During summer solstice sun's rays are vertical over the Tropic of Cancer. Therefore, all wind and pressure belts of the globe shift towards the north. At this point of time, ITCZ shifts northwards and becomes NITCZ (Northern Inter Tropical Convergence Zone). It extends up to 30º N Latitude in South and South-East Asia. The excessive heating of Indian sub-continent further intensifies this process. According to Flohn, at this point of time the equatorial Westerlies of doldrums shift northwards and get extended as southwest monsoon winds. Some other scholars consider south-west monsoon winds as an extension of south-east trade winds of southern hemisphere towards NITCZ. They become south-westerly under the influence of Coriolis force as they cross the equator. NITCZ also result into tropical disturbances which play significant role in surface weather conditions. Heavy rainfall is received during summer season because south-west monsoon winds are on-shore.



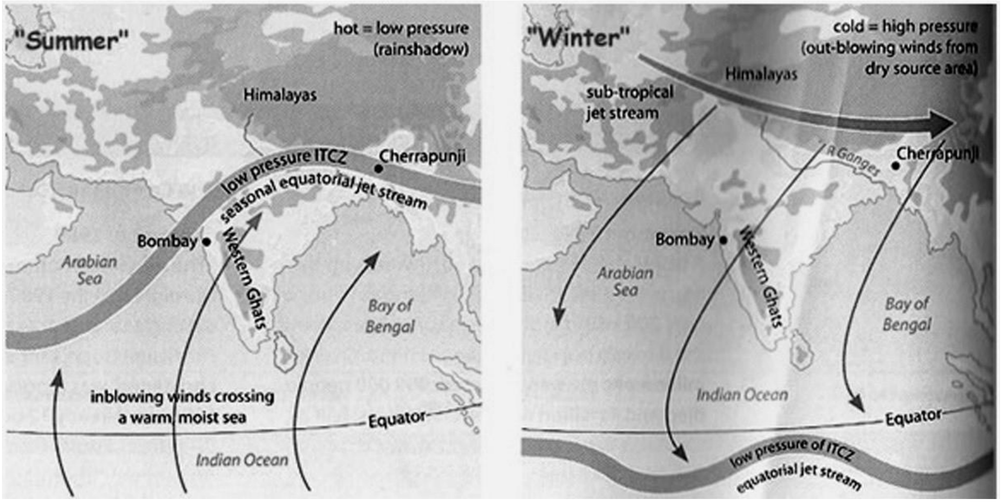
Dynamic Concept of Shifting of Inter Tropical Convergence Zone

During winter season due to southward shifting of ITCZ the pressure and wind belts, the planetary system of north-east trade winds gets re-established over this region. These are called north-east winter monsoons. They prevail over majority area as off-shore winds. Therefore, are generally dry and devoid of rains. But on Tamil Nadu coast they are on-shore and bring precipitation in winter months. The SITCZ (Southern Inter Tropical Convergence Zone) position is associated with north-west monsoon rainy season over northern part of Australia. When the ITCZ shifts towards Tropic of Capricorn in winter, the Trade Winds of northern hemisphere will cross the equator, will be deflected to left hand side and the southern hemisphere tropical zone will experience northwesterly winds. The reversal of wind direction thus occurs in both hemispheres in the tropical zone.

Jet Stream Concept ofMonsoon

- Jet stream is a band of fast moving air from west to east usually found in the middle latitudes in the upper troposphere at a height of about 12 km. The wind speeds in a westerly jet stream are commonly 150 to 300 kmph. with extremes reaching 400 kmph. Jet stream is the latest theory regarding the origin of the monsoons and has earned worldwide acclaim from the meteorologists.
- In winter the western jet stream flows along the southern slopes of the Himalayas but in summer it shifts northwards, rather dramatically, and flows along the northern edge of the Tibet Plateau. The periodic movements of the Jet stream are often indicators of the onset and subsequent withdrawal of the monsoon.
- Tibet is an ellipsoidal plateau at an altitude of about 4,000 m above sea level with an area of about 4.5 million sq km. This plateau is surrounded by mountain ranges which rise 6,000 – 8,000 m above sea level. It gets heatedin summer and is 2°C to 3°C warmer than the air over the adjoining regions.
- Koteswaram, supported by Flohn, feels that because the Tibet Plateau is a source of heat for the atmosphere, it generates an area of rising air. During its ascent, the air spreads outwards and gradually sinks over the equatorial part of the Indian Ocean. At this stage, the ascending air is deflected to the right by the earth's rotation and moves in an anti-clockwise direction leading to anticyclonic conditions in the upper troposphere over Tibet around 300- 200 mb (9 to 12 km). It finally approaches the west coast of India as a return current from a south-westerly direction and is termed as equatorial Westerlies. It picks up moisture from the Indian Ocean and causes heavy rainfall in India and adjoining countries.

