A HIMALAYAN BOOKS PRESENTATION

GROUND SUBJECTS : CPL / ATPL

AVIATION METEOROLOGY

Sixth New Edition 2019

GROUP CAPTAIN IC JOSHI (RETD.)

AVIATION METEOROLOGY

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Group Captain (Retd.)

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Dedicated to
My parents, family members and
Specially to Mehak, Uday, Nitya and Gauri

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Thanks are due to my daughter-in-laws Vibha and Abha for helping me in computerizing the text, tables and diagrams.

Thanks to my wife Kamla and sons Jiten and Pankaj for encouraging me to write this book.

Last but not the least thanks to Mr. B Chowdhry, Pawan Chowdhri and Mr Suresh of English Book Stores for motivation and valuable suggestions.

(IC Joshi)
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PREFACE

Meteorology is the science of atmosphere. All weather activities occur in the lowest portion of the atmosphere, called the Troposphere. International and local flying activities are confined to this region only. An aviator has, therefore, to understand the weather phenomenon which occur in the region and influence Air Operations.

This book deals in brief with the various aspects of weather which are essential for an aviator. Material for the book has been drawn from the standard publications of World Met Organisation, International Civil Aviation Organisation (Annex -3) and IMD Publications, Met Services for Air Navigation in India, and the Internet.

The chapters of the book cover syllabus prescribed by the Director General of Civil Aviation (India) for Pilots and by the Chatrapati Sahu Ji Maharaj University, Kanpur for B Sc (Aviation). Frequently asked questions by the trainees and their answers have also been included. Important chapters like Met Services for Aviation and Aviation Codes are considered useful for the trainees to interpret Met information provided to them by the Met Offices.

The author has closely observed the weather from the ground and equally from the air. Some of the material in the book is his own experience and some from the interaction with the air crew and their debriefings.

A few Chapters of the book have been revised, and a few Figures re-shaped. **75 more Questions and Answers have been added to this Revised Edition**. In total there are over 800 Questions and Answers.

The contents of this book are intended to be of general guidance and are not to be quoted as authority. Readers are advised to refer to the Original Documents and Standard Books on Meteorology and the Internet.

The **DGCA(India) has included** this book in its Syllabus as one of the **Reference Books for Aviation Met.**

Suggestions for improvement of the book are most welcome.

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2019

1. ATMOSPHERE

COMPOSITION AND STRUCTURE

Atmosphere

Atmosphere of the earth is an envelope of homogeneous mixture of gases, called Air. It surrounds the earth and is attached to it due to gravitation. It moves with the earth at the same speed and direction. The Earth's atmosphere is about 480 km thick, but about 80% of the atmosphere is within 16 km. There is no exact height where the atmosphere ends, it just gets thinner and thinner until it merges with the outer space.

Characteristics

The atmosphere has weight and hence exerts pressure. It is compressible and expandable. It occupies space and has no definite shape. It is mobile in which transfer of heat and moisture occurs. It is a **poor conductor of heat and electricity**.

Constituents

Nitrogen	**Oxygen**	**Argon**	**Carbon dioxide**
78.09%	20.95%	0.93%	0.035%.

Traces of:

Neon	Helium	Methane	Krypton	Xenon	Nitrous Oxide
Iodine	H_2	O_3(0.000007%)	Amonia		Carbon Monoxide
CO_2	SO	Nitrogen Dioxide			

In addition, air contains water vapour (WV) and solid particles.

Nitrogen and Oxygen constitute almost 99% of the air. Their ratio by proportion is

Nitrogen : Oxygen :: 4 : 1 by Volume
Nitrogen : Oxygen :: 3 : 1 by Weight

Due to rapid reduction of gases with height, **supplementary Oxygen is needed above 10,000 ft.**

The atmosphere is generally well mixed. It has a nearly similar composition, except for ozone, up to a height of about 80 km, **due to earth gravitation**. The atmosphere up to 80 km is called the **Homosphere** and above it the **Heterosphere**.

Variable Gases

The gases like Water Vapour (WV), Carbon Mono Oxide, Sulphor di Oxide, Nitrogen di Oxide and Methane vary in amount from place to place, being concentrated more in industrial areas, cities and water bodies, than in open areas.

Though very small in quantity, these gases are very significant for weather and life.

Green House Gases

Water vapour, CO_2, O_3, Methane and some other gases are transparent to solar (Short Wave) radiation but they partially absorb terrestrial (Long Wave) radiation, and reradiate them. These **Green House Gases** cause **green house effect**. They keep the earth warmer than it would have otherwise been. Excessive amount of these gases is causing **Global Warming, which is a serious threat to our life and needs to be limited.**

Dry Air and Saturated Air

Water in the atmosphere can exist in three states-solid (Snow, Ice, Hail), liquid (Drizzle, Rain, Shower) and gas (WV). The concentration of WV rapidly decreases with height. The WV content in the air largely depends on its temperature. Warmer air can hold greater amount of WV.

In the tropics (23 ½ N to 23 ½ S), air can hold as much as 4% of WV by volume. WV is almost negligible at the Poles and above 30,000 ft, due to very low temperatures.

With 4% WV the air is termed as **Saturated Air** and has 100 % Relative Humidity (RH). When RH is < 100 %, the air is **Unsaturated** and is called **Dry Air**.

Carbon Dioxide (CO_2)

CO_2 is produced by burning of fuel, wood etc. Its concentration is substantial in industrial areas, whereas in Polar regions and higher altitudes it is negligible. A large amount of CO_2 is dissolved in the oceans. Plants absorb CO_2, use its carbon as food and release O_2 into the atmosphere.

Ozone (O_3)

Ozone forms in the upper atmosphere. It absorbs the Ultra Violet (UV) radiation from the Sun, and raises temperature. O_3 molecules then become heavier and sink and accumulate in the lower levels. **Ozone protects us from the ill effects (like skin cancer, sunburn and cataracts) of UV radiation.**

Appreciable O_3 is found between 10 and 50 km, with maximum concentration at **20-25 km**.

Ozone Hole. In recent times the O_3 layer has thinned and large holes have developed mainly over the Polar and other latitudes due to atmospheric pollution and excessive use of halocarbon refrigerants, solvents, chlorofluoro carbons, etc. On reaching Stratosphere they release halogen atoms through photodissociation, which the break down of O_3 into O_2.

The particles such as salt from evaporating sea water, dust from arid regions, industrial and similar other particles obscure solar radiation and affect visibility and temperature. They also act as condensation nuclei and promote condensation of water vapour, prematurely. In larger cities and industrial areas frequent fog and smog (a mixture of fog and smoke) is due to the high concentration of such particles.

Vertical Distribution of Air Mass

Due to gravitational attraction, the approximate distribution of airmass with height is:

below	**6 km**	**1/2**
below	**10 km**	**3/4**
below	**35 km**	**99%**

THERMAL STRUCTURE OF ATMOSPHERE

Solar radiation heat the earth and the earth in turn heats up the atmosphere by conduction, convection, radiation and release of latent heat by condensation of water vapour. Hence

temperature falls with height, up to a certain height. **The atmosphere is thus heated from below and not from above.**

The flow of heat from the earth surface to the atmosphere is due to:

Sensible Heat (Conduction, Convection, Radiation)	**23 %**
Latent Heat (Evaporation, Condensation, Sublimation)	**77 %**

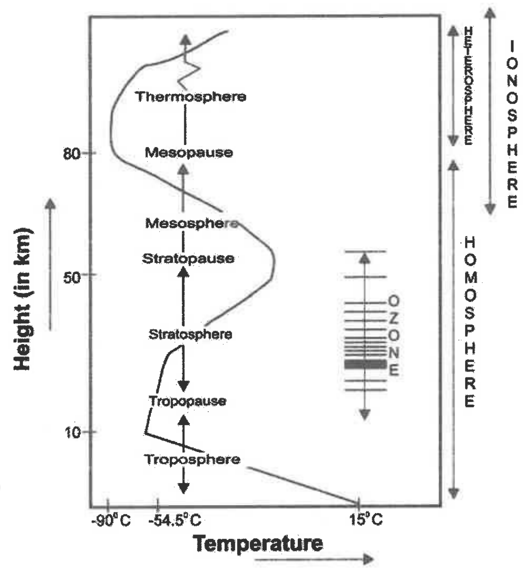


Figure 1.1. Thermal Structure of Atmosphere

Satellite and Space flights have confirmed that based on temperature distribution, the atmosphere has reasonably well defined horizontal layers, as follows:

Troposphere

Troposphere is the lowest portion of the atmosphere. The term has been derived from Greek "tropos", meaning "turn" and "sphere", the earth. The turbulent mixing is responsible for the occurrence of weather. It extends to 16-18 km over the Equator and 8-10 km over the Poles. In this layer the temperatures generally fall with height, called **lapse rate**, at the rate of about 6.5°C/km. The **lapse rate is produced by the rising air.** However, sometimes the temperatute also rises with height (**inversion**) or remain the same (**isothermal**). **Inversion is negative lapse rate**. Troposphere is generally **unstable**. Most of the weather is confined to this region and so is the flying. About 75% of the atmospheric mass and 99% of WV and aerosols lie within the troposphere. It is classified as:

Lower Troposphere	Surface to 2.1 km
Mid Troposphere	2.1 km to 7.6 km
Upper Troposphere	7.6 km to Tropopause

The equator is much warmer than the poles, and tropopause is much higher at equator. Hence **warmer the surface higher is the height of the tropopause.**

Tropopause

It is the top of the troposphere and marks the boundary between Troposphere and Stratosphere. At tropopause the lapse rate reduces to 1-2°C/km or temperature stops falling with height.

The height of tropopause is controlled by : Surface Temperature, Latitude, Season, Land - Sea distribution, and Synoptic Situation. It is higher over the equator (-70° to - 75°C) than at Poles (-40° to - 45°C). Tropopause is at a lower height in Winters than in Summers.

Since in troposphere temperatures fall with height up to tropopause, above 8 km the poles start warming up and become warmer than the equator. Thus, **there is reversal of temperature and density above 8 km**.

There are two regions where tropopause abruptly changes height, called **breaks/ folds,** at about 40° Lat and 60° Lat. Break at 40° lat is more prominent. Jet streams occur at these breaks. These breaks broadly divide the tropopause into three sections.

Polar Tropopause. It occurs near 300 hPa level polewards of Lat.45° to 60°. It may be noticed occasionally over Srinagar (Jammu and Kashmir) in winters when polar air incursion occurs. Polar Front Jet Stream is found at its southern end.

Tropical Tropopause. This is usually at 100 hPa level. It extends from the equator to Lat. 35°- 40°. Over India it is found at about 16-16.5 km.

Middle Tropopause. It occurs near 200 hPa, between Polar and Tropical Tropopause. In India it is at about 11.5 km (temperature -45°C). In winters it may be at 23°N. Subtropical Jetstream (STJ) occurs at its Southern end.

Importance of Tropopause

It is the maximum height to which clouds may reach. Jetstreams, maximum wind speeds and Clear Air Turbulence (CAT) occur just below it.

Stratosphere

Stratosphere extends from tropopause to 50 km. This layer initially, for 8-10 km, is isothermal.Thereafter, temperature increase slowly and towards the top sharply.The **inversion is produced by the absorption of UV radiation from sun** by ozone. It is a very **stable region** with low humidity and no weather. **Nacreous Clouds** or **Mother of Pearl Clouds**, are sometimes seen in upper stratosphere in the higher latitudes in winters.

Stratopause. It is the upper boundary of the Stratosphere.

Mesosphere

It extends from Stratopause to 80 km. Lack of absorption of solar radiation and weak vertical mixing causes temperatures to fall with height in this layer. On rare occasions **Noctilucent Clouds** are seen in the upper Mesosphere, in Polar regions.

Mesopause

The top of the mesosphere is Mesopause. At this level temperatures stop falling. The **Lowest temperatures**, about - 90° to - 100°C, in the atmosphere occur at Mesopause.

Thermosphere

It extends from Mesopause to the end of the atmosphere, where temperatures increase with height. Above 700 km, it is called the **Exosphere**. In this layer the air is very thin and has only few molecules. These molecules may be very active and have very high temperature. But since they are a few and far apart, very little heat is present in this layer.

Ionosphere. The atmosphere above 60 km is also called the **Ionosphere**. It is important for radio wave propagation. Serious interference in radio prorogation occurs during solar disturbances, due to absorption of radio waves.

(**Note**: The Tropopause, Stratopause and Mesopause merely represent zones between the layers where vertical temperature distribution changes).

International Standard Atmosphere (ISA)

A standard average atmosphere has been specified for various purposes like the design and testing of aircraft, evaluation of aircraft performance, calibration of altimeters, etc.

The most widely used atmosphere is the one defined by the ICAO, known as the International Standard Atmosphere (ISA) or ICAO ISA. Its specifications are:

- Air is Dry
- Temperature at Mean Sea Level — 15°C (288.15 K)
- Pressure at Mean sea level — 1013.25 hPa
- Density at Mean Sea Level — 1225 g/m^3
- Acceleration due to gravity — 980.665 cm/s^2
- Lapse rate up to 11 km (36,090 ft) — 6.5°C/km (1.98° C/1000 ft)
  Temperature is assumed constant — –56.5°C from 11 to 20 km (65,617 ft)
- From 20 to 30 km there is a rise of temperature at the rate of 1°C/ km (0.3°C/1000 ft) with a temperature of –44.5°C at 32 km (104987 ft)

ISA Deviation: For evaluating aircraft performance or making corrections to instruments, the actuals are compared with ISA values, called ISA Deviation. If the observed temperature is 08°C warmer than ISA, the deviation is + 08°C.

(To find ISA Deviation: Subtract ISA value from Actual value)

i.e. ISA Deviation = **(Actual - ISA)**

Jet Standard Atmosphere (JSA)

The ISA values are quite satisfactory for aircraft operating below 30,000 ft, but not above this level. For space flights and very high altitude flying and engine manufacturing additional specific values are required. To meet these requirements JSA was introduced, as follows:

- Mean sea level temperature — 15°C (288.15K)
- Lapse Rate — 2°C/ 1000 ft
- There is no Tropopause

QUESTIONS ON ATMOSPHERE

Q1. Lowest layer of atmosphere is ....
(a) Troposphere (b) Tropopause (c) Stratosphere

Q2. Height of Tropopause at equator is ....
(a) 10-12 km (b) 16-18 km (c) 12-14 km

Q3. Height of Tropopause at Poles is ....
(a) 12-14 km (b) 12-13 km (c) 08-10 km

Q4. Higher the surface temperature .... would be the tropopause
(a) Higher (b) Lower (c) Same

Q5. Height of tropopause ....
(a) Is constant (b) Varies with altitude (c) Varies with Latitude

Q6. Above 8 km the lower temperatures are over ....
(a) Equator (b) Mid Latitudes (c) Poles

Q7. Atmosphere is heated by ....
(a) Solar Radiation (b) Heat from earth surface (c) From above

Q8. Tropos means ....
(a) Turning (b) Under current (c) Convection

Q9. CO_2 and H_2O are also called ....
(a) Green House Gases (b) Rare Earth Gases

Q10. Troposphere is generally ....
(a) Stable (b) Unstable (c) Neutral

Q11. Stratosphere is ....
(a) Unstable (b) Neutral (c) Stable

Q12. Tropopause is discontinuous at about ....
(a) 30°lat (b) 40°lat (c) 80°lat

Q13. Most of atmospheric mass is contained in ....
(a) Troposphere (b) Stratosphere (c) Heterosphere

Q14. Stratosphere extends from Tropopause to ....
(a) 50 km (b) 60 km (c) 40 km

Q15. The middle atmosphere layer with temperature inversion and stability ....
(a) Troposphere (b) Tropopause (c) Stratosphere

Q16. Mother of Pearl clouds occur in ....
(a) Mesosphere (b) Thermosphere (c) Stratosphere

Q17. The temperature in ISA at 17 km is ....
(a) –56.5°C (b) –65.5° C (c) –35.5° C

Q18. By weight, approximate ratio of O_2 to N_2 in the atmosphere is ....
(a) 1:3 (b) 1:4 (c) 1:5

Q19. By volume, the approximate ratio of O_2 to N_2 in the atmosphere is ....
(a) 1:3 (b) 1:4 (c) 1:5

Q20. By volume, the proportion of CO_2 in the atmosphere is ....
(a) 3% (b) 0.3% (c) 0.03%

Q21. In ISA, the mean sea level temperature is ....
(a) 15° C (b) 10° C (c) 25°C

Q22. Maximum concentration of ozone is at a height of ....
(a) 10-15 km (b) 20-25 km (c) 30-35 km

Q23. Additional oxygen is needed while flying above ....
(a) 5000 ft (b) 7000 ft (c) 10000 ft

Q24. CO_2 and H_2O keep the atmosphere ....
(a) Warm (b) Cold (c) Have no effect

Q25. Noctilucent clouds occur in
(a) Thermosphere (b) Mesosphere (c) Stratosphere

Q26. Temperature at 2 km is 05°C what is ISA deviation. Hint: (Actual – ISA)
(a) –05°C (b) –02° C (c) 03°C

Q27. Pressure at MSL is 1002.25 hPa. Find the ISA deviation Hint: (Actual – ISA)
(a) –11 hPa (b) 10 hPa (c) 12 hPa

Q28. In actual atmosphere temp. at 19 km is –60°C. Find the ISA deviation?
(a) –4.5°C (b) –05.5° C (c) –03.5°C

Q29. Nacreous clouds occur in
(a) Thermosphere (b) Mesosphere (c) Upper Stratosphere

Q30. The atmosphere up to 80 km has a nearly similar composition and is called the Homosphere. Its uniform composition is due to
(a) Pressure (b) Gravitation of earth (c) Mixing due to turbulence

Q31. Half of the atmospheric air mass is contained .... below
(a) 20,000 ft (b) 15,000 ft (c) 10,000 ft

Q32. In jet standard atmosphere the Lapse Rate is
(a) 2°C/1000 ft (b) 2°C/km (c) 5°C/km

Q33. The rate of fall of temperatures with height, called
(a) Isothermal rate (b) Inversion Rate (c) Lapse Rate

Q34. In actual atmosphere the lapse rate could
(a) Assume any value (b) fall up to 8 km. (c) rise up to 50 km

Q35. Tropical Tropopause extends from the equator to Lat. 35°– 40°.Over India it is at
(a) 20–21 km (b) 14–15 km (c) 16–16.5 km

Q36. Lapse rate in the troposphere is produced by.......... and in the stratosphere by..........
(a) Evaporation; condensation (b) rising air; solar radiation
(c) Terrestrial radiation; solar radiation (d) solar radiation; convection

Q37. Most of the water vapour in the atmosphere is confined up to
(a) stratosphere (b) 30,000 ft
(c) Mid troposphere (d) lower troposphere

Q38. Negative lapse rate of temperature is
(a) Isothermal rate (b) temperature rise with lowering height
(c) Temperature rise with height (d) temperature fall with height

Q39. In ICAO ISA the atmosphere is assumed to be isothermal
(a) in stratosphere (b) 11 to 16 km
(c) 11 to 20 km (d) 11 to 32 km

Q40. One of the characteristics of our atmosphere is
(a) Poor conductor of heat and electricity
(b) Equator is warmer than poles above 10 km
(c) Lapse rate in the stratosphere is positive
(d) Density is constant above 8 km

Q41. Heat transfer in the atmosphere is maximum due to
(a) convection (b) radiation
(c) sensible heat (d) latent heat

Q42. The knowledge of the height of tropopause is important for a pilot because
(a) weather is mainly confined up to this level
(b) clouds rarely reach up to this height due to jetstreams
(c) stratosphere starts at this height where all solar radiation are absorbed

Q43. In ISA atmosphere the tropopause occurs at a height of
(a) 8 – 10 km (b) 11 km (c) 16-18 km

Q44. Most of the transfer of heat in the atmosphere is due to
(a) Conduction and freezing (b) convection and evaporation
(c) Condensation, sublimation and freezing (d) sublimation and radiation

Q45. There is reversal of temperature in the atmosphere at 8 km because
(a) Lapse rate at poles is always higher than at equator
(b) Lapse rate at equator is always higher than at poles
(c) Lapse rate at equator is the same as at poles even above the poles
(d) Lapse rate reverses at poles and becomes negative

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	a	b	c	a	c	a	b	a	a	b	c	b	a
Q.	14	15	16	17	18	19	20	21	22	23	24	25	26
A.	a	c	c	a	a	b	c	a	b	c	a	b	c
Q.	27	28	29	30	31	32	33	34	35	36	37	38	39
A.	a	c	c	b	a	a	c	a	c	b	b	c	c
Q.	40	41	42	43	44	45							
A.	a	d	a	b	c	d							

2. ATMOSPHERIC PRESSURE

Static and Dynamic Pressure

When air is at rest its molecules are in random motion all over. The pressure (force per unit area) exerted by the molecules is uniform in all directions. This pressure is called **Static Pressure** or **Barometric Pressure**. If the air is in motion an additional pressure is exerted in the direction opposite to the flow. This is called **Dynamic** or **Wind Pressure**.

Pressure as Weight of the Air Above

The atmospheric pressure at any level is the weight of the column of air of unit cross-section extending vertically to the top of the atmosphere. As the amount of air in the column decreases with height, the pressure also decreases with height. ICAO, has adopted hecto-pascal (hPa) as its unit. 1 hPa = 1000 dynes. Dyne is the force required to produce an acceleration of $1 cm/s^2$ in a mass of 1 gm.

The Unit of force is Newton (N). Atmospheric pressure at sea level is 100,000 N/m^2, also called Bar. To measure small changes in pressure Bar is divided by 1000, called millibar (mb) or hectopascal (hPa). Hecto means 100.The other units are mm and inches.

1013.25 hPa = 760 mm = 29.92 in

To Convert hPa to inches: multiply hPa value by 0.02953

e.g. Q. 1013.25 hPa = ? inches ; Ans 1013.25 x 0.2953= 29.92inches

The Air pressure changes cause ears to pop up when traveling over significantly varying topography and during rapid descent of an aircraft.

Relationship between Pressure and Altitude

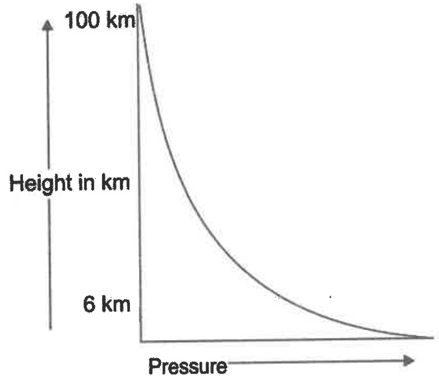


Figure 2.1. Variation of Pressure with Height

Vertical Variation of Pressure

The pressure decreases with height, **at a decreasing rate**, from sea level to 600 m at 4%, up to 1.5 km at 3% and up to 3 km 2.5%. At 6 km it reduces to half the value at sea level. At 100 km it is negligible and can be regarded as vacuum.

Height difference with 1 hPa change of pressure = 96 T / p feet

The difference of 1 hPa at pressure 1000 hPa with temperature 300K, would be:

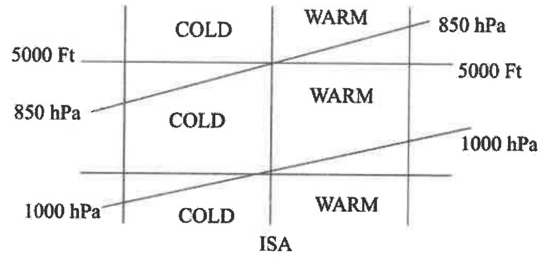
96*300/1000 = 28.8 ft

In ISA conditions, 1 hPa pressure change at different heights roughly correspond to:

at	MSL	2,000 ft	20,000 ft	40,000 ft
	27 ft	30 ft	50 ft	100 ft

If air is warmer than ISA change in heights will be **more** than above values
If air is colder than ISA change in heights will be **less** than above values

Variation of Pressure. Cold air is denser than Warm air. The pressure will fall at a faster pace over a cold column of air than over a warm column of air. A pressure



Isobaric Levels are at Lower Height over Cold Column than over Warm Column
Hence at higher Levels Low Over Cold Column and High over Warm Column

Figure 2.2 Variation of Pressure in Warm and Cold Air

value, say 850 hPa, will be at a higher height over a warm column than over a cold column, see Figure 2.2. Therefore, **pressure at any given height will be higher over warm air than over cold air.** Isobars will **Dip** if going **from High to Low** and will **Rise** if going **from Low to High** pressures. **Isobar** is the line joining places of equal pressure.

Semi Diurnal Variation of Pressure

Atmospheric pressure follows a bimodal curve during a day, with maxima at 1000 hr (primary) and 2200 hr (secondary) and minima at 0400 hr and 1600 hr local time, Figure 2.3. Such variations are very small at the Poles and are large, about 3-5 hPa, at Equator due to solar influence.

When the temperature is highest in the afternoon, the density of air at the surface is low. Hence the pressure should be the lowest and just after sunrise when the temperature is lowest, the pressure should be the highest. But it is not so due to a phase difference of about 3 hour between the temperature and the pressure.

Semi diurnal variation of pressure is probably a natural oscillation of the atmosphere, having a period of almost 12 hours. As the air is continuous, if there is a high pressure on one side of the globe, there should be a low on the other side. With the rotation of the earth, the pressures also rotate. Hence, two maxima and two minima during 24 hr.

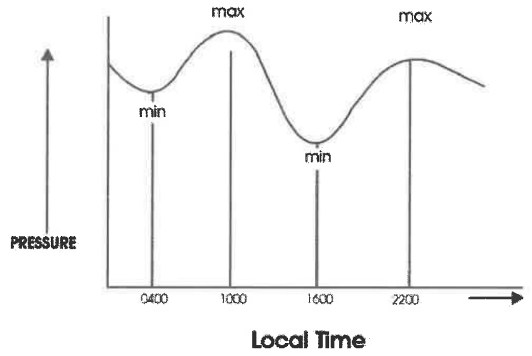


Figure 2.3 Semi-diurnal Variation of Pressure

Measurement

Pressure is accurately measured by Mercury Barometer, in which atmospheric pressure is balanced by the height of the mercury column. Another instrument is Aneroid barometer. Although aneroid barometer is not as accurate as mercury barometer, for its ease of handling and convenience, it is widely used. **Altimeter** is an aneroid barometer with its scale graduated to read altitude instead of pressure. Altimeter has a sub-scale, which can be set to the desired value of pressure. For continually recording the pressure a **Barograph** is used. It could be a **Daily Barograph** or **Weekly Barograph**.

Altimeter Correction (Alticor / D Value)

The correction applied to the indicated altitude to obtain the true altitude is called altimeter correction. This is frequently required for mountain flying and bombing operations.

Alticor = Indicated Altitude – True Altitude

D Value = True Altitude – Indicated Altitude

D value decreases when aircraft flies from **High** to **Low**

Rough calculations of Alticor

(a) **Pressure. Add** 30 ft for every 1 hPa when MSL pressure is **higher** than 1013.2 hPa and **subtract** 30 ft when **lower** than 1013.2 hPa.
(b) **Temperature. Add** 1% of indicated altitude for every 3°C temperature **higher** than ISA and **subtract** when **lower** than ISA.
(c) Add these algebraically to get the final correction.

Contours and Thickness

The mean temperatures of the vertical columns of air differ from place to place. Accordingly the height of a pressure value (say 850 hPa), would be lower over a colder place and higher over a warmer place. Also the pressure would be lower over the colder place corresponding to lower height and higher pressure over warmer place having higher height. **The line joining places of equal height is called Contour.** The Contour lines may also be regarded as isobars.

In **Contour Charts** the contours are drawn at an interval of 40 gpm (geopotential meter) in 700 hPa and 500 hPa level charts and at 80 gpm in 300 hPa and 200 hPa level charts. A gpm is gravitational potential energy per unit mass, called geopotential meter. 1 gpm = 9.8 Jules/kg. The contour lines are numbered in geopotential decametres e.g. 5280 gpm is indicated as 528. If the gpm is 700, then an air parcel is located approximately 7000 m above msl. Centres of Low and High are marked as in surface pressure charts.

The height interval between the lower and the upper level is called **Thickness** of the layer. Low thickness occurs where mean temperature of the layer is lower and high thickness where mean temperature of the layer is higher. Thus **the isopleths of thickness coincide with the isotherms of mean temperature of the layer**.

Pressure Gradient

It is the horizontal rate of change of pressure perpendicular to the isobars, directed from high to low pressure. **Isobar is the line joining places of equal pressure**. It is steep or weak according as the isobars are close or far apart. Pressure gradient is said to be flat when it changes slowly and isobars are far apart.

Pressure Tendency and Isallobars

The change of pressure with time is called **pressure tendency**. In India pressure tendency is worked out for the past 24 hr and in the higher latitudes for the past three hours of the current observation. The **lines joining places of equal pressure change** are called **Isallobars**. At a glance the isallobars, indicate areas of rising or falling pressure tendency. The region of greatest fall enclosed by isallobars is termed as **Isallobaric Low** and the region of highest rise, **Isallobaric High**. Surface Lows are likely to move towards isallobaric low and intensify. Isallobaric High indicates weakening of a pressure system.

ALTIMETRY

Definitions

Mean Sea Level. A reference level taking average of high and low Tides.

Altitude. It is the vertical distance from the mean sea level (MSL).

Height. It is the vertical distance from a specific datum (e.g. from the ground).

Elevation. The vertical distance of a point or a level on the surface of the earth from MSL.

Transition Altitude (TA). This is the highest altitude below which an aircraft will always fly on local QNH. At or below TA the vertical position of an aircraft is controlled with reference to height above the aerodrome.

Transition Level (TL). The lowest Flight Level above which an aircraft will always fly on standard QNH 1013.2 hPa. Above TL the vertical position of an aircraft is from datum 1013.2 hPa. TL is expressed in hundreds of feet.

Transition Layer. The airspace between T A and TL.

Flight Level. These are levels of constant pressure at or above the TL separated by a pressure interval corresponding to 500 ft, with MSL pressure as 1013.25 hPa. (e.g. FL50 = 5,000 ft, FL300 = 30,000 ft, FL200 = 20,000 ft).

Pressure Altitude. When the altimeter sub-scale is set to 1013.2 hPa the altimeter indicates Pressure Altitude. Using 1013.2 hPa setting avoids the need to update QNH.

Pressure Altitude is expressed as e.g. 3500, 19000, 40000, etc., whereas the altitude is expressed (by avoiding last two zeros) as FL 35, FL190, FL 400.

Pressure Settings

A barometer provides pressure reading. To this reading certain corrections are applied. These corrections are: **Index correction** (to compensate for instrumental error), **Gravity correction** (gravity being different at different latitudes) and **Temperature correction** (it changes continually). The pressure is then reduced to a common level, called the mean sea level (msl). Such practice is called **pressure setting**. The pressure settings are QFE, QFF and QNH.

QFE. It is the pressure at the Aerodrome Reference Point (ARP), which is the highest point on the runway. The altimeter reads Zero, or height of the altimeter from the ARP, when its sub-scale is set to QFE. It is also called **zero setting**.

QFF. It is the barometric pressure of an aerodrome reduced to msl, assuming the temperature of the place to be the temperature the column of air extending up to the msl. This value is used for **plotting on Synoptic charts and drawing isobars**.

QNH. It is the station level pressure reduced to the msl assuming ISA conditions. When QNH is set on the sub-scale, the altimeter indicates the station elevation. This setting is useful for vertical separation of aircraft and from terrain. QNH should be updated from time to time, as it keeps changing with time and place due to change in temperature and pressure. It is also called **Absolute Altitude**.

Regional QNH. This is the forecast value of the lowest pressure expected in an Altimeter Setting Region (ASR). It is issued every hour and is valid for one hour. Correct use of regional QNH ensures adequate terrain clearance.

QNE. It is the altitude indicated on an altimeter when the sub-scale is set to 1013.25 hPa (29.92 inches). The altitude is known as QNE value. Normally QNE is used for high altitude airfields.

Relation between QNH, QFE and QNE

(i) **If QNE > QNH i.e. sea level is lower than MSL**
suppose QFE is 950 hPa, QNH is 1000 hPa and 1 hPa = 30 ft, the Elevation of Station would be = (QNH - QFE) * 30 ft = (1000 - 950) * 30 = 50 * 30 = 1500 ft

If the Altimeter is set to QNE (1013 hPa), the Station level would be
= (QNE - QFE) * 30 ft = (63 hPa) * 30 = 1890 ft

(ii) if QNE < QNH i.e. sea level is higher than MSL
For: QFE 970 hPa, and QNH 1020 hPa, the indicated Station elevation would be
= (QNH – QFE) * 30 = (50 hPa) * 30 = 1500 ft

If Altimeter is set to QNE of 1013 hPa, indicated Station level would be
= (QNE - QFE) * 30 ft = (1013 - 970)* 30 = 43 * 30 = 1290 ft

As a rule:

Hotter than ISA QFF < QNH
At MSL QFF = QNH
Pressure set on altimeter < QNH then Indicated Altitude < True Altitude
Pressure set on altimeter > QNH then Indicated Altitude > True Altitude

Standard Isobaric Levels. Corresponding to ISA pressure the Pressure Altitude (Ft) and Flight Levels are as follows:

Level (hPa)	850	700	500	400	300	200	100
Pressure Altitude (Ft)	5,000	10,000	18,000	24,000	30,000	38,000	53,000
Flight Level	50	100	180	240	300	380	530

Table 2.1

Under Reading Over Reading

When a pressure value is set on the sub scale of an altimeter, it indicates height as per ISA specifications. **The altimeter over reads if the pressure falls during the flight and under reads if it rises.** Also it **over reads in air colder than ISA and under reads in air warmer than ISA.** As a general rule:

(H-L-H)	and	(L-H-L)
High to Low – Over Read		**Low to High – Under Read**
Warm to Cold – Over Read		**Cold to Warm – Under Read**
If **QNH** is **High**	and	**Altimeter Setting** is **Low,**
Then **True Alt** will be **High**	and	**Indicated Alt** will be **Low**

In ISA 1.5 km altitude corresponds to a pressure of 864 hPa and 2 km to 795 hPa, see Figure 2.4. When an aircraft flies into a column of warm air from 864 hPa level, the

pressure being lower over warmer column will have the same pressure at a higher level, say at 2 km (where ISA pressure is 795 hPa). **The isobars dip from H to L and rise from L to H.** Hence altimeter will indicate an altitude lower than true altitude, Figure 2.4.

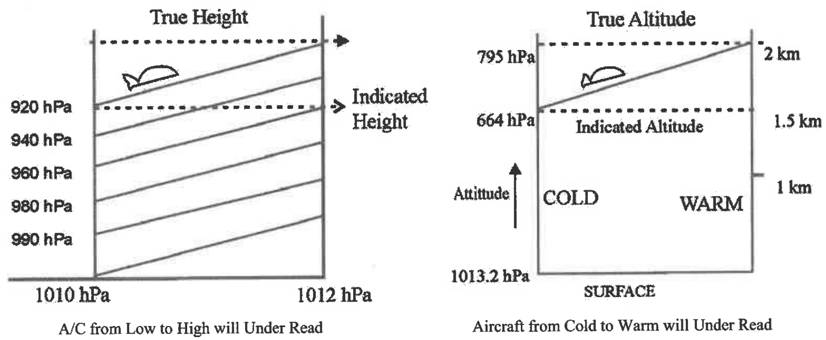
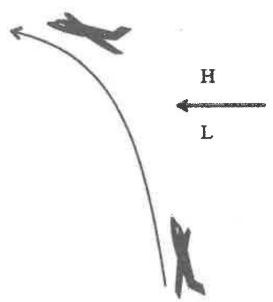


Figure 2.4 Altimeter Response with changing Pressure and Temperature

Results of this type can be related with the wind also, Figure 2.5. In the case of winds the general rule in the N hemisphere is:

Port Drift of Aircraft



For Port Drift wind is from right to left. In the N Hemisphere, Low is to the left of the wind and High to the right. A/C is thus moving from L to H. Hence Altimeter would UNDER read.

Figure 2.5 Altimeter Response to Wind from Starboard

When flying with **winds from port the altimeter will over-read, and with winds from starboard under-read.** The error increases with strength of the wind and length of the route. In S hemisphere opposite is true.

Pressure Patterns

To represent the spatial distribution of pressure at a given time, all pressures are reduced to the msl. When pressures at different stations are plotted on a chart and isobars are drawn at 2 hPa interval the following patterns, Figure 2.6 and Figure 2.7, emerge.

Low (lowpar). It is an area enclosed by an isobar, with lowest pressure at the centre. When there are two or more closed isobars at 2 hPa interval, it is called a Depression. A further intense system is Cyclone or Severe Cyclone. **Winds around a low blow in anticlockwise direction in N hemisphere, converging towards the centre.** There is convergence and upward motion at a low. Hence **a low** is associated with **bad weather, visibility is better than a High. Winds back** in a low. Wind speed on the surface is less than 17 kt.