- The south-west monsoon in southern Asia is overlain by strong upper easterlies with a pronounced jet at 100 to 200 mb. These easterly winds, which often record speeds exceeding 100 knots are known as the Easterly Jet Stream of the tropics.
- The periodic movements of the sub-tropical jet stream provide a useful indication of the onset and subsequent withdrawal of the monsoon. In fact, northward movement of the subtropical jet is the first indication of the onset of the monsoon over India.
- The easterly jet does not come into existence if the snow over the Tibet Plateau does not melt. This hampers the occurrence of rainfall in India. Therefore, any year of thick and widespread snow over Tibet will be followed by a year of weak monsoon and less rainfall.



Jet Stream Concept of Monsoon

Southern Oscillation and theEl Nino

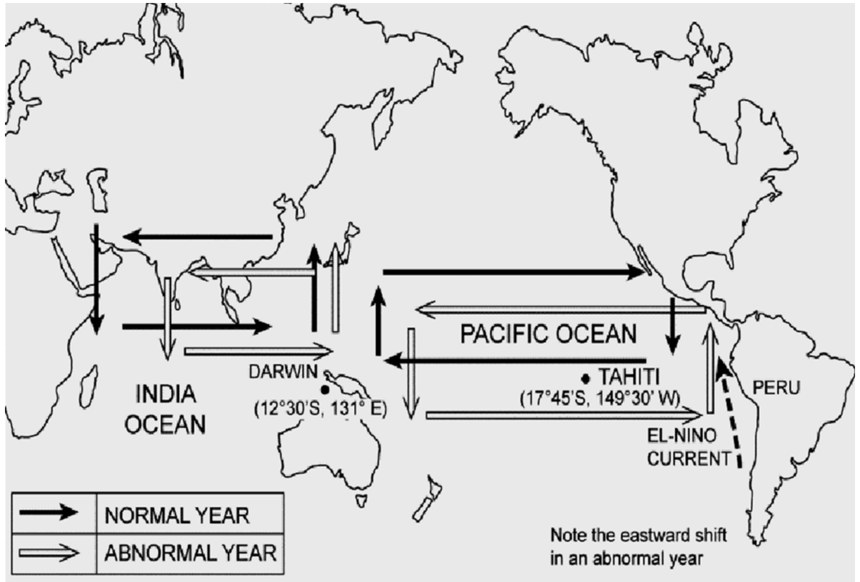
Recent studies have revealed that there seems to be a link between meteorological events which are separated by long distances and large intervals of time. They are called *meteorological teleconnections*. The one which has aroused considerable interest among the meteorologists is the difference between an El Nino and the Southern Oscillation. **El Nino (EN) is a narrow warm current which appears off the coast of Peru in December**.

In Spanish, it means The **Child Christ** because it appears around Christmas. In some years this warm current is more intense than usual.

The El Nino phenomenon, which influences the Indian monsoon, reveals that when the surface temperature goes up in the southern Pacific Ocean, India receives a deficient rainfall. However, there have been some years during which the El Nino phenomena did not occur, but India still got deficient rainfall, and conversely, India received sufficient rainfall during an El Nino year.

Southern Oscillation (SO) is the name ascribed to the curious phenomenon of sea-saw pattern of meteorological changes observed between the Pacific and Indian oceans. This great discovery was made by Sir Gilbert Walker in 1920.

- While working as the head of the Indian Meteorological service, he noticed that when the pressure was high over equatorial south Pacific, it was low over the equatorial south Indian Ocean and the vice versa. The pattern of low and high pressures over the Indian and Pacific Oceans (SO) gives rise to vertical circulation along the equator with its rising limb over low pressure area and descending limb over high pressure area.
- This is known as Walker Circulation. The location of low pressure and hence the rising limb over Indian Ocean is considered to be conductive to good monsoon rainfall in India.
- In other words, when there is low pressure over the Indian Ocean in winter months, the chances are that the coming monsoon will be good and will bring sufficient rainfall. Its shifting eastward from its normal position, such as in El Nino years, reduces monsoon rainfall in India.
- Due to the close association between an El Nino (EN) and the Southern Oscillation (SO), the two are jointly referred to as an ENSO event. Some of the predictors used by Sir Gilbert Walker are still used in long-range forecasting of the monsoon rainfall.
- The main difficulty with the Southern Oscillation is that its periodicity is not fixed and its period varies from two to five years. Different indices have been used to measure the intensity of the Southern Oscillation, but the most frequently used is the Southern Oscillation Index (SOI).