Trough of Low. A tongue like extension of isobars from a low is called trough of low. **Pressure along the trough is lower than on either side**. Isobars along the

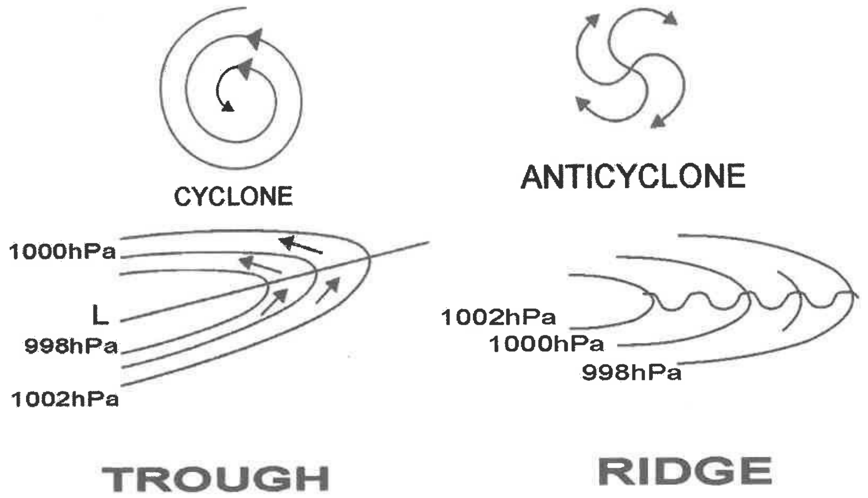


Figure 2.6 Pressure Patterns

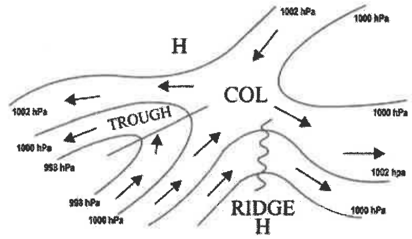


Figure 2.7 Pressure Patterns in Isobaric Analysis

trough are "V" shaped and **wind direction abruptly changes and backs**. It is also associated with bad weather. The monsoon trough along the Indo-Gangetic plains is an example of a trough.

High (H). It is a region enclosed by isobars with highest pressure at the centre. H is associated with **fair weather but visibility is poor** due to subsidence. In N hemisphere **winds blow in a clockwise direction, veer, and diverge outwards**.

Any high (or anticyclone) that remains nearly stationary or moves slowly, and blocks the movement of migratory cyclones across its latitudes, is known as **blocking anticyclone**.

A **Cold anticyclone** forms over a ground in the cold region behind a cyclone, as it moves away, before the next cyclone advances into the area. Due to the downward air motion in an anticyclone the descending air is compressed and after sometimes the cold anticyclone warms up.

Ridge. It is a wedge like extension of isobars from a high pressure area. Pressure is higher along the ridge than on either side. Isobars along the ridge are rounded and not "V" shaped as in a trough. It is a region of fair weather. Winds **veer** at a ridge.

Col. Col is a region enclosed between two highs and two lows. The isobars towards high pressure areas are 2 hPa higher than towards lows. Weather within a Col is a mixture of high and low, **winds are light variable**. Pressure at Col is uniform.

Note: Synoptic Systems at Appendix A

QUESTIONS ON ATMOSPHERIC PRESSURE

Q1. Winds in a low pressure
(a) Converge (b) Diverge (c) Go straight

Q2. Low pressure is associated with
(a) Good Weather (b) Bad Weather (c) None

Q3. In a high pressure area winds are
(a) Normal (b) Strong (c) Weak

Q4. Flying from Low to High an altimeter would read
(a) Over (b) Under (c) constant

Q5. Isallobars are lines of equal
(a) Pressure (b) Temperature Tendency (c) Pressure Tendency

Q6. What kind of a barometer is an altimeter
(a) Aneroid (b) Mercury (c) Alcohol.

Q7. A region between two Lows and Two Highs is
(a) Depression (b)Secondary Low (c) Col

Q8. Bad weather and better visibility is associated with
(a) High (b) Low (c) Col

Q9. The relationship between height and pressure is made use in construction of
(a) Altimeter (b) ASI (c) V S I

Q10. Altimeter always measure the height of aircraft above
(a) MSL (b) datum of 1013.2 hPa
(c) datum at which its sub-scale is set

Q11. Two aircraft flying at same indicated altitude with altimeters set to 1013.2hPa.One is flying over cold air mass and other over warm air mass. Which of the two has greater altitude?
(a) Ac flying over warm air mass (b) Ac flying over cold air mass

Q12. The rate of fall of pressure with height in a warm air mass compared to cold air mass will be
(a) Same (b) More (c) Less

Q13. An increase of 1000 ft at msl is associated with decrease of pressure of
(a) 100 hPa (b) 1000 hPa (c) 3 hPa (d) 33 hPa

Q14. Lines drawn through places of equal pressure are known as
(a) Isobars (b) Isotherms (c) Isogonal (d) Isoclinal

Q15. Which is true?
(a) Trough has frontal characteristics
(b) At trough winds back in N-hemisphere
(c) At trough winds veer in N-hemisphere

Q16. Semi diurnal pressure changes are most pronounced in
(a) Polar region (b) Middle latitudes (c) Tropics

Q17. Flying from Delhi to Kolkata at constant indicated altitude but, experiencing drift to Starboard. The actual altitude will be (vis-à-vis) indicated altitude
(a) Lower (b) Same (c) Higher

Q18. In the Southern Hemisphere, around a Low Pressure Area wind blows
(a) In clockwise direction
(b) In anticlockwise direction
(c) Across isobars towards the centre

Q19. Altimeter of a/c on ground reads aerodrome elevation; its sub-scale is set to
(a) QNH (b) QNE (c) QFF (d) QFE

Q20. Instrument for recording pressure is called
(a) Anemograph (b) Barometer (c) Hygrograph

Q21. Poor visibility is associated with
(a) High (b) Low (c) Trough

Q22. On either side, perpendicular to the .... pressures rise
(a) Trough (b) Ridge (c) Low

Q23. Fall of pressure with height is more rapid in
(a) Cold areas (b) Warm areas (c) Humid areas

Q24. 300 hPa in ISA corresponds to the level
(a) 20,000ft (b) 30,000 ft (c) 35,000 ft

Q25. 18,000 ft height in ISA corresponds to the pressure level
(a) 700 hPa (b) 200 hPa (c) 500 hPa

Q26. 200 hPa in ISA corresponds to the level
(a) 20,000ft (b) 30,000 ft (c) 40,000 ft

Q27. 24,000 ft height in ISA corresponds to pressure level
(a) 400 hPa (b) 500 hPa (c) 300 hPa

Q28. 700 hPa in ISA corresponds to the Flight level
(a) 20,000ft (b) 10,000 ft (c) 18,000 ft

Q29. 40,000 ft height in ISA approximately corresponds to pressure level
(a) 400 hPa (b) 500 hPa (c) 200 hPa

Q30. 850 hPa in ISA corresponds to the height
(a) 7,000ft (b) 5,000 ft (c) 10,000 ft

Q31. Atmospheric pressure is due to
(a) wind (b) temperature (c) gravity (d) density

Q32. An aircraft is gaining altitude, inspite of altimeter reading constant altitude. Why?
(a) Standard pressure has risen (b) Flying towards High
(c) Flying towards Low (d) Temperature has decreased

Q33. A contour of 9160 m can be expected on a constant pressure chart for pressure level
(a) 500 hPa (b) 400 hPa (c) 300 hPa (d) 200 hPa

Q34. In contour chart of 300 hPa, isohypse (contours) are drawn at interval of
(a) 20 gpm (b) 40 gpm (c) 60 gpm (d) 80 gpm

Q35. In constant pressure chart of 500 hPa, isohypse are drawn at interval of
(a) 20 gpm (b) 40 gpm (c) 60 gpm (d) 80 gpm

Q36.QNH of an aerodrome 160 m AMSL is 1005 hPa. QFE? Assuming 1 hPa =8m
(a) 1010 hPa (b) 985 hPa (c) 1005 hPa (d) 990 hPa

Q37. Steep pressure gradient would mean
(a) Contours far apart , weak wind
(b) Contours far apart ,strong wind
(c) Isobars far apart and temperature low
(d) Isobars closely packed and strong wind

Q38. What type of inversion occurs when a stable layer lies in a high pressure area
(a) Negative (b) Radiation (c) Subsidence (d) Airmass

Q39. Which of the following would cause true altitude to increase when altimeter indicates constant altitude?
(a) Warm/ Low (b) Cold/ Low (c) Hot/ High (d) Cool/ Low

Q40. The movement of wind in relation to a cyclone is
(a) Descending and subsiding (b) Ascending and converging
(c) Descending and cooling (d) Ascending and diverging

Q41. An aerodrome is at the mean sea level. Its QNH is 1014.0 hPa. Its QFF will be
(a) 1014. 0 hPa (b) 1013.25
(c) Difficult to tell (d) More than QNH

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**a**	**b**	**c**	**b**	**c**	**a**	**c**	**b**	**a**	**c**	**a**	**c**	**d**
Q.	14	15	16	17	18	19	20	21	22	23	24	25	26
A.	**a**	**b**	**c**	**a**	**a**	**a**	**b**	**a**	**a**	**a**	**b**	**c**	**c**
Q.	27	28	29	30	31	32	33	34	35	36	37	38	39
A.	**a**	**b**	**c**	**b**	**d**	**b**	**c**	**d**	**b**	**b**	**d**	**c**	**c**
Q.	40	41											
A	**b**	**a**											

3. TEMPERATURE

Temperature is a measure of heat. It is measured by a thermometer in degrees Celsius (Centigrade) or Fahrenheit. These scales are arbitrarily fixed with reference to the melting point of ice and the boiling point of pure water at normal pressure. On the Celsius scale these are respectively as 0°C and 100°C and in the Fahrenheit scale 32° F and 212° F. Celsius scale is used internationally, in aviation and science. Use of the Fahrenheit scale is confined to a few English-speaking countries only. A third scale is based of the following argument.

Heat is a form of energy. As heat is extracted from a substance, its internal energy is reduced and the random motion of its molecules slows down. The molecules get arranged in a more orderly pattern than before. As more heat is extracted the cooling and the orderliness increases. Finally a state is reached when the molecules attain their maximum orderliness and the molecular motion almost ceases. After this state no more heat can be extracted and the temperature reaches its lowest possible value. **This minimum temperature is the same for all substances**, and is accordingly called the **absolute zero** (K). 1 K = – 273.16 °C

Conversion to C,F and K

The conversion from one scale to another can be done by the following equations:

$$F = (9C/5) + 32 \; ; \; C = 5/9\,(F-32) \; ; \; K = C + 273$$

It may be noted that **–40° C = –40° F**

Instruments for Measurement

Dry Bulb Thermometer, Wet Bulb Thermometer (the bulb is covered with a muslin cloth which is kept moist), Maximum Thermometer (like Doctor's Thermometer), Minimum Thermometer and Thermograph, are used for measuring temperature. Mercury is used in thermometers, except that in **Minimum thermometer Alcohol** is used instead of mercury. In Thermographs and in Upper Air temperature measurements Bi-metallic strips are used. Thermograph gives a continuous record of temperature. A minimum thermometer has a dumbbell shaped iron index, which permits alcohol to pass through when temperature rises. When temperature falls the alcohol, which has a concave meniscus, drags the index back to indicate minimum temperature.

Surface Temperature

It is the temperature recorded at a height of 4 ft (1.25m) above the ground in shade (inside a Stevenson's Screen).

Ambient Temperature. The temperature of the surroundings is called Ambient Temperature.

Virtual Temperature (VT). In a thermodynamic process the temperature at which dry air parcel would have the same pressure and density as that of a moist parcel of air, is called virtual temperature. VT allows use of dry air equation of state for moist air also.

Heat and Temperature

Heat is the sum total of the KE of all molecules and atoms of a substance. **Temperature is the average KE** of all the molecules and atoms of a substance. The water in a bath tub at 60°C will have more heat than the boiling water in a cup. In the thermosphere although the temperatures are very high yet the heat content is less as there are very few particles and they too far apart. Hence there is hardly any effect of high temperatures to the rockets and spacecraft in the region.

Specific Heat. It is defined as the heat required to raise the temperature of unit mass of a substance by 1°C. The specific heat of water, regarded as the highest, is 1, that of ice 0.5 and of the soil 0.2. Hence land gets heated/cooled much faster than the water.

Latent Heat. Latent heat is defined as the "amount of heat absorbed or released during change of phase from/to solid/liquid/vapour". It is absorbed during change of solid to liquid and liquid to gas and released during the reverse processes.

Evaporation, Condensation and Latent Heat

When water changes to vapour, a certain quantity of heat is supplied. To change boiling water into vapour, more than five times as much heat is required as is needed to bring the same amount of ice cold water to the boil. Once boiling has begun, the temperature remains constant and the heat supplied in this stage becomes latent. It is released as latent heat when the vapour condenses to water.

Heat Transfer

Heat is transferred from one place to the other by **conduction, convection, radiation** and some other methods, as follows. In the atmosphere all these processes are important. However, radiation plays a significant role in heat transfer.

Conduction. In this process heat is physically transferred by the molecules by contact. Conduction is an important process of heat transfer very close to the ground.

Convection. In this process hot fluid is bodily transferred to the colder part of the fluid. As more than 70 % of the earth is covered with water, hence the importance of convection. In the atmosphere **Free Convection** is triggered by intense solar heating and the **Forced Convection** by topography. The hot air lifts to higher levels and transfers heat.

Radiation. Every body radiates heat at its temperature. In this process of heat transfer the medium is neither affected nor required. The solar radiation directly heat up the earth without affecting the atmosphere.

Other Methods of Heat Transfer. Advection, Latent heat release, Turbulence, Up and Downward motion of air are some of the other methods of heat transfer. The **advection** transfers heat horizontally by winds. The irregular eddy motion of the atmosphere, called **turbulence,** causes redistribution of heat. The **latent heat** which is absorbed by the melting of ice or evaporation of water, mostly at the earth's surface, is subsequently released as **latent heat** in the atmosphere by **condensation or freezing**.

In the troposphere all the above processes transfer heat. In the stratosphere, however, neither convection nor latent heat have any influence but short wave radiation heat it up due to absorption by ozone.

Insolation

Total amount of solar radiation received over a particular area is called insolation. The insolation depends on the obliquity of sun's rays, Figure 3.1. Hence, insolation at any place is maximum when sun is overhead and least during sunrise and sunset. Similarly maximum insolation is received over the Tropics, the region between Tropic of Cancer and Tropic of Capricorn, and least at the Poles.

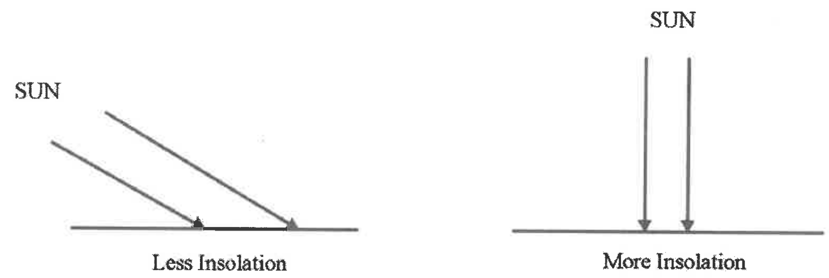


Figure 3.1 Insolation and Obliquity of Sun Rays

Black Body. Everybody emits radiation at its temperature in the from of electromagnetic waves over a wide range of wavelengths simultaneously. A radiating body is called a black body.

Laws of Radiation

Stefan Boltzmann Law. The law states that the total amount of energy radiated by a black body is proportional to the fourth power of its absolute temperature. Hence intense radiation are emitted by hot bodies like the sun.

$$E \propto T^4$$

Wien's Law. The wavelength of most intense radiation is inversely proportional to the absolute temperature. Hence hot bodies (like sun) radiate Short Waves and colder bodies like earth, radiate Long Waves.

Planks Law. This law describes the distribution of radiated energy with absolute temperature. The curve is a right skewed central distribution.

Solar Radiation

The temperature of the surface of the sun is about 6000° C. The solar radiation is, therefore, mainly Short Waves. In the solar spectrum the white visible light consists of various wavelength colours (VIBGYOR), in which the longest waves appear red, the shortest violet. In addition to visible light, the solar spectrum consists of wavelength too short to be seen by the eye. The wavelength beyond the violet end of the spectrum are called Ultra-Violet (UV) and those on the other extreme beyond the red wavelengths are called Infra-Red (IR) waves. The complete solar radiation, including visible light, UV and IR, is responsible for all the heat that the earth receives from sun as short wave radiation. The solar radiation consists of about:

IR 46 % Visible 45 % and UV 09 %

Terrestrial Radiation

The earth radiates at its own temperature and looses heat. These are called terrestrial radiation, which are long wave radiation. These are invisible and are mostly IR radiation. The earth receives heat as short-wave radiation from the sun and loses heat as long wave radiation.

Nocturnal Radiation

At night when the short-wave radiation is absent only the earth radiates and looses heat. The radiation emitted by the earth at night are called Nocturnal Radiation.

Radiation and Heat Budget

Since the mean temperature of the earth has remained almost unchanged for a long period, it follows that heat received from the sun as Short wave radiation is returned to the space by the earth as Terrestrial Radiation and are equal.

About 30% of the solar radiation is reflected back or scattered by the earth atmosphere, 19% is absorbed by atmospheric constituents (such as ozone) and 51% are absorbed by the earth surface.

The 30% of the solar radiation which are reflected back to the space by the earth and clouds is the reflecting power of earth. It is called "Albedo".

Absorbed by	**Total**	
	Earth surface 51%	
	Water Vapour, Dust, Ozone 16%	
	Clouds 3%	**70%**
Back Scattered by		
	Air 6%	
	Clouds 20%	
	Earth Surface 4%	**30%**

Table 3.2

Albedo = Reflected Radiation/Incident Radiation

In clear weather about 5/6 of the solar radiation reach earth surface. Of this energy earth reflects about 10%. Snow surface reflects about 80% of the incident energy.

Diurnal Variation of Surface Temperature

Due to the nature of surface the diurnal temperature changes are much smaller over the sea than over land. The sea surface temperature shows a variation from day to night of less than 1°C, whereas over land, the diurnal variation may average as much as 20°C. Near the coast the diurnal variation depends on the direction of the wind. With a wind off the land the diurnal variation near the coast may be as large as inland, but with a wind off the sea it will be small. The sea breezes have a pronounced cooling effect.

The diurnal variation is maximum when the wind is calm. With strong wind, the surface air mixes with the air above and the heat gained by day and lost by night spreads through the **Friction Layer (up to 1 km above)**. Consequently the diurnal variation is small when winds are strong.

Due to nocturnal cooling the surface temperatures continue to fall even after the sunrise, till a balance is reached between the incoming and outgoing radiation. The balance occurs a little after the sunrise, when temperature is minimum at the surface. Thereafter some time may elapse for this temperature to reach the screen level (1.25m). **Minimum temperature,** therefore, **occurs ½ to 1 hour after the sunrise or dawn**. Thereafter, the incident radiation exceed until mid day. The surface temperature is the highest at noon. It takes another 2-3 hours for transfer of this temperature to the screen level, when the maximum temperature is recorded.

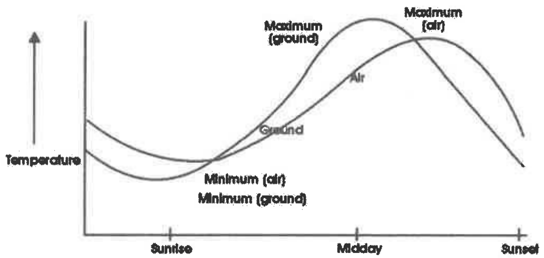


Figure 3.3 Diurnal Variation of Surface Temperature

Effect of Clouds on Surface Temperature

A cloud cover obscures the sun and reflects major part of the radiation back to space. A thin sheet of cirrostratus cloud can cut off a fair proportion of the solar radiation, and a thick layer of lower cloud or a deep layer of fog may completely block the radiation and reduce the heating of the earth by day. During night, the cloud cover absorbs most of the outgoing radiation from earth. At the same time the lower surface of the cloud radiates towards the earth. Hence **cloudy nights are warmer**.

When sky is covered with low clouds the diurnal variation of temperature at the ground is small. The lower the cloud the more effectively it reduces the nocturnal cooling.

QUESTIONS ON TEMPERATURE

Q1. Diurnal variation of temperature is greatest when wind is
(a) calm (b) light (c) strong

Q2. Diurnal variation o f temperature is maximum over
(a) forest (b) ocean (c) land

Q3. On a clear day the amount of solar radiation received by earth surface is
(a) ¾ (b) 30% (c) 5/6

Q4. ALBEDO is
(a) Radiation received by earth (b) Amount of heat
(c) Reflecting power of earth

Q5. During Day the ambient temperature is .... than ground
(a) Lower (b) Higher (c) Same

Q6. Diurnal variation of temperature over ocean is ....
(a) More than land (b) Above 3°C (c) Less than 1°C

Q7. At a coastal station the diurnal variation of temperature depends on ....
(a) Wind direction (b) Wind speed (c) Radiation

Q8. Snow surface reflects about .... % of solar radiation.
(a) 75% (b) 80% (c) 90%

Q9. Amount of Solar radiation received per unit area is ....
(a) Insolation (b) Convection (c) Radiation

Q10. Solar radiation received by the earth is
(a) Long Wave (b) Albedo (c) Shortwave

Q11. Rise in temperature of a surface is proportional to its specific heat
(a) Directly (b) Inversely

Q12. Specific heat of land is .... than that of water
(a) Lower (b) Same (c) Higher

Q13. Minimum temperature is reached at ....
(a) sunrise (b) midnight (c) ½ -1 hour after dawn

Q14. An air parcel is lifted till it gets saturated. The temperature attained by it is called
(a) Potential temperature (b) Dew Point (c) Wet bulb

Q15. Cloudy nights are........
(a) cold (b) normal (c) warm

Q16. Water vapour is transparent to terrestrial radiation
(a) completely (b) partially (c) indifferent

Q17. Higher the temperature .... would be the wavelength of emitted radiation
(a) longer (b) shorter

Q18. Air is a bad conductor of heat. A parcel of air can therefore be regarded as insulated from the environment
(a) False (b) True

Q19. Warmer the earth........... will be the Nocturnal radiation
(a) intense (b) weaker (c) moderate

Q20. Heat is the ......of the KE of all the molecules and atoms of a substance
(a) sum total (b) average

Q21. The solar radiation consists of about 46 %.....
(a) UV (b) IR (c) Visible

Q22. The total energy radiated by a black body is proportional to its temperature(T)
(a) T^2 (b) T^3 (c) T^4

Q23. Intense radiation are emitted by
(a) Hot bodies (b) Cold bodies (c) Stars

Q24. The wavelength of most intense radiation is inversely proportional to its........
(a) Absolute temperature (b) Humidity (c) Albedo

Q25. Hot bodies (like sun) radiate
(a) Short Waves (b) Long Waves (c) Both

Q26. The flow of heat from earth surface is 77% by
(a) Sensible Heat (b) Latent Heat

Q27. – 40° C = – 40° F
(a) True (b) False

Q28. Surface Temperature is recorded at a height of .... above ground
(a) 1.5 m (b) 1.25m (c) 2 m

Q29. The door of Stevenson's screen should open
(a) opposite to sun (b) into sun (c) any direction

Q30. The liquid used in Minimum Thermometer is
(a) mercury (b) alcohol (c) sprit

Q31. Freezing point of water is
(a) 0°F (b) 12°F (c) 22°F (d) 32°F

Q32. Boiling point of water is
(a) 100°F (b) 112°F (c) 212°F (d) 312°F

Q33. Freezing point of water is
(a) 173 K (b) 273 K (c) 373 K (d) 473 K

Q34. Boiling point of water is
(a) 373K (b) 273°K (c) 173K (d) 312° K

Q35. Convert 68°F into Kelvin temperature
(a) 233 K (b) 283K (c) 294 K (d) 293 K

Q36. Diurnal variation of temperature is least on a day when it is
(a) Clear (b) Partly cloudy (c) Cloudy (d) Overcast

Q37. A clear and calm night is cooler than a cloudy night, because nocturnal radiation
(a) escape through cloud (b) are partly radiated back by clouds to earth
(c) are fully absorbed by H2O (d) are fully prevented by clouds to escape

Q38. Which surface will cause higher diurnal variation
(a) Forest (b) Desert (c) Water (d) Snow

Q39. If temperature does not change in a layer with height on a day indicates
(a) Isothermal layer (b) Inversion (c) Instability (d) Uniform Lapse Rate

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**a**	**c**	**c**	**c**	**a**	**c**	**a**	**b**	**a**	**c**	**b**	**a**	**c**
Q.	14	15	16	17	18	19	20	21	22	23	24	25	26
A.	**b**	**c**	**b**	**b**	**b**	**a**	**a**	**b**	**c**	**a**	**a**	**a**	**b**
Q.	27	28	29	30	31	32	33	34	35	36	37	38	39
A.	**a**	**b**	**a**	**b**	**d**	**c**	**b**	**a**	**d**	**d**	**b**	**b**	**a**

4. AIR DENSITY

Atmospheric density is an important factor in aviation. Density affects performance of an aircraft significantly. It affects lift, thrust, drag, climb rate and airspeed of an aircraft. In low density the climb outs are slower, both landing and take-off speeds are greater, the thrust of the engine is reduced and longer runways are required for take off and landing. Allowance has to be made for these effects in planning the length of runway and calculating the all-up weight of an aircraft.

Definition and Units

The atmospheric **density is defined as the mass of air contained in a unit volume**. Its unit is g/m^3 or kg/m^3.

Density is also expressed as the **Density Altitude.**

Density altitude is defined as the altitude above msl at which a given atmospheric density occurs in the ISA. **The Pressure altitude and the Density altitude have the same value in the ISA.**

With temperature constant if pressure increases density altitude also increases.

1°C temperature deviation from ISA is equal to 120 ft.

If temperature is > ISA : Density altitude is > Pressure Altitude.

The Density altitude is higher if the atmosphere is warmer than the ISA.

High density altitude would mean taking off from or landing at an airfield at a higher altitude.

Density of Dry Air

The air density (ρ) can be is obtained by substituting observed values of the pressure (P hPa) and temperature (T Kelvin) in the fundamental gas equation:

$$PV = RT$$

Since for a unit mass of gas density ρ is the reciprocal of the volume V, therefore:

$$P/\rho = RT \text{ or } \rho = P/RT$$

where V is the volume, T the absolute temperature and R the gas constant for the particular gas.

Substituting the values of the gas constant for dry air $R = 2.87 * 10^3$, ISA surface pressure 1013.25 hPa and temperature 15°C (288°K), the equation gives the density as 1225 g/m^3.

Density of Moist Air

Being a gas, water vapour obeys the fundamental gas equation. The gas constant for water vapour is 8/5 times that for dry air. The total pressure P of moist air may be regarded as the sum of the partial pressure (p) exerted by the dry air and the partial pressure exerted by the water vapour (e). Then from the gas equation:

Density of water vapour :	5e/8 RT
Density dry air, having partial pressure	(p – e) : (p–e)/RT
Density of the moist air (the sum of the above two)	(p–3 e/8)/RT

Thus the **moist air** is **less denser than dry air,** under similar conditions of pressure and temperature. Since the effect of humidity on density is small, it can be ignored for aviation purposes.

Factors affecting Density. Air density is affected by the following three factors:

Altitude. The higher the altitude, the less dense the air is.

Temperature. The warmer the air, the less dense it is.

Humidity. It is not a major factor in affecting density, yet humid air is lighter than dry air. At high temperature, the atmosphere can retain a high water vapor content. If humidity is high, it is wise to add 10% to the computed take off distance and anticipate reduced climb rate.

Variations in Surface Density

At a given pressure, the density is inversely proportional to the absolute temperature. The warm air is thus comparatively lighter and the cold air is heavier. Variations in density during a day occur due to the diurnal variation of temperature. The lowest densities occur in the afternoon and the highest just after sunrise. Seasonal density changes occur due to variations in temperature and pressure.

It is noteworthy that a decrease of density of about 1% is produced by a fall of pressure of 10 hPa, or by an increase of temperature of 3° C, or by an increase in height of 300 feet.

Variation of Density with Height

In ISA the density decreases with height at all levels. The decrease at lower levels for 1000 ft is approximately 3% of the value for any given level. This rule gives good approximation up to about 20,000 feet.

If the density of the air was to remain uniform with height, the atmosphere would extend up to 8 km. But since density decreases with height, at every 5-6 km it reduces to its previous half value.

It is **1/2 of the surface value at 6 km, 1/4 at 11 km and 1/8 at 17 km.** However, at 240 km also there is sufficient density to offer resistance. It is, therefore, believed that the atmosphere extends up to about 800 km.

Latitudinal Variation

Density of air at sea level is lowest near the equator and greatest at the poles. This distribution is maintained unto about 8.0 km. Above 8.0 km a reversal occurs and the density becoming more near the equator than at poles (higher lat.). This will mean:

For aircraft with low cruising altitudes (piston-engine type) the operational efficiency at any level would be greater in high latitudes than in the tropics.

For aircraft with high cruising altitudes (jet aircraft) the operational efficiency would be greater in the tropics than at high latitudes.

QUESTIONS ON AIR DENSITY

Q1. Density is .... at poles than equator
(a)Higher (b) Lower (c) Same

Q2. Above 8 km density is .... at poles than at equator
(a)Higher (b) Lower (c) Same

Q3. The altitude in ISA at which air density is the same as the observed density is
(a) Density Altitude (b) ISA Density (c) Real Density

Q4. Density is usually expressed as ....
(a) Kg/sq m (b) g/cu m (c) N/sq m

Q5. Higher density altitude means .... density
(a) Higher (b) Lower (c) Same

Q6. For given pressure and temperature moist air has density
(a) Higher (b) Lower (c) Same

Q7. Air is less denser in
(a) High Altitudes (b) Warm Air (c) High humidity (d) All these

Q8. Density altitude may be defined as:
(a) The altitude in ISA at which the prevailing pressure occurs.
(b) The altitude in ISA at which the prevailing density occurs.
(c) The altitude in actual atmosphere at which the prevailing density occurs.

Q9. Temperature being constant, if pressure increases the density altitude
(a) increases (b) lowers (c) remains the same

Q10. For every1°C change in temperature, density altitude differs from pressure altitude by
(a) 33 ft (b) 100 ft (c) 120 ft (d) 210 ft

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10
A.	a	b	a	b	b	b	d	b	a	c

5. HUMIDITY

Water vapour is always present in the air to a greater or lesser extent, in the troposphere. This water vapour plays a very important role in all the atmospheric processes.

Water evaporates into the air from oceans, lakes, rivers, vegetation etc. It ascends and forms clouds which cause precipitation. The **water cycle** is thus completed.

Water exists in **three phases:** the gas (water vapour), liquid (rain, drizzle, shower) and solid (snow, hail). The capacity of dry air to hold water vapour depends largely on temperature and to some extent on pressure. Higher the temperature higher is the capacity of air to hold the water vapour.

Various terms used for describing water content in the atmosphere are:

Dry Air. Air that contains no water vapour is called dry air. Such an air may exist in the upper troposphere or stratosphere.

Moist Air. The normal air, that we breathe is the moist air. It is also called unsaturated or dry air at the existing temperature and pressure.

Saturated Air. Air is like a sponge which can absorb certain amount of water and no more. When the air holds maximum water vapour, it is called saturated air.

Vapour Pressure (VP). The partial pressure exerted by water vapour in the air is called vapour pressure. If p is the total pressure of air and e is the vapour pressure, then (p-e) is the pressure of dry air.

Saturation Vapour Pressure (SVP). It is the pressure exerted by water vapour when air is saturated

Absolute Humidity. It is defined as the actual amount of water vapour contained in a given volume of air at a given temperature. It is expressed in g/m^3.

Humidity Mixing Ratio (HMR). It is defined as the mass of water vapour contained in a given mass of air. It is expressed as g/kg.

HMR for Saturated Air. It is defined as the maximum mass of water vapour that can be contained in a given mass of air at a particular temperature and pressure. It is also expressed as g/kg of dry air.

With the increase of temperature the saturation humidity mixing ratio also increases.

If there is no addition or removal of water vapour, the HMR remains **constant when air is lifted adiabatically.**

Relative Humidity (RH). It is defined as the ratio, in percentage, of the actual water vapour present in the air to the maximum it can contain at the same temperature and pressure.

RH (%) = (HMR x 100) / (HMR for Saturated Air)
RH (%) = (VP of Air x 100) / (SV of Air)

Measurement. Humidity is measured by the instruments Psychrometer and Hygrometer, and is recorded by Hygrograph.

Wet Bulb Temperature (T_w T_w). It is the lowest temperature which air would attain by evaporating water into it to saturate it. Desert coolers work on this principle. Dryer the air more effective would be the cooling.

Dew Point Temperature ($T_d T_d$). It is the lowest temperature to which air should be cooled at constant pressure to saturate it with respect to water. Cooling below Dew Point (DP) causes condensation.

DP is only affected by change in water content, whereas RH is affected by change in water content and temperature both.

DP is higher if air contains more water vapour.

By cooling or warming the air, RH changes but DP does not change.

Frost Point. It is the temperature to which air must be cooled to reach saturation with respect to ice. Cooling below the frost point causes formation of hoar frost.

Cloud Base . Theoritcally height of the base of cloud can be determined using surface temperatures in °C by the Emperical fomula : **(Temperature – DP) x 400 ft**

It is important to note that:

As the temperature of the air increases, the amount of water vapour required to saturate it also increases.

At subzero temperatures water molecules have more energy and a greater degree of freedom than ice, consequently **the saturation vapour pressure over water drops is more than that over the ice particles.** If water drops and ice particles co-exit, water drops will evaporate and condense on the ice particles. This principle is applied in explaining rainfall from clouds which extend above 0ºC level in the atmosphere and have both super-cooled water drops and ice crystals co existing.

Small water droplets can exist in super cooled state in the clouds up to – 40ºC and in CB clouds up to – 45ºC.

For saturated air: (in Fog, during rain)

Air temperature (TT) = Wet Bulb (T_w T_w) = Dew point (T_d T_d)

For Unsaturated air:

TT > T_w T_w > T_d T_d

QUESTIONS ON HUMIDITY

Q1. The ratio in % between the amount of water vapour present in the air to the amount of water vapour that it can hold at the same temperature is
(a) Humidity (b) Relative humidity (c) Dew point

Q2. The temperature to which air be cooled at constant pressure to become saturated, is called
(a) Wet bulb temperature (b) Dry bulb temperature
(c) Dew point (d) Humidity

Q3. Free air temperature, Wet bulb temperature and Dew point temperature are equal when
(a) Air temperature is 0°C
(b) Relative humidity is 100%
(c) Air temperature is not below 0°C

Q4. On a rainy day compared to sunny day the length of runway required is
(a) More (b) Less (c) Same

Q5. The spread (difference) between Free air temperature and Dew point temperature is .... when air is saturated
(a) Large (b) Least (c) Same

Q6. The saturation vapour pressure over water is .... than the ice
(a) More (b) Less (c) Same

Q7 As the temperature of the air increases, the amount of water vapour required to saturate it ....
(a) decreases (b) increases (c) remains same

Q8. The actual amount of water vapour contained in a given volume of air at a given temperature is termed as ....
(a) Relative Humidity (b) Specific Humidity (c) Absolute Humidity

Q9. Humidity Mixing Ratio .... when air is lifted adiabatically
(a) decreases (b) remains constant (c) increases

Q10. It is the lowest temperature which air would attain by evaporating water into it to saturate it.
(a) Wet bulb temp (b) Dry bulb temp (c) Dew point

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10
A.	**b**	**c**	**b**	**a**	**b**	**a**	**b**	**c**	**b**	**a**

6. WINDS

In the atmosphere air moves horizontally and vertically. **The horizontal movement of the air is called wind**. The wind is closely related to the horizontal variation of pressure and consists of a succession of strong winds (**gusts**) and weak winds (**lulls**). It has two components: the **Direction** and the **Speed**.

Wind Direction

The direction of the wind is the direction from which wind is blowing or wind is coming from. A Southerly wind blows from S to N and an Easterly wind from E to W. Wind direction is indicated on 16 points of compass (N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, NNW) or in degrees at intervals of 10°, for example 350°, 330°, 020°, 090°, 160° etc. The direction is measured from True North.

Wind Speed

Wind speed is expressed in nautical mile per hour (knot). The relationship between the alternative speed units are:-

1 kmh = 0.278 mps = 0.540 kt, Roughly 1mps = 2 kt = 4kmh

(kmh – kilometre per hour; mps - metre per second)

Wind speed is generally **reported** at an interval of 05 kt as follows:

0-2 kt as Calm; 03-07 kt as 05 kt; 08-12 kt as 10 kt;...... 48-52 kt as 50 kt etc.

Cross Wind. Runways are oriented along the most prevailing wind directions of a locality, based on the climatological records. However, sometimes, especially during adverse weather and transition seasons, the winds deviate from these directions. A wind 90° to the runway in use is called Cross Wind Component. Critical cross wind components for each type of aircraft are specified. Great caution is exercised whenever this value exceeds. Cross winds tend to swing the aircraft during take off and landing, especially lighter aircraft.

Instruments for Measuring Wind

The surface wind speed is measured by **Anemometer** and Wind direction by **Wind Vane**. Upper winds are measured by – RAWIN and Pilot Balloon equipment. These Hydrogen filled balloons are tracked by RADAR and Optical Theodolite respectively.

Exposure of Wind Instruments

To record surface wind the Anemometer and Wind Vane are installed at a **height of 10 m**, in an area free of obstructions. The wind is **averaged for 10 minutes** for all weather observations. For **take off and landing** purpose, however, the wind is **averaged for 2 minutes**.

Gust and Lull

A gust is an irregular and rapid fluctuation in the wind. Gusts are caused by the turbulence due to the ground friction and by the uneven heating of the ground, specially in the hot afternoons. The positive fluctuations are called **Gusts** and the negative fluctuations **Lulls,** Figure 6.1.

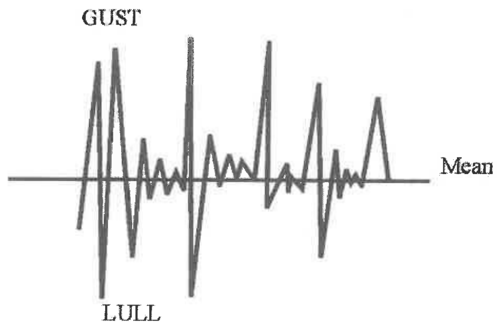


Figure 6.1 Gust and Lull

Squall

Squall is defined as the sudden increase in wind speed by 32 kmh (16 kt, 08 mps), should last for one minute or more and speed should increase to 44 kmh (22 kt, 11 mps) or more. Squall is associated with large CB clouds and violent convective activity. Squall extend some km horizontally and several thousands of feet vertically. Both speed and direction in squall may differ widely from the prevailing winds.

Violent squalls are experienced in Norwesters, Thunderstorm (TS) and Duststorm (DS) from March to June. Line squalls occur ahead of Cold Fronts and sometimes with the Norwesters.

The **main difference between squalls and gusts is the duration**. A gust is a transient increase in speed lasting for a few seconds, the squall is an increase in wind lasting for some minutes. A squall is associated with CB or Thunderstorm and may be accompanied by a marked drop in temperature and precipitation.

Strong sudden squalls are more dangerous than the strong mean winds. A parked aircraft may easily sustain a **gale** (defined as persistent mean wind of 34 knot or more) but may not sustain a squall or sudden gust of say 60 kt, even though the mean wind may not reach gale force.

Gale

Gale is defined as the persistent mean wind of speed 34 kt or more. It is associated with depressions and cyclonic storms.

Backing and Veering

Backing is the change of wind direction anti-clockwise, e.g. wind direction changing from 090° to 060° or from 270° to 160° etc. Conversely, **change of wind direction clockwise is veering** (change from say 060° to 090° etc). In a low pressure area the wind blows in an anticlockwise direction **(Backs)** whereas in a high it blows clockwise **(Veers)**, in the N hemisphere.

Pressure and Wind: The Buys Ballot's Law

The law states that, in the N hemisphere, if an observer stands with his back to the wind, low pressure is to his left and high pressure to his right and converse in the S hemisphere. Thus in N hemisphere wind blows anticlockwise around a cyclone (Low) and clockwise around an anti-cyclone (High).

Effect of Rotation of Earth

To visualize this force consider a disk rotating from W to E. On this rotating disc draw a straight line instantaneously. Stop the disc. It will be seen that the line drawn curves to the right. The effect of motion over the surface of the earth is exactly alike. A moving object is deflected to the right in the N hemisphere, Figure 6.2, and to the left in the S hemisphere. This deflection is due to the Coriolis force, also called the Geostrophic Force. It is an apparent force and acts perpendicular to the wind direction

Coriolis Force (f) = $2\,\Omega\,\rho\,V\sin\varphi$

Where Ω is the angular velocity of the earth, V the wind speed, unaffected by the frictional forces, and φ is the latitude. For a unit volume of air, magnitude of the force is $2\rho V\sin\varphi$ (where ρ is the density of unit volume)

At poles φ is 90°, $\sin\varphi = 1$ the Coriolis force would be maximum
At equator φ is 0°, $\sin\varphi = 0$ the Coriolis force would be minimum

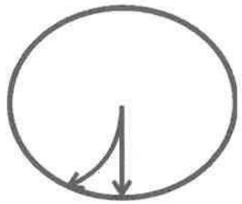


Figure 6.2 Coriolis Effect

It is directly proportional to the speed of motion of the air particles, and to the air density.

The wind blows from higher to lower pressure (H to L) along the isobars under the influence of pressure gradient force (P). The pressure gradient force is directed from high to low pressure. It is the difference of pressure between the consecutive isobars divided by the distance between them or the rate of change of pressure with distance in the horizontal.

Due to the rotation of the earth from W to E, the wind is constantly deflected to its right (in N hemisphere), until it attains a uniform speed along the isobars.

DIFFERENT TYPES OF WINDS

Geostrophic Wind

The friction less wind which blows parallel to straight isobars due to balance between Pressure Gradient force and Coriolis force, with low to the left in the N hemisphere, Figure 6.3. Closer the isobars stronger is the wind. It is not a real wind, but is calculated wind.

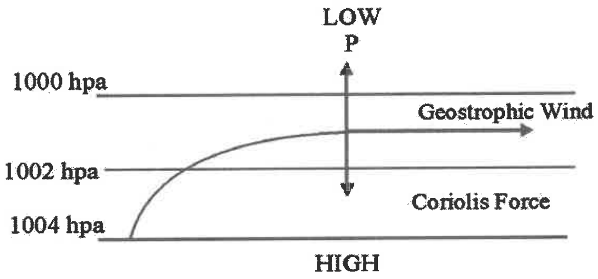


Figure 6.3 Geostrophic Wind

For geostrophic wind (Vg) Pressure Gradient Force (P) = Coriolis Force (f)

$$\mathbf{P / \rho = 2\,\Omega\,Vg\,sin\,\varphi}$$

For geostrophic wind (Vg) Pressure Gradient Force (P) = Coriolis Force (f)

$$\mathbf{P / \rho = 2\,\Omega\,Vg\,sin\,\varphi}$$

Where ρ is density and P/ρ is pressure gradient force for unit mass. Therefore

$$\mathbf{Vg = P / 2\,\Omega\ \rho\,sin\,\varphi}$$

The speed of geostrophic wind is inversely proportional to the sine of the latitude. Vg is stronger at lower latitudes than at higher latitudes. The wind speed tends to be infinity at the equator where $\varphi=0$ and sine 0 = 0, which is not possible. Hence at equator, the geostrophic wind formula breaks down and not used. However, beyond 30° the formula gives a good approximation to the actual wind.

Limitations of the Geostrophic Rule

The geostrophic formula gives satisfactory wind only when the pressure gradient and the Coriolis force are in balance and the isobars are straight and parallel. If they are curved or if the pressure changes with time, additional forces get involved. The geostrophic formula then becomes inapplicable. **The winds like gusts, squalls and the local winds land and sea-breezes, etc do not follow this rule**. They differ in both direction and speed from the geostrophic wind. However, the geostrophic wind gives a satisfactory approximation to the actual wind, especially in middle latitudes.

Cyclostrophic Wind

If wind is blowing along the curved isobars of radius r with a velocity V it has an acceleration towards the centre, called **centripetal force** (V^2/r). The centripetal force acting on a unit volume of air is ρ V^2/r. If the Coriolis force is negligible as compared to the forces P and f, Centripetal force (C) must be provided by the pressure gradient force. Hence

$$\mathbf{\rho\,V^2 / r = P \text{ therefore } V = (P\,r / \rho)^{1/2}}$$

Such a motion is called **Cyclostrophic**. Near the centre of a tropical revolving storm or in a circular tornado, the equation gives a close approximation to the actual wind.

Cyclostrophic Wind is defined as the wind which is markedly curved and blows due to balance between Pressure Gradient and Cyclostrophic force. The frictional force is disregarded.

Gradient Wind

It is the wind which blows parallel to the curved isobars under the balance of pressure gradient, Coriolis and Centripetal forces, Figure 6.4. In middle latitudes this wind is a closer approximation to actual wind than Geostrophic wind. It is a calculated wind and the frictional force is disregarded.

In a **low pressure** P and C are directed inwards along the radius of curvature (r), towards low pressure, and are balanced by f, which is directed outwards. Here a part of P provides C and the remaining balances f. In effect P < f. Hence the actual wind velocity (V) is less than V_g for the same pressure gradient. Or in other words the gradient wind is **Sub geostrophic** in a cyclone.

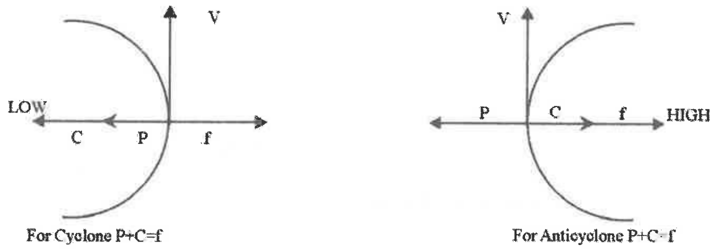


Figure 6.4 Gradient Wind: Balance Between P, f and C

In an **anticyclonic motion** P is directed outwards and f and C are directed inwards. The force C is provided by the difference between the forces f and P. Thus in an anticyclonic motion P > f and the actual wind V is greater than V_g for the same pressure gradient. Or in other words the gradient wind is **Super geostrophic** in an anticyclone

If isobars are straight and parallel gradient wind = geostrophic wind.

If Coriolis force is negligible gradient wind = Cyclostrophic wind

Isallobaric Wind. When the pressure changes rapidly, the geostrophic and gradient rules do not apply. In such a case another force called Isallobaric Force comes into play. This force is directed from higher isallobar to the lower isallobar. This deflects wind towards the falling pressure. The wind under the influence of P, f and the Isallobaric force is called the Isallobaric wind.

Inertial Wind

It is a frictionless flow under the balance between the Centrifugal Force and the Coriolis Force, and there is no Pressure Gradient Force. The constant Inertial wind speed V_i is given by

$$V_i = fR$$

where f is the Coriolis Force and R the radius of curvature (1/radius) of the path.

The inertial flow is Anticyclonic in both the hemispheres.

Effect of Surface Friction

The rough earth causes friction. Depending upon the wind speed, lapse rate and roughness of the surface, the effect of friction may extend in the atmosphere up to about 1 km. This layer is called **friction layer.** The thickness of this layer is variable. Within the friction layer the wind slows down and the Coriolis force reduces proportionately and is insufficient to balance the pressure gradient force. The wind is, therefore, **deflected towards the low pressure** and the flow becomes **cross isobaric,** Figure 6.5.

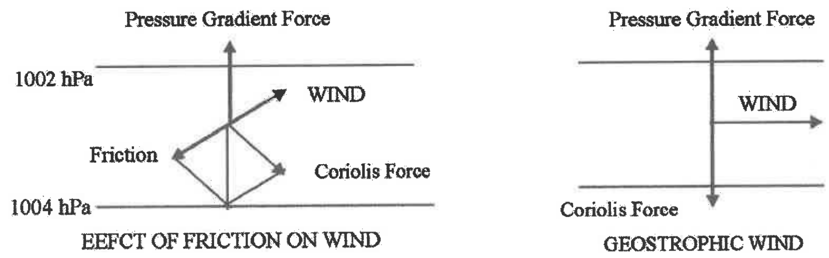


Figure 6.5 Effect of Friction on Geostrophic Wind

As a **rough rule**: over the sea, where friction is small, the surface wind blows at about 15° to the isobars while its speed is about 2/3 of the geostrophic speed. Over the land friction is greater, the inclination to the isobars is about 30° and speed is 1/3 to 1/2 the geostrophic value.

Turbulence and Gustiness

Wind is seldom steady. It fluctuates. The peak fluctuations are called the **Gusts** and the lowest the **Lulls**. The width of the fluctuations between gusts and lulls is an indication of the **degree of gustiness**. The air flow with such fluctuations is termed as **turbulent**.

Types of Turbulence

There are two types of turbulence or gustiness, viz. **Frictional and Thermal**. When the speed of the stream is low, the flow remains smooth or laminar, but when the speed surpasses a certain limit the flow becomes unstable. Eddies form and drift away into the stream, making the flow turbulent.

The **thermal** type of turbulence is caused by the convection currents due to surface heating. The heating may result from insolation over the land or from the passage of a relatively cool mass of air over a warmer land or sea surface.

Factors affecting Turbulence

The turbulence and the thickness of the friction layer are accentuated by flow over buildings, trees or rugged country. The eddies so created involve both vertical and horizontal velocities. They develop more easily when the lapse rate is steep. Open sea or relatively smooth ground, light wind and stable lapse rate are unfavourable for turbulence. The thermal turbulence is less on cool surface and stable atmosphere. Over land the turbulence is more by day when the lapse rate is steep and least on a clear night with an inversion.

Turbulence and Aircraft

To the occupants of an aircraft, turbulence is recognized as bumpiness. In turbulent conditions the landing and taking off of aircraft may be difficult due to sudden changes in wind.

Thermal Eddies

The eddies of thermal origin are often of large dimensions and produce stronger gusts than those produced by friction. They are more noticeable by occupants of an aircraft than the frictional eddies. They may also extend to considerable heights when the lapse rate is favourable.

Diurnal Variation of Surface Wind (effect of Temperature and Friction).

During day the convection due to ground heating creates thermal eddies. These eddies cause turbulence and stretch the friction layer upwards and slacken the frictional effect.

The turbulence enables the upper level strong winds, above the friction layer, to descend to the surface, making it **strong and gusty.** It also **backs** and is slightly weaker than the upper winds.

At night the thermals die down, and friction layer shrinks close to the surface. Due to friction the wind blows across isobars. Friction layer also prohibits strong upper winds to penetrate to the surface. The **surface wind** is, therefore, **weak and backs.** There may be marked **wind shear** around 500 m, with strong winds above and weak winds below, which is serious an aviation hazard.

The diurnal variation of temperature over sea is very little (about 1°C), and also over land under continuously overcast skies. The surface winds are thus nearly the same 24 hr.

The diurnal variation is most apparent in fine weather, clear night and sunny days.

Wind Shear (WS)

Definition.	The variation in wind vector along the path of an aircraft, which can displace the aircraft from its intended path.
Low Level WS	The WS along final approach, runway, take off path, and initial climb out flight path.
Vertical WS	The change in horizontal wind vector with height.
Horizontal WS	The change in horizontal wind vector with distance.
Up – Downdraughts	Change in vertical component of wind vector with distance

Causes of WS :

- **Thunderstorm (TS)**

(a) **Gust Front (GF).** The cold downdraught from TS spreads all around and creates GF as it meets the warm air near the ground. The GF may extend as far as 30 km in the direction of storm movement, and extend to about 6000 Ft from ground. Great turbulence and WS and are produced in the area, due to opposing winds and eddies.

(b) **Microburst.** It is a highly concentrated downdraught from TS, about 4 km across and lasts for 1-5 min. It is most hazardous and powerful. At times the difference between surface and the microburst winds can be 90 kt and their directions may also be opposite. It could be **Dry or Wet.**

Wet microburst occurs in the heavy downpour under TS, due to evaporation and cooling of the cold downdraught. The dry downdraught occurs from high based TS or under the overhanging AC or Anvil (CI) in the region of Virga. **Virga** is the rain shaft evaporating before reaching the ground.

- **Low Level Inversion.** Low Level Inversion develops in clear nights. The inversion may extend to about 1 km. In this friction layer, winds are weak, and the winds aloft are strong.
- **Gusty Surface Winds.** WS may develop due to strong gusts and lulls.
- **Solar Heating.** Intense solar heating cause, WS and turbulence due to up and downdraughts.
- **Topography.** When strong winds blow across natural and man made obstacles, like mountain ranges, high rise buildings, flow along valleys, etc., all lead to WS.
- **Fronts.** There is abrupt change of temperature and wind at a front. With the passage of a front strong WS is caused due to changing winds. The winds may become cross, head or tail wind. Ahead of a Cold front very strong winds may also be encountered.
- **Jetstream.** Strong vertical and horizontal WS are associated with jetstreams in upper air.

Effects of WS

Level Flight	-	If WS reduces head wind component, IAS will decrease and A/C will loose height
Descent	-	IAS will increase and A/C will gain height
Climb	-	IAS will decrease and A/C will loose height

Tail wind will reverse the effect. These effects are critical during landing and take offs.

LOCAL WINDS DUE TO TOPOGRAPHY

Anabatic and Katabatic Winds

During the day, a mountain slope is heated by the sun. The air in contact becomes warmer than the wind at the same level. It is therefore, lighter and tends to ascend the slope. Such ascending winds are called **Anabatic Winds**. As the Anabatic winds are masked by irregular convection, they may not be felt clearly, except where they are intensified by the funnel effect of a valley. In such cases they are called **Valley winds**. On a coastline an up-slope wind may be augmented by the sea breeze.

The reverse of Anabatic wind is the down slope **Katabatic Wind**. During night, due to nocturnal cooling the mountain slope becomes cold. The air in contact also becomes colder

than the wind at the same level in the free atmosphere, so it sinks. A down slope wind sets in, called Katabatic wind. It is a natural phenomenon. Even in gently sloping country cold Katabatic wind occurs on a clear quiet night. The speed of the wind may be not more than a few knots, but it forms pools of cold on low lying ground, causing local frost, mist and fog.

Over NE parts of India Katabatic winds are common and cause fog and TS in the morning.

If the mountain slope is snow covered, the Katabatic wind may occur during the day time as well as at night. **Bora**, an off shore wind on the northern shores of the Adriatic, is a Katabatic wind. It sets in suddenly, and frequently reaches well over gale force with gusts of over 100 kt. It is extremely dangerous to shipping and low flying aircraft. Similar winds also occur on the coast of Greenland and the shores of Black sea.

Fohn wind

If air is forced over the top of a mountain barrier, the adiabatic cooling may lead to the formation of cloud and precipitation. Within the cloud, the rising air cools at the saturated adiabatic lapse rate (SALR). If some of the condensed water falls

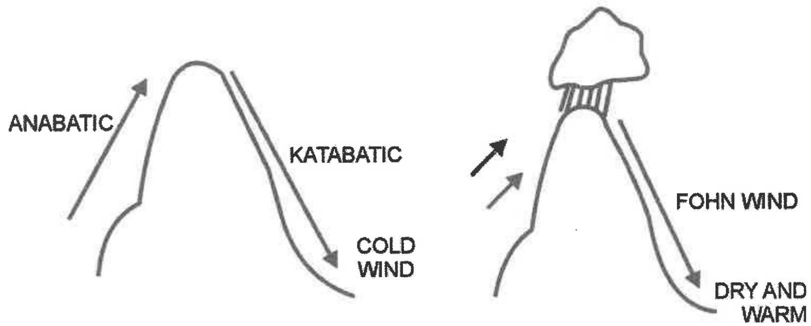


Figure 6.6 Anabatic Katabatic and Fohn Winds

out as precipitation and the air descends on the lee slopes, then the latent heat liberated during condensation is partly used to evaporate the cloud droplets in the descending air. After cloud disappears the descending air warms up at the dry adiabatic lapse rate (DALR). The more the precipitation on the mountain, the warmer the air gets on descent. The local name for these warm dry winds in the Alps is the Fohn.

In high mountains the Fohn wind may be 10°C or more warmer. The Chinook of the Rocky mountains is an example of Fohn wind. Dry wind may not produce Fohn wind. For Fohn wind to occur it is essential that: (a) there is substantial mountain range (b) wind blows within 30° of the range and (c) wind has high moisture content.

The **distinction between the Fohn and the Katabatic winds** is that the former is warm and dry, while the latter is cold. Both are down slope winds off high ground.

Ravine winds

These occur in and near narrow valleys. If there is a pressure difference, level for level between the two sides of the hills, air is impelled through the ravine by the pressure gradient. Such winds may be very strong in the ravine but also after leaving its mouth.

Land Breeze and Sea Breeze

Due to the diurnal variation of temperature in coastal areas, the wind blows from the sea towards the land during the day-time, called **Sea Breeze**, and from the land towards the sea during night, called **Land Breeze**.

After sunrise the land becomes warmer. The air over land starts rising due to convection. The pressure aloft becomes slightly greater than before. This causes the upper air to drift from the land towards the sea. The surface pressure over the sea slightly increases and reduces, over the land. In consequence a wind starts blowing from sea to land, as sea breeze. At night reverse happens due to radiative cooling and land breeze sets in.

The sea breeze often sets in abruptly a few hours after the sunrise. If there is an off-shore wind, its onset is delayed, until the afternoon. The breeze generally brings sharp fall in temperature and an increase in humidity. It is sometimes gusty. It gradually extends 15-25 km on either side of the coast line. Due to peculiar topography the sea breeze, may have greater extent over the land. Case in example is Pune, about 170 km from Mumbai, where sea breeze is observed in the afternoons. In tropics and subtropics, it occurs as a routine.

The sea breeze is initially perpendicular to the coast, later on as the Coriolis effect becomes apparent, it tends to align along the coastline, with land on the left (right in the S - hemisphere). It weakens after sunset and after a few hours is replaced by the land breeze. In tropics the land breeze is light and does not develop with regularity of the sea breezes.

On certain occasions the effect of the sea-breeze extends to 3000 or 5000 feet. The warmer air from the land lifts over the cooler air from the sea and a line of small cumuliform cloud

develop. It has small dimensions and although of use to glider pilots, its effect goes unnoticed by powered aircraft. The land breeze is shallower than sea-breeze, and does not extend above a few hundred feet.

Thermal Wind

The thermal wind in a layer is **defined** as that wind which must be added vectorially to the geostrophic wind at the lower level in order to obtain the geostrophic wind at the upper level.

Is may be recalled that the **rule for vector addition** is: Draw one vector, from the head of this vector draw the other vector. Join the tail of the first vector to the head of the second vector.

For vector **subtraction** the above rule applies, except that the direction of the second vector is reversed, as in Fig 6.7

Thermal Wind (Vt) is the vector difference of lower level geostrophic wind (Vo) from the upper level geostrophic wind (V1), which blows parallel to isotherms, keeping **low temperature to the left** in the N hemisphere.

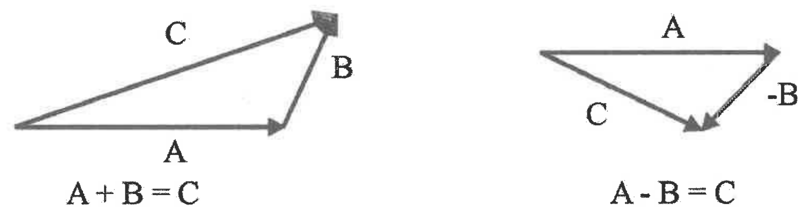
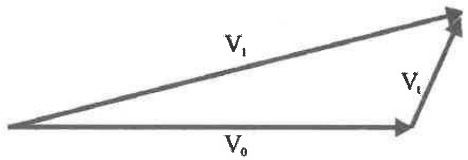


Figure 6.7 Vector addition and subtraction

Thermal Wind is the vertical wind shear in a layer. The term thermal wind has been adopted because the wind shear is determined by the mean temperature in the layer. It is a fictitious wind which blows parallel to the thickness lines (mean isotherms) keeping low thickness (low temperature) on the left in the N- hemisphere. The speed of Thermal wind is proportional to the temperature gradient.



$$V_t = V_1 - V_0$$

Figure 6.8 Thermal Wind

Example: Calculation of Upper Level Wind

Lower Level Wind	Thermal Wind	Upper Level Wind will be
270/10kt	270/15 kt	270/10kt +270/15 kt = 270/25 kt
270/10kt	090/15 kt	270/10kt + (-270/15 kt)
		= -270/05 kt = 090/05 kt

Table 6.1

If the south is warm and the north is cold, a temperature gradient acts from S to N. In such a case the thermal wind will be westerly. If such temperature distribution continues in the higher levels also, the thermal wind will continue to be westerly from level to level and keep on increasing with height. The subtropical westerly Jet stream is an example of thermal wind.

Wind and Contours

The lines joining equal heights are called **Contours**. Over warm atmosphere a contour will be at a higher height and over cold at lower height. Heights of a particular pressure value, say 500 hPa, vary from place to place depending on the variations in temperature.

The contour lines depict centres of High and Low heights, in exactly the same way as height of ground is indicated on a survey map.

A contour line is horizontal and the pressure is the same at all the points on the line. Thus a contour line, of height say 5520 m, is an isobar in the horizontal surface at that height. The

geostrophic wind blows along the contours with the lower value contours on the left in the N hemisphere and on the right in the S hemisphere.

The contour charts can be used for determining cyclostrophic and gradient winds. The limitations of the geostrophic rule equally apply to the contour charts.

Variation of Wind with Height

The temperatures in the troposphere decrease from the equator towards the poles. Therefore the **thermal wind throughout the troposphere blows from the west and the Wly component increases with height.** In the upper troposphere the winds are therefore, mainly Wly.

Over India Easterly winds prevail above 500 hPa level during the monsoon months (June, July, August and September), which strengthen with height. They are weaker over N India and stronger over the S India. Tropical Easterly jetstream lies near 13N latitude at about 15 km. Its position, however, fluctuates N and S during the season.

Outside tropics low level westerly winds usually increase with height with little change in direction. On the other hand easterlies tend to weaken and eventually become westerly. Due to this the easterlies are often shallow.

A westerly thermal wind also implies that **northerly winds would back with height** and **southerly winds would veer**.

In winters, the speed of the westerlies above the tropopause reduces and eventually become Ely, which strengthen with height. The strongest westerlies in troposphere occur at about 40,000 ft in a belt between 25 N - 40N. Due to weak thermal gradient in summer this belt of stronger winds shifts to 40 - 45N. There is almost similar distribution of winds in the S hemisphere but with a smaller seasonal variation in speed.

In the low stratosphere in winters, temperature is lowest in polar regions and maximum between 40° and 60° latitude. Hence, westerly winds increase with height from the troposphere into the stratosphere. In lower latitudes, equatorwards of the temperature maximum, westerly decrease with height above the tropopause.

In the summer hemisphere, temperatures in the stratosphere are highest in the polar regions and lowest over the tropics resulting in an easterly thermal wind.

Vorticity

Vorticity is a measure of rotation or turning. The rotation can be cyclonic or anticyclonic.

Vorticity plays an important role in the formation and development of weather systems, such as cyclones, depressions, anticyclones. Change in Vorticity causes divergence and convergence. It is caused by:

(a) **Horizontal Wind Shear**: When a belt of strong winds lies along side a belt of lighter winds, the faster flow rotates around the slower flow. It may be cyclonic or anticyclonic, depending on the orientation of the two flows.

(b) **Curvature of the Flow**: Flow around a curve has cyclonic Vorticity when air deflects to its left (as in a trough) in the N hemisphere and anticyclonic (as in a ridge) when it deflects to right.

(c) **Rotation of the Earth**. Earth rotates from W to E (anticlockwise, which is cyclonic for N-hemisphere). Hence the Vorticity due to earth is cyclonic in both the hemispheres.

Absolute Vorticity. It is the sum of all the above vorticities. Since Vorticity due to earth is always cyclonic, and it predominates, the **absolute Vorticity is always cyclonic**.

Beaufort Scale (For details of BF see at the end of this chapter)

Names of Winds of the World

Bora- Cold Katabatic wind that originates in the mountains of Yugoslavia and NE Italy and flows in the coastal plains of the Adriatic sea.

Burans- (Russian Burans Turkish Boran): Strong NEly wind in Russia and central Asia. It occurs most frequently in winters and often blows snow (is then called 'Purga').

Chinook. Warm dry Wly wind on the eastern side of Rocky Mountains.

Doldrums - Calm wind near Equator where opposing trade winds converge.

Haboobs- (Arabic hubbub: blowing furiously): Any strong wind which raises sand into a sand storm, particularly in Sudan.

Harmattan. Hot dusty NEly wind in central Asia.

Khamsin: Oppressive, hot, dry, often laden with sand, Sly wind over Egypt Apr -June.

Mistral: A well known Katabatic wind which descends from snow clad Alps down the Rhone River Valley of France and into Gulf of Lyons along the Mediterranean coast.

Monsoon. Any markedly seasonal wind, particularly in E and SE Asia.

Roaring Forties. These are Wly winds which blow in both the hemispheres between 35° and 60° lat. In S hemisphere they are of a very stormy nature beyond 40° lat. throughout the year. In the olden days sailors called them **Roaring Forties** or **Brave West Winds**, **Furious Fifties**, and **Crying Sixties**, since these winds created very noisy surroundings and were not favourable to them.

Trades. Steady wind blowing between latitudes 10° and 30° from the NE in N hemisphere and from SE in S hemisphere. They were of importance to sailing ships, hence were called **'wind that blows trade'** by navigators in 18th century. Trade winds change direction according to seasonal shift in the high - pressure belts.

QUESTIONS ON WIND

Q1. In S hemisphere if an observer faces wind, low will be to his ....
(a) Right (b) Left

Q2. In N hemisphere due to rotation of earth winds are deflected to ....
(a) Left (b) Right

Q3. Local Winds follow Buys Ballots law .....
(a) False (b) True

Q4. Coriolis force acts perpendicular to the .... of wind direction in N hemisphere
(a) Left (b) Right

Q5. Geostrophic wind is due to the balance between the forces ....
(a) Coriolis and Frictional
(b) Pressure gradient and Cyclostrophic
(c) Pressure gradient and Coriolis

Q6. Coriolis force is strongest at ....
(a) Mid latitudes (b) Poles (c) Equator

Q7. Geostrophic rule breaks down at ....
(a) Mid latitudes (b) Poles (c) Equator

Q8. Fohn winds are .... on the Leeward side of a mountain.
(a) Dry &Warm (b) Cold & Humid

Q9. The wind sliding down a hill during night is called .... wind.
(a) Fohen (b) Anabatic (c) Katabatic

Q10. With the onset of sea breeze there is a .... in temperature and .... in RH.
(a) Fall/Rise (b) Rise/Fall (c)Fall/Fall

Q11. Sea breeze sets in by .... and dies off at ....
(a) Night/Day (b) Day/Night (c) Both Day and Night

Q12. If an aircraft in N-hemisphere flies from H to L it will experience
(a) Starboard drift (b) Port drift

Q13. In N-Hemisphere if you experience Port drift, altimeter will read
(a) Under (b) Over

Q14. Lines of constant wind speed drawn on weather charts are called
(a) Isobars (b) Isotachs (c) Isogons

Q15. Squall are distinguished from gusts by:
(a) Shorter duration (b) Longer duration (c) Lower wind speed

Q16. The thermal wind is:
(a) The wind that blows because of thermals
(b) The warm wind that blows down the hill on the leeward side
(c) The wind which must be added vectorially to the lower level geostrophic wind to obtain the upper level geostrophic wind

Q17.On a weather map if isobars are closely packed, the surface winds are likely to be
(a) Light and parallel to isobars
(b) Strong and parallel to isobars
(c) Strong and blowing across the isobars

Q18. Anabatic wind occurs
(a) At night (b) Any time of day and night (c) During day

Q19. Anabatic wind is stronger than katabatic
(a) True (b) False

Q20. Katabatic wind is down slope cold wind due to nocturnal cooling
(a) True (b) False

Q21. Katabatic wind occur due to sinking of cold air down the hill slope
(a) True (b) False

Q22. Anabatic wind occur due to downward movement of air along valley
(a) True (b) False

Q23. Sea breeze is stronger than land breeze
(a) True (b) False

Q24. The wind blows clockwise around a low in N-hemisphere
(a) True (b) False

Q25. The wind blows clockwise around a low in S-hemisphere
(a) True (b) False

Q26. The wind blows anticlockwise around a low in N-hemisphere
(a) True (b) False

Q27. The wind blows anticlockwise around a low in S- hemisphere
(a) True (b) False

Q28. The resultant wind that blows under the influence of pressure gradient force, geostrophic force and cyclostrophic force is called
(a) Gradient wind (b) Geostrophic wind (c) Cyclostrophic wind

Q29. Due to friction, from day to night for an isobaric pattern (in N hemisphere) the surface wind backs and weakens
(a) True (b) False

Q30. The winds which spirals inward counter-clockwise in the N Hemisphere are associated with
(a) Turbulence (b) High pressure area (c) Low pressure area

Q31. Lower level wind 05010 kt, upper level wind 23005 kt, what is the thermal wind
(a) 05005 kt (b) 23015 kt (c) 05015 kt

Q32. A change in wind direction from 310° to 020° is
(a) Backing (b) Veering

Q33. A change from 270° to 250° is
(a) Backing (b) Veering

Q34. Sudden changes in wind speed from 10 kt to 30 kt and then to 15 kt are
(a) Gust (b) Squall (c) gale

Q35. Sudden change in wind speed from 10 kt to 30 kt for 2 - 3 minutes
(a) Squall (b) Gust

Q36. A significant wind shear is generally associated with TS or line squall
(a) False (b) True

Q37. Cyclostrophic wind gives a good approximation of the 2000' wind in an intense tropical storm
(a) True (b) False

Q38. Rotor clouds have extremely turbulent flying conditions
(a) False (b) True

Q39. Friction causes winds to flow cross isobaric by .... over land and .... over sea
(a) 20°/10° (b) 30°/15° (c) 40°/30°

Q40. If the S is warmer than the N, level by level, from surface up to higher levels, then the .... wind will strengthen with height with no change in direction in N hemisphere
(a) Ely (b) Wly (c) Sly (d) Nly

Q41. Gradient wind is .... of the geostrophic wind in an anticyclone
(a) Under estimate (b) Accurate (c) Over estimate

Q42. Gale is
(a) Persistent strong winds with mean speed 44 kt, associated with thunderstorm
(b) Marked increase in wind speed lasing few minutes associated with CB or DS
(c) Persistent strong winds exceeding 33 kt, associated with depression

Q43. In N hemisphere thermal wind is parallel to .... with low value to left
(a) Isobars (b) Isotherms (c) Isallobars

Q44. The inertial flow is
(a) cyclonic in both the Hemispheres
(b) anti cyclonic in both the Hemispheres
(c) anti cyclonic around an anticyclone

Q45. Upper level wind is 24025 kt, lower level wind is 06015 kt, the thermal wind is?
(a) 16010 kt (b) 24040 kt (c) 24010 kt

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**b**	**b**	**a**	**b**	**c**	**b**	**c**	**a**	**c**	**a**	**b**	**a**	**a**
Q.	14	15	16	17	18	19	20	21	22	23	24	25	26
A.	**b**	**b**	**c**	**b**	**c**	**b**	**a**	**a**	**b**	**a**	**b**	**a**	**a**
Q.	27	28	29	30	31	32	33	34	35	36	37	38	39
A.	**b**	**a**	**a**	**c**	**b**	**b**	**a**	**a**	**a**	**b**	**a**	**b**	**b**
Q.	40	41	42	43	44	45							
A.	**b**	**c**	**c**	**b**	**b**	**b**							

The **Beaufort Force (BF) Scale** as adopted by Admiral Beaufort to estimate wind force is as follows:-

BF Scale		**Speed at 10 m (kt)**	**BF Scale**		**Speed at 10 m (kt)**
0	Calm	<1	7	Near Gale	28 – 33
1	Light air	1 - 3	8	Gale	34 – 40
2	Light breeze	4 - 6	9	Strong Gale	41 – 47
3	Gentle breeze	7 - 10	10	Storm	48 – 55
4	Moderate breeze	11 - 16	11	Violent Storm	56 – 63
5	Fresh breeze	17 - 21	12	Hurricane	64 or more
6	Strong breeze	22 - 27			

7. VISIBILITY AND FOG

Visibility on the ground and from the air are of great importance to a pilot for landing and take off. He is interested to see various land marks, targets, obstructions, beacon lights, other aircraft, runways etc, while in flight and during approach and landing. Poor visibility is a serious aviation hazard. Even at the airfields where Instrument Landing Systems (ILS) are installed, a pilot would prefer better visibility conditions for safe landings and take offs.

Definition Visibility for aeronautical purposes is the greatest of:

The greatest distance at which a black object of suitable dimensions, situated near the ground, can be seen and recognized when observed against the bright background.

The greatest distance at which lights in the vicinity of 1,000 candela can be seen and identified against an unlit background.

In simple terms it is **the distance up to which prominent objects can be seen by naked eye and recognized as such under natural light**.

Visibility Reports

The visibility reported by a Met Office is the lowest **horizontal visibility** at an airfield. It may be different in different directions due to varying amounts of atmospheric obscurities. This visibility may also differ from **vertical and slant** visibilities, as estimated by an aircraft while in-flight.

During Day visibility is estimated by seeing the runway markings and objects at pre-measured distances, along the runway, within and around the airfield. **At night** it is estimated from the existing lights at known distances in and around the airport. These are called **Visibility Land Marks**.

Runway Visual Range (RVR)

It is the range over which the pilot of an aircraft on the centre line of runway can see runway markings or the lights delineating the runway or identifying its centre line.

The airports having RVR equipment, installed along various runways, measure RVR close to the takeoff and landing areas. RVR is reported when the visibility or RVR **is less than 1500 m**. RVR 2000 and 1500 are included in METAR as supplementary information, but not disseminated internationally.