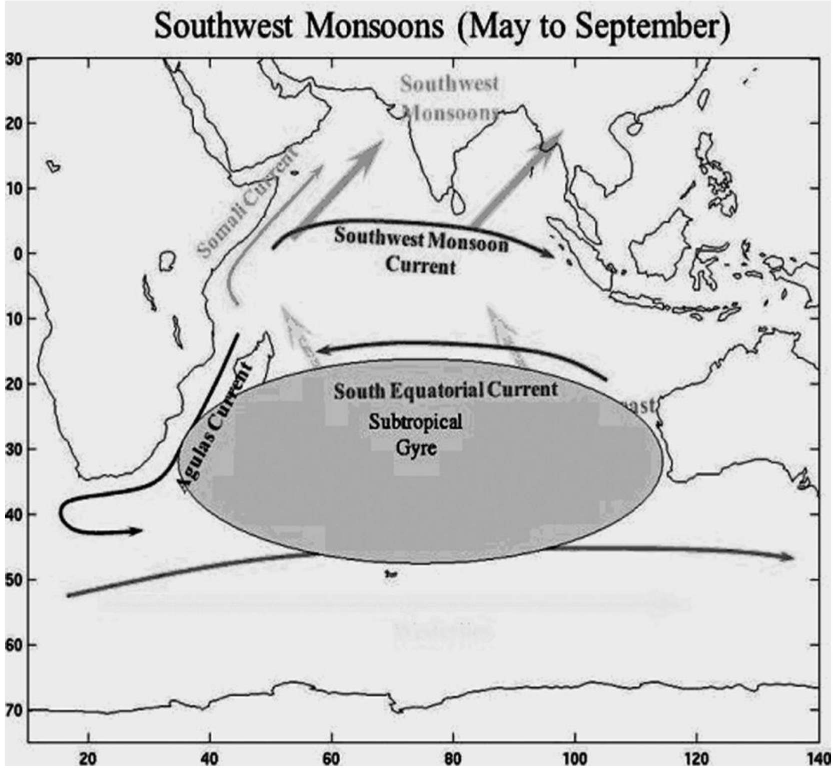
El. Nino, Walker Circulation and Southern Oscillation

This is the difference in pressure between Tahiti in French Polynesia, representing the Pacific Ocean and Port Darwin, in northern Australia representing the Indian Ocean. The positive and negative values of the SOI i.e. Tahiti minus the Port Darwin pressure are pointers towards good or bad rainfall in India.

Scientists of India Meteorological Department (IMD) joined an international study programme called the Tropical Oceans and Global Atmosphere (TOGA) in 1985. This is an interesting and ambitious programme, which investigates both teleconnections effects and the internal variability. As a follow up to TOGA, the climate variability (CLIVAR) was set up in January 1995, to develop an internationally operational climate forecasting system.

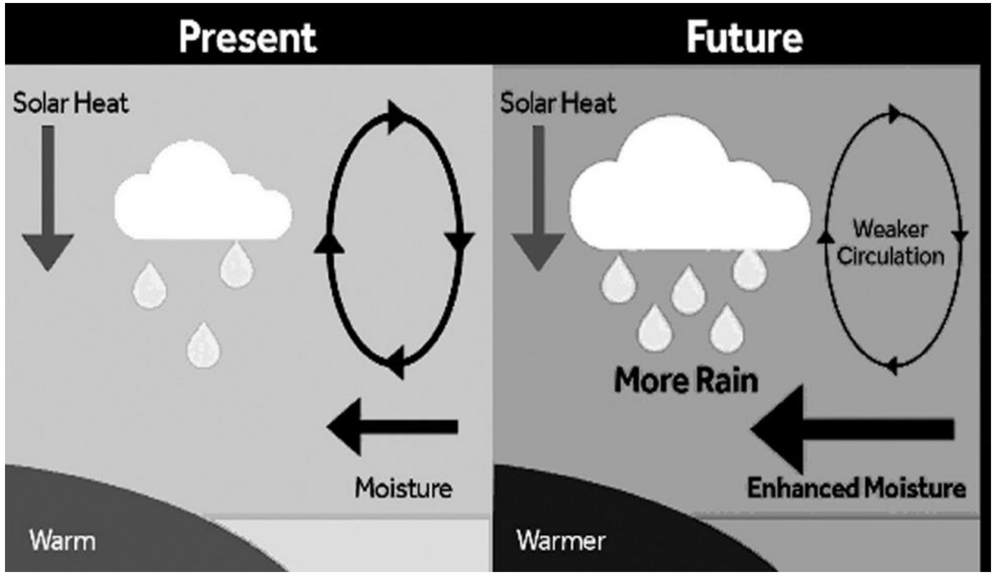
Overall, monsoonal rainfall is projected to become more intense in future, and to affect larger areas, because atmospheric moisture content increases with temperature. However, the localized effects of climate change on regional monsoon strength and variability are complex and more uncertain.

Monsoon rains fall over all tropical continents Asia, Australia, the Americas and Africa. The monsoon circulation is driven by the difference in temperature between land and sea, which varies seasonally with the distribution of solar heating. The duration and amount of rainfall depends upon the moisture content of the air, and on the configuration and strength of the atmospheric circulation.



The Soutwest Monsoon

- The regional distribution of land and ocean also plays a role, as does the topography. For example, the Tibetan Plateau — through variations in its snow cover and surface heating — modulates the strength of the complex Asian monsoon systems. Where moist on-shore winds rise over mountains, as they do in southwest India, monsoon rainfall is intensified. On the lee side of such mountains, it lessens.
- Since the late 1970s, the East Asian summer monsoon has been weakening and not extending as far north as it used to in earlier times, as a result of changes in the atmospheric circulation. That in turn has led to increasing drought in northern China, but floods in the Yangtze River Valley farther south. In contrast, the Indo-Australian and Western Pacific monsoon systems show no coherent trends since the mid-20th century, but are strongly modulated by the El Nino- Southern Oscillation (ENSO).