Causes of Poor Visibility

The surface visibility is reduced by the atmospheric obscurities, such as smoke particles, sea spray, dust, industrial particles, vehicular emission, Volcanic Ash etc. The weather phenomenon which affect visibility are:

Haze. Haze is a suspension of very small particles of smoke, dust, water, etc. Visibility in haze is **5000 m or less**. It gives a milky appearance to the atmosphere.

Dust Haze. Dust kicked up by strong winds, especially in desert and semi-arid areas, is suspended in the air, causes Dust Haze. It is thicker during day time than at night because at night the winds weaken and part of the dust settles down. It is a summer hazard. Dust haze is usually widespread and diversionary airfields in the vicinity are also equally affected. Sometimes the Dust haze may extend from Rajasthan to Punjab, Haryana, UP, Bihar and adjoining states. Vertically it may extend to 6-8 km.

Smoke Haze. Smoke from industrial or domestic sources spreads as a haze layer, especially when the wind is calm or very light and there is strong ground inversion.

Mist. Mist is the suspension of water droplets in the atmosphere. In mist visibility is **at least 1000 m but not more than 5000 m**. In mist RH is almost 100%.

Fog. It is the suspension of water droplets or ice crystals in the atmosphere. In fog visibility reduces to **less than 1000 m and** RH is nearly 100%. Fog is classified as: Thick, Moderate, Light. **Fog is the cloud sitting on ground**. Fog occurs due to condensation of water vapour present in the layers of air close to the ground. The condensation can occur either by cooling of the air to dew point or by feeding moisture into the air to saturate it.

Smog. When fog and smoke haze co-exist it is called smog. In smog visibility is very poor. It severely limits visibility and is a health hazard.

Dust Storm. The visibility in a dust storm is **5000 m or less**. If the dust storm is followed by rain visibility improves fast.

Sea Spray. Under the favourable wind conditions salt particles get sprayed from wave crests in the lower levels, which encourage condensation. The water drops so formed can reduce visibility considerably. In rare cases a thin layer of salt may form on the wind screen of an aircraft flying at low level and render forward visibility to almost zero. Salt spray may also reduce visibility during monsoons and cyclones in the coastal areas.

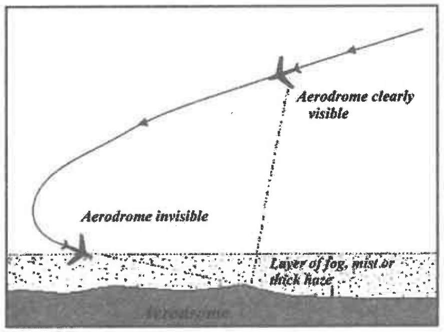


Figure 7.1 Obscuring of an aerodrome through surface fog as an aircraft descends

Volcanic Ash (VA). Volcanic ash consists of solid matter emerging from a Volcano. The thick ash is carried by the winds to large distances and remains suspended in the air for a long time. Surface and inflight visibility are reduced to almost nil. VA can cause serious damage to engine and other parts of aircraft. It severely restricts flying. Volcanoes are active in Japan, Philippines, Indonesia, America, Mexico, Iceland, Russia, etc. Indian Volcano at Barren Island (12.16N 93.51E), last erupted in 2009, and Baratang (12N 93E), last erupted in 2005, in Andaman Seas are not very active.

Precipitation. The visibility in rain depends on its intensity and the drop size. In moderate rain visibility may reduce to 1-3 km, in heavy rain or showers to less than 1000 m, in drizzle to 3 km or less and during snowfall it may lower to < 1000 m.

Vertical and Slant Visibility

Haze and fog layers are generally confined to a few thousand feet above ground level. In a shallow layer of haze or fog, the horizontal visibility is poor. A pilot flying over an airfield above a shallow fog layer may see the airfield clearly, through a vertically thinner layer of fog, but on approach for landing, his view being slant, he has to see through an elongated layer of fog and he may loose the sight of the runway. In such a case **Vertical Visibility** may be good but **Slant visibility** is poor. This is illustrated in figure 7.1 above.

As one goes higher and higher the transparency of the atmosphere increases considerably, except in cloud and precipitation. **Visibility is lower looking towards the sun is better into the moon**, due to reflection of the moon light.

Instruments for Measuring Visibility

Scopograph or Transmissometer are used for measuring visibility along the different runways on an aerodrome. The RVR equipment are installed along various runways close to take off and landing areas. The equipment consists of a light source and a photoelectric receiver, which generates electric current according to the obscurities present between the receiver and the source. The current so generated gives a measure of RVR. The display units are located in the Met Office and ATC Tower. At some of the Indian Met Offices, Automatic Visual Range Assessor (AVRA) is used for measuring RVR.

TYPES OF FOG

Radiation Fog

Radiation fog forms due to the nocturnal cooling of the ground and the adjacent air layers. It is essential that the cooling should lower the temperature below the dew-point. If the wind is light, there is no turbulent mixing. The cooling of the ground is unable to extend upwards at a sufficient rate. In such cases the moisture close to the ground settles down as **dew**. If the wind is strong the cooling may extend upwards due to turbulence to too thick a layer. The temperature may not fall sufficiently for fog formation. In such cases **stratus cloud** may form at the top of the layer of turbulence.

For fog formation a delicate balance is required between the rate of cooling and the degree of turbulence, which depends on the wind speed and roughness of terrain. This is the reason why under almost identical meteorological conditions one locality may have fog while another close-by may be free from fog.

Favourable conditions for Fog Formation

(a) **High Relative Humidity**: This is necessary so that little cooling is required to reach the dew-point, and condensation of water vapour to occur.

(b) **Clear Sky**: Clear skies permit maximum nocturnal cooling of the ground and adjacent layers of the air.

(c) **Light Wind**: Surface wind of 3-7 kt enables turbulent mixing and cooling of the layers close to the ground and bring their temperature to the dew-point.

(d) **Stability**. A generally stable atmosphere, so that mixing and cooling are confined to a shallow layer.

In Anticyclone, Ridges, Cols and ground Inversions the wind is light, there is subsidence and stability and the skies are clear. Fog would form if the air has adequate moisture.

Radiation fog forms even when the RH is less than 100% due to the presence of hygroscopic condensation nuclei, on which condensation occurs prematurely.

The minimum temperature occurs usually just after sunrise. At about the same time there is slight strengthening of the wind. **Fog formation is, therefore, most frequent at about sunrise or it thickens at that time**. The radiation fog dissipates about two- three hours after sunrise due to heating, but if it is deep, the sun's heat may take longer to penetrate to the ground, and the fog may last till about midday. Fog usually lifts into low stratus clouds before finally dissipating.

Radiation Fog in India is a winter hazard. It usually forms after the passage of a Western Disturbance, which caused rain and then sky cleared. It is almost a daily feature in winters in the valley of the Brahmaputra river where adequate moisture is present and Katabatic flow provides the required turbulence and additional cooling. The most susceptible areas of radiation fog are: NW India, UP, Bihar, Jharkhand, Chhattisgarh, Bengal and Assam (particularly Southern banks of Brahmaputra river).

Vertical Extent of Radiation Fog

Vertically radiation fogs extends to only a few hundred feet to 1500 ft, may be to a maximum of 1 km. The upper surface of fog is sharp with clear air above.

Pressure Systems Associated with Radiation Fog

A High or Col with weak pressure gradient is favourable for fog formation. Fog does not form when the pressure gradient is steep and low level winds are strong.

Advection Fog

Advection fog forms when **warm moist air from elsewhere is transported over the cold surface** (ground or water) where the surface temperature is less than the dew point of the advected air. **Advection fog forms both over land and sea**. The coastal fogs of Bengal and Orissa in the winters are due to a combined effect of advection and radiation. The Brahmaputra valley, Sunder Bans, the coastal belts and the hills of Indian Peninsula experience advection fog.

Steaming Fog

This type of fog occurs in high latitudes when cold air mass flows over a warm sea surface. The water vapour from warm sea when comes in contact with the cold air aloft condenses to form steaming fog. It is common over frozen land, ice covered polar regions and in Icelandic and Norwegian regions. Over sea, it is often referred to as **sea smoke**. It looks like the steam coming out of the surface.

Frontal Fog

Frontal fog forms near the front due to the saturation of the air near the surface in the area of continuous rain ahead of a front. It also forms due to the lowering of cloud to the surface with the passage of a front.

Fog Dispersal

Thermal Method. When air is heated to temperature above the dew point, fog or clouds will dissipate. During the Second World war heaters, burners, fires were used to disperse fog but the method involved large expenditures and was discontinued.

Use of Hygroscopic Nuclei. When hygroscopic particles are injected into fog water drops form. This lowers the RH of the air leading to dissipation of fog.

QUESTIONS ON VISIBILITY AND FOG

Q1. Fog is reported when visibility is reduced to
(a) Less than 1000 m (b) 1000m (c) 1000 to 2000

Q2. RVR is reported when visibility falls below
(a) 500 m (b) 1000 m (c) 1500 m (d) 2000 m

Q3. Radiation fog occurs
(a) Over land (b) Over sea (c) During day

Q4. When visibility reduces between 5000 m and 1000 m and RH is almost 100%, it is
(a) Mist (b) Haze (c) Fog

Q5. Radiation Fog forms over N India during
(a) May to June (b) Dec to Feb (c) Oct to Nov.

Q6. Warm and moist air moving over a cold ground gives rise to:
(a) Thunder clouds (b) Fog and stratus (c) Frontal clouds

Q7. Warm and moist air moving over a cold surface causes
(a) Radiation Fog (b) Advection Fog (c) Frontal Fog

Q8. The radiation fog forms due to
(a) Heating of the earth during day
(b) Radiational cooling of earth at night
(c) Advection of cold air

Q9. The radiation fog activity increases after the passage of a ....
(a) WD (b) Depression (c) Col

Q10. Radiation fog is essentially a .... phenomena
(a) Nocturnal (b) Dusk (c) Day

Q11. The radiation fog forms over ....
(a) Water (b) Land (c) Both

Q12. The ...... fog forms due to horizontal movement of warm moist air over cold surface
(a) Radiation (b) Advection (c) Frontal

Q13. Advection fog forms during
(a) night only (b) day time only (c) any time of day and night

Q14. For formation of Radiation fog
(a) There should be sufficient moisture in atmosphere, cloudy sky, nil wind
(b) There should be sufficient moisture in atmosphere, clear sky, light wind.
(c) There should be sufficient moisture in atmosphere, cloudy sky, strong wind.

Q15. Instrument used for measuring visibility is called
(a) Visiometer (b) Transmissometer (c) Ceilometer

Q16. Advection fog forms
(a) over sea (b) over Land (c) both over land and sea

Q17. Fog is .... cloud on ground
(a) Stratocumulus (b) Stratus (c) Nimbostratus

Q18. Frontal Fog is more common with a
(a) Western Disturbance (b) Cyclone
(c) Warm Front (d) Cold Front

Q19. The favourable pressure system for formation of fog is
(a) Lows and Cols (b) High and Trough
(c) Lows and Ridges (d) Highs and Cols

Q20. Thermal processes / temperature distribution which favours formation of fog is
(a) Isothermal (b) Adiabatic (c) Inversion (d) SALR

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**a**	**c**	**a**	**a**	**b**	**b**	**b**	**b**	**a**	**a**	**b**	**b**	**c**

Q.	14	15	16	17	18	19	20
A.	**b**	**b**	**c**	**b**	**c**	**d**	**c**

8. VERTICAL MOTION AND CLOUDS

VERTICAL MOTION

Compared to the horizontal motion of the air (Wind) the vertical motion is of very little magnitude, yet its importance in causing weather is no less. The vertical motion of air in the atmosphere is important for aviation, as it causes weather, turbulence, convergence, divergence, wind shear etc. Vertical motion induced by fractional turbulence is an important factor in generation of fog and clouds. For aviation, frictional turbulence at low levels assumes special significance during landing and take-off.

Types

Localised Vertical Motion. Local vertical motion is caused by the friction, terrain and convection. The occurrence of Sea/Land Breeze, Katabatic Winds, Anabatic Winds, Valley Winds etc are due to the local vertical motion. Mostly the local vertical motions are confined to a few kilometers only, except in case of Thunder storms.

Large Scale Vertical Motion. Large scale vertical motion is caused by the pressure systems, frontal systems, upper air troughs and ridges and mountains. It may extend to hundreds of kilometers horizontally and to great heights. The vertical motion due to mountain waves may even extend to upper stratosphere.

Causes

Frictional Eddies. Ground friction disrupts the smooth airflow and produces a number of small circulations, called eddies. They could be horizontal, vertical or slant. In an unstable atmosphere these eddies grow and may ascend to about 1 km height.

Terrain. Air flow across mountains causes air to ascend on the windward side and descend on the leeward side. These vertical motions are accentuated due to instability and are damped due to inversion. When winds are strong, mountain waves are produced on the leeward side. Eddies form on both the slopes of a mountain. The disturbance due to mountain waves sometimes extends to upper stratosphere where Nacreous Clouds form due to transported water vapour from the lower levels.

Convection. Heating of the ground causes air to rise as convection cells. These are called thermal eddies or thermals. Gliders use them to their advantage. Thermal eddies cause bumpiness and also favour the formation of convection clouds (CU and CB), in which there are strong up and down draughts.

Pressure Systems. All the pressure systems viz. low, cyclone, anticyclone etc cause large mass of air to ascend or descend over a wide area. These generate weather and affect air operations. Such systems also cause convergence and divergence.

Frontal Zones. Fronts provide sloping surfaces along which wind rises. Along a warm frontal surface the vertical motion is gradual over a large area. Along a cold frontal surface there is abrupt and sharp upward motion leading to convection, TS and squally weather.

Wind Shear. Vertical wind shear produces strong eddies and turbulence. The Clear Air Turbulence (CAT) associated with the Jet Stream is due to vertical wind shear. The effect is amplified over the mountains due to the Mountain Waves.

CONVERGENCE AND DIVERGENCE

Convergence

Convergence occurs when there is a net horizontal inflow of air into a region. The air accumulated due to convergence (called velocity convergence) and causes ascent of air near the ground whereas in the upper levels, the convergence may lead to both upward and downward motion, especially below tropopause (stratosphere being stable acts as a barrier). Lows, cyclones, depressions and troughs are associated with convergence which cause upward motion and bad weather but better visibility, except in precipitation.

Divergence

A net out flow of air it is called divergence. For example wind to the West of a station is Wly 10 kt and to the East is Wly 20 kt. In this case less wind is entering a place and more is outflowing, hence divergence (also called velocity divergence). In the upper air the divergence causes subsidence. Anticyclones and ridges are associated with divergence leads to fine weather, but poor visibility conditions.

CLOUDS

Cloud is an aggregate of visible water droplets or ice particles. Clouds form by adiabatic lifting and cooling of air until water vapour condenses as water drops or **deposits** as ice particles. The height at which this occurs is called **Lifting Condensation level (LCL)**. **Deposition** is the process by which water vapour directly changes into ice particles.

Clouds are continuously evolving and decaying. They present unlimited variety and forms. The recognition and understanding of various characteristics and peculiarities of clouds are essential for safe conduct of air operations. To fully appreciate the state of sky, an aviator should be familiar with their classification, names, appearance, nature and associated aviation hazards. Photographs of a few clouds are presented at Appendix H.

Classification

There are 10 major **genera** of clouds. They are classified on the basis of **Form** and **Height**. By Form they are **Stratiform, Cumuliform** and **Cirriform**. According to Height they are placed in three categories:

(a) **High Clouds**. These clouds form at a height of 6-18 km, in tropics. They consist of ice crystals and some of them may cause precipitation which remains confined to high/medium levels only. They give an advance indication of impending weather.

(b) **Medium Clouds**. In tropics they occur at about 2-8 km and contain water droplets and ice crystals. They cause snow and rain.

(c) **Low Clouds**. These clouds occur below 2 km. They consist of water droplets or ice crystals.

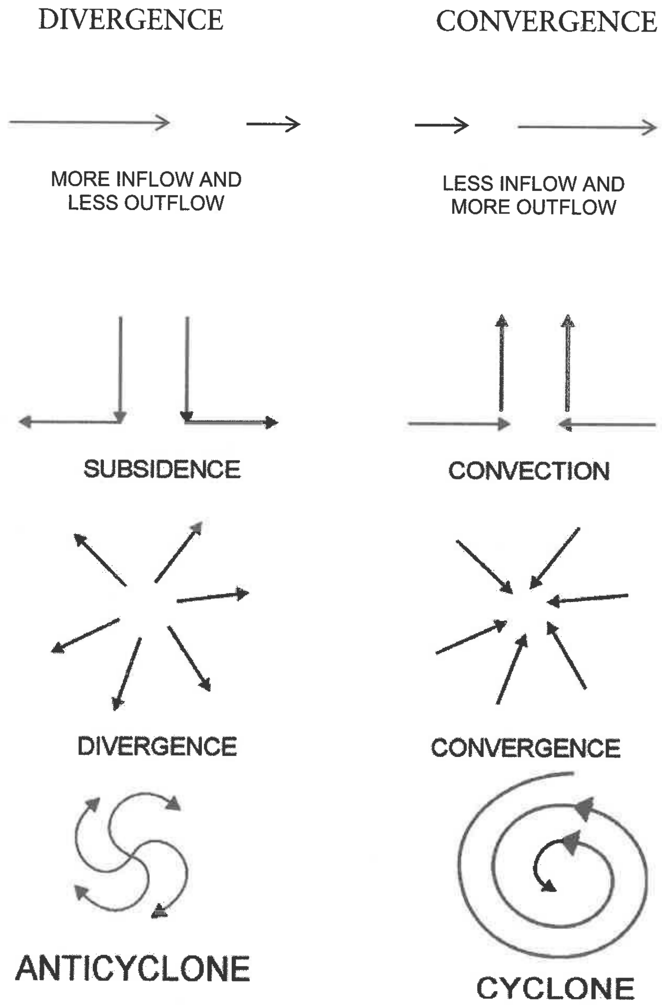


Figure 8.1 Divergence and Convergence

High Clouds

Cirrus (CI). These clouds are white and fibrous delicate filaments or patches or narrow bands**.** They are composed of ice crystals. They do not cause precipitation or ice accretion.

Cirrostratus (CS). CS clouds are thin whitish veil of fibrous or smooth appearance, composed of ice crystals. They cover almost the whole sky. They generally produce **Halo,** a coloured circular ring around the sun or moon with violet colour inside. When thick they may cause snow fall, which remains confined to high and medium levels. They hardly cause any ice accretion.

Cirrocumulus (CC). CC clouds are thin, white, wave like very small puffs, composed of ice crystals. They are more or less regularly arranged. The sky is visible in between the puffs. They do not cause precipitation and hardly any ice accretion.

Medium Clouds

Altocumulus (AC). These are white–grey clouds, composed of patches, puffs, rounded masses, rolls, etc. The round masses are generally well arranged in long waves, rows or lanes. The sky is visible in between the puffs. Altocumulus Lenticularis are lens shaped clouds, which form at the crests of mountain waves on the leeward side of high mountains. They do not cause precipitation but may cause ice accretion.

Altostratus (AS). These are uniformly grayish or whitish cloud sheets or layers of fibrous appearance. They totally or partly cover the sky. If thin, they reveal the sun, as through ground glass. Optical phenomena Corona occurs in these clouds. Thick altostratus causes continuous rain or snow. Ice accretion is possible below freezing temperatures.

Low Clouds

Stratus (ST). A gray cloud layer with a uniform base. ST clouds may stretch from horizon to horizon. ST may give **drizzle**, ice prisms or snow grains. ST cloud touching the ground or sitting on the ground is called Fog. In bad weather sometimes ST is in the from of ragged patches or small fractures, called **Fracto Stratus**.

Stratocumulus (SC). These are low clouds of large, irregular puffs or rolls, gray or whitish in appearance. SC clouds are regularly arranged.

Nimbostratus (NS). These are dark grey and thick cloud layer, causing **continuous rain or snow**. They are thick enough to blot out the sun. Usually extend both medium and lower levels. Ice accretion is possible below freezing temperatures. Ice Pellets fall from thick NS clouds, especially in Warm Fronts. Ice pallets are transparent ice particles, spherical/ irregular in shape of about less than 5 mm dia.

Clouds with Vertical Development

Cumulus (CU): CU are detached clouds, generally dense with sharp outlines. Their base is dark and nearly horizontal. They develop vertically as rising mounds, domes or towers. The bulging upper part of CU often resembles a cauliflower. The sunlit parts of these clouds are brilliant white. Sometimes cumulus is ragged. A well developed CU with great vertical extent is termed as **Towering Cumulus (TCU).**

Fair Weather Cumulus: These clouds have limited vertical extent and they do not cause precipitation. They are caused by thermal currents due to surface heating. Hence they occur during day time only. They develop in the forenoon, reach maximum development in the afternoon and dissipate in the evening.

Cumulonimbus (CB): Heavy and dense cloud of large vertical extent, as mountains or huge towers. Part of its upper portion is usually smooth, fibrous and nearly flattened and spreads out as anvil. The base of this cloud is often very dark, under which there are low ragged cumulus fractus or stratus fractus clouds. Sometimes the precipitation is seen as **Virga** (ie a shaft of rain or snow falling from a distant cloud which vapourises before reaching the ground). CB cause all type of precipitation viz. RA, SH, GR, SN. This cloud is the most hazardous for aviation, and should be avoided.

Very High Level Clouds

Nacreous Clouds (Mother of Pearl Clouds). Observations of nacreous clouds are infrequent, and are mainly from Scotland and Scandinavia. These clouds resemble cirrus or altocumulus Lenticularis. They show very strong irisation (rainbow coloured patches) and may be composed of ice crystals or supercooled water droplets. They form in the upper Stratosphere.

Noctilucent Clouds. These clouds resemble cirrus but have a bluish or silvery and sometimes orange to red colour. They occur in the upper Mesosphere (between 80 and 85 km). They are visible soon after sunset and just before sunrise between 72° N and 45° N, but mostly around 55°N, in summers (late May - mid August). Earlier it was believed that they were made up of meteoric dust but rocket measurements reveal that they consist of ice-particles.

Reporting of Cloud Base

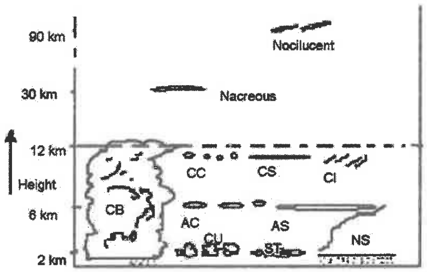
The base of cloud is reported from above ground level in Reports (METAR, SPECI etc), TAF, Local forecast. Only in area forecast charts, it is from above mean sea level.

Altitude of the Various Cloud Genera

The clouds can be identified by the approximate altitudes at which they normally occur. The approximate altitudes of low, medium and high clouds are:

Level of Clouds	Polar Region	Temperate Region	Tropical Region
High	10,000 – 25,000 ft (3 – 8) km	16,000 – 45,000 ft (5 – 13) km	20,000 – 60,000 ft (6 – 18) km
Medium	6,500 – 13,000 ft (2 - 4) km	6,500 – 23,000 ft (2 - 7) km	6,500 – 25,000 ft (2-8) km
Low	up to 6,500 ft (2 km)	up to 6,500 ft (2 km)	up to 6,500 ft (2 km)

Table 8.2



CLOUDS AND THEIR APPROXIMATE HEIGHTS

Figure 8.2

Flying Conditions In Clouds

Stratiform Clouds. Flying in stratiform clouds (AS and CS) is generally smooth. Even during the monsoon months when there are thick cloud layers of AS and NS, the flying may be very smooth. In NS clouds the visibility is reduced due to continuous precipitation. ST clouds reduce slant visibility and cause difficulty in locating the runway during landings. Ice accretion also occurs in AS and NS clouds above freezing levels.

Cumuliform Clouds. The CC and AC may cause some amount of turbulence. Fair weather CU and SC cause bumpiness while flying through. Well developed CU, TCU and CB can pose serious aviation hazards. The hazards like severe turbulence, hail, strong up and downdraughts, gusts, ice accretion, lightening etc are common. Flying though CB should be avoided. Even areas 10– 20 km around an active CB cloud there is likelihood of turbulence. Squalls associated with the CB clouds adversely affect landing and take off, hence such operations should be avoided during TS. Hail may also be experienced in clear air below the anvil.

Cloud of Operational Significance

A cloud with cloud base below 1500 m (5000 ft) or below the highest minimum sector altitude, whichever is greater.

Cloud Amount For expressing cloud amount, the sky is divided into eight imaginary parts. Each part of it is called one Octas as:

Cloud Amount	Nil	1-2 /8	3-4/8	5-7/8	8 / 8	
Termed as	SKC (Sky clear)	FEW (Few)	SCT (Scattered)	BKN (Broken)	OVC (Overcast)	Sky not visible
Sky Condition	Fine	Fair	Partly cloudy	Cloudy	Overcast	Sky Obscured

Table 8.3

Cloud Ceiling

The height, above the ground or water surface, of the lowest layer of the cloud below 6000 m (20000 ft), covering more than half of the sky (5/8 or more).

Height of Cloud Base Height (distance from surface)

The height of the base of clouds in the weather reports is **from above the ground level** (AGL) and in area forecast charts **from above the sea level** (AMSL)

Cloud Species

The cloud species, based on the form and structure are briefly described below:

- **Fibrous**. Clouds in the form of filaments without tufts or hooks.
- **Lenticularis**. Elongated lens shaped CC, AC or SC clouds with sharp margins. These clouds are mostly of orographic origin, or on lee side of CB or TCU clouds.
- **Castellaneous.** CI, CC, or AC cloud with cumuliform protuberances. Such clouds are generally connected by a common base and seem to be arranged in lines.
- **Fractus**. Ragged ST or CU cloud.
- **Congestus**. CU clouds which have strong sprouting and great vertical development. Its bulging resemble a cauliflower.
- **Calves**. CB with no cirrus at the top but some of the protuberances begin to change to fibrous structure.
- **Capillatus**. CB with distinct anvil. This cloud is generally accompanied by a SH, TS, SQ and GR. It also produces well defined Virga.

CONDENSATION TRAILS

Condensation trails are visible streaks of condensed water vapour formed in the wake of a moving aircraft. These are:-

Wing Tip Trails. Thin transient and short lived contrails, which form near the wing tips and propeller edges due to aerodynamic reduction of pressure, expansion of air and consequent adiabatic cooling and condensation of the atmospheric vapour.

Exhaust Trails. These form due to the condensation of moisture from aircraft exhaust at about 9 km and above. They are long, persistent and visible. They reveal position and track of an aircraft.

Distrails or Dissipation Trails. Sometimes the passage of an aircraft through a cloud is marked by the appearance of clear lanes. These are termed as distrails (opposite to contrails). Distrails occur where heat released by the aircraft exhaust is sufficient to evaporate the cloud in its wake.

Mintra, Drytra and Maxtra Levels

Mintra Level (ML). Below ML no condensation trails from. The flight level at which temperature is about -45° C gives a good estimate of ML at 100% RH for jet aircraft.

Drytra Level. When temperatures are very low, contrails form even when RH is 0%. In such cases the moisture from the exhaust is sufficient to produce saturation. This is known as Drytra level. It is usually 2 km above the mintra level for saturated air.

Maxtra Level This level lies in the stratosphere, above which no contrails form.

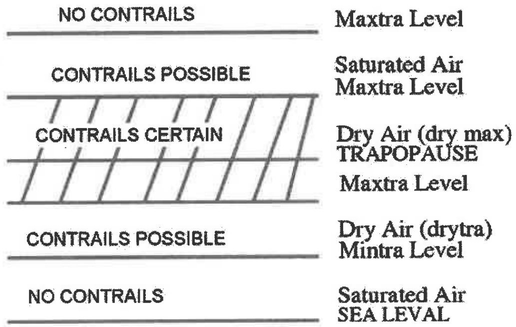


Figure 8.4 Mintra, Drytra and Maxtra Levels

QUESTIONS ON VERTICAL MOTION AND CLOUDS

Q1. Drizzle occurs from
(a) CS (b) ST (c) NS (d) CU

Q2. Altostratus (AS) is
(a) Low cloud of sheet type (b) A medium cloud of sheet type
(c) A cloud of large vertical growth (d) A high cloud of sheet type

Q3. Showers occurs from
(a) CU (b) CB (c) AS (d) AC

Q4. Heavy icing is possible in
(a) CI (b) CS (c) ST (d) CB

Q5. To avoid icing in cloudy conditions, a pilot is advised to fly through a cloud which shows optical phenomena
(a) Halo (b) Corona (c) With multi-coloured clouds

Q6. Dark gray cloud giving continuous rain is called
(a) AS (b) NS (c) ST (d) CB

Q7. A uniform layer of cloud resembling fog but not on the ground
(a) AS (b) NS (c) ST

Q8. The clouds composed of ice crystals having feathery appearance
(a) CI (b) CS (c) AS

Q9. NS clouds occur
(a) At cold front (b) At warm front

Q10. Halo is associated with the cloud
(a) AC (b) AS (c) CS (d) CI

Q11. Corona is associated with the cloud
(a) AS (b) AC (c) CC (d) CS

Q12. Lenticular clouds indicate presence of
(a) Warm Front (b) Cold front (c) Mountain waves

Q13. The lowest level below which condensation trails will not form is
(a) Mintra Level (b) Drytra Level (c) Maxtra Level

Q14. Rain falling from cloud but not reaching ground is
(a) Virgo (b) Virga (c) Mirage

Q15. CB with distinct anvil is called
(a) Castellaneous (b) Capillatus (c) Uncinus

Q16. Cloud ceiling is the height of the cloud covering...........
(a) 3-4/8 (b) 8/8 (c) 5/8 or more

Q17. No condensation trails occur above
(a) Maxtra Level (b) Dytra Level (c) Mintra Level

Q18. Cloud of operational significance has base below........ m or below the highest minimum sector altitude, which is greater
(a) 1500 (b) 2000 (c) 1000

Q19. AC cloud with cumuliform protuberances are indicative of
(a) Stability (b) Instability (c) Neutrality

Q20. Hail may be experienced under the anvil of a CB
(a) True (b) False

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**b**	**b**	**b**	**d**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**c**	**a**

Q.	14	15	16	17	18	19	20
A.	**b**	**b**	**c**	**a**	**a**	**b**	**a**

9. STABILITY AND INSTABILITY OF ATMOSPHERE

Atmospheric Processes

Air is bad conductor of heat. Hence a small (rising or falling) parcel of air, involved in atmospheric processes, can be regarded as insulated from the surroundings.

Isothermal Process. In this process heat is allowed to enter or leave the system so that its temperature remains the same.

Adiabatic Process. In an adiabatic process heat does not enter or leave the system. (Greek a = not, diabano = pass through). If a parcel of air ascends adiabatically it moves in a region of lower pressure and expands. The work done by the parcel in expanding is at the expense of its internal energy. Consequently its temperature falls. Conversely the temperature of a descending parcel rises as its internal energy increases due to work done by the air in compressing it. Adiabatic processes, to a large extent, determine the vertical distribution of temperature in the atmosphere.

Lapse Rate (LR). It denotes decrease of temperature with height in the atmosphere. It is taken positive when temperature decreases with height. The average lapse rate in the troposphere is about 6.5°C/km.

DALR ELR and SALR

Dry Adiabatic Lapse Rate (DALR). The rate at which temperature of a parcel of air decreases with height when it is made to ascend adiabatically is known as DALR. For unsaturated air it is 9.8°C per km (3°C /1000 ft).

Environmental Lapse Rate (ELR). It is the actual lapse rate existing in the atmosphere. It is intermediate between DALR and SALR, being closer to SALR. In ISA, ELR is 6.5 °C per km. However, in actual atmosphere it may have any value. It may have super adiabatic lapse rate i.e. more than DALR, may have negative lapse rate (inversion) or may even have zero lapse rate (isothermal).

Saturated Adiabatic Lapse Rate (SALR). When saturated air is lifted adiabatically, it cools. The extra water vapour condenses and latent heat is liberated. This offsets the adiabatic fall of temperature. The residual lapse rate, is called SALR. It is about 5°C per km. Unlike DALR, it is not constant. At higher levels where temperatures are low, very little water vapour is present and the latent heat released in condensation is small. Hence the SALR approaches DALR, at the levels where temperature is below – 40°C.

Inversion. Increase of temperature with height is called Inversion. It is the negative lapse rate. Low level inversion is common during winters due to nocturnal cooling. It is also associated with ridges, high pressure areas and anticyclones. Inversion indicates stability and lack of turbulence in the atmosphere. Lower level inversion does not allow surface air to rise and mix with the upper winds. Hence smoke, haze, mist, dust and fog stagnate over the ground causing poor visibility. Inversion is often present at the top of a stratified cloud layer or of fog, especially radiation fog.

Inversion Layer. It is an atmospheric layer in which there is an inversion of temperature. The vertical motion through such a layer is inhibited due to stability in the layer. An inversion layer near the earth's surface occurs during cloudless cool nights. Inversion at higher levels is associated with anticyclones and sometimes with the fronts.

INSTABILITY AND STABILITY

A system is unstable, if on displacement it does not return to its original position, e.g. a glass ball placed at the top of an inverted watch-glass if displaced will roll down further and will not return to its original spot (unstable). On the other hand if the ball is placed at the center of a convex glass, displaced and left, will oscillate and finally come to its original spot like a pendulum (stable). The Stratosphere and Thermosphere have stable atmosphere.

Atmospheric Instability. A layer is stable if a parcel of air in it is given a small push upwards, sinks back to its original level. It is neutral if it remains at the new level. It is unstable if it continues to move up at its own. To estimate static stability in a layer of air, changes in the kinetic energy (KE) of a test parcel of the layer is estimated from Aerological Diagram (T-phi gram). The atmosphere is stable, neutral or unstable according as the KE of the parcel decreases, remains constant or increases. Troposphere and Mesosphere, where temperature falls with height, have instable atmosphere.

Conditional Instability. It is the state of atmosphere in which DALR > ELR > SALR i.e. the atmosphere is unstable for saturated air and stable for unsaturated air.

Latent Instability. An atmospheric layer in which an initially stable parcel of air eventually becomes unstable due to forced ascent possesses latent (hidden) instability. It is **Real Latent** if the force required to lift the parcel is much less than the energy released when it becomes unstable. It is **Pseudo Latent** if the energy required to lift it is more than the energy released later.

Potential (Convective) Instability. Sometimes when a layer as a whole lifted bodily becomes unstable. The instability occurs if the latent heat released on lifting produces a sufficient temperature difference between the bottom and top of the layer to steepen the LR of lifted layer. For potential instability to occur it is essential that **the RH is high in the lower levels and low in the higher levels.**

Stability Criteria

		When
Dry air is	**Stable**	DALR > ELR
Saturated air is	**Stable**	SALR > ELR
Air (Dry or Saturated) is	**Absolutely Stable**	SALR > ELR
Air (Dry or Saturated) is	**Absolutely Unstable**	ELR > DALR
Conditional Instability		DALR > ELR > SALR

When lifted a parcel of dry air follows DALR and Saturated air follows SALR. On comparing the temperature at any level, AB in Figure 9.1, of the lifted air with the environmental temperature (as given by ELR), Stability or Instability can be found out. If the temperature of lifted parcel is more than the environmental temperature, it will shoot up i.e. Instable atmosphere. If colder it will sink i.e. Stable atmosphere.