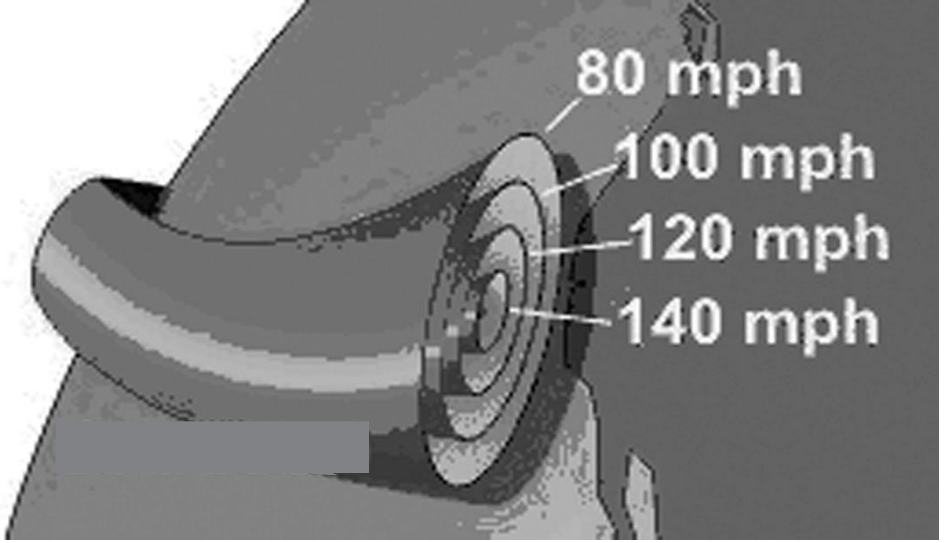
Monsoon Climate Change Impacts

The Monsoon Impact in India

- The land surface warms more rapidly than the ocean surface, so that surface temperature contrast is increasing in most of regions. The tropical atmospheric overturning circulation, however, slows down on average as the climate warms due to energy balance constraints in the tropical atmosphere. These changes in the atmospheric circulation lead to regional changes in monsoon intensity, area and timing.
- Surface heating varies with the intensity of solar radiation absorption, which is itself affected by any land use changes that alter the reflectivity (albedo) of the land surface. Also, changing atmospheric aerosol loadings, such as air pollution, affect how much solar radiation reaches the ground, which can change the monsoon circulation by altering summer solar heating of the land surface. Absorption of solar radiation by aerosols, on the other hand, warms up the atmosphere, changing the atmospheric heating distribution.
- The strongest effect of climate change on the monsoons is the increase in atmospheric moisture associated with warming of the atmosphere, resulting in an increase in total monsoon rainfall even if the strength of the monsoon circulation weakens or does not change. Climate model projections through the 21st century show an increase in total monsoon rainfall, largely due to increasing atmospheric moisture content.
- The total surface area affected by the monsoons is projected to increase, along with the general poleward expansion of the tropical regions. Climate models project from 5% to an approximately 15% increase of global monsoon rainfall depending on scenarios. Though total tropical monsoon rainfall increases, some areas will receive less monsoon rainfall, due to weakening tropical wind circulations.
- Monsoon onset dates are likely to be early or not to change much and the monsoon retreat dates are likely to delay, resulting in lengthening of the monsoon season. Future regional trends in monsoon intensity and timing remain uncertain in many parts of the world. Year-to-year variations in the monsoons in many tropical regions are affected by ENSO. How ENSO will change in future — and how its effects on monsoon will change — also, both remain uncertain. However, the projected overall increase in monsoon rainfall indicates a corresponding increase in the risk of extreme rain events in most of the regions.

Jet Streams

The jet stream is a river of wind that blows horizontally through the upper layers of the troposphere, generally from west to east, at an altitude of 20,000 - 50,000 feet (6,100 - 9,144 meters), or about 7 miles (11 kilometres) up.

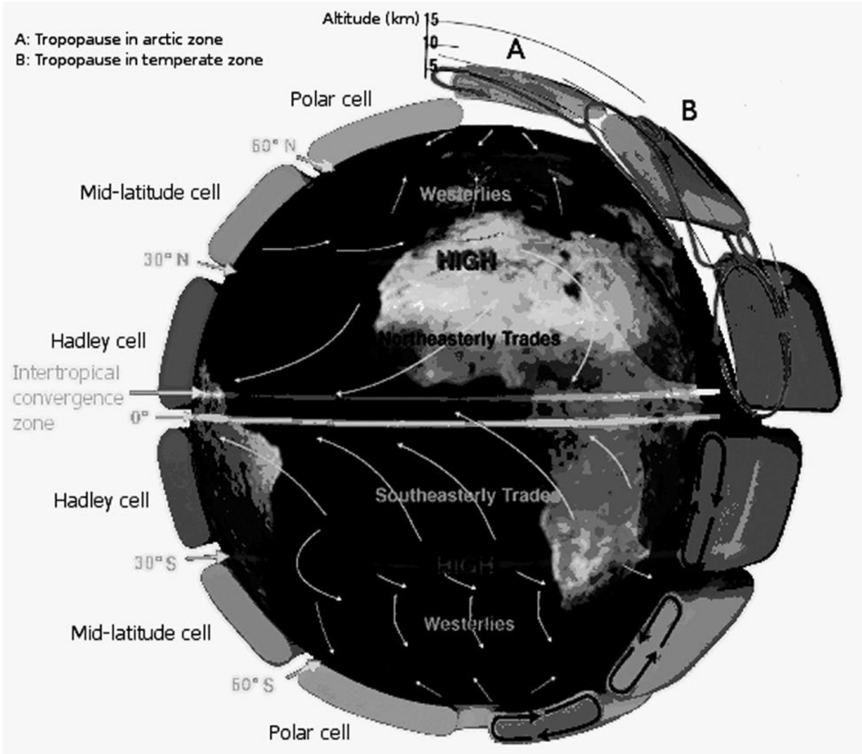


Jet Stream

A jet stream develops where air masses of differing temperatures meet. For this reason, surface temperatures determine where the jet stream will form. The greater the difference in temperature, the faster the wind velocity inside the jet stream.

They flow at very high speeds since air at the equator rotates around the earth's axis much faster than they do at more northerly or southerly latitudes. Thus, as the warmer air is drawn toward the poles, it moves faster, relative to the earth's surface. The rising warm air feeding the jet stream happens all along the equator, the effects accumulate, giving rise to high-speed winds.

A jet stream develops where air masses of differing temperatures meet, so surface temperatures help determine where they will form. The jet stream is snakelike, undulating like a river, because of the pressures on either side from the warm and cold air masses.



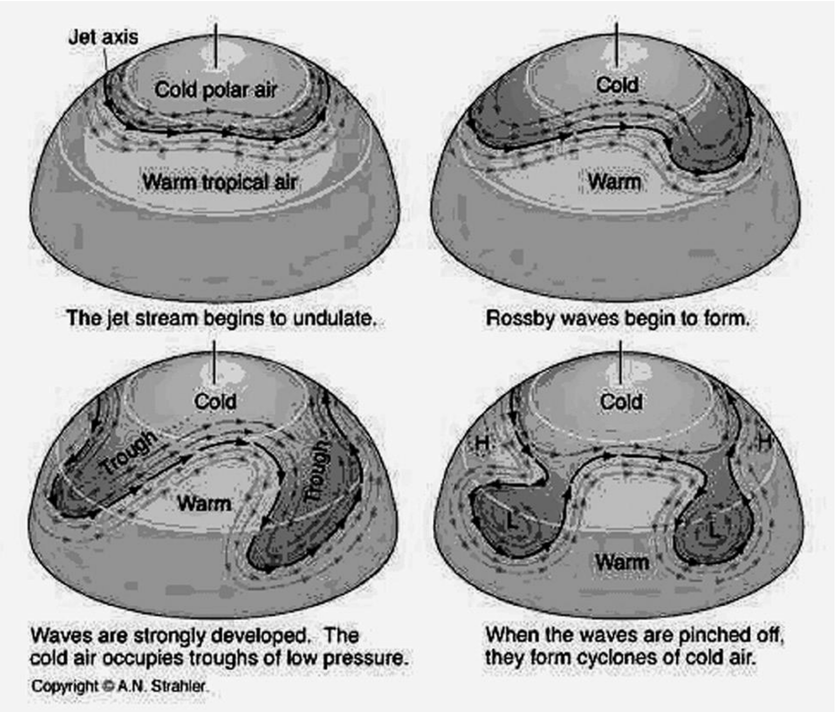
The Formation of Rossby Waves

- When the jet stream is pushed south by a cold air mass, it allows high pressure to sink and create colder-than-normal weather in the South. In the opposite situation, when northern regions get warmer than normal, the jet stream has been pushed north by the tropical air.
- Meandering of jet streams are due to the fact that when the temperature gradient is more, jet stream flows in near straight path, but when temperature gradient reduces, the jet stream starts to follow a meandering path. So, the meandering depends upon the temperature contrast (temperature gradient). A meander is called peak or ridge if it is towards poles and trough if it is towards equator.

Rossby Waves

- Rossby waves are formed when polar air moves towards the Equator while tropical air is moving polewards. Because of the temperature difference between the Equator and the poles due to differences in the amounts of solar radiation received, heat tends to flow from low to high latitudes; this is accomplished, in parts, by these air movements.
- Rossby waves are a dominant component of the Ferrel circulation. The tropical air carries heat polewards, and the polar air absorbs heat as it moves toward the Equator. The existence of these waves explains the low- pressure cells (cyclones) and high-pressure cells (anticyclones) that are important in producing the weather of the middle and higher latitudes.
- In temperate region, Westerlies moves from west to east. When these winds move towards pole where landmass is less to balance the angular momentum, then they form meanders or wavy structure called Rossby waves & follow the cycle.

- At higher latitudes, the warm air cools and sinks, drawing more warm air in behind it. The cooled air flows back towards the equator, creating a loop or convection cell.
- The reason for very high speeds of the winds of jet streams is that the Pressure gradient increases with altitude and creates high velocity winds at higher altitudes. The friction in the upper troposphere is quite low due to less denser air. Hence the Jet streams flow at great velocities. Temperature also influences the velocity of the jet stream. The greater the difference in air temperature, the faster the jet stream, which can reach speeds of up to 250 mph or greater, but average about 110 mph. The jet streams have an average velocity of 120 kilometers per hour in winter and 50 km per hour in summer. The speed of Jet streams in winter is faster than in summer