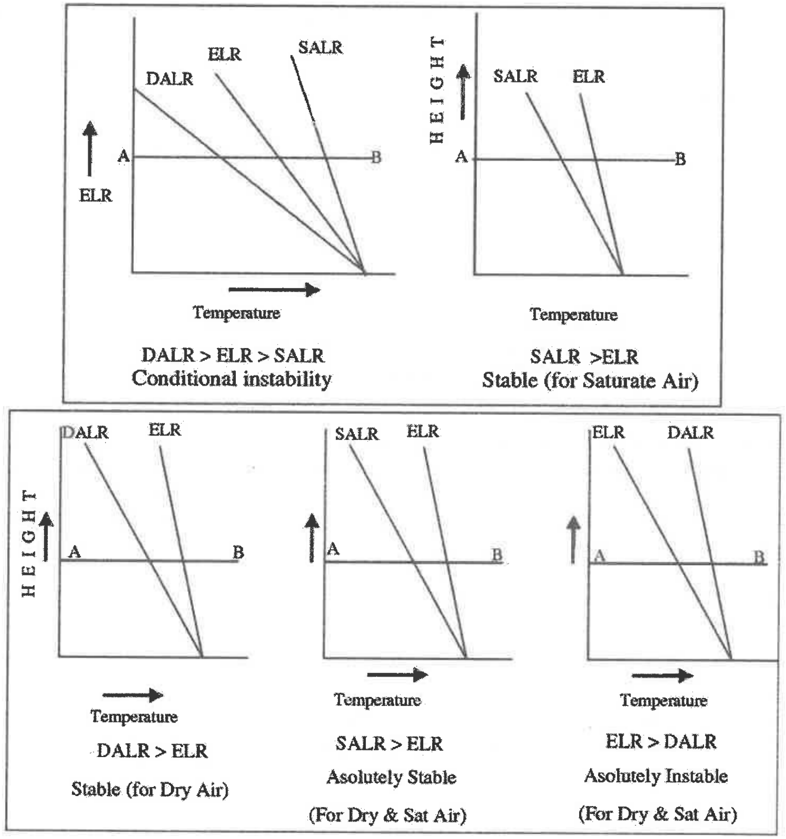
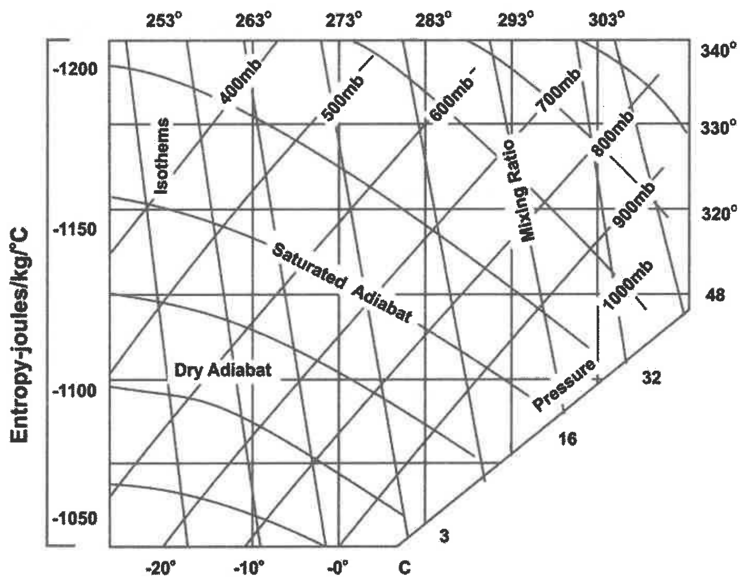


Figure 9.1 Stability Instability Diagrams

Tphigram. It is a thermodynamic diagram on which upper air temperatures, winds and dew point temperature, as obtained from Radiosonde and Rawin are plotted at various levels. It is used for estimating various meteorological parameters viz. Instability Stability in the atmosphere, Temperature and winds at various levels, Altimeter correction, Tropopause, Mintra Level, Lifting Condensation Level (LCL), base and top of cloud, Potential and Latent Instability, wet bulb temperature etc.

The Tphigram, used in India has of the following lines:

• Horizontal Lines	Potential Temperature or DALR
• Vertical Lines	Temperature
• Slanting Lines 45° to DALR	Pressure at different levels



Tephigram

Figure 9.2 Tphigram

• Curved lines slanting to left gradually becoming parallel to DALR at higher levels	SALR
• Dashed Lines slightly slanting left	Isohygric or lines of equal saturation mixing ratio (g/kg). At temperatures separate lines for saturation over water and over ice.

Normand Theorem. It states that if we draw upwards DALR from dry bulb (TT), SALR from wet bulb (TwTw) and Isohygric from the dew point (TdTd) temperatures, the three lines meet at a point, called Normand Point. Hence by knowing TT and TdTd we can calculate TwTw at any level. The first such point (First Normand Point) from the surface temperatures is also called **Lifting Condensation Level (LCL)** and gives an idea of the **height at which cloud may form.**

QUESTIONS ON STABILITY OF INSTABILITY ATMOSPHERE

Q1. DALR = 9.8 °C, ELR = 6.8 °C ; atmosphere is
(a) stable (b) unstable (c) indifferent

Q2. SALR = 5.5 °C, ELR= 4.5 °C ; atmosphere is
(a) unstable (b) stable (c) indifferent

Q3. DALR > ELR > SALR
(a) conditionally unstable
(b) latently stable
(c) potentially stable

Q4. Dry air is unstable when:
(a) ELR=DALR (b) ELR>DALR (c) ELR<DALR

Q5. The saturated air is said to be unstable if
(a) SALR=ELR (b) SALR<ELR (c) SALR > ELR

Q6. If ELR = SALR = DALR the atmosphere is
(a) Stable (b) Instable (c) Indifferent

Q7. DALR means:
(a) The rate at which temperature of unsaturated parcel of air falls with height when made to ascend adiabatically
(b) The rate at which temp falls with height
(c) The rate at which ascending parcel of saturated air cools

Q8. Surface temp. is 30° C. Assuming DALR what is the temperature at 2 km
(a) 18° C (b) 10° C (c) 42° C

Q9. An Isothermal atmosphere is:
(a) Stable (b) Unstable (c) Neutral

Q10. If ELR is less than SALR, the atmosphere is said to be:
(a) Absolutely unstable
(b) Conditionally unstable
(c) Absolutely stable

Q11. DALR is approximately
(a) 5° C /km (b) 15° C /km (c) 10° C /km

Q12. SALR at mean sea level is about
(a) 10° C/Km (b) 5° C/Km (c) 5° F/Km

Q13. SALR approaches DALR
(a) at 0°C (b) at -15°F (c) at -40°C

Q14. Dry air having a temperature of 35°C on surface when forced to rise adiabatically by 1 km would attain a temperature of
(a) 29°C (b) 25°C (c) 45°C

Q15. Inversion in the atmosphere indicates
(a) Stability (b) Instability (c) Neutrality

Q16. Inversion is ……… Lapse Rate (LR)
(a) Positive (b) Negative (c) Neutral

Q17. Environmental LR can be more than DALR
(a) True (b) False

Q18. The process which to a large extent determines the vertical distribution of temperature in atmosphere is
(a) Adiabatic (b) Isothermal (c) Isentropic

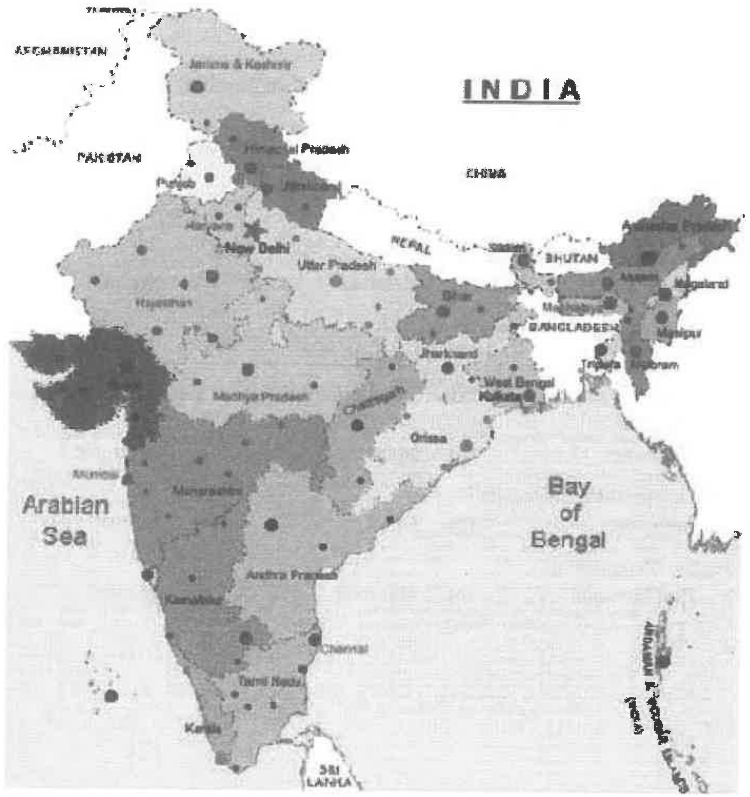
Q19. Rise in temperature with height is
(a) Inversion (b) Lapse (c) Normal

Q20. Inversion is common in
(a) Post Monsoon (b) Monsoon (c) Winters

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	a	b	a	b	b	c	a	b	a	c	c	b	c

Q.	14	15	16	17	18	19	20
A.	b	a	b	a	a	a	c



10. OPTICAL PHENOMENA

A number of optical phenomenon frequently occur in the atmosphere. They provide useful information about the constitution and type of the clouds and their recognition, atmospheric turbulence, lapse rate, ice accretion etc. This information is of importance for aviation. Some of the optical phenomenon important in aviation are briefly discussed in the following paragraphs.

Rainbow

Rainbow is a group of concentric arcs with colours ranging from violet to red, produced on a background of water drops (raindrops, droplets of drizzle or fog) in the atmosphere by light from the sun or moon. Sometimes simultaneously two rainbows are observed, the Primary and the Secondary rainbows.

A **primary rainbow** is a circle or arc of circles, of colored light, in the sky while it is raining. The circle subtends an angle of 42° at the eyes. It is seen opposite to the sun or moon. Its centre is on the line joining the luminary and the observer. The rainbow may form a complete ring when seen from a hill, high tower or from an aircraft.

The bow is due to the double refraction of sun rays, once on entering the rain drop and second time on leaving the drop, with one total internal reflection. The colures of rainbow are due to refraction of different colours VIBGYOR (red, orange, yellow, green, blue, indigo, and violet) of the sunlight. The red colour is on the outside and violet on the inside.

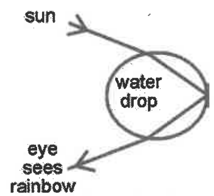


Figure 10.1 Double Refraction and one Total Internal Reflection of Sun Rays in a Raindrop

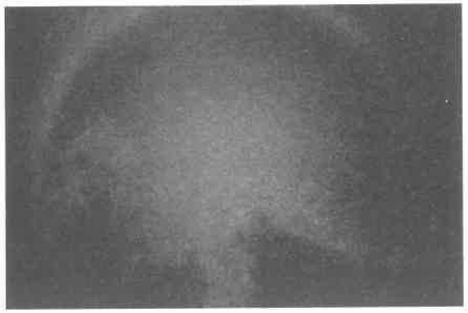
A **secondary rainbow**, concentric with the primary is occasionally seen whose radius is about 52°. It is much less bright than the primary, and with a breadth almost twice that of the primary. The red is on the inside (radius of the arc 50°) and the violet on the outside (radius of the arc 54°).

Halo

Halo is a circle of light around the sun or moon. It is produced by refraction of light through ice crystals present in Cirrostratus (**CS**) clouds. The most frequent halo phenomenon, called the **Small Halo**, is mostly white luminous ring of 22° radius with the sun or moon at its centre. When well developed, the halo round the sun shows a pure clear **red on the outside** but other colours are usually difficult to recognize. The presence of a halo signifies the predominance of ice crystals in the cloud and hence **negligible chances of ice accretion**. To remember **H**alo from **H**igh cloud CS. The portion of the sky inside the ring is conspicuously darker than the rest of the sky. Sometimes a circular halo with a radius of 46°, called the **Large Halo**, is also observed. This halo is less bright.

Corona

Corona are luminous one or more (seldom more than three) coloured rings of relatively small radius, not more than 5°, centred on the sun or moon. In each ring red appears on the out side and violet or blue on the inside. The colures are usually dull. Corona are formed **due to the diffraction of light**, passing through mist, fog or through a thin cloud composed of very small water drops or ice particles (Altostratus clouds). Diffraction is the slight bending of light wave as it moves along the boundary of an object like water drop. Corona indicate **moderate icing**, if the cloud is above the freezing level.



Halo (in Cirrostratus)

Corona (in Altostratus)

Figure 10.2 Halo and Corona

Sometimes corona have a distorted form, due to differences in the size of the particles in various parts of the clouds. Distorted corona of small radius may also be observed around the moon when not full, because of its crescent form.

Mirage

Light rays are refracted (bent) as they travel from one medium to other of different density. In the atmosphere density reduces with altitude. Therefore, the light reflected from a distant object travels in a curved path, keeping lower density on the convex side of the curve. The rising sun or moon thus appear slightly higher than they actually are.

Mirages are due to the curving of light rays passing through layers of air in which refractive index changes considerably with height due to differences in density. Mirages are observed when the temperature of the earth's surface differs markedly from that of the air above.

A mirage may occur as a **lower mirage (Inferior Mirage)** over intensely heated water surface, soil, beach, road, etc. (i.e. when the lapse rate is steep) or as **upper mirage (Superior Mirage)** over snow field, cold sea surface, etc (i.e. when there is inversion).

Bishop's Ring

It is a whitish faint ring, centred on the sun or moon, with a slightly bluish tinge on the inside and reddish brown on the outside. Bishop's ring is due to the diffraction of light by fine dust particles present in the high atmosphere. The dust may also be of volcanic origin. The radius of the ring is about 22°.

Twilight Colours

Various colours in the sky are produced at sunset and at sunrise by refraction, scattering or selective absorption of light rays from the sun.

Irisation

Sometimes due to diffraction of sun light, colours or bands nearly parallel to the margin of the clouds appear in which pink colour predominates.

Glory

One or more of coloured rings, seen by an observer around his own shadow on a cloud consisting of numerous small water droplets, on fog or, very rarely, on dew. The coloured rings are due to the diffraction of light; their arrangement is the same as in a corona. Airborne observers often see a glory around the shadow of the aircraft in which they are flying.

Crepuscular Rays

These are dark bluish streaks which radiate from the sun. They are the shadows of clouds at or below the horizon.

Aurora

In Latin, aurora means dawn. In this phenomenon visible light is emitted by the high atmosphere, at heights varying from 70 and 1000 km, with peak frequency at about 100 km.

Aurora are the ghostly displays of light in the form of streamers, rays, arches, hands, curtains, draperies, sheets or patches. They appear to shimmer or flit across the sky. Aurora are most common in higher latitude, centering around magnetic poles. They are greenish white or pronounced red or yellow.

Aurora results from bombardment of gases in the rarefied upper atmosphere by the electric particles, from magnetic storms. These cause excitation of gases with consequent emission of radiation. They impair radio communication.

Aurora may be compared with the coloured commercial **sign displays** in which high voltage electric discharge are passed through tubes containing particular gas under low pressure, from which the colour light, characteristic of the gas, is then emitted.

Figure 10.3 Aurora

Aurora Borealis occur in the N hemisphere (generally over NW Greenland) and are called **Northern Lights**. **Aurora Australis** occur in the S hemisphere and are called **Southern Lights.**

Atmospheric Electricity

In fine weather, earth is negatively charged and the electric potential is directed towards the earth and has a mean value of 100 volts/m. During a thunderstorm the direction of current is locally reversed, ie from earth to air. Precipitation particles carry a net positive charge towards the ground. Air to ground lighting flashes convey predominantly negative charge to ground.

Types of Lightning:

(a) **Ground Discharge** (**Thunderbolts**). It is the lightning between cloud and ground. It usually branches downward from a distinct main channel (streak or ribbon lightning).
Occasionally a luminous ball, generally between 10 and 20 cm diameter, is observed soon after a ground discharge. It moves slowly in the air or on the ground and disappears with a violent explosion. This is known as **ball lightning**.

(b) **Cloud Discharge** (**Sheet lightning**). This type of lightning takes place within the cloud.

(c) **Air Discharge**. This type of lightning occurs from cloud to the air and does not strike the ground.

Saint Elmo's Fire

Sometimes when flying in CU/CB clouds, an aircraft may experience bluish or greenish luminous discharge due to strong electrical field in the cloud. The continuous luminous glow is also accompanied by cracking sound. Intensity of the glow is weak to moderate.

QUESTIONS ON OPTICAL PHENOMENA

Q1. Aurora Australis occur in the
(a) S hemisphere (b) N hemisphere (c) Equator

Q2. Aurora Australis called .... Lights
(a) Northern (b) Southern (c) Temperate

Q3. Aurora Borealis occur in the
(a) S hemisphere (b) N hemisphere (c) Equator

Q4. Aurora Borealis are called .... Lights
(a) Northern (b) Southern (c) Temperate

Q5. Corona occur in .... clouds
(a) AS (b) NS (c) CS

Q6. Bishop's ring is due to the diffraction of light by fine particles of
(a) water (b) dust (c) ice

Q7. The radius of the Bishop's ring is about
(a) 32° (b) 22° (c) 42°

Q8. Superior Mirage occurs in marked
(a)Lapse (b) Isothermal (c) Inversion

Q9. Inferior Mirage occurs when there is
(a)Lapse (b) Isothermal (c) Inversion

Q10. Corona are formed due to the .... of light
(a) Refraction (b) Diffraction (c) Scattering

Q11. Corona are formed due to light, passing through
(a) Mist only (b) Fog only
(c) small water or ice particles only (d) Any one of all these

Q12. Halo is produced by
(a) Refraction (b) Diffraction (c) Scattering

Q13. Halo is produced when light passes through
(a) water particles (b) ice crystals (c) both

Q14. Halo occur in the cloud
(a) AS (b) NS (c) CS

Q15. Halo is luminous ring of .... radius
(a) 32° (b) 22° (c) 42°

Q16. Halo round the sun shows a pure clear .... on the outside
(a) Red (b) Yellow (c) Violet

Q17. Halo signifies predominance in the cloud of
(a) Supercooled water drops (b) Ice crystals (c) Both

Q18. The cloud which cause Halo has .... chances of ice accretion
(a) negligible (b) maximum (c)medium

Q19. Sometimes a halo with a radius of .... is observed, called Large Halo
(a) 32° (b) 42° (c) 22°

Q20. Halo occurs from .... cloud
(a) Low (b) Medium (c) High

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**a**	**b**	**b**	**a**	**a**	**b**	**b**	**c**	**a**	**b**	**d**	**a**	**b**

Q.	14	15	16	17	18	19	20
A.	**c**	**b**	**a**	**b**	**a**	**b**	**c**

11. PRECIPITATION

Liquid water drops or solid water particles falling from clouds to the ground are termed as precipitation. Drizzle (DZ) is the water drops of very small size, Dia 0.2 - 0.5 mm, Rain (RA), Dia 0.5 - 5 mm, Shower (SH) are solid or liquid drops of Dia > 5 mm. Hail (GR) is solid balls or pieces of ice (hailstones) with diameters 5 to 50 mm or more. Snow (SN) is assembly of ice crystals, sleet is wet snow and Ice Pellets (PL) are small transparent ice particles, spherical or irregular in shape. Snow Grain (SG) and Ice Crystals (IC) also constitute precipitation. 1 kg hail has also been reported.

For precipitation to occur water drops or ice crystals should be large enough to overcome the vertical currents inside the clouds. The exact process by which cloud particles attain sizes large enough to overcome the vertical currents is not yet fully known. However, the following theories have been put forward to explain the occurrence of precipitation.

Bergeron Ice Crystal Theory

In **Cold clouds**, the clouds whose tops extend well above the freezing level, super cooled water drops and ice particles co-exist. The saturation vapour pressure being more over water drops than over the ice crystals, the water drops evaporate and sublimate (direct conversion of ice into water vapour, without going through the liquid phase) over the ice crystals. The ice crystals grow at the expense of the water drops. While falling, the bigger ice crystals encounter supercooled water drops, which continually freeze on to them. The ice crystals thus grow to large sizes and fall out of the cloud base as snow or rain.

Coalescence Theory

The above theory is unable to explain rainfall from the Warm clouds i.e. the clouds which do not reach the freezing level. In tropical areas showers occur from clouds which do not extend much above the freezing level and sometimes not even up to the freezing level. To explain the occurrence of rain from such clouds, the coalescence theory was advanced. Large drops initially form by collision and coalescence of the smaller droplets in the cloud. Coalescence increases markedly due to vertical currents and the drops become larger. As these large drops fall, the pressure falls in their wake, and the smaller drops get sucked in and get attached to the falling drops. During fall a large drop collides with the smaller drops on its path, which also get attached to it. Ultimately number of large drops form.

Giant Nucleus Theory

In the maritime areas clouds with lesser vertical development can give rain, due to the presence of In a large number of salt particles, from salt spray. These giant hygroscopic nuclei are carried up to the cloud in vertical currents. They absorb water vapour and form large water drops and initiate the chain reaction of coalescence.

Clouds and Precipitation

The type of precipitation from a cloud depends on the strength of the vertical currents which is has to overcome, and this in turn depends on the mechanism by which the cloud is formed. The types of precipitation from different clouds are:-

Types of Cloud	Precipitation
Stratus (ST)	Drizzle
Altostratus (AS)	Rain and Snow
Nimbostratus (NS)	Continuous precipitation
Towering Cumulus (TCU) and Cumulonimbus (CB)	Rain, Showers, Hail and Snow
Cumulus (CU) of slight vertical development (fair weather CU), Altocumulus (AC) and high clouds (CI, CC).	No precipitation
Thick Cirrostratus (CS)	Snow at high to medium levels

Table 11.1 Types of Clouds and Precipitation

Snow and Sleet

When the surface temperature is less than about 4°C and the mean temperature between the base of the cloud and the surface level is less than 0°C, precipitation may be in the form of snow or sleet. Snowfall is usually in the form of flakes, which are made up of minute ice-crystals of various shapes. **Sleet is mixture of rain and snow.**

Cloud Burst and Flash Floods

Very heavy showers or rain over an area in a short period is called **Cloud Burst**. A sudden rise in the level of rivers or streams causing floods, is called **Flash Floods**.

Rainy Day

When the rainfall amount in a day is **2.5 mm** or more, it is called a **Rainy Day**. Terms used to describe Spatial distribution of Rainfall are at Appendix D

Diurnal and Seasonal Variation Rainfall

In the tropics, the clouds form mainly due to convection, which is most vigorous in the afternoon. The precipitation is therefore most common in the **afternoons**. In **coastal areas** due to land/sea breeze effect) and in the **valleys, NE India**, (due to Katabatic /Aanabatic effect), maximum rain occurs **at night or during early morning hours**, but elsewhere it is mostly in afternoon and early night. Similarly, **rainfall in the summer is more than that in the winter**.

In the **temperate latitudes** the clouds form due to the convergence caused by depressions or fronts, which are frequent in winters. Therefore in these middle latitudes, **rain or snowfall is maximum in the winters**. The precipitation in the extreme northwestern parts of India more or less follows this pattern, due to WDs, which are occluded fronts and have high frequency in winters and hence maximum precipitation in winters.

Artificial Rain Making or Cloud Seeding

Cloud seeding is an attempt to stimulate precipitation by injecting into the clouds the nucleating agents, like silver iodide, common salt, solid carbon di oxide etc. Spraying of Potassium Chloride in small clouds have shown encouraging results, wherein either clouds grow rapidly or cause rain in 15-20 minutes.

The particles sprayed act like ice forming nuclei to initiate Bergeron process. Mixture of Potassium chloride and sodium chloride act in the same way. However, the rain so created may deprive some other area of rainfall where it would have occurred naturally. It is found useful in fighting fires, ending draught, promoting harvests, draining clouds and fog dispersal.

Fog Dispersal

Fog can also be cleared for a short period either by increasing the air temperature or by seeding the fog as above, especially to enable aircraft to land and take off.

Classification of Rainfall

Light < 7.5 mm; Moderate 7 - 35.5 mm; Rather Heavy 35.6 - 64 mm;
Heavy 65 – 84.9 mm; Very Heavy 85 mm or more; Exceptionally Heavy 250 mm

QUESTIONS ON PRECIPITATION

Q1. When super cooled water drops and ice particles co-exist, the ice crystals grow at the expense of the water drops because
(a) Saturation vapour pressure over water drops is less than over the ice crystals
(b) Saturation vapour pressure over the ice crystals is less than over water drops
(c) The ice crystals convert into water drops

Q2. The clouds whose tops extend well above the freezing level are called
(a) Warm Clouds (b) Cold Clouds (c) Moderate Clouds

Q3. The clouds whose tops do not extend to the freezing level are called
(a) Warm Clouds (b) Cold Clouds (c) Moderate Clouds

Q4. Coalescence Theory explains occurrence of rainfall from the
(a) Warm Clouds (b) Cold Clouds (c) Both types of Clouds

Q5. Ice crystal Theory explains occurrence of rainfall from the
(a) Warm Clouds (b) Cold Clouds (c) Both types of Clouds

Q6. Giant Nucleus Theory explains occurrence of rainfall over
(a) Maritime areas (b) Inland areas (c) Hilly areas

Q7. Very heavy precipitation as showers over a short period is called
(a) Flash floods (b) Cloud Burst (c) Orographic Rain

Q8. Rain shadow area is on the .... of the mountain range
(a) Top (b) Windward side (c) Leeward side

Q9. Sleet is a mixture of
(a) Hail & Snow (b) Rain & Snow (c) Frozen Rain

Q10. Rainfall in the tropics is more in
(a) Winters (b) Summers (c) Post monsoon

Q11. Rainfall in the tropics is more in the
(a) Morning (b) Afternoon (c) Night

Q12. Rainfall in the temperate latitudes is more in
(a) Winters (b) Summers (c) Spring

Q13. Over J&K and western Himalayas Rainfall is more in
(a) Winters (b) Summers (c) Post monsoon

Q14. Rainfall over coastal areas is more in the
(a) Evening (b) Afternoon (c) Night & early morning

Q15. Areas to the .... of western Ghats of India are rain shadow areas
(a) W (b) S (c) E

Q16. A sudden rise in the level of rivers or streams causing floods is called
(a) Cloud Burst (b) Catchments flooding (c) Flash Floods

Q17. Artificial rain making is also termed as
(a) Simulation (b) Cloud seeding (c) Nucleation

Q18. Fog can be dispersed for a short period by artificial stimulation
(a) True (b) False

Q19. Showery precipitation occurs from
(a) NS (b) AC (c) CB

Q20. A day is called Rainy day when rainfall in 24 hr is .... mm or more
(a) 1.5 (b) 2 (c) 2.5

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**b**	**b**	**a**	**a**	**b**	**a**	**b**	**c**	**b**	**b**	**b**	**a**	**a**

Q.	14	15	16	17	18	19	20
A.	**c**	**c**	**c**	**b**	**a**	**c**	**c**

12. ICE ACCRETION

Formation of ice on an aircraft in flight is termed as ice accretion or icing. Icing seriously affects the aerodynamics of an aircraft, leading even to loss of controls. It is a serious aviation hazard. Although aircraft are fitted with de-icing devices, they provide only a partial protection. For successfully combating icing knowledge of the type of icing, conditions for formation and techniques to avoid icing is essential.

Types of Icing: Ice accretion is of two types:
(a) Airframe icing
(b) Engine icing

Airframe Icing

Hoar Frost: Hoar frost occurs on airframe in clear air when the temperature of airframe is below the frost point. **It occurs both on ground and in the air**. It is a feathery deposit of ice crystals formed due to the sublimation of water vapour on the cold airframe. Hoar frost forms on aircraft parked on the tarmac on a cold night. It may also form when an aircraft flying at high altitude rapidly descends to lower levels into warm and moist air. Hoar frost dissipates quickly when the aircraft warms up and also gets shaken off due to the vibrations of the airframe. This icing does not constitute a serious aviation hazard.

Opaque Rime: This consists of a white opaque deposit of ice having light porous texture. It is formed by **freezing of small supercooled water droplets** on the airframe when an aircraft is flying through clouds above the freezing level.

It accumulates on the leading edges of wings, struts etc. A large amount of air is entrapped between the particles exhibiting a white opaque appearance. Rime usually does not have much weight but may alter the aerodynamics of the wings. It is like the ice crystals deposited on the inner walls of a refrigerator freezer chamber, which can be easily wiped off.

Translucent Rime or Glaze Ice: This is also known as **clear ice** because of its glassy appearance. It forms due to freezing and spreading after the impact of large supercooled water drops on the airframe. Since the drops unite on spreading, very little air is entrapped while freezing and hence the glassy appearance. The deposit occurs on the leading edges, and spreads backwards due to freezing of the left over liquid water. The initial deposit may have a flat surface, but with subsequent deposits the surface is generally uneven but still smooth. Ice of this type is sticky and cannot be easily shaken off. If it breaks off at all, it comes away in lumps of dangerous size. The glazed ice poses serious aviation hazard. It alters the aerodynamic, is heavy and may set up vibrations due to unequal loading of wings, struts and propeller blades. It is like the ice cubes formed in ice tray of a refrigerator, which is difficult to break.

Temperature Range for Airframe Icing

Except for cumulonimbus clouds, the optimum temperature ranges in which different degrees of icing is likely are as follows:

Severe	Moderate	Light	Very light
0°C to - 7°C	- 7°C to - 12°C	- 12°C to - 20°C	- 20°C to - 40°C

Table 12.1

Airframe Icing in Relation to Cloud Forms

Ice accretion is dependent primarily on the size and the number of drops in a cloud, as follows:

(a) **CI, CS and CC**: These consist mostly ice crystals. Icing hazard is therefore, negligible.

(b) **AS, NS**: They consist of supercooled water drops and ice crystals in varying proportion. Light to moderate icing is possible.

(c) **AC**: Light to moderate icing is likely but severe icing is possible in mountains

(d) **TCU**: Icing may range from light to severe type at least up to - 20°C level.

(e) **CB**: Icing may range from light to severe type up to -20°C level. Below this temperature severe icing is not significant.

Effect of Airframe Icing

Airframe icing can affect flying characteristics of an aircraft in many ways:-

(a) The icing alters aerodynamics, increases weight and decreases lift.

(b) Icing increases the stalling speed appreciably.

(c) Icing increases drag.

(d) Unequal loading of ice on propeller blades decreases their efficiency and sets vibrations and consequent loss of effective power.

(e) Hinges of ailerons, elevator and trimming tabs may get jammed due to icing and their smooth and free movement may be restricted.

(f) ASI may give erroneous readings due to icing of pitot tube.

(g) The icing on aerials may render communication difficult.

Engine Icing: Engine icing is of two main types:-

(a) **Impact Icing**: This occurs due to the impact of supercooled water drops on the air intake. Icing restricts air inflow, which reduces the engine power.

(b) **Carburetor Icing**: When air passes through the carburetor choke and past the throttle butterfly, the pressure falls inside the carburetor and due to adiabatic cooling the temperature drops to a very low value. The cooling is further enhanced by the evaporation of fuel. If humidity is high icing may occur due to sublimation. This type of icing may also occur in clear air even at the ambient air temperature of + 30°C. Below -10°C this type of icing is negligible unless liquid water is present. Carburetor icing is unlikely when the relative humidity is less than 60%.

Height of Freezing Level in India

In the North, Central and Southern parts of India the Freezing Level occurs approximately at the pressure levels, in various seasons:

Season	North	Central	South
N E monsoon	700 hPa	600 hPa	600 hPa
Pre - monsoon	650 hPa	600 hPa	550 hPa
SW monsoon	550 hPa	500 hPa	500 hPa
Post monsoon	550 hPa	600 hPa	650 hPa

Table 12.2

QUESTIONS ON ICE ACCRETION

Q1. Hoar frost occurs on airframe in clear air when the temperature of airframe is
(a) below the frost point (b) frost point (c) just above the frost point

Q2. In clouds at temperatures below 0° C an aircraft may encounter icing of the type
(a) only Glazed (b) only Rime (c) intermediate between these two

Q3. Opaque Rime ice is
(a) Light porous (b) Solid (c) Mixture of porous and solid

Q4. Rime is formed by freezing of .... supercooled water droplets on airframe when aircraft is flying through clouds
(a) Small (b) Large (c) Medium

Q5. Glazed ice is formed by freezing of .... supercooled water droplets on airframe when aircraft is flying through clouds
(a) Small (b) Large (c) Medium

Q6. The .... ice poses serious aviation hazard
(a) Rime (b) Hoar Frost (c) Glazed

Q7. Airframe icing occurs below 0°C. Its probability of occurrence decreases progressively below -20°C, as at lower temperatures the proportion of super-cooled water drops in a cloud
(a) Increases (b) Decreases (c) Does not change

Q8. CI, CS and CC clouds consist mostly ice crystals. Icing hazard is therefore
(a) Maximum (b) Medium (c) Negligible

Q9. AS, NS consist of supercooled water drops and ice crystals in varying proportion .... icing is possible.
(a) Maximum (b) Light or moderate (c) Negligible

Q10. In AC clouds .... icing is possible in mountainous areas
(a) Light (b) Moderate (c) Severe

Q11. In TCU icing may range from light to severe type at least up to .... level.
(a) – 40 °C level (b) 30 °C level (c) – 20 °C level

Q12. In CB icing may range from light to severe type up to -20°C level. Below this temperature severe icing is
(a) not significant (b) significant (c) maximum

Q13. Liquid water content is an important factor in icing. As the maximum water concentration is around ...., maximum ice formation in clouds may also be expected around that level.
(a) –25° C level (b) –20° C level (c) –15° C level

Q14. Carburetor icing occurs when air from intake passes through a ventury (choke) and causes expansional cooling and vaporization of fuel. Serious icing can occur at extreme temperatures
(a) 13°C (b) 30°C to –10°C (c) 20°C

Q15. .... occurs in a moist cloudless air on an aircraft surface having temp. below 0° C, due to sublimation of water vapour onto feathery ice crystals.
(a) Rime (b) Glazed (c) Hoar Frost

Q16. .... occurs in St, Sc, Ac, Cu, Ns at temperature -10 to –40° C and in Cb at temperature –20 to –40°C
(a) Rime (b) Glazed (c) Hoar Frost

Q17. In clouds .... occurs when a wide range of water drop sizes are present at temperatures between 0° C and –40° C
(a) Rime (b) Glazed (c) Mixture of rime and clear ice

Q18. .... occurs in AS, NS, AC and towering CU or CB between 0° C and –20° C, in warm front below 0° C, especially if the aircraft has rapidly descended from a colder region.
(a) Glazed (b) Rime (c) Mixture of Rime and Clear ice

Q19. When fog freezes on parked aircraft it produces ....
(a) Hoar Frost (b) Rime (c) Clear ice

Q20. Icing .... the stalling speed appreciably
(a) Decreases (b) Increases (c) Does not increase/decrease

ANSWERS

Q	1	2	3	4	5	6	7	8	9	10	11	12	13
A	a	c	a	a	b	c	b	c	b	c	c	a	c

Q.	14	15	16	17	18	19	20
A.	b	c	a	c	c	a	b

13. THUNDERSTORM

A **thunderstorm (TS)** is a weather system produced by strong convection currents. TS occur in CB clouds and are characterized by lightning flashes and rumbling sound of thunder. They are usually accompanied by sudden cool strong and squally winds, blackning of sky, sharp showers, and at times hail, snow, sleet, sometimes no precipitation at all, and at times warm winds. Some of the TS are very violent and cause floods, forest fires due to lightning, tornadoes, water spouts, microburst etc. **For aviation TS is one of the most hazardous phenomenon. TS is reported when thunder is heard**. TS is also known as Electrical storm, Lightning storm or Thundershower . Under suitable conditions sometimes they line up in a series and become a squall line or rain band.

The diameter of individual CB cells varies from one to 10 km. In a cluster of CB cells there are narrow cloud-filled lanes between neighboring cells.

Severe TS. TS which are accompanied by locally damaging winds, frequent lightning, thunder, or large hail are called Severe TS.

Types of TS

(a) Heat (or air-mass) TS
(b) Frontal TS
(c) Steady State TS
(d) Mesoscale Convective Complex (MCC)

Frontal TS occur at a Cold Front and occasionally at a warm front. These are triggered by the vigorous uplift of moist air along or ahead of a cold front or sometimes in a warm front. Frontal TS are more violent than the air mass TS. They may develop any time of day or night. Sometimes along or ahead of a cold front a line of TS develops. This is called **Squall Line** and causes severe weather.

An **Air mass TS** is associated with intense heating and convergence due to low pressure. Air mass TS also occur when cold air passage over a warmer sea.

These pop out randomly anywhere within a mass of warm humid air. They are relatively weak systems than the Frontal TS. As these are caused by intense convection, they mostly develop in the afternoons in the plains. In valleys and hills they may develop during night/morning.

Steady State TS. These are associated with Fronts, Converging Winds and Troughs aloft, which force air upwards. These are different from squall lines. Afternoon heating intensifies them. The precipitation falls outside updraughts, which become stronger in mature stage. They last for several hours, hence the name Steady State.

Mesoscale Convective Complex (MCC). It is a nearly circular cluster of many interacting TS over a very large area. This area may be thousand times the area of an Air mass TS. New TS develop continually within an MCC. This increases the life of TS from 6 to 24 hr. These produce severe weather and even Tornadoes and Flash Floods (a sudden rise in the level of rivers or streams causing floods). These are synoptic scale systems. They form near fronts and in tropics in ITCZ.

Meso-Scale Weather. The local scale phenomenon, for example TS, DS, Land and Sea breeze, Katabatic wind etc, are Meso Scale weather.

Classification

Single Cell. A single cell TS has one main updraught. Such storms are rarely severe and are due to local instability and heating in summers **(Heat or Airmass TS)**. They also occur in cold front in winters.

Multi Cell Cluster. They form as clusters of storms due to convective updrafts in or near mountain ranges and strong cold fronts or troughs of low pressure. While each cell may last 20 min, the cluster may persist for hours.

Multi Cell Lines. These are commonly called **squall lines, can** form along or ahead of cold fronts. They can be hundreds of kilometer long and move swiftly. They cause heavy rain, hail, lightning, very strong winds and even isolated tornadoes. An unusually powerful squall line is called a **derecho**. Occasionally, squall lines also form near the outer rain band of tropical cyclones.

Super Cell. These are large and severe storms, having separate up and down draughts due to wind direction changing with height (WS), and rotating updraughts (a mesocyclone). Due to powerful updraughts they can reach the lower stratosphere. They can produce destructive tornadoes, very large hailstones (10 cm dia.), winds >130 km/h, and flash floods. Most tornadoes occur from such TS. These can be 24 km wide.

Favourable Conditions for TS Formation:

TS is an instability phenomenon. The following conditions are essential for its formation:

(a) Steep Lapse Rate: Lapse rate steeper than the SALR throughout a layer at least 5-6 km in depth, permitting development of clouds above 0° C level.