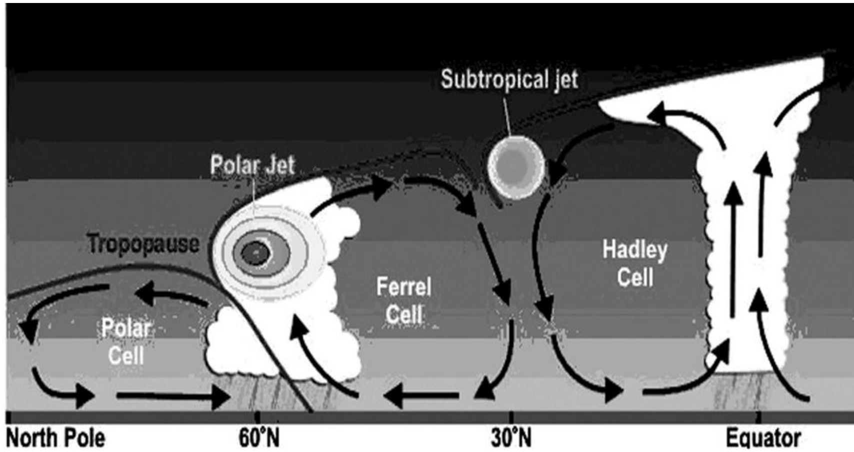


The Formation of Rossby Waves

Types of Jet Streams

(i) **Polar Front Jet Stream:** They are formed above the convergence zone of the surface polar cold air mass and tropical warm air mass. The thermal gradient is steepened because of convergence of two contrasting air masses. It has a more variable position than the sub-tropical jet. In summer, its position shifts towards the poles and in winter towards the equator. (Ref. Fig 1. 30)

(ii) **Subtropical JET Streams (SJT):** These jets, like the polar-front jets, are best developed in winter and early spring. During summer, in the Northern Hemisphere, the subtropical jet weakens considerably, and it is only identifiable in sporadic velocity streaks around the globe. During winter, subtropical jets intensify and can be found between 20° and 50° latitude. Their maximum speed approaches 300 knots, although these higher wind speeds are associated with their merger with polar-front jets. The core is most frequently found between 35,000 and 40,000 feet. A subsidence motion accompanies subtropical jets and gives rise to predominantly fair weather in areas they pass over. These jets are also remarkably persistent from time to time, but they do fluctuate daily. Sometimes they drift northwards and merge with a polar-front jets. Over Asia in summer, the subtropical jet is replaced by the tropical easterly jet stream. During winter, the Sub-Tropical Jet stream (STJ) is nearly continuous in both hemispheres. The STJ exists all round the year in the southern hemisphere. However, it is intermittent in the northern hemisphere during summer when it migrates north.



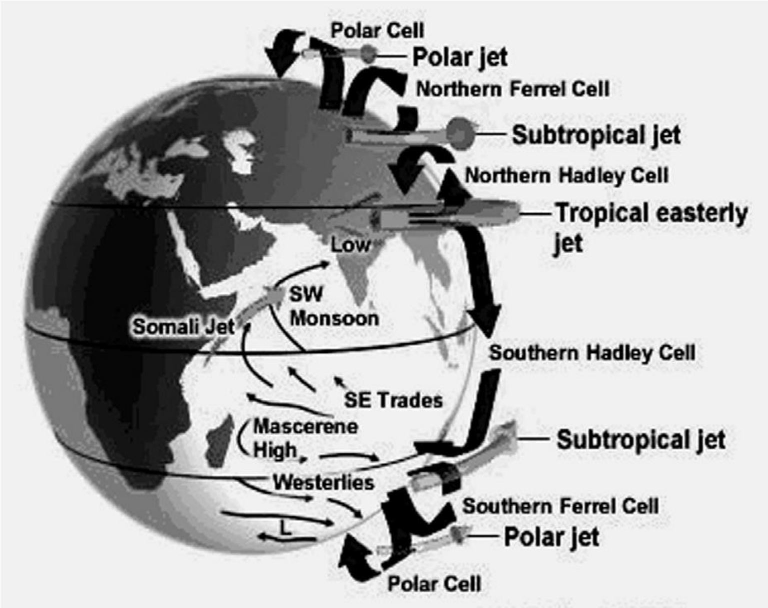
The Polar and Subtropical Jets

iii) Tropical Easterly Jet Streams:

This jet occurs near the tropopause over Southeast Asia, India, and Africa during the summer. The strongest winds are over southern India, but they are not as intense as the winds encountered in polar-front or subtropical jet streams. This jet is closely connected to the Indian and African summer monsoons. The existence of this jet implies that there is a deep layer of warm air to the north of the jet and colder air to the south over the Indian Ocean. This warm air is of course associated with the maximum heating taking place over India in summer, while the colder air is over the ocean. The difference in heating and cooling and the ensuing pressure gradient is what drives this jet. Tropical easterly jet streams are responsible for bursting of monsoon in India.

iv) Polar Night Jet Stream: This jet meanders through the upper stratosphere over the poles. It occurs only during the long winter night, since the night is 6 months long over the pole in which winter is occurring. The polar stratosphere undergoes appreciable cooling due to the lack of solar radiation. The horizontal temperature gradient is strongly established between the equator and the pole, and the pressure gradient creates this westerly jet. The temperature gradient breaks down intermittently during middle and late winter in the Northern Hemisphere; therefore, the jet is intermittent at these times. In the Southern Hemisphere the temperature gradient and jet disappear rather abruptly near the time of the spring equinox.

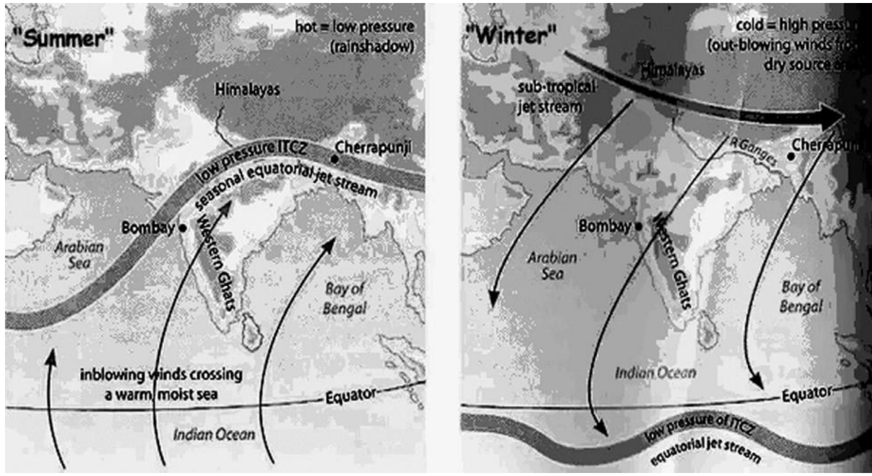
v) Local Jet Streams They are formed due to local thermal and dynamic conditions and have limited local importance.



Various Types of Jet Stream

Jet Streams and the Weather

- Jets streams play a key role in determining the weather because they usually separate colder and warmer air. Jet streams generally push air masses around, moving weather systems to new areas and even causing them to stall if they have moved too far away.
- While they are typically used as one of the factors in predicting weather, jet streams don't generally follow a straight path — the patterns are called peaks and troughs — so they can shift, causing some to point at the poor forecasting skills of meteorologists.
- Climatologists say that changes in the jet streams are closely tied to global warming, especially the polar jet streams, because there is a great deal of evidence that the North and South poles are warming faster than the remainder of the planet. When the jets streams are warmer, their ups and downs become more extreme, bringing different types of weather to areas that are not accustomed to climate variations. If the jet stream dips south, for example, it takes the colder air masses with it.
- The end of the monsoon season is brought about when the atmosphere over the Tibetan Plateau begins to cool; this enables the Sub- Tropical Jet-Streams to transition back across the Himalayas. This leads to the formation of a cyclonic winter monsoon cell typified by sinking air masses over India and relatively moisture-free winds that blow seaward. This gives rise to relatively settled and dry weather over India during the winter months.



The Jet Stream and Monsoon in India

- Jet streams also have an impact on air travel and are used to determine flight patterns. An airplane can travel much faster, and save fuel, by getting “sucked up” in the jet stream. That can also cause a bumpy flight, because the jet stream is sometimes unpredictable and can cause sudden movement, even when the weather looks calm and clear.
- The world’s jet streams are also impacted by El Nino and La Nina. During El Nino for example, precipitation usually increases in California because the polar jet stream moves farther south and brings more storms with it. Conversely, during La Nina events, California dries out and precipitation moves into the Pacific Northwest because the polar jet stream moves more north. In addition, precipitation often increases in Europe because the jet stream is stronger in the Northern Atlantic, and is capable of pushing them farther east.
- In winter the sub-tropical westerly jet streams bring rain to the western part of India, especially Himachal Pradesh, Haryana and Punjab.