(b) High Humidity: Adequate supply of moisture from below and high humidity aloft. If the humidity of the surrounding air is very low, the growth of cloud is arrested due to evaporation of rising parcel of air.

(c) Trigger Action: A lifting mechanism which can produce saturation in the region of the steep lapse rate.

The Triggering Mechanisms are:

(a) Insolation (local convection) (b) Frontal Lifting
(c) Convergence (d) Orographic Lifting
(e) Radiational or Katabatic cooling

Life Cycle

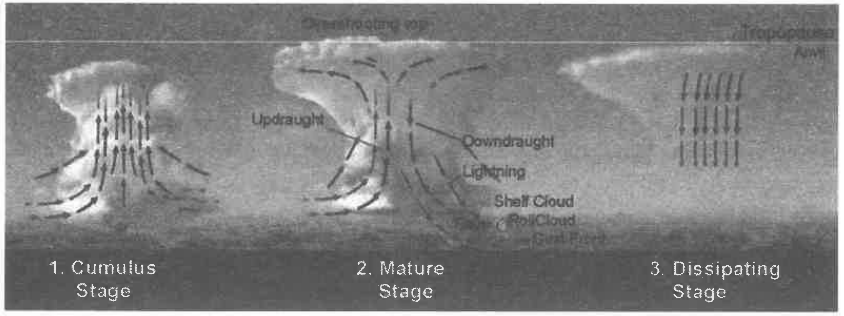
Cumulus Stage

The triggering mechanism lifts a parcel of air. It expands and cools. Further lifting causes condensation and formation of CU cloud. As the water vapor condenses into liquid, latent heat is released, which warms the air, causing it to become less dense than the surrounding drier air. The air further rises due to convection and creats an updraught. A low pressure area develops within and beneath the cloud. Inflow to the cell (called **entrainment**) takes place through the sides at all levels and the base of the cloud. Entrainment is the mixing of environmental air into a cloud. The parcel of air rises higher and higher as long as it is warmer than the surroundings. The CU after growing buildups into a CB cloud.

This stage is characterized by **updraught throughout the cell**. The updraughts of speed 30 m/sec or 60 kt are not uncommon. They carry warm air upwards and sustain water drops, including supercooled drops, and ice crystal in the cloud.

The rain/snow/hail particles keep growing inside the cloud till the updraughts can sustain them. When they become too large and heavy they fall out of the cloud as precipitation.

Aviation hazards from this stage include turbulence and icing.



Mature Stage

In this stage the warmed air continues to rise up to tropopause level (which is the cap), and can rise no farther.The air is then forced to spread out as cirrus clouds, giving the cloud **Aanvil** shape (also called **False Cirrus).** The water droplets coalesce into larger and heavier droplets and become ice particles. As these fall, they melt to become rain. If the updraught is strong enough, the droplets are held aloft for a long and fall as hail. The falling precipitation drags the adjacent air and generates downdraught. Being cold, the downdraught descends and accelerates. Thus in this stage **both up and downdraughts co-exist**. The entrained air being drier causes some of the precipitation particles to evaporate. This cools the downdraught further and acclerates it. Finally at ground there is a sudden rush of **very strong cold winds** as **squall**. On rare occasions, warm downdraughts may occur if there is dryness in the atmosphere. The downdraught close to the ground spreads out horizontally in all directions. Its leading edge is called the **First Gust.** It presents an arc shaped surface, called **Gust Front** due to its resemblance with a cold front. The gust may be followed by heavy rain or showers. The gust front undercuts the warm air at the surfaces and lifts it to generate new TS cells.

During this stage, there is lightning and considerable **turbulence** within and around the cloud.

Mature stage is characterized by production of precipitation and coexistence of up and down draughts, side by side.

This stage lasts for 20 – 40 min. As the old cells dissipate and new cells may form continually, the TS activity sometimes prolongs.

If there is little vertical wind shear (WS), the storm rapidly enters the dissipating stage but, if there is sufficient vertical WS, the downdraught separates from the updraught, and the storm may become a super cell. The mature stage then can sustain itself for several hours. Even Tornadoes may then develop.

This is the most violent stage of a TS and presents serious aviation weather hazards.

Dissipating Stage

During this final stage, the updraught ceases and the storm is dominated by downdraughts. Due to no updraughts, further growth of the cloud ceases. Precipitation may still occur, but decreases with time as moisture is depleted. The downdraughts spread across the lower portion of the CB and the cloud gradually dissipates.

The following clouds may emanate from a CB :

Roll Cloud. It is an elongated cylindrical dark cloud which appear to rotate slowly about its horizontal axis. It occurs behind the First Gust, but is detached from CB. It is seldom associated with severe weather.

Shelf Cloud. It is a wedge shaped elongated cloud having flat base. It occurs at the edge of Gust Front and beneath and is attached to CB. It form due to the uplift of the warm air along the Gust Front. It is associates with Severe weather.

Structure of a Severe TS

Severe TS are tilted due to vertical WS. Due to tilt the precipitation and downdraughts fall away from the updraughts and are unable to cut off the updraughts. This enables the cell to grow to great heights and last longer.

Movement of TS

The 700-500 hPa level winds influence the movement of TS.

Jet Stream and TS

Upper level Jet stream is important for the development of a severe TS. It produces wind shear and tilts the updraughts, thus favouring great vertical development of the cell.

Intensity of TS

(a) **Light**. Faint peals of thunder and lightning flashes at long intervals.

(b) **Moderate.** Loud peals of thunder and frequent flashes of lightning, moderate or heavy showers and light hail. Maximum wind speed generally 15-40 kt.

(c) **Severe.** Almost continuous thunder and lightning, heavy rain/shower, may be hail, at the station or its vicinity. Maximum wind may exceed 40 kt.

Diurnal and Seasonal Variation

Over the plains TS mostly occur during the afternoon and die out in the evening.

Over the valley and foot hills they generally occur during night and early morning.

Over the sea TS are more frequent at night.

In middle latitudes, TS over the land are most frequent in summers. However, the frontal TS are more frequent in winters, due to frequent Cold Fronts

TS and Pressure

There are marked fluctuations of pressure due to TS. The first gust causes sudden pressure rise.

Aviation Hazards of TS

TS pose a variety of hazards to aircraft on ground and in flight. The important ones are:

(a) **Turbulence:** Turbulence and icing are the most serious hazards of a TS. Turbulence is caused by gusts, eddies and up and down draughts in a CB. A considerable amount of air is entrained from outside the cloud. Consequently there are strong upcurrents around CB in clear air. These cause turbulence. Moderate to severe turbulence can occur inside TS (on the boundary between up and down draughts), between adjacent cells, 10-20 km around CB in clear air, 25-30 km downwind, thousands feet above the CB top (especially when winds are very strong), and below the cloud base up to surface.

Turbulence increases gust load which may exceed the stress limit of an aircraft. If attempts are made to regain control, structural failure may occur. Turbulence below cloud base to surface may make landing/take off dangerous.

Effect of Turbulence Inside an Aircraft :

Light Turbulence*: Occupants feel slight strain on seat belt, unsecured objects are displaced, and walking is difficult.*

Moderate Turbulence*: Occupants feel definite strain on seat belt, unsecured objects are dislodged, and walking is very difficult.*

Severe Turbulence*: Occupants forced violently against seat belt, objects tossed around, and walking and food serving is impossible.*

(b) **Wind Shear (WS)**. Strong WS is often associated with TS. The outflow of TS can cause extreme changes in wind speed and direction near the surface during critical phase of flight. The cold strong downdraught from CB on striking the surface rises up to about 2000 ft. A WS zone forms between this outflow and the warm air above it, blowing in the opposite direction, towards CB. An aircraft attempting to land would experience initially head wind and then close to ground a tail wind. For light aircraft the air speed may go below stalling speed and the landing angle may become dangerously steeper. Accidents may occur during landing, take off, climb/descent, and final approach. In strong downdraught the wind changes in a few hundred feet by as much as 90° or more. WS is hazardous at all levels in TS. Beneath a TS it may be of disasterous consequences. WS has caused accidents during landing and take-off phase. Strong vertical WS is nessary for the occurrence of severe TS.

(c) **Squall:** The initial downdraught from the cloud spreads all around horizontally on the ground as squall. The speed of squall is normally up to 40 kt but can be as high as 100 kt. The strongest speeds are ahead of the cloud in the direction of its movement.

(d) **Draughts:** Within the cloud strong up and down draughts occur. Up draughts are often stronger and of greater vertical extent. They can suck in gliders, light aircraft and parachutists up to great heights. The updraughts may impose sudden strong negative g force, may be greater than an aircraft can absorb. Downdraughts are stronger from the middle of cloud to the surface. They can force even powerful jet aircraft on to the ground, if flight is beneath the cloud. These cause sudden variations in the altitude of aircraft, at times to 3-5,000 ft. The horizontal extent of draughts can be more than one km in a TS.

(e) **Gusts:** Gusts occur all over the CB cloud. However, near the boundary between up and down draughts vigorous eddies form, which travels within the cloud and cause gusts. Severe turbulence results from the combined effect of gusts and draughts. Gusts impose severe load factor, exceed the turbulence penetration speed, and cause abrupt changes in aircraft attitude. Structural failure may occur if the pilot attempts to correct these attitude changes too quickly or harshly. Many accidents are attributed to this phenomenon.

(f) **Icing:** Icing is always possible in temperature range 0° to -30°C. Icing affects aerodynamics, jams controls, blocks pitot tube, engine and carburetor. Glazed clear icing is worst within the first 10,000 ft from the freezing level, due to presence of large supercooled water drops. Towards the top of the cloud more of brittle rime ice forms. In turbine engine aircraft flame out is possible due to icing. In piston engine aircraft carburetor icing may cause loss of power. In CB clouds along a frontal line icing may become serious problem. In any case icing more than light adds to the problems of aircraft. To avoid icing, use of de-icing devices and carburetor heat is essential.

(g) **Hail:** A hailstone starts as an ice crystal. It grows progressively by collision with supercooled water drops while being tossed up and down in the cloud. Hailstone has onion like structure of alternate layers of rime and clear ice. Clear ice forms nearer the freezing level and rime ice above. When updraughts are unable to hold it, hail falls out of the cloud. Worst hail occurs from freezing level to about 25,000 ft height. Hail encounters by aircraft are rare, but even if encountered it is only in a small region of the cloud. Aircraft encountering small hail may cause superficial damage, but large hail cause serious damage. With large hails the airframes get badly dented, windscreens holed, astrodomes shattered, deicer boots ripped off and fins badly bent. Damaging hail may occur up to 45,000 ft in CB and under the Anvil. (Size of hail - max Dia 5.5in). Hail weighing up 4.5 kg has been eported in China and 3.4 kg in India.

(h) **Heavy Showers:** These may reduce visibility to a very low value. It may create a thick film of water over the runway surface and result in hydroplaning and skidding aircraft of the runway. Ingestion of heavy showers in the engine can reduce power considerably. The noise of heavy showers may disturb aircrew concentration and coordination. Fractostratus Clouds bases below 1000 ft generally accompany showers. Hence best is to avoid landing and take-off during heavy rains/showers. A number of accidents have been attributed to this phenomenon.

(i) **Lightning:** For a lightning flash to occur a potential difference of about $3*10^6$ volts/ m in clear air, and $1*10^6$ volts/ m in cloud, is required. A lightning strike on an aircraft is relatively harmless, but some accidents are attributed to it. The bonding of the aircraft prevents any electrical discharge from penetrating to the interior. Lightning can burn or puncture small holes in the skin of an aircraft. The

magnetic compass may shows erroneous readings, electronic equipment may be damaged and radio noise occurs. There may be smell of burning and explosive noise. The lightning flash may cause temporary blinding of the crew and passengers in a dimly lit environment. Lightning strikes are most likely in the temperature range +10°C to -10°C. The extreme heat due to lightning expands the surrounding air and creats a shock wave which causes thunder.

(j) **Noise:** The horrendous noise of hail striking aircraft and especially wind- screen can be very frightening. More so in turbulence affected area.

(k) **Darkness and Disorientation:** In a thick CB there is absolute darkness, which may lead to disorientation; hence a constant eye on the Artificial Horizon is essential.

(l) **Instrumental Error:** Below the base of growing and mature CB, there is reduction in pressure. The altimeter will tend to over read (more than actual height). Hence adequate ground clearance is essential. The pitot tube may be blocked by heavy water ingestion. The ASI reading would be misleading.

Radar Detection of Thunderstorms

Storm Detection Radars (weather radars) specially designed for TS detection are used for locating TS and watching their development, movement and dissipation. They can be either ground based or air borne. For detecting precipitation a wavelength in the range 3 to 20 cm s suitable. For precipitation measurements wavelength of 10 cm is widely used. The wavelength in various bands are given in Table 13.1. For further details refer to Chapter 22.

Nomenclature	K Band	X Band	C Band	S Band	L Band
Wavelength (cm)	0.86	3.0	4.0	10.0	20.0

Table 13.1

Air Pocket

An air pocket is an **updraught** or a **down draught**. They are caused by: the **localized regions of warm or cool air** and **High and Low pressure areas**. A pocket of warm air, being less dense than the surroundings, rises to a level where the air is less dense, and a mass of cool air descends. Similarly a low pressure region creates an updraft, and a high pressure region creates a downdraught. Extreme cases of air pockets are **downburst** and **microburst**.

Downburst

The downburst is a local intense severe downdraught (> 4km horizontally) with damaging winds from a TS.

Microburst and Macroburst

Definition. Microburst and Macroburst are localised severe down-draughts of great intensity. Dry Microburst occur under a CB or under the anvil and Wet Microburst below a CB in intense precipitation, due to evaporation of precipitation in the warm air.

Dimensions. Microburst are of dia. less than 4 km and Macroburst of dia. 4 km or more. On hitting the ground they spread and produce one or more horizontal rings around the downdraught, 2 km to 4 km across, and expand vertically to over 600 m.

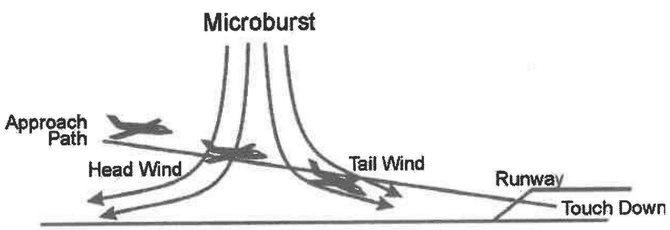
Life. Microburst generally die down in 1-5 minutes. However more than one microburst may be produced by the same system and their duration may prolong to 15-20 min.

Causes. One of the most probable causes of microburst could be the dryness of the atmosphere in which falling rain rapidly evaporates (as in **Virga**). The evaporation reduces temperature of the air column through which rain falls. The column, being colder than the environment, descends and accelerates towards the ground as a microburst.

Wind Speeds. Speed of downdraught may exceed 75 kmh close to ground. Average horizontal wind speed of 90 kmh is common (at times it may exceed 200 kmh).

Systems which produce Microburst

(a) CB cloud (about 5% of all TS produce microburst)
(b) Heavy rain (high probability of microburst)
(c) Virga (medium probability of microburst)



Attitude of Aircraft during Landing Approach Due to Head and Tail Wind Components

Microburst Figure 13.2

Aviation Hazards

Microburst may be experienced all of a sudden. Where and when it would occur and how violent it would be cannot be predicted. It affects aircraft in three stages:

(i) **Contact Stage** : The cold downdraught accelerates towards the ground
(ii) **Outburst Stage** : The downdraught curls upwards after hitting the ground.
(iii) **Cushion Stage** : Wind above curls accelerates and poses danger to aircraft.

Microburst may be encountered by an aircraft:-

(a) **At levels much above the ground.** If an aircraft is pushed suddenly downwards by a microburst at higher levels, it may still have sufficient ground clearance to recover.

(b) **At levels close to the ground.** During landing or low level flying, due to microburst an ac encounters three distinct winds viz. first a head wind, then a strong downdraught and finally a tail wind. The head and tail wind components are due to horizontal spreading of the microburst. The reaction time may be too short or may not be available.

The **time for recognition and avoidance** is as less as 5-15 sec. Hence it can best be avoided by not flying below a CB cloud, through a TS/DS, in heavy rain and below Virga. No take off and landing is advisable during TS/DS.

Effects on Aircraft

(a) **Head Wind Tail Wind Response**. An increasing head wind component lifts the aircraft above the angle of attack for landing, and may cause overshoot Conversely an increasing tail wind component would cause undershoot.

(b) **Vertical Wind Shear Response**. The alternating up and down draughts cause fluctuations in the angle of attack of an aircraft. If severe, these may cause momentary stick shaking or airframe shuddering and additional strain on pilot.

(c) **Cross Wind Shear Response**. It causes aircraft to roll and or yaw.

(d) **Turbulence**. Turbulence may be quite intense. Its effects can mask changing airspeed and delay the recognition of severe downburst.

(e) **Rain Effect**. Heavy rain may reduce visibility, increase cockpit noise and make aircrew coordination and concentration difficult. Hence avoid.

Dust Storms (DS) or Sand Storms (SS)

In the Pre Monsoon season, the surface temperatures are very high (35°C or more) over N India. The atmosphere is highly unstable over the desert or semi-arid areas. With a small amount of moisture incursion conditions become favourable for the formation of CB clouds.

As the humidity aloft is not high, the convective clouds do not build up to great heights. However, such clouds can still cause storms if their tops extend to a sufficient height above the freezing level. These local storms raise loose dust or sand from the ground up to over 10,000 ft.

They are therefore called Duststorms or Sandstorms. They reduce visibility badly, to 50 m or less. In N India these storms are called **Andhi** (blinding storms).

Duststorms form in the same way as the TS. The vertical growth of the clouds is restricted due to low humidity aloft. The precipitation from the cloud evaporates completely before reaching the ground due to the prevailing high temperature and low humidity. The updraughts in the cloud are so vigorous that they carry the dust or sand up to great heights in and outside the cloud. A duststorm approaches like a very high wall of dust.

If Humidity aloft is high, the DS is followed by light showers and visibility improves. The life cycle of DS is shorter than that of TS. Squalls associated with DS are at times severe. DS mostly occur in the afternoons of the summer months. The radars echoes of DS are less intense than TS echoes.

Classification of DS

	Wind	Visibility
Light DS	up to 21 kt	500 to < 1000 m
Moderate DS	22 to 40 kt	200 to < 500 m
Severe DS	> 40 kt	< 200 m

Table 13.2

The aviation hazards associated with DS/SS are almost the same as of TS. In addition, visibility is very low in DS/SS. If no rain follows it remains poor for a long after the DS has moved away. Moderate to severe wind shear may also be experienced during take-off or landing when DS/SS is approaching.

Norwesters

During the Pre Monsoon period (March to May), West Bengal, Chhattisgarh, Bihar, Jharkhand (Chotanagpur), North-East states and Bangladesh are affected by violent TS. These cause considerable damage to the life and property. These storms are called **Norwesters** because they often approach from North West. Norwesters commence in March and continue with increased frequency till the monsoon establishes over NE India. Locally they are known as **Kalbaishakhi**, because of their demon like destructive character. Most of the Norwesters are accompanied by strong squalls and sometimes by hail. On rare occasions even tornado may accompany them.

Flying through Norwesters can be extremely dangerous as they have the most violent features of TS. Sometimes they regenerate TS in a line, like **Line Squalls**. Circumnavigating or penetrating these may be disastrous. The safest way is to avoid them.

Tornado

It is a rotating funnel in which air is sucked up from below the base of a CB. Tornado (TDO) is a strong instability phenomenon. In tornado the strong rotational wind is produced when an existing circulation of air below a CB is drawn into its base through convergence. Rotation may also be caused by low level wind shear below the CB. The rotation is lifted at one end by the updraught. The speed of rotating winds inside a tornado in excess of 150 kt have been recorded. The pressure in the core may drop hundreds of hPa and the fall in temperature makes tornado visible due to condensation. The diameter of a tornado is from a few metres to about 200 m and life a few minutes to more than an hour. Small scale tornadoes (dust devils or willy – willy) develop in hot arid regions in dry season. The very low pressure at the core causes devastation, in a narrow path. Tornadoes uproot trees, objects, articles, explode buildings etc and suck them up into the air. Their occurrence is rare in India. Tornado generally gives hook shaped radar echo.

In April 1978, a tornado struck New Delhi and caused severe damage to the life and property.

Fujita Damage Scale Number for Tornadic Winds is at Appendix B

Figure 13.3 Tornado

Water Spout A tornado over the sea is called Water Spout (WTSPT). The funnel sucks up sea water and sometimes rain of Fish is observed over the adjoining coastal area.

Dust Devil During hot summer months sometimes local surface winds converge towards a hot spot. They start rotating about a vertical axis and a whirl of dust raising wind rises from ground, known as Dust Devil. Vertically it may reach up to 2 km and may have a diameter of about 10 m. It is a short lived phenomenon. It is capable of lifting light loose articles, like paper.

QUESTIONS ON TS

Q1. The condition necessary for the formation of a thunderstorm are:
- (a) Steep lapse rate, strong winds
- (b) Shallow lapse rate, adequate supply of moisture
- (c) Steep lapse rate, adequate supply of moisture and trigger action

Q2. Hail is most likely to fall from a cloud
- (a) Having layers
- (b) Composed of Ice crystals
- (c) Having strong vertical development

Q3. Norwesters are
- (a) The western disturbances which affect NW India
- (b) Severe thunderstorms which occur over NE India during hot weather period
- (c) Severe thunderstorms which occur over Peninsula during hot weather period

Q4. Duststorm usually occurs over NW India during
(a) Post-monsoon (b) Winter (c) Pre-Monsoon

Q5. A 'mature' thunderstorm has strong
(a) updraft only (b) downdraft only (c) updrafts and downdrafts

Q6. Aircraft icing is most favoured in the cloud which have temperatures ranging between
(a) – 20° C and – 40° C (b) 0° C and – 20° C (c) below – 40° C

Q7. A short duration, showery precipitation is associated with
(a) ST (b) AS (c) CB

Q8. Hail is
- (a) Solid precipitation commonly occurring over the mountainous regions in winters.
- (b) Frozen or partly frozen rain falling from sheet type of clouds
- (c) Solid precipitation falling from a deep convective cloud

Q9. The most hazardous cloud for aviation is
(a) CB (b) CU (c) NS

Q10. The life of a Cb cell is usually
(a) 7 to 8 hrs (b) 3 to 4 hrs (c) 2-3 hr

Q11. Generally the severest activity of a , heat type, TS is for
(a) 2 hrs (b) 30 to 45 min (c) 3 to 4 hr

Q12. Norwesters occur during
(a) Jan-Feb (b) Mar-May (c) June-Sep (d) Oct – Dec

Q13. Norwesters occur during
(a) Winter (b) Hot weather (c) Monsoon (d) Post Monsoon

Q14. Norwesters affect
(a) N India (b) Bengal, Bihar, Orissa and Assam (c) Central India

Q15. The trigger action may take place due to
(a) Clear night sky, no wind (b) Orographic lifting (c) high pressure

Q16. Norwesters normally occur during
(a) Mornings (b) Afternoons (c) Nights

Q17. Norwesters originates over
(a) Chota-Nagpur hills (b) Deccan Plato (c) Khasi hills

Q18. Andhi (blinding storms) occur generally over
(a) S India (b) N India (c) NE India

Q19. Wind speed in Light DS is
(a) 25 kt (b) 30 kt (c) up to 21 kt

Q20. The diametre of Microburst is
(a) less than 4 km (b) less than 2 km (c) less than 6 km

Q21. The diametre of and Macroburst
(a) < 4 km (b) 4 km or more (c) > 8 km

Q22. For detecting precipitation a Radar wavelength in the range ……….. is suitable
(a) 30 to 200 mm (b) 400-500 mm (c) 600-700 mm

Q23. For airborne radars wavelength generally used
(a) 20 mm (b) 40 mm (c) 60 mm

Q24. The wavelength of TS detection X band radar is
(a) 10 mm (b) 20 mm (c) 30 mm

Q25. The wavelength of storm detection S band radar is
(a) 50 mm (b) 100 mm (c) 200 mm

Q26. Over plains TS mostly occur during the
(a) afternoon (b) night (c) early morning

Q27. Over valley and foot hills TS generally occur during
(a) afternoon (b) night & early morning

Q28. Over the sea TS are more frequent
(a) afternoon (b) night (c) early morning

Q29. The life of Mesoscale Convective Complex TS is
(a) 2-3 hr (b) 3-4 hr (c) 6 to 24 hr

Q30. Loud peals of thunder, frequent flashes of lightning, moderate or heavy showers accompanied by light hail with maximum wind speed 15-40 kt is classified as
(a) Light TS (b) Moderate TS (c) Severe TS

Q31. For a severe TS one of the requirements is strong Wind Shear
(a) Horizontal (b) Vertical (c) Slant

Q32. Severe TS cells are tilted
(a) in vertical (b) to the South (c) to the North

Q33. When flying through on active TS, lighting strikes are most likely
(a) Above 5000 ft and under the anvil.
(b) In the clear air below the cloud in rain
(c) In the temperature band between +10° and – 10°C
(d) At or about 10000 ft

Q34. Hazards of the mature stage of a TS Cell include lighting, turbulence and:
(a) Microburst, wind-shear and anvil (b) Icing, microburst and WS
(c) Icing, drizzle and microburst (d) WS, hail and fog

Q35. Hail grows by
(a) freezing as it leaves the cloud (b) up and down forces in CU cloud
(c) collision with ice crystals (d) collision with supercooled water drops

ANSWERS

Q	1	2	3	4	5	6	7	8	9	10	11	12	13
A	**c**	**c**	**b**	**c**	**c**	**b**	**c**	**c**	**a**	**c**	**b**	**b**	**b**
Q	14	15	16	17	18	19	20	21	22	23	24	25	26
A	**b**	**b**	**b**	**a**	**b**	**c**	**a**	**b**	**a**	**c**	**c**	**b**	**a**
Q.	27	28	29	30	31	32	33	34	35				
A	**b**	**b**	**c**	**b**	**b**	**a**	**c**	**b**	**d**				

14. AIR MASSES FRONTS AND WESTERN DISTURBANCES

Definition Air mass is a large body of air covering an area of thousands of square kilometer in which the horizontal and vertical distribution of temperature (density) and moisture are nearly uniform.

Air masses move with the wind and carry their properties. The weather associated with air masses depends on their properties and interplay with other air masses. The characteristics of air masses differ with their origin and travel. During travel they get modified.

Source Region. An air mass forms when a large body of air stagnates for a long period over an area having fairly uniform temperature and moisture content. High pressure areas which have slack pressure gradients and hence light winds are the most suitable source regions for air mass formation. Accordingly the main source regions are **poles** and **sub-tropical highs**. The stagnation over these regions enables a large body of air to acquire properties of the underlying surface.

Classification of Air Masses

Temperature (density) and **humidity** are the two main characteristic which distinguish air masses. The temperature characteristics is determined by the latitude zone of the source region of the air mass. The moisture characteristics depends on whether the source region is over continental area or over maritime area. Thus, from the temperature characteristics we have

Polar air mass and **Tropical air mass** and from the moisture characteristic, **Continental air mass** and the **Maritime air mass.**

Types of Air Masses

There are six main types of air masses, whose names, symbols, places of origin and properties in brief are as follows:

Air mass	Symbol	Place of origin	Properties
Arctic	**A**	Polar regions	Extreme low temp, low humidity in winters, but humidity increases in summers.
Polar Continental	***Pc***	Sub-polar continental areas	Low temperatures which increase with movement towards lower latitude, low humidity.
Polar Maritime	**Pm**	Sub-polar and Arctic oceanic areas	Low temperatures which increase with movement towards lower latitude, high humidity.
Tropical Continental	**Tc**	Subtropical High Pressure land area	High temperatures, low humidity
Tropical Maritime	**Tm**	Southern border of oceanic sub-tropical highs.	Moderately high temperatures, high humidity.
Equatorial (Maritime)	**Em**	Equatorial and tropical seas	High temperatures, high humidity (SW Monsoon is Em air mass).

Table 14.1

Modification of Air Masses

When an air masses bodily moves, its temperature and moisture characteristics get modified according to the nature of the area over which it moves.

Air Masses in Indian Sub-Continent

Tropical Maritime Air (Tm): This air mass originates in the subtropical highs of the north Pacific ocean and arrives over India during the monsoon season, after travel over SE Asian countries. It has high temperature, high relative humidity and high dew point.

The air mass is characterised by excellent visibility, a fairly high diurnal range of temperature and cumuliform clouds causing showers or thunderstorms in some places.

Tropical Continental Air (Tc): This is the most common air mass over India, particularly in the winter season. It originates in the Siberian high and moves over India as a cold dry current with fair weather and poor visibility conditions.

Equatorial Maritime Air (Em): This air mass originates over the Indian Ocean and has a long travel over water. Em prevails over India to the south of 25° N during the monsoon season. It has high humidity content, hence causes sultry weather. Visibility is good except in showers. The diurnal range of temperature in the air mass is small.

In **winters** India is over-run by Tc air mass. In the extreme south there is occasional incursion of Tm air from the south of the equator (in India Tm air arriving from the southern hemisphere across the equator is known as Em air or equatorial maritime air). The Western Disturbances which affect northern India draw Tm air from Arabian sea and Bay of Bengal. After the passage of a WD, some times in winters there is an incursion of Pc air mass, which causes Cold Wave conditions.

In the **summer months** the equatorial low moves northwards and by June gets established over the Gangetic plains as Monsoon Trough. To the south of this trough is the Em air from the southern hemisphere. To the north of it there may be two types of air masses. In northwest India there is usually Tc air, while in northeast India and along the Himalayan ranges there is Tm air which originates in the sub-tropical high of the Pacific Ocean. This air mass gets modified in its land travel over the countries of southeast Asia and has different characteristics than the Em air which comes from the southern hemisphere.

FRONTS

Front. A **Front** is a narrow zone of transition between two air masses of contrasting densities. The contrasting densities are due to different temperatures and humidity of the air masses. At a front there is change in temperature, wind, clouding and precipitation.

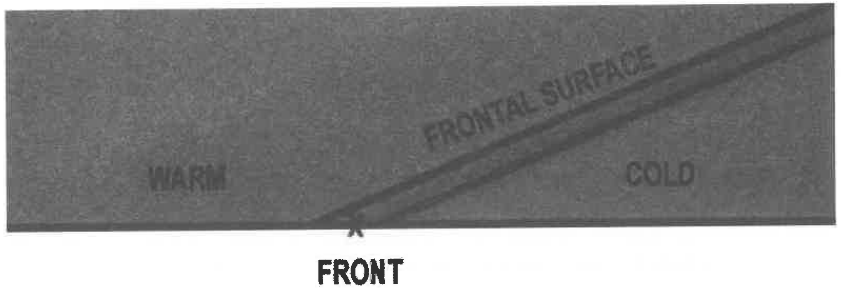


Figure 14.1 Front and Frontal Surface

Frontal Surface. Frontal Surface is the sloping surface along which the two air masses exist and Front is the place where this frontal surface meets the ground.

Frontogenesis. In a front weather occurs only when there is a significant density contrast between the two air masses. If density contrast is insignificant the front passes off unnoticed except for some change in winds. If the density contrast increases the front becomes active. The formation or strengthening of a front is called Frontogenesis.

Frontolysis. Weakening of front with time and dissipation of frontal weather is called Frontolysis.

TYPES OF FRONTS

Cold Front

It is a demarcation zone between **cold air overtaking warm air**. The cold air provides a wedge on which warm air glides. Most of the **cold fronts are associated with CU and CB** clouds. The average slope of the front is **steep, 1: 50**, which becomes shallower at higher levels. There are two types of cold fronts, based on vertical motion of air at the front :

(a) **Kata Type Cold Front**. It has a shallow **slope of 1:120** and speed is about 20 kt. There is general **sinking** of warm air at high levels (term kata denotes katabatic). Due to this the vertical cloud development is restricted. It has stratiform (ST, NS, AS) and CU, CB clouds. The precipitation is widespread. Showery precipitation occurs in advance and just behind surface front, due to CB. Further behind precipitation is from NS and AS. Sometimes the front moves very fast causing **line squall** to develop 100 - 300 km ahead of the front.

(b) **Ana Type Cold Front**. It has a steep **slope of 1:50** and speed exceeds 30 kt. There is instability and **rising** warm air at high levels (term ana denotes anabatic). Main clouds are CU, CB clouds. **Violent TS, hail and showers of short duration are its basic features, confined to 100-150 km.** After the passage sky clears rapidly. **Behind the front there may be CU, CB clouds and isolated showers.**

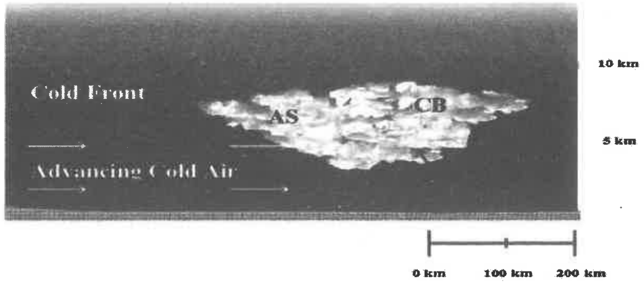
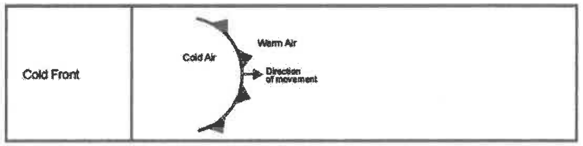


Figure 14.2 (a) Cold Front



Cold Front as Represented in Synoptic Chart

Warm Front

It is a demarcation zone between **warm air overtaking cold air**. Its **slope is** shallow, **1:150 to 1:180 and speed is about 10-15 kt.** If the advancing warm air is unstable, stratiform and cumuliform clouds would form. If the warm air is stable and air sinks at higher levels, clouds are mainly stratiform. Stable warm fronts are called **Kata Type** and unstable **Ana Type warm Fronts**.

(a) **Kata Type Warm Front**. Approach is indicated by CI,CS, about 1000 km ahead. As front nears clouds thicken and NS, AS clouds appear 400-500 km from front. Precipitation gradually becomes heavy and persists. Just ahead of the warm front there is drizzle, low stratus and sometimes fog, called **frontal fog**. After the passage of warm front, fog dissipates, sky becomes partially clear, with warmer and humid weather.

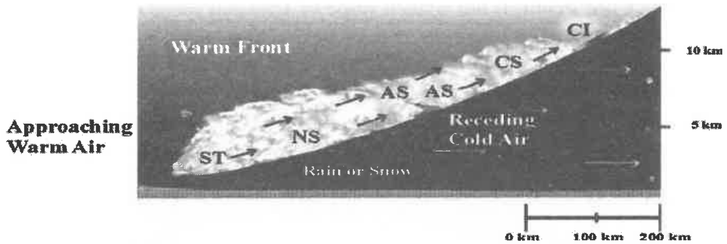
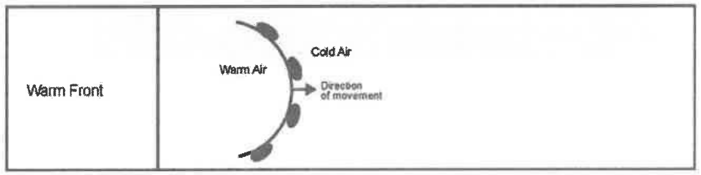


Figure 14.2 (b) Warm Front



Warm Front as represented in Synoptic Chart

(b) **Ana Type Warm Front**. In this type of front air is unstable. CU and CB clouds may be embedded in the stratiform clouds, causing brief spells of heavy precipitation. Just ahead of the front drizzle may occur from ST clouds. After the passage of the front fog dissipates and skies practically clear.

(Note: For weather with Cold and Warm Fronts Refer **Appendix - C)**

Occluded Front

A cold front normally moves at twice the speed of a warm front. An **occluded front forms when a cold front catches up with a warm front**. Occluded fronts are of two types:

(a) **Cold Occlusion**. If the air mass of the advancing cold front is colder than the cool air mass of the warm front, the advancing cold front undercuts and lifts both the warm and cool air masses of the warm front. The weather is initially warm front type but during the passage of front, showery weather of cold front occurs. This occlusion is common in summers.

(b) **Warm Occlusion**. When the air mass behind the advancing cold front is less colder (cool) than the cold air mass of the warm front ahead, the advancing cold front overrides the warm front ahead. The weather in such a case is similar to that of warm front. This type of occlusion occurs in winters and is less common.

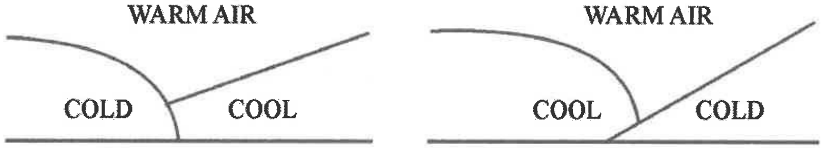
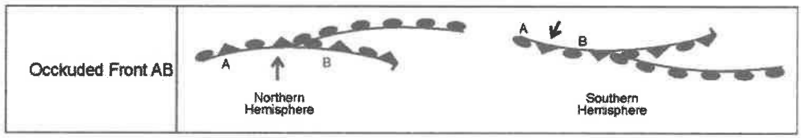


Figure 14.3 Cold and Warm Occlusions



Occluded Front as represented in Synoptic Chart

Stationary Front

A stationary front is one that exhibits almost no movement. On either side of the front there are two contrasting air masses. Winds on either side blow parallel to the front but in opposite direction. Polar front is an example of stationary front.

Fronts of the World

(a) **Polar Front:** Polar Front is a transition zone between polar easterlies and mid latitude westerlies. It is located around latitude 60°. The polar front is not continuous. It is active only in segments.

(b) **Arctic Front:** This is the boundary between arctic and polar air masses. It lies normally further north than the polar front but is often displaced southwards into temperate latitudes in winters.

(c) **Mediterranean Front:** This is the boundary between the Pc air from Europe and the Tc air from North Africa. It extends roughly from west to east over the Mediterranean in winter.

Fronts In India

India is not affected by fronts, except in the extreme NW India. The Western Disturbances which affect NW India are of frontal origin. However, when they reach India they are in the occluded stage.

WESTERN DISTURBANCES (WD)

WDs are lows or troughs which move from W to E, N of 20° N and cause weather. Whenever the low has two or more closed isobars, at 2 hPa interval, it is termed as **Western Depression**. The troughs above 500 hPa level are called **Troughs in Westerlies**. (Satellite Imagery of WD at Appendix I)

These disturbances are noticed as cyclonic circulation/trough in the mid and lower tropospheric levels or as a low pressure area on the surface. They **originate over the Mediterranean Sea, Caspian Sea and Black Sea and move eastwards across north India.**

WDs belong to extra tropical cyclone family. Over India they are in occluded state and cause warm/cold front type of clouding and weather. They intensify over NW India due to orography and moisture feed from the Arabian sea.

Induced Low and Induced Cyclonic Circulation

Under the influence of the WD, sometimes a low develops to the south of the system as induced low and sometimes a cyclonic circulation developes to the south of the system as induced cyclonic circulation

The average **frequency of WDs is 5-7 per month in winters,** which subsequently decreases to **Nil in monsoon** months. They reappear from Oct onwards.

Movement. From Pakistan/Rajasthan they move NE towards W Himalayas. Some of them subsequently glide along foot hills towards E. A few WDs move E towards UP, MP, Bihar and subsequently reach up to NE India. The rate of movement is about 250-300 km per day.

Weather. In about 50% cases, weather is confined to J&K, HP, Punjab, Haryana, Uttarakhand, Sikkim, Bhutan and Arunachal. In remaining cases weather is affected over UP, MP, Bihar and adjoining states, Orissa, WB and NE India. The area of maximum clouding and precipitation is always along the foot hills. **Widespread fog and cold waves are common after the passage of WD**. Fog lifts up by forenoon but sometimes it persists for a few days.

Aviation Hazards. Low clouds, poor visibility, rain, TS, hail, icing are the main hazards during approach/passage and after the passage, widespread fog. Under the influence of WDs during premonsoon widespread dust haze and dust storm are experienced over NW India and TS over the northern plains.

Trough in Westerlies. A series of trough in upper air westerlies keep moving from W to E. Sometimes these have large amplitudes. They cause upper air divergence ahead of them. Whenever these troughs lie on the rear of a surface system, the weather activity enhances considerably. Severe TS/DS, Norwesters and heavy rains are associated with these troughs.

QUESTIONS ON AIR MASSES, FRONTS AND WD

Q1. The airmass which originates at sea in high Latitudes is called
(a) Polar maritime (b) Tropical continental (c) Tropical maritime

Q2. The airmass which originates over equatorial region is
(a) Warm and dry (b) Warm and Moist (c) Cold and dry

Q3. If the advancing cold front is **colder** than the **cool** air mass of the warm front, the advancing cold front undercuts and lifts both the warm and cool air masses of the warm front. This is
(a) Warm Occlusion (b) Cold Occlusion

Q4. The airmass which originated over land area located in polar region is:
(a) Warm and dry (b) Warm and Moist (c) Cold and dry

Q5. If a warm airmass overtakes a cold air mass, it is called
(a) Cold Front (b) Warm Front (c) Occluded Front

Q6. At warm front
(a) Warm air overtakes the cold air (b) Cold air undercuts the warm air

Q7. The conditions are always unstable at a
(a) Cold front (b) Warm front

Q8. Sometimes Line squall occurs about 100-300 km ahead of a
(a) Warm front (b) Cold front

Q9. Precipitation occurs over a belt of 30 – 50 km on both side of front
(a) Cold front (b) Warm front

Q10. Cold front moves at … the speed of a warm front moves
(a) Same (b) Double (c) Half

Q11. Line Squalls occur …… of Cold front
(a) Ahead (b) Behind (c) At the

Q12. Fronts are associated with
(a) Tropical cyclone
(b) Monsoon Depression
(c) Extra-tropical Cyclones

Q13. CB, Roll-type clouds, SC, AC with embedded CB are associated
(a) Cold front (b) Warm front

Q14. The surface of discontinuity between the Polar Ely and the temperate Wly is called
(a) Equatorial Front (b) Tropopause (c) Polar Front

Q15. The air mass which originates from sea area located in lower Lat is
(a) Warm and Dry (b) Warm and Moist (c) Cold and Moist

Q16. WDs approach India as
(a) Cols (b) Occluded Fronts (c) Highs

Q17. Maximum WDs occur in
(a) Summers (b) Post Monsoon (c) Winters

Q18. Ahead of a warm front the surface wind
(a) Backs & weakens (b) Veers & strengthens (c) Backs & strengthens

Q19. On approach of a Warm Front temperature
(a) Fall (b) Rise (c) Remain same

Q20. CI, CS, AS, NS, ST in sequence are associated with the front
(a) Warm (b) Cold (c) Occluded

Q21. During the passage of a Cold Front winds
(a) Suddenly become squally
(b) Back and weaken
(c) Veer and are of moderate strength

Q22. Visibility is poor in a Warm Front
(a) Ahead (b) Ahead & During (c) After & During

Q23. Fog occurs in Cold Front
(a) Ahead (b) During (c) After

Q24. WD is a ……….. front
(a) Cold (b) Warm (c) Occluded

Q25. FZRA and FZFG occur ……….. of a warm front
(a) Ahead (b) During (c) After

Q26. Precipitation ceases after the passage of a front
(a) Cold (b) Warm (c) Occluded

Q27. During the approach of a Warm Front wind
(a) Backs (b) Veers (c) Does not change

Q28. A WD with two or more closed isobars, at 2 hPa interval, it is termed as
(a) Troughs in Westerlies (b) Western Depression (c) Western Cyclone

Q29. A WD originate over
(a) Baluchistan (b) Caspian sea (c) Mediterranean, Caspian and Black Seas

Q30. Induced lows develop to the …….. of a WD
(a) N (b) S (c) NE

ANSWERS

Q	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**a**	**b**	**b**	**c**	**b**	**a**	**a**	**b**	**a**	**b**	**a**	**c**	**a**
Q.	14	15	16	17	18	19	20	21	22	23	24	25	26
A.	**c**	**b**	**b**	**c**	**b**	**b**	**a**	**a**	**b**	**c**	**c**	**a**	**b**
Q.	27	28	29	30									
A.	**a**	**b**	**c**	**b**									

15. JET STREAMS

Jet stream is a strong narrow current of winds along a semi horizontal axis in the upper troposphere. Jet streams are present in both the hemispheres all year round. The path of a jetstream is zigzaz wavy like a serpentine. Normally a jet stream is thousands of km in length, hundreds of km in width and some km (often less than 5 km) in depth. A jet steam has strong vertical and horizontal wind shears. The **vertical WS is about 5m/s per km.** The arbitrary **lower limit** of **jet core velocity** has been assigned as **30m/sec (60 kt).**

Jet streams feature one or more velocity maxima. The **path of maximum speed** is called the **axis** and the **tubular volume** immediately surrounding it is the **core**.

The wind speed along the axis is not always uniform. There are distinct maxima along the axis. The speed of these maxima is much lower than the wind speed itself. At certain places the maxima speed reduces below 60 kt, constituting breaks in the jet stream. Sometimes jet streams may split into two or more parts, combine into one stream, or flow in different directions.

Along the axis of a jet stream there are **centres of high speed winds**, called **Jet streaks** (wind maxima), with weaker winds in between. Jet streaks retain their strength but move slower, by up to 25 kt, than the jet stream. **In a wavy jet they are located over or near the ridge.**

Types of Jet Streams: There are four types of jet streams in the troposphere:-

(a) **Arctic Jet Stream (AJ).** It a **westerly jet stream** at 7 to 8 km height over the Arctic region, close to polar tropopause.

(b) **Polar Front Jet Stream (PFJ).** It is also called mid latitude jet and flows over N America, Europe and Asia,while the S hemisphere it mostly circles Antarctica all year round. It is a **Wly jet stream** located at about 250 hPa level, above the surface polar front, at about 9-12 km (30,000-39,000 ft) close to the middle-latitude tropopause break.The PFJ migrates in winter to 30° N and in summers to 60° N. The core speeds are stronger in winters than in summers. Its main direction is Wly, although on many occasions it may be NWly or SWly. Normal speeds are 80 to 100 kt in winters. It is produced by a temperature difference between the cold polar air and warm tropical air.

(c) **Sub-tropical Jet Stream (STJ).** It is a **Wly jet stream**, between 10 and 16 km, above the sub-tropical high pressure belt, hence the name. In winters its normal position is about 30° N and is strong. Its southern most position is S of 22° N in February. In summers it moves to N of 35° N and weakens. The STJ lies close to the middle latitude tropopause break. The STJ affects India in the non-monsoon months (Oct to May). Its speed varies from 100 to over 215 kt (398 km/h).

(d) **Tropical Jet Stream (TJ).** It is more commonly known as the **Easterly jet stream**. It is found at a mean height of about 15 to 16 km. It is prominent during the monsoons and becomes very weak in winters. The average core speed varies from 60 to 80 kt, with a maxima of 150 kt. The axis in July-August is near latitude 13° N (Chennai Lat.) over India.

(e) **Stratospheric Jet Stream(SJ).** A stratospheric jet stream is found at levels above 20 km in the Arctic and Antarctic regions. These are westerlies in winter and easterlies in summer.

Jet Streams over India

Sub-tropical Jet Stream

The STJ appears over the N India in October after the withdrawal of monsoon and shifts progressively southwards with the progress of the winter. Its mean position is roughly at 27° N at a height of 12 km. It reaches its southern most position of 22° N in February. STJ prevails over the Indian subcontinent for about eight months (Oct to May). After May it shifts northwards and moves out of the Indian subcontinent.

The mean wind speed of STJ is 100 kt, with a maximum of 200 kt. The speeds are the lowest (60 to 70 kt) in October and May and the highest (100 to 120 kt) in January. Higher speeds are more common in January and February than December. On occasions the core speeds reach 200 kt. The level of maximum wind in STJ is a few kilometer below the tropopause.

Sometimes the STJ splits due to the Himalayas, with one branch to the south and another to the north of Himalayas. These branches later recombine to form a single stream over China.

STJ has a layered structure. There are often two layers of maximum wind, to the S of the jet core. The jet stream strengthens by 10- 15 kt downstream, along the axis from Jodhpur to Guwahati.

STJ is located 3-4 km below the tropopause in the region where there is a break in tropical and middle tropopause at 300 – 200 hPa.

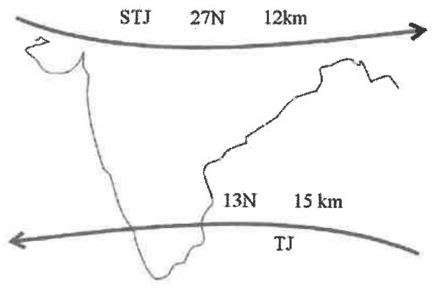


Figure 15.1 Normal Positions of STJ and TJ In deep westerly troughs the jetstream tends to be S of the mean position and in ridges N of the mean position.

Temperature Distribution.

STJ is caused by a concentration of horizontal temperature gradient below the jet and reversal above it. From surface to 300 hPa the horizontal temperature gradient is from S to N, particularly at 500 and 300 hPa. Consequently thermal wind builds up and jet maxima is reached at 200 hPa. At 200 hPa thermal gradient is slack and thereafter it reverses. **Lapse rates are more to the S of the jetstream than to the N**, both above and below. **At and near the STJ the temperature gradient is very small or negligible.**

Vertical Shear. Strong vertical wind shear is often concentrated just above and below the core. **It is greater above the core than below it.**

Horizontal Shear. In STJ the horizontal shear is more to the north than to the south of the core. At core level the winds weaken by about 35 kt/100 NM to the south (right). To the north the fall is steeper, about 100 kt/ 100NM. Shear is more below the core and to the north (left).

STJ and Weather. With the passage of a WD, STJ strengthens (130 – 150 kt) and moves south. **Divergence in the left entrance and right exit of the jet core in combination with a low level system (Low pressure) enhance its activity and may cause severe TS.**

Tropical Jet Stream

Over the peninsular India, strong Easterlies blow to S of 25° N at 100 hPa during the monsoon period. This is called Easterly Jetstream or Tropical Jetstream (TJ). **It is found only over Asia and Africa and not over Atlantic and Pacific.** In July there are 10-20 kt Ely winds at 300 hPa S of 27° N and Wly to the N. **During monsoon months, there is a southward decrease of temperature throughout the troposphere, due to sun being N of 20° N. Tibetan plateau also has some influence on temperature gradient.** The temperature gradient from N to S, opposite of winters, causes lower level westerlies to change to easterlies above 500 hPa level. Easterlies strengthen with height up to about 16 km, where wind speed is about 80 kt or so, maximum being 150 kt. **TJ is seen over India from June to August and disappears by September. The TJ is located at 13° N (near Chennai) at a height of 15 - 16 km.**

The level of maximum wind in TJ is just below the tropopause.

In the TJ the wind shears are much less than the STJ.

Low Level Jets(LLJ)

In addition to the above jet streams very strong winds appear in the lower levels, between 1 km and 3 km at many places, in the sub-tropics. These are called LLJ. A prominent LLJ is noticed over the Indian Peninsula during southwest monsoon, when low level winds become very strong. This LLJ is probably a continuation of the jet stream off the Somalia Coast in Africa. The LLJ enhances the monsoon activity over Indian peninsula.

Cause and Weather associated with Jetstream

Cause. Jetstream is caused by the **large horizontal temperature gradient**. Larger the temperature difference between two air masses stronger is the jet stream.

Clouds. Jetstream has extensive sheets of high clouds on warm side, with sharply defined edges, usually parallel to the jet axis. CI clouds are more common on the cold side while CS and CC clouds on the warm side. On cold side cloud tops are invariably just below the tropopause whereas on the warm side tops are a few thousand feet below the tropopause. Roll type of CI or CS may be seen all along the length. Where moisture is less a thin layer of haze is noticed on the warm side and clear on the cold side.

CAT

CAT occurs around boundaries of Jetstream due to large vertical and horizontal wind shear. It is also more in a developing and rapidly moving jet.

Strongest CAT occurs near or just below the axis on colder (low pressure) side with a secondary maxima above the Jetstream. Looking downstream it is to the left in N hemisphere and to the right in S hemisphere.

CAT in a jetstream is most severe in

(a) Strong Winds

(b) Curved Jets. Sharper the curve stronger is the turbulence.

(c) On the leeward side and above the mountain ranges.

QUESTIONS ON JETSTREAM

Q1. The arbitrary lower limit of jet core velocity has been assigned by WMO as
(a) 60 kt (b) 60 m/s (c) 70 m/s

Q2. Jet stream has
(a) one maxima (b) one or more maxima (c) only two maxima

Q3. The vertical wind shear in a Jet stream is about
(a) 5m/s/ km (b) 6m/s/km (c) 8m/s/km

Q4. Compared to horizontal wind shear the vertical wind shear in a Jet stream is
(a) weaker (b) stronger (c) same

Q5. In a jet stream, the path of the maximum speed is known as
(a) Core (b) Axis (c) Jet streak

Q6. The wind speed along the axis of a jet stream is always
(a) Uniform (b) Not uniform

Q7. Along the axis of a jet stream there are centres of high speed winds, these are called
(a) Jet streaks (b) Core (c) Axis

Q8. In a wavy jet the Jet streaks are located over or near the
(a) Ridge (b) Trough (c) Between Trough and Ridge

Q9. Sub-tropical Jet Stream (STJ) is
(a) Westerly (b) Easterly (c) Southerly

Q10. The normal position of Sub-tropical Jet Stream is
(a) 30° N (b) 27° N (c) 35° N

Q11. The southern most position of STJ is in February is
(a) 22° N (b) 20° N (c) 18° N

Q12. The STJ affects India from
(a) Jun to Jul (b) Oct to May (c) Aug to Sep

Q13. STJ has a layered structure. There are often two layers of max wind to the........of jet core
(a) S (b) N (c) SW

Q14. The STJ strengthens
(a) Northwards (b) Upstream (c) Downstream

Q15. At and near the STJ the temperature gradient is very
(a) Small (b) Large (c) Moderate

Q16. Vertical wind shear in STJ is greater .... the core
(a) above (b) below (c) along

Q17. The TJ prevails over the Indian Peninsula from
(a) May to Jun (b) Sep to Oct (c) Jun to Aug

Q18. The TJ is located over the Indian Peninsula, approximately at
(a) 13° N (b) 17° N (c) 18° N

Q19. The TJ is located over Indian, approximately at a height of
(a) 15 –16 km (b) 12 – 13 km (c) 11 – 12 km

Q20. The TJ is strongest in
(a) July – Aug (b) Sep - Oct (c) June

Q21. In the TJ the wind shears are much .... than the STJ
(a) more (b) less (c) same

Q22. TJ is
(a) Westerly (b) Easterly (c) Southerly

Q23. A jet stream can be recognized by
(a) High level dust (b) High Pressure (c) Streaks of CI (d) Lenticular clouds

Q24. Flying at right angles to a jet stream with falling pressure you will experience
(a) Wind from left (b) Increasing head wind
(c) Increasing tail wind (d) Wind from right

Q25. When and where tropical jet stream occurs
(a) All year along equator (b) In Middle East in summers
(c) In winters over Russia (d) In summers over SE Asia and Central Africa

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**a**	**b**	**a**	**b**	**b**	**b**	**a**	**a**	**a**	**b**	**a**	**b**	**a**
Q.	14	15	16	17	18	19	20	21	22	23	24	25	
A.	**c**	**a**	**a**	**c**	**a**	**a**	**a**	**b**	**b**	**c**	**a**	**d**	

16. CLEAR AIR TURBULENCE

Clear Air Turbulence (CAT) is the bumpiness experienced by aircraft at high altitudes in cloud-free conditions, excluding CI clouds. CAT is caused when bodies of air moving at widely different speeds meet. The Upper Troposphere (about 23000 - 39000 ft), near Tropopause, is the most susceptible region for occurrence of CAT. It is most frequently found in the regiions of jet streams. Unstable atmosphere enhances CAT. In lower altitudes it may occur near mountain ranges.

Necessary conditions for the generation of CAT are:

(a) Marked horizontal or vertical wind shear
(b) Steep lapse rate in the atmosphere.

Such conditions normally exist just below the tropopause, especially in the vicinity of a jet stream core. In the lower stratosphere even though the lapse rate is small or negative, the marked decrease of wind speed with height may give rise to temporary zones of CAT.

Most CAT occurs on the fringes of (not within the core of) a jet stream and in the vicinity of upper level frontal zones where temperature contrasts are strong.

CAT also occur when strong winds cross a mountain range under suitable stability conditions. These amplify the gravity waves and propagate them vertically towards the stratosphere. The mountain waves may generate smooth up and downdraughts or may breakdown and cause CAT.

The combined effect of mountain wave and jet stream may cause severe CAT. Severe CAT is more frequent on the leeward side of high ground than over the plains.

CAT also occurs when strong winds encounter the tops of thunderstorm clouds, resulting in waves that extend well downstream from the cloud. Sometimes a train of lenticular clouds can be noticed on the leeward side of a CB cloud.

CAT Over India

(a) From October to May the frequency of CAT is highest over N, Central and NE India, due to the presence of the Sub Tropical Jet stream and over S India in July and August due to the peak activity of Tropical Jet stream.

(b) Most of the CAT in India are weak to moderate. Severe CAT occur from December to February when STJ is in its peak.

(c) CAT is a patchy phenomena. Its average dimensions are about 120 km in N-S direction and about 250 km in the E-W direction.

(d) Vertically a CAT zone may be about 2000 ft, but in may extend through a deep layer.

Aviation Hazards

(a) CAT causes discomfort to the crew and passengers.
(b) In CAT difficulty may be experienced in controlling an aircraft.
(c) CAT is encountered suddenly and is amplified by the mountain waves.

Avoidance

(a) Avoid flying close to a Jet stream.
(b) Climb up or descend down, or turn N or S to get out of CAT.
(c) Avoid flying below tropopause, about 1 km above it may be clear of CAT.

17. MOUNTAIN WAVES

The airflow over mountains is disturbed due to the underlying undulated surface. Under suitable stability conditions when an air stream strikes a mountain range, **a train of waves is generated on the leeward side of the range**, called **Mountain** wave.

Definition. Mountain Wave is defined as oscillations to the lee side of high ground due to disturbance in the in horizontal air flow caused by the high ground.

Mountain Waves, extend vertically to a great heights and horizontally downwind to a considerable distance. **Flying over such terrain is bumpy and unsafe**. For the safety of aircraft and comfort of passengers, an understanding of the flow pattern, its extent, scale and degree of turbulence associated with it is vital for the aviators.

Necessary Conditions

• **Wind:**

(a) A definite air flow across the ridge, within 30° perpendicular to the ridge.
(b) A wind of atleast 7m/s for smaller mountains and 15m/s for larger mountains.
(c) A deep steady directional flow over a significant height band, strengthening with height.

• **Stability:**

(a) Stable layer below the ridge.
(b) Stable air above the crestof the ridge, with less stable air above.

Vertical Currents

In the mountain waves there are alternate areas of rise and sink. The areas of sink occur immediately downward of the ridge. The vertical currents associated with the mountain waves can be intense and extensive. Over large mountains, vertical currents of 10 to 25 m/sec are not uncommon. An aircraft flying parallel to a ridge, if caught in the down current, would suffer constant loss of height till the whole length of the ridge is traversed. Whereas an aircraft caught in up currents would constantly gain height. Adequate terrain clearance is therefore essential while flying over the mountains.

Clouds

In humid atmosphere the mountain waves form characteristics clouds, namely: cap, rotor, lenticular, ST, SC, AS, CI and Nacreous (in upper stratosphere). These clouds continuously form on the upwind side and dissolve on the downwind side, thereby appear stationary. Lenticular clouds are lens shaped and form at successive crests of the waves, up to some distance. On large lee slopes on certain occasions the clouds sweep down like a cloud fall or **Fohn wall** and resemble **waterfalls.** Mountains have a tendency to increase the cloud cover and also cloud depth.

Lee waves of long amplitude, often produce **rotors** in the crests of waves. If the mountain range is long, a succession or a train of lee waves may be seen.

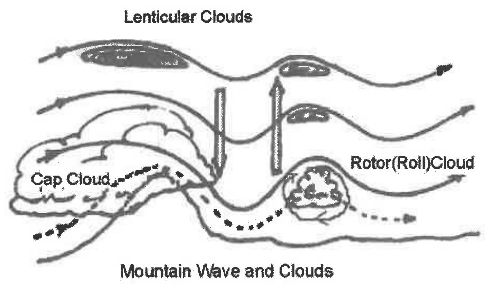


Figure 16.1 Mountain Waves and Clouds

When winds are strong at lower levels only and weaken or reverse at higher levels, violent rotors form on the lee slope and move down wind from the ridge. These are called **Rotor Streaming.**

Visual Recognition

(a) Lenticular clouds on the leeward side a few thousand feet above crests. Their ragged edges indicate turbulence.
(b) Rotor Clouds. Strongest rotor is normally in the first wave crest, level or slightly above the crest.
(c) Cap Clouds. These clouds cover mountain top. Strong winds may sometimes sweep them down the lee slope, as Fohn Wall.

Turbulence

Flying over the mountains is not always turbulent. It is smooth in certain regions and turbulent in others, due to additional wind shears. However, the transition from smooth to turbulent motion is extremely abrupt and without any warning.

Sometimes, the outlines of wave clouds are not smooth but have ragged appearance. This is an indication of turbulence. Severe turbulence occurs in cap clouds, Fohn wall and rotor clouds. The worst kind of turbulence is encountered in the vicinity of rotor clouds, similar to that of violent TS. In rotor clouds both vertical and horizontal gusts occur and an acceleration of 2 to 4g is not uncommon, at times 7g has also been exceeded.

The degree of bumpiness experienced by an aircraft depends upon its size, speed and aerodynamic characteristics.

In extensive mountain ranges one wave system generated by one range is modified by the further ridges downstream. Such modifications may result in violent turbulence.

Altimeter Errors

In mountain waves an aircraft is subjected to rapid height fluctuations, due to up and down currents. The aneroid capsules of the altimeter are unable to respond correctly to these fluctuations. This is called **Hysteresis** effect. Altimeters also give erroneous readings if the temperature defers from ISA. If colder than ISA, the readings are too high and vice versa. Hence altimeter readings are not reliable and deceptive when used for terrain clearance.

Seasonal and Diurnal Variation

The atmosphere becomes stable at lower levels after sunset due to radiational cooling. At the same time the winds also weaken in the lower layers. This results in the formation of waves, on the lee side of small and medium height mountains, called **evening waves**. These waves continue throughout, till the warming up after sunrise destroys the stability structure. In the case of large mountains, however, this effect is negligible.

In winters the winds are steady and strengthen with height and the atmosphere has suitable stability. Hence the mountain waves are more frequent in the winters.

Extent

Mountain waves may extend 100-200 km downstream and vertically sometimes well into Stratosphere. Wavelength of mountain waves is about 10 km or more.

Aviation Hazards

The mountain waves deform the air flow over mountains and create several aviation hazards. The main hazards are:

(a) Strong up and down currents may make it difficult to maintain altitude and loss of control.
(b) Turbulence, often severe, up to great heights, may lead to structural damage.
(c) Unexpected winds of large magnitude may cause loss or gain of altitude.
(d) Increase in frequency and intensity of icing.
(e) Errors in pressure altimeter.

QUESTIONS ON CAT AND MOUNTAIN WAVES

Q1. For mountain waves to form there should be flow of air across the ridge, generally within .... of the perpendicular to the ridge.
(a) 30° (b) 45° (c) 60°

Q2. For mountain waves to form the wind speed for small mountains should be atleast
(a) 15 m/s (b) 10 m/s (c) 7m/s

Q3. For mountain waves to form the wind speed for large mountains should be atleast
(a) 15 m/s (b) 10 m/s (c) 7m/s

Q4. For mountain waves to form there should be ..... air beow the ridge and less stable air above.
(a) Stable (b) Unstable (c) Indifferent

Q5. The worst kind of turbulence is encountered in the vicinity of rotor clouds.
(a) Rotar Clouds (b) Lenticular Clouds (c) Cap Clouds

Q6. In Mountain waves the Rotor clouds form in
(a) Troughs (b) Ridges (c) Valley

Q7. Clear air turbulence is often encountered
(a) At the boundary of a jet stream
(b) In the wake of a passing airplane
(c) In the wake of a larger airplane at take off and landing
(d) All of the above

Q8. Most CAT occurs on the .... of a jet stream and in the vicinity of upper level frontal zones where temperature contrasts are strong.
(a) Fringes (b) Within the core (c) Axis

Q9. CAT is the bumpiness experienced by aircraft at high altitudes. Over North India its maximum frequency is during :
(a) Oct - May (b) Jul - Aug (c) Jun - Sep

Q10. When approaching an area where mountain waves have been reported, a pilot should expect:
(a) Possible presence of roll clouds and lenticular clouds
(b) Intense up draughts and down draughts on the lee side of the mountains.
(c) Moderate to severe turbulence as far as 20 to 30 nm from range on leeward side.
(d) All of the above

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10
A.	a	c	a	a	a	b	a	a	a	d

18. TROPICAL SYSTEMS

TROPICAL DISCONTINUITIES

In tropics the temperature (or density) contrast between two air masses is not as discernable as in the higher latitudes. Hence fronts can not be marked. However, a line of discontinuity can be drawn in the wind field in the upper air charts and by the inspection of the cloud pattern. Such discontinuities are called **Tropical Discontinuities or Convergence Zones**.

Inter Tropical Convergence Zone (ITCZ)

It is a narrow zone along which Tm or Tc air from the N meets the Tm or Em air from the S. Since the air masses within the tropics from N and S converge, hence the name. ITCZ usually lies along the Equatorial Trough (ET). With the movement of the sun, in summers it migrates up to 20° N and in winters up to Australia. ITCZ is therefore encountered by aircraft in winters when flying from India to the SE Asian countries and Australia. ITCZ embraces the whole globe. It is active in certain portions, of about 75-150 km length, where heavy showers occur and CB clouds predominate. In inactive areas scattered showers occur from large CU/CB. On rare occasions, it may be pushed up to S Bay of Bengal in winters and may initiate formation of cyclonic storms. During rainy season, the ITCZ/ET coincides with the Monsoon Trough. (Satellite Imagery of ITCZ at Appendix I)

Equatorial Front. It is an alternative term for ITCZ.

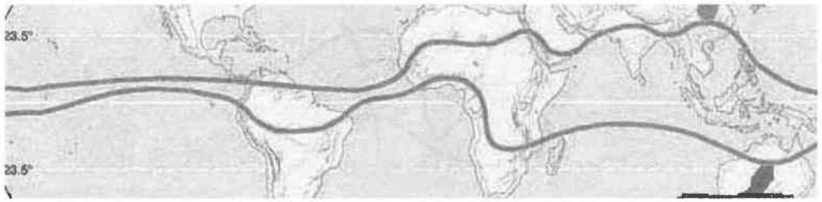


Figure 18.1 Inter Tropical Convergence Zone (ITCZ) July (top) and January (bottom) Locations

Equatorial Trough (ET). It is a shallow trough in the region of doldrums near equator.

Easterly Waves

Easterly waves are troughs in tropical easterly winds. These waves form on the ITCZ with fairly high frequency. They originate at sea at the boundary of Tm and the Em air masses. A minor surge of Em air may distort the ITCZ and start the **Easterly Wave**. The wave moves in a more or less east-west direction.

The Easterly Waves are weak at the surface but better developed at 500 hPa level and above. Their wavelength is about 1500 km. They move from W to E with speed 20-25 kmh along the ITCZ. Most of the weather occurs in the rear of the wave trough.

Easterly Waves in India

In winters these waves are first noticed in the Andaman sea as shallow lows with troughs in the upper air. They move westwards across south peninsula and emerge into the Arabian Sea. Their speed is about 15 kts over the sea and about 10 kts over the peninsula. Their further progression westwards beyond the Arabian Sea cannot be easily traced, but they also affect Africa. In winters the ITCZ is to the south of the equator, but on rare occasions it moves into the extreme south Bay. The resulting wave may cause a spell of disturbed weather for 3-4 days over Bay Islands, Tamil Nadu, Kerala and the Arabian Sea Islands.

During pre-monsoon season the ITCZ advances further north. Consequently the frequency of easterly weaves over India increases. These help the formation and development of premonsoon cyclonic storms over the Indian seas.

During the monsoon season the easterly waves from the Pacific Ocean move across SE Asia and reach the head of Bay of Bengal. Some of them move further WNW along the ITCZ with only slight intensification. Others develop into depressions, move NW and

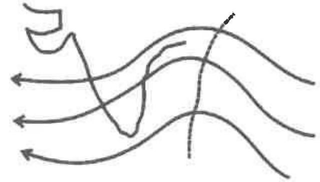


Figure 18.2 Easterly Wave

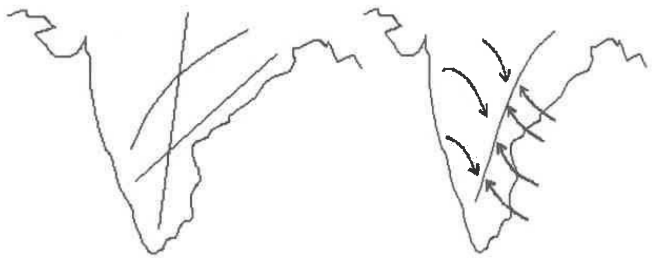
weaken gradually. Very infrequently an easterly wave may develop into a depression over the north Arabian Sea.

In the post-monsoon season as the ITCZ gradually moves southwards, the depressions and cyclones form in the central and S Bay of Bengal in the Arabian sea.

Peninsular Discontinuity (PD)

Another discontinuity of importance in India is a discontinuity which forms over peninsular India (south of Lat. 23 N) in April and May. This discontinuity (also called **Dry Line**) is between hot and dry Tc air form the northern India and comparatively cooler and moist air from the Bay of Bengal.

This discontinuity gives rise to afternoon thunderstorms, at times with hail, strong northwesterly squalls and heavy showers. It remains more or less stationary for 3-4 days before dissipating.



Various Positions of PD   Wind pattern at PD

Figure 18.3 Peninsular Discontinuity

Surge

Surge or pulse is the sudden strengthening of an air current in the same air mass. At a surge the air arrives faster than it is removed. This leads to accumulation of air at the surge line and vertical ascent. This process is known as **velocity convergence**. A surge is a common disturbance in the monsoon season over the Arabian Sea. To the west of the surge line the wind may be about 40 kt while ahead of it, to the east, only about 10- 15 kt.

Vertical ascent at a surge line causes growth of CU clouds, showers and gusts or squalls. The surge line moves in the direction of the wind. It ultimately reaches over the head of the Bay of Bengal.

When a surge arrives, the sky becomes overcast with very frequent and sharp showers, and strong gusty or squally winds. The surge line activates ITCZ and favours the formation of depressions or cyclones on the ITCZ.

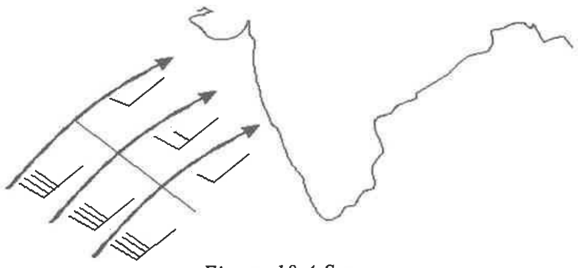


Figure 18.4 Surge

Shear Lines

Shear Lines are created when in the same air mass the wind speed decreases markedly from south to north or vice versa. Such situations are common over Arabian sea during the monsoon season. At a shear line, due to friction between the air moving with different velocities, there is a small scale ascent of the air. If the shear line extends vertically, the ascent extends to higher levels and thick stratiform layer clouds (ST, AS and NS) form, which may extend to about 500 km across. When a fresh surge arrives large CU and CB

clouds also get embedded in these, specially at the leading edge of the surge, which are at right angles to the shear line. Surge and Shear Lines are a characteristic feature of vigorous monsoon.

Figure 18.5 Shear Line

Low Pressure Systems

The Low pressure systems are classified on the basis of wind speed over the sea (at 900 m over land) as follows:

	Wind Speed Over Sea
Low Pressure	- < 17 kt
Depression	- 17-27 kt
Deep Depression	- 28 - 33 kt
Cyclonic Storm	- 34 - 47 kt
Severe Cyclonic Storm	- 48 - 63 kt
Very Severe Cyclonic Storm	- 64 - <120 kt
Super Cyclone	- 120 kt or more

Note:- Over land area the winds are considered at 900 m. Wind Speed Over Sea

Monsoon Depressions

A Depression is a low-pressure area with two or more closed isobars at 2 hPa interval. In India, they form over the North Bay of Bengal during monsoon season and are termed as **Monsoon Depressions**. In a depression surface winds are 17-33 kt. They also form over the Arabian Sea and over land too. Land depressions mostly form over NE India. In June, July and August depressions form over the head Bay of Bengal (N of 18 N). They move N/NW/NE into land. In September they form around 14 N. In Arabian Sea they originate 5° off the coast, N of 12 N and move N. If they form during the arrival of monsoon period, they help in advancing the monsoon northwards.

The average life of a monsoon depression is 3-5 days.

In a monsoon depression the worst **weather occurs in the SW sector** where rainfall is steady and heavy, in a belt of about 400 km width. Elsewhere it is scanty. At the time of re-curvature the rain belt shifts to N- NE sector. Showery precipitation occurs in the rear of depression when winds are strong S-SWly.

The associated upper air cyclonic circulation extends up to about 300 hPa. The monsoon depression slope SWwards with height. For example if the system at the surface is over Kolkata, it would be over Visakhapatnam at 300 hPa (9km).

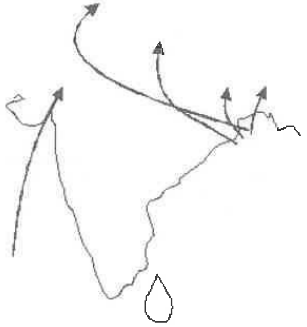


Figure 18.6 Tracks of Monsoon Depressions

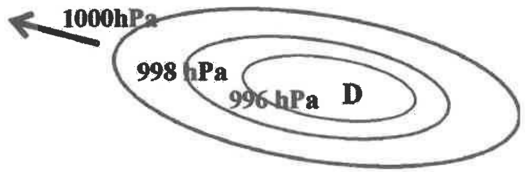
Fair weather over Assam during monsoon indicates intensification or formation of a depression over head Bay or vice versa.

Tropical Cyclones(TC) Tropical Revolving Storm (TRS)

TC are non-frontal low pressure system with numerous TS, strong winds and heavy rain. They form over warm tropical waters (temperature > 26°C), between Lat 5-25°. Below 5° there is no coriolis force and above 25° it is cold.

The **maximum sustained wind** in a TC is 34 kt or more. As per IMD it is the **highest 3 min** (in some countries 1and 10 min) averaged surface wind within the circulation at 10 m height.

Depending on its location and strength, a TC is termed as **Hurricane**, **Typhoon**, **Tropical Storm**, **Cyclonic Storm**, **Tropical Revolving Storm** and simply **Cyclone**.



Isobars in Depression are Elliptical

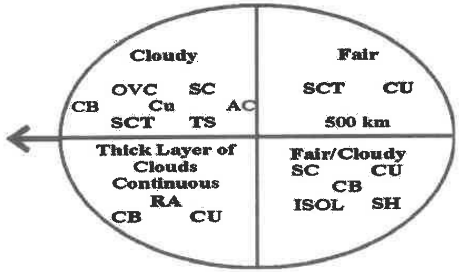


Figure 18.7 Isobars and Weather in a Depression

Depending on its location and strength, a TC is termed as **Hurricane, Typhoon, Tropical Storm, Cyclonic Storm, Tropical Revolving Storm** and simply **Cyclone**.

TC can produce extremely powerful and damaging winds, torrential rain, high waves, storm surge, as well as tornadoes. On the positive side, TC can relieve drought conditions and they also transport heat and energy from the tropics towards the temperate latitudes. They thus help in maintaining equilibrium in the troposphere, and a relatively stable and warm temperature worldwide.

Necessary conditions for Formation

(a) **Warm sea** (> 26°C) to a depth of 60 m to provides abundant evaporation.

(b) **High RH** to above 7000 m to facilitates condensation of water vapors into drops and release latent heat, there by inducing a fall in pressure.

(c) **Instability** for vertical development, and **Coriolis Force** to spiral wind inward.

(d) **Very little Wind Shear**. WS preferably below 20 kt from 850 to 200 hPa. WS will distribute latent heat over large area and intensification would suffer.

Characteristics. In the mature phase a cyclone has four parts:

(a) **The Eye**. The eye is the region of light winds and often clear skies, lowest surface pressure, warmer by 0-2°C and at 12 km may be by 10°C or more. Inversion from 1 to 3 km. The warmth is due to compression of the subsiding air. It is surrounded by eyewall, a ring of towering CB clouds. **Diameter of the Eye is mostly 30-65 km**.

(b) **Inner Storm Area (Hurricane Core)**. The eye is surrounded by an area of, width 50–150 km, with very strong winds (> 64 kt), violent squalls, torrential rains, thick dark CB clouds, called **Eye Wall /Wall Clouds**. The eye wall is the most hazardous part of the cyclone. In this region pressure gradient is very steep. Some of the intense TC exhibit concentric eye walls.

(c) **Outer Storm Area**. Outside the core is the outer storm area, extending to about 400 km, in which winds of gale force (34 kt or more) and occasional squalls occur. Winds decrease outwards. There are **spiral bands** of clouds.

(d) **Edge of Storm**. In this region winds are weak and clouding diminishes.

Extent and Movement. TC is a vast violent whirl of 150 to 800 km, spiraling around a centre. It move over the sea at a rate of 300 to 500 km a day at 15 – 20 kmh. Generally TC move westwards up to about 25° N/ S and then recurve and move E.

Pressure. The central pressure in a TC is between 1000 - 900 hPa. On an average the central pressure is 5 to 6 hPa below the surrounding pressure and in extreme cases may be about 70 hPa less. The pressure gradient is very steep up to a radius of 100 km.

Worst Weather. The worst weather and winds in a cyclone are to the **right forward sector** in the N- hemisphere and **left forward sector** in the S – hemisphere.

Upper Air Circulation

The cyclonic circulation in a TC may extend to 40,000 ft. The axis of circulation is almost vertical. In the inner storm area winds of hurricane force persist up to about 7000 ft. Thereafter, winds weaken.

Wind speeds, at surface and in the upper air, are stronger in the right half of a cyclone than in the left half. The difference being almost twice the speed of the cyclone.

Tropical Storms over India

The size of a TC over Indian seas varies from 50 - 2000 km radius, with an average of 300 – 600 km. Cyclonic storms form over the Bay of Bengal and the Arabian Sea and move inland. They cause damage and devastation over the coastal areas. The damage is mainly due to the very strong winds, torrential rain and inundation caused by the storm wave and high tides.

The storms in the Bay of Bengal or the Arabian Sea have a very small life span, as they travel over the water surface for a relatively small period. Hence they are in an immature or slight mature stage when they strike the coast. That is why the majority of Indian cyclones are not as violent as their counterparts, the typhoons and hurricanes. The average span of life of the Indian cyclones is 3 - 5 days, maximum being 6 to 7 days, even in the case of recurving storms. There have been cases when storms have kept recurving over the Bay of Bengal for a few days and assumed the vigour of a severe cyclonic storm before entering land. Such storms take a heavy toll of life and property. In exceptional cases, some storms can last even up to 2 weeks.

In the pre and post-monsoon seasons, some of the Bay of Bengal cyclones recurve N or NE and strike the West Bengal, Bangla Desh or Myanmar. The Arabian Sea storms, when recurve, may strike Maharashtra and Gujarat coast. The low latitude Bay cyclones cross the coast of TN or south Andhra Pradesh, weaken over land and then emerge into the Arabian Sea. Here they may intensify and again become cyclones. They sometimes recurve NE, to strike Maharashtra and Gujarat coast. In the recent times SCS which affected Odissa, AP and TN : on 12 Oct 2013 a **VSCS (Phailin)** struck Odisha coast, (max wind 220 kmh (sustained wind 175-185 kmh), in Oct 2014 an extremely **SCS Hudhud** hit AP and Odissa (max wind 205 kmh and central pressure 960 hPa), in Dec 2016 **VSCS Varda** (max wind 155 kmh) hit Andman and Nicobar,TN and AP (sustained wind 80-90 kmh). In Oct 2014 an extremely **SCS Nilofar** formed over Arabian sea (max wind 215 kmh). **See *Appendix I***

Flying Conditions

Flying conditions within the storm are extremely hazardous. Clouds are arranged in spiraling bands. The central area outside the eye has extensive unbroken cloud mass or the eye wall. Cloud bases may lower down to the surface and the tops in the CB towers may reach 18–20 km. Severe turbulence occurs in the towering clouds. Frictional turbulence is experienced in the lowest layers due to the strong winds. Strong up and down draughts occur in various parts of storm. Rain in certain portions is torrential. Winds are very strong.

Frequency of Cyclones

The frequency of cyclones in the Bay of Bengal and Arabian Sea is almost nil in February and March. They are frequent in May, June, October and November. Their frequency is **maximum in October and November.**

- TC do not form in S Atlantic ocean as ITCZ never moves S of 5° S in S Atlantic.
- In NW Pacific TC occur throughout the year.
- Annual frequency of TC in the Bay of Bengal is 4.5 and 1.1 in the Arabian Sea.

Avoidance of a Tropical Cyclone while in Flight

On whatever compass course the cyclone is approached, strong winds from the port indicate that the centre lies somewhere ahead. To avoid the cyclone alter the course until the wind is from starboard and is weakening.

FRONTAL DEPRESSIONS

Formation of a Frontal Depression / Cyclone

A stationary or a quasi stationary polar front, in the northern hemisphere, has warm tropical air to the south and colder air to the north. When the warm tropical air penetrates into a stationary polar front, a wave is generated. If this wave is stable, it moves eastwards along the front without intensification. If it is unstable, it intensifies. Pressure falls in the region where the bulge has occurred on the front and the cyclonic circulation develops into a depression. Ahead of the cyclonic centre, warm air displaces cold air (**warm front)**. In the rear of the cyclonic centre cold air replaces warm air (**cold front**). These fronts are carried along with the winds as the depression moves with the warm front preceding the cold front.

These depressions of the middle latitudes are called **extra-tropical depressions**. They generally move towards E or ENE, being steered by the westerly currents in these latitudes. When a depression on the polar front occludes, the unoccluded portion of the front is left behind, usually trailing at a lower latitude.

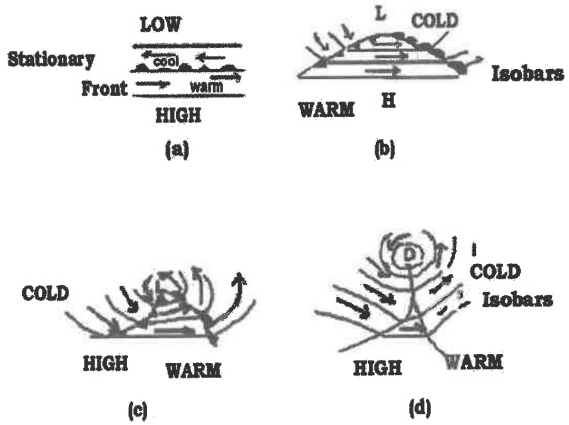
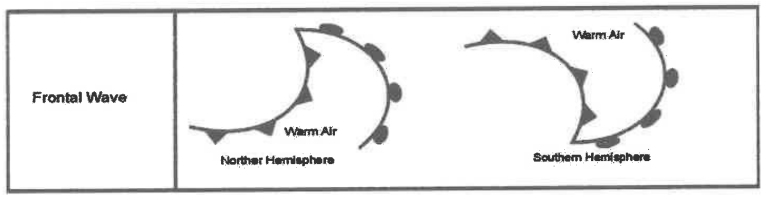


Figure 18.8 Frontal Depression



Frontal Wave of Frontal Depression as Represented in Synoptic Chart

Conditions then become favourable for secondary depressions to form at a lower latitude. This process may be repeated at a still lower latitude. In this way a **family of 3 or 4 depressions** may be generated, one SW of the other. They sometimes move eastwards together. These are called Cyclone Families.

Saffir-Simpson Scale of CS and **T Classification** and for Cyclones is at Appendix B

QUESTIONS ON TROPICAL SYSTEMS

Q1. Wind speed in a tropical severe cyclone is:
(a) 27 -33 kt (b) 48 – 63 kt (c) 17-27 kt

Q2. Fronts are characteristic of:
(a) Tropical cyclone (b) Extra-tropical depressions (c) Monsoon depressions

Q3. In a mature tropical cyclone, the eye area is characterised by:
(a) moderate winds and heavy rains (b) hurricane force winds and squalls
(c) calm wind, little clouding and practically no rainfall

Q4. Cyclonic storm cross Tamil Nadu coast in:
(a) Oct-Nov (b) Jul- Aug (c) Feb -May

Q5. Cyclonic storms form over Indian seas during
(a) SW monsoon (b) Winter Season (c) Pre-Monsoon & Post Monsoon

Q6. TRS occurs over Indian seas in:-
(a) Equatorial Region (b) 5 - 15° N (c) 0 - 5° N

Q7. In the Bay of Bengal during the months of Jul, August, Monsoon Depression form
(a) Over Head Bay (b) Central Bay (c) South Bay

Q8. In a monsoon depression maximum weather occurs in
(a) SE sector (b) NW sector (c) SW sector

Q9. During re-curvature maximum weather in a monsoon depression occurs in
(a) SE sector (b) NW sector (c) SW sector (d) NE sector

Q10. On whatever compass course the cyclone is approached, strong winds from the port indicate that the centre lies somewhere
(a) Ahead (b) Behind (c) Port (d) Starboard

Q11. The well developed extra tropical cyclonic storm is composed of two main frontal systems and an occluded front, which varies in extent:
(a) A stationary Front followed by a warm front
(b) A low with a warm front radiating out Southwards followed by a cold front.
(c) A warm front and an occluded front
(d) None of the above

Q12. Cyclonic storms are confined almost entirely to the
(a) Latitudes near Equator (b) Tropical latitudes
(c) Polar lat. (d) Mid lat.

Q13. The weather expected in a well developed cyclonic storm is:
(a) Moderate Weather (b) Stormy weather
(c) Clear skies (d) No wind or temperature change

Q14. After entering land the Cyclones gradually die down
(a) True (b) False

Q15. The .... is the most dangerous part of the cyclone is
(a) eye wall (b) eye
(c) Outer storm area (d) complete cyclone

Q16. No CS form
(a) At Poles (b) At Equator (c) At Lat 40 deg (d) All these

Q17. Average life of a tropical cyclone in India is
(a) 10 Days (b) 6-8 Days (c) 3-4 Days

Q18. CS in India are mostly of intensity
(a) Severe (b) Very Weak (c) Moderate

Q19. Eye of a CS is surrounded by
(a) Shelf Clouds (b) Wall Clouds (c) Rotor Clouds (d) Roll clouds

Q20. CS in Indian region are less intense because
(a) They have a very short travel over the sea
(b) Sea surface temp. are not high (c) India is close to Equator

Q21. Surge is sudden strengthening of wind in the .... air mass
(a) Same (b) Different (c) Both

Q22. Surge and Shear Line are features of .... monsoon
(a) Vigorous (b) Weak (c) Moderate

Q23. Peninsular discontinuity occurs along
(a) West Coast (b) East coast (c) Central Peninsula

Q24. Peninsular discontinuity occurs during
(a) Monsoon (b) NE Monsoon (c) Pre Monsoon

Q25. Surge is also
(a) Velocity Divergence (b) Velocity Convergence (c) like ITCZ

Q26. In a depression the wind speed is
(a) < 17 kt (b) 34 – 47 kt (c) 17 – 27 kt (d) 48 – 63 kt

Q27. In a CS the wind speed is
(a) < 17 kt (b) 34 – 47 kt (c) 17 – 27 kt (d) 28 – 33 kt

Q28. A monsoon depression slopes .... with height
(a) SE (b) NW (c) SW (d) NE

Q29. Average life of a monsoon depression is
(a) 2–3 days (b) 8–9 days (c) 3–5 days (d) 10–12 days

Q30. Monsoon depressions move faster over
(a) Sea (b) Plains (c) Hills (d) Rivers

Q31. For formation of a CS sea surface temperature should be
(a) 26 –27 ºC (b) 23 –24 ºC (c) 24 –25 ºC (d) 30 ºC

Q32. In extra tropical cyclone family there are 3 – 4 CS or depressions, one to the … of the other
(a) SE (b) NW (c) SW (d) NE

Q33. In TRS the central pressure is about
(a) 1002-1010 hPa (b) 1000-900 hPa (c)1010-1020 hPa

Q34. TRS develop over
(a) Sea (b) Land (c) Islands (d) at equator

Q35. TRS develop over .... deg Lat
(a) 0-5 (b) 5-15 (c) 25-30 (d) 30 - 40

Q36. In TRS pressure gradient is very steep up to a radius of
(a) 30 km (b) 50 km (c) 100 km (d) 400 km

Q37. Extra Tropical Storms originate in
(a) Equatorial Front (b) Tropical Front (c) Polar Front

Q38. Extra-tropical Storms generally move in the direction
(a) S to E (b) W to E (c) S to W (d) E to W

Q39. A Tropical Cyclone moves .... in a day
(a) 300-500 km (b) 500-700 km (c) 700-900 km

Q40. A Tropical CS has outer storm area of about
(a) >400 km (b) >700 km (c) >900 km

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11
A.	**b**	**b**	**c**	**a**	**c**	**b**	**a**	**c**	**d**	**a**	**b**
Q.	12	13	14	15	16	17	18	19	20	21	22
A.	**b**	**b**	**a**	**a**	**b**	**c**	**c**	**b**	**a**	**a**	**a**
Q.	23	24	25	26	27	28	29	30	31	32	33
A.	**c**	**c**	**b**	**c**	**b**	**c**	**c**	**b**	**a**	**c**	**b**
Q.	34	35	36	37	38	39	40				
A.	**a**	**b**	**c**	**c**	**b**	**a**	**a**				

19. CLIMATOLOGY OF INDIA

India has variety of climate. There is Tropical climate in the South and Temperate and Alpine climate in the Himalayan north. Himalayas receive sustained winter snowfall. Indian climate is strongly influenced by the Himalayas and the Thar Desert. The Himalayas act as a barrier to the cold winds flowing down from Central Asia. This keeps most of the Indian subcontinent warmer, compared to the most locations at similar latitudes. The land areas in the north have severe summer and cold winter. In contrast, the coastal regions are warmer and the rains are frequent.

The country is influenced by two seasons of rains, accompanied by seasonal reversal of winds from January to July. During the winters, dry and cold NWly winds blow over the north, which become NEly over the peninsular India due to Coriolis force. In summer months the Indian land mass becomes hot due to intense heat, and draws moist winds from the Arabian Sea and Bay of Bengal, causing a reversal of the winds, called the SW monsoon. This is the most important feature which controls the Indian climate.

About 75% of the annual rainfall is received during the short span of four months (June to September). There is a large variation in the amounts of rainfall received at different locations. The average annual rainfall is less than 13 cm over the W Rajasthan, while at Mawsynram, in Meghalaya, it is as much as 1187.3 cm (467.4 in). Cherrapunji gets 1177.7 cm (463.7 in) of rainfall during the year. The rainfall pattern roughly reflects the different climate regimes of the country, which vary from humid in the NE (about 180 days rainfall in a year), to arid in Rajasthan (20 days in a year).

The term Monsoon has been derived from the Arabic word "Mausim". **It is the seasonal reversal of winds and the rainfall**. As the sun oscillates between the Tropics of Cancer and Capricorn, the region of maximum heating (thermal equator) also moves N and S.

This causes the annual oscillation of temperature, winds, pressure, cloudiness, rain etc, and the seasons. The differential heating of land and oceans causes variations in the intensity of thermal equator and hence regional variations in the intensity of monsoon. The prominent monsoon regions are Africa, S Asia and N Australia.

According to our scriptures, the six seasons (Ritu) are :

1. **Vasant Ritu** Spring, Lunar Months **Chaitra and Vaisakh** (Mar-Apr). The temp. are around 20-30°C. Vernal Equinox occurs in the middle of this season.
2. **Grishm Ritu** Summer, **Jyeshtha and Asadha** (May-Jun). Very hot temperatures around 40-50°C. Summer Solstice occurs.
3. **Varsha Ritu** Monsoon, **Shravana (Swan) and Bhadrapad (Bhado)** (Jul-Aug). Very hot, very humid and heavy monsoon rains
4. **Sharad Ritu** Autumn, **Ashwina (Kwar, Asauj) and Kartika**, late- Sep, Oct and mid-Nov, Mild temperatures; 19-25°C; autumnal equinox in the mid of this season.
5. **Hemanta Ritu** Fall, **Margashirsha (Agrahayana, Agahan) and Pausha (Pus)**, late Nov- Dec, Very pleasant temperatures 19-25°C ; ends with the winter solstice.
6. **Shishira Ritu** Winter **Magha and Phalguna**, (Jan-Feb), Moderately cold, but pleasant during occasional sunshine; temperatures may fall below 10°C.

While Northern India mostly conforms to this marked change of Ritus, it is less so in Southern India, which is close to Equator.

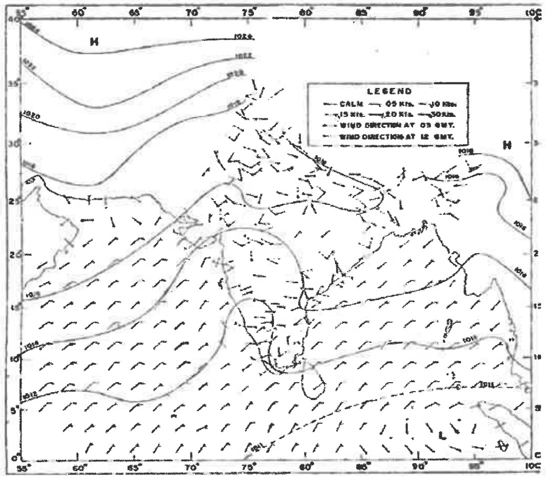
The IMD has designates Four Climatological Seasons :

Winter Season / Cold Weather Season	January – February December-February (NW India)
Summer / Pre-monsoon Season	March to May
SW monsoon (Rainy Season)	June to September
Post /NE monsoon(Cool Season)	October - November

Winter Season/ Cold Weather Season

(January and February and December to February for NW India).

Pressure Distribution. During this season there is an extensive belt of high pressure from Sahara to Siberia. The high is centered at 45° N and 105°E. India is at the southern periphery of this high. Accordingly, there is High pressure over N India and Low pressure over the Indian ocean. On the surface isobaric chart, about four isobars (1012-1018 hPa), at 2 hPa interval, cover the country. The 1012 hPa isobar extends from Arabian sea islands to Andaman area and the 1018 hPa isobar over Pakistan and J&K. A shallow trough extends from Kerala to Gujarat along the West Coast and a shallow ridge over the Gangetic plains. Under this pressure distribution, NWly winds prevail over N India and NEly winds over the S India.



Mean Presure(hPa) and winds at surface level (JANUARY)

Figure 19.2 Sea Level Pressure and Winds January

Surface Temperatures. December and January are the coldest months of the year. The mean daily minimum temperatures range from 22 °C in the extreme south, to 10 °C in the

northern plains and 6 °C in Punjab. Over most parts of the country the **diurnal range** of temperature is about 13°C, about 10°C over the coastal areas and 5° C over Tamil Nadu.

Surface Winds. Surface winds are light, mainly NEly south of 25° N, NWly over N India and Ely over Assam.

Upper Winds. Up to about 10,000 ft the winds are NWly over N and the Central India and are NEly over S India. Thereafter, Wly winds prevail aloft which strengthen with height and spread S wards up to the tip of Peninsula. The Sub Tropical Jet Stream (STJ) prevails over N India at a height of about 12 km and 27° N, with strong Westerly winds of 80-100 kt, maximum being 200 kt.

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Synoptic Systems. N India is affected by STJ and 5-7 WDs per month. A few CS and Eastely waves affect S India.

Weather

In N India, clear skies, poor visibility, dry weather, low humidity and low temperatures are the normal features. The dry spells are broken by the passage of WDs, which are mostly Occluded Fronts of extra tropical origin. Initially they cause Warm Front type weather. The weather sequence is, backing of winds from NWly to SWly/SEly, rise in temperature, fall in pressure, appearance of CI clouds and then thickening and lowering of clouds to AS, NS and ST. DZ and RA may occur. This is followed by the Cold Front type of weather, i.e. the appearance of CU and CB, rise in pressure and occurrence of TS. As the WD passes off the skies become clear and cold dry continental N-NWly winds set in. Widespread Radiation Fog and **Cold Waves (temperature≥ 4.0° C below minimum normal)** follow. The cold wave conditions may last for 2-3 days. When maximum temperature is≤ 16°C in Plains, it is declared as a **Cold Day.**

Cold Waves are common in Jan and Feb in W India N of 20° N. J&K, Rajasthan, West MP and Gujarat are most affected regions. Punjab receives comparatively lesser number of severe cold waves.

In the S India, the moisture laden winds from the Bay of Bengal cause rains and TS activity over TN and other parts of S Peninsula. Sometimes CS cause heavy rains.

Aviation Weather Hazards

Poor visibility is the main aviation weather hazard during winter season, specially over N India. **Fog, mist and haze** are common all over the country in the morning and evening. Smoke from industries and automobiles reduces visibility. Low level inversion further favours reduction in visibility. Conditions become most favourable for **radiation fog** after the passage of a WD, over NW India, UP, Bihar, Central India, N Bengal and Assam (particularly S banks of Brahmaputra river). Sometimes the fog prolongs, disrupting air traffic adversely, especially over polluted airfields like Palam (Delhi). On such occasions, there may be little improvement in visibility to 1000-2000 m during noon, but may again deteriorate in the evening and night. Such conditions sometimes may last for a few days.

Advection Fog occurs over coastal areas and where large water bodies are present. The fog generally lifts by 1000-1100 hr IST.

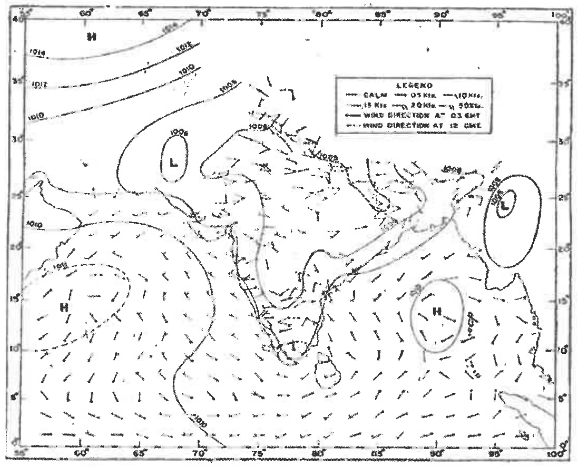
CAT is experienced over NE India and in the vicinity of STJ. Mountain waves are also common during this period over high terrain over N and E India.

Icing. During the season the freezing level lowers. Hence ice accretion may be experienced at lower levels.

Summer Season

Pre-monsoon Season/ Hot Weather Season/ TS Season (Mar, Apr, May)

Pressure Distribution. This is a transition season when winter pattern commences to change over to the monsoon pattern. There is continuous rise in temperature and fall in pressure over the country. There is weak pressure gradient over the country. Only two isobars (1006 and 1008 hPa) cover the entire country. These isobars run parallel almost along the Indian coast line. There is a trough over the Peninsula with its axis along 78° E longitude. This trough shifts to 79° E along Chennai coast by May. A weak low lies over Pakistan (upper Sindh) and a weak trough over E UP and Bihar. A low lies over Myanmar and a closed high over the E Central Bay, W of Bay Islands.



Mean Pressure(hPa) and winds at surface level (APRIL)

Figure 19.3 Sea Level Pressure and Winds April

Surface Temperatures. Due to the N wards march of the sun, the land progressively gets heated up after January. By April, the temperatures are of the order of 30-35° C over the central peninsula. The mean **maximum** temperatures are about 40-42°C over the country. The day temperatures are highest in May. In Andamanss they are highest in April, in Saurashtra in June and in Rajasthan and Kashmir in July. The maximum diurnal range of 18°C is over Gujarat, Saurashtra and MP. Along the coasts it is about 6°C. Sometimes **heat wave** conditions **(≥ 4°C above the normal maximum)** are also experienced. Also when **maximum temperature is 5°C or more heat wave is declared.**

Surface Winds. In March N of 17° N the surface winds are Wly, they are Ely to the S of it. In April they are N-NWly up to E UP and eastwards to NE India. In May SWly prevail over Rajasthan and Ely from E UP to NE India. Over Orissa, WB, Bihar, Jharkhand and Chhattisgarh, they are Sly. In rest of the country NWly to SWly winds prevail. In June Ely winds prevail N of the line joining Lahore, Allahabad and Silchar. Ove W Bengal winds are Sly and are W-SWly 10-15 ktover rest of the country. On certain occasions the wind becomes gusty and dust laden over the Gangetic plains. Dust Raising Winds (DRW) mostly start at about 0900 hr and continue up to 1700 hr. Thereafter they weaken.Visibility on such occasions reduces considerably over a large area.

Upper Winds. In April Wly strengthen with height over N India and Peninsula. At 300 hPa maximum speeds are 40 kt and at 200 hPa, 60 kt N of 22° N. The wind weakens slowly aloft. In May Wly belt shifts to 30° N and Ely 15-20 kt establish over the Peninsula. In June winds are Wly up to 700 hPa and Ely aloft S of 25° N, which strengthen with height to 50 kt at 100 hPa.

Synoptic Systems and Weather

The season is characterised by widespread dust haze and extremely high temperatures over N India. There are dust storms over N India and Kalbaishakhi (Norwesters) over E and NE India. These are triggered by the WDs. A few tropical cyclones (TC) strike Bengal coast and move NW. The STJ weakens and moves North wards.

Aviation Weather Hazards

This is the most hazardous season for flying, as discussed below :

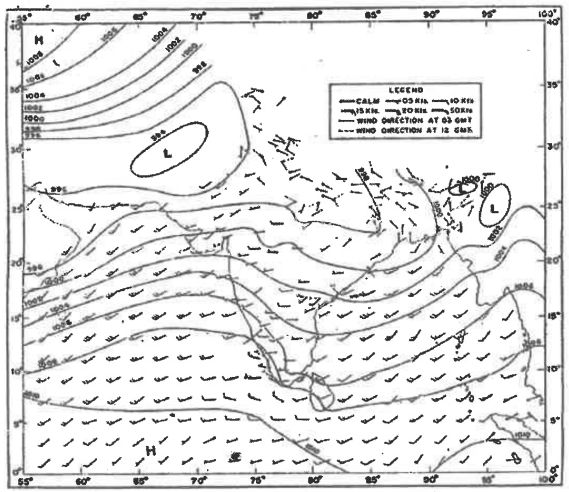
(a) TS and DS Activity. Violent TS are common during this season with their all attendant hazards. DS are common over Rajasthan and NW India. Norwesters affect Eastern parts of the country. Line squall type of development is also reported by the aircrew. Poor visibility due to widespread dust haze is experienced over entire N India. Dust haze may extend to 7-8 km aloft.

(b) Dust Raising Winds. Strong surface winds of 30 –50 kt may be experienced between 0900 to 1700 h. The visibility may reduce to a few hundred metres.

Monsoon / Rainy Season / South West Monsoon

The SW monsoon is the most significant feature of the Indian climate. The season is spread over four months **(June to September)**, but the actual period at a particular place depends on onset and withdrawal dates. It varies from less than 75 days over W Rajasthan, to more than 120 days over the SW regions of the country. The onset of the SW monsoon normally starts over Bay Islands by mid May, Kerala coast by 01 June and covers the whole country by middle of July. The monsoon is a special phenomenon which exhibits regularity in onset and distribution of rainfall within the country.

Pressure Pattern. A low pressure area lies over Baluchistan (994 hPa). A trough called, Monsoon Trough (MT), lies over the Gangetic plains with its axis extending from Sriganganagar to the Head Bay, through Allahabad. A high pressure is over S Hemisphere,



Mean Pressure(hPa) and winds at surface level (JULY)

Figure 19.4 Sea Level Pressure and Winds July

centered at 30° S 60° E. Pressure gradually decreases towards India from this High. Weak ridges lie over Arabian Sea off the West Coast of India, in the Bay of Bengal off Tenasserim Coast and over Myanmar. A weak trough lies off the E coast in S Peninsula. The pressure gradient is steep along the west coast. Seven isobars at 2 hPa interval (994 hPa over Baluchistan and 1008 hPa over S Peninsula) stretch across the country. A shallow low lies over extreme NE India (Arunachal Pradesh) and another over adjoining Myanmar.

Surface Wind. Ely to SEly winds prevail to the N of the MT and SW to Wly elsewhere. They have more of Sly component over West Bengal. NWly winds prevail over Malabar coast. The wind speed over the land is about 5-10 kt and over the seas 15kt. Strength of monsoon depends on the strength of these winds

Surface Temperature. Temperatures over the southern parts of the country are about 26° C and over Rajasthan 31° C. The spatial range over India is about 9° C and the diurnal range is about 04° C to 09° C. Temperatures rise during the break monsoon.

Upper Winds. Up to about 10000 ft the winds are W-SWly to the S of the MT and to the N they are SEly. From 500 hPa upwards Ely winds prevail over almost entire India. At 200 hPa and aloft an anticyclone lies over Tibet and another over Baluchistan. The winds are about 20 kt over central India and 40 kt to the South. At 100 hPa they strengthen to 40 kt and 60 kt respectively. Ely jet stream (Tropical Jet Stream) prevails at 15-16 km with speed of 70-80 kt (max. 150 kt) roughly along 13 N.

Advance of Monsoon

The southwest monsoon current advances in **two distinct branches** – the Arabian Sea branch and the Bay of Bengal branch. The former moves to Kerala and the latter to Myanmar, Bangla Desh and Bengal.

Normal date for Onset of southwest monsoon are: South Andaman Sea: 20 May, Kerala: 01 June, Mumbai: 10 June, New Delhi: 29 June, Entire country: 15 July.

Normal date of Withdrawal. SW monsoon generally starts withdrawing from Rajasthan by 1st Sept and from NW parts of India by 15th Sept. It withdraws from almost all parts of the country by 15th Oct and is replaced by a northerly continental airflow called North-East Monson.

Weather

The rainfall during monsoon oscillates between active spells of widespread rains over most parts of the country and breaks with little rainfall over the plains and heavy rains across the foothills of the Himalayas. Heavy rainfall in the mountainous catchments under 'break' conditions results flooding over the plains. However, very uncomfortable weather due to high humidity and temperatures is the feature associated with the Breaks

Monsoon Depressions form in the northern part the Bay with an average frequency of about two to three per month and move in a Nly/ Wly direction bringing well-distributed rainfall over the central and northern parts of the country. The distribution of rainfall depends on the path followed by these depressions.

Flying in monsoon clouds is relatively smooth in stratiform type of clouds but would be turbulent in embedded CU/CB clouds. Visibility is exceptionally good, except in precipitation. Clouds are in different layers and there are clear gaps in between various layers of clouds. Hence one can mostly find a suitable cloud free level for flying, except when affected by a depression.

Axis of Monsoon Trough (MT). The normal position of the monsoon trough on sea level chart passes through **Ganganagar-Allahabad-Kolkata to Head Bay.** The trough fluctuates N-S of its normal position and accordingly governs the rainfall. To the N of this

trough lies the Bay branch and to the S, Arabian sea branch. This trough more or less coincides with ITCZ. The MT slopes southwards with height. At 10000 ft (700 hPa) it lies almost parallel to 22° N from Gujarat to Orissa and at 500 hPa it can be seen around 10-15° N across S peninsula. Thereafter it is not traceable.

Break Monsoon. Monsoon trough shifts northwards and runs close to foot hills of Himalayas, resulting in drastic reduction in rainfall over the country outside the foot hills and southernmost Peninsula. During this period pressure rises over the country. Heavy rains occur over foot hills of Himalayas, particularly over Sub Himalayan West Bengal, Nepal and Bhutan resulting in floods over NE India and Bihar. Very strong Wly surface winds are also experienced over East UP, Bihar and adjoining states. During this phase the weather is of Pre monsoon type with widespread dust haze of moderate intensity.

Subtropical (Mid-tropospheric) Cyclone. Sometimes during SW monsoon a cyclonic circulation establishes at Lat/Long 60-80E and 18-28 N, between levels 500 and 700 hPa, and a trough at the surface. Heavy rainfall in western India and NE Arabian sea are mostly attributed to this system. Even the very heavy, unprecedented rains in the year 2005 over MP, Maharashtra, especially Mumbai were attributed to the prolonged presence of such a system over the area. The heavy rainfall is due to thick stratiform clouds in which CB clouds are embedded. Such heavy build up and rainfall occur is mainly to the W and SW of the subtropical cyclone centre.

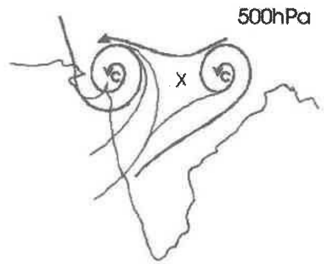


Figure 19.5 Subtropical Cyclone over Gujarat and adjoining areas

Fixing Normal Date of Monsoon. A comparison is made with the rainfall of previous two/ three pentads. One year is divided into 72 pentads, of five days each, commencing 01 Jan. Normals are made for each pentad. If there is a significant increase in rainfall, the mid date of the pentad is declared as the date of onset, provided increase is maintained.

Strength of Monsoon. The strength of monsoon is described in terms of winds at sea and rainfall over the land, as follows:

Strength	Wind speed over Sea	Rainfall over Land
Weak Monsoon	up to 12 kt	< 1 / 2 times the normal
Moderate Monsoon	13 – 22 kt	1/ 2 to 1 ½ times the normal
Strong Monsoon	23 – 32 kt	1½ to 4 times the normal
Vigorous Monsoon	> 32 kt	> 4 times the normal

Strength of Monsoon

Table 19.1

El Nino/Southern Oscillation (ESNO)

El Nino is the warm phase of the El Nino Southern Oscillation (ENSO). It is the warming of a band of central and E Pacific ocean and the Indian ocean. ESNO is a cycle of warm and cold Sea Surface Temperature (SST). It is accompanied by high pressure in the W Pacific and low pressure in the E Pacific. The cool phase of ENSO is called **La Nina** when the pressure and temperature patterns reverse.

El Nino occur at irregular intervals of two to seven years, and last for nine months to two years. Since 1900 about 26 El Nino have occurred with the 1982-83, 1997–98 and 2014–16 events being the strongest.

The ENSO cycle of El Nino and La Nina affects the global climate and disrupts normal weather patterns. There are intense storms in some places and droughts in others. Fewer TC occur in our region and in the Atlantic Ocean. There is increased hurricane activity in the E Pacific and change in the location of TC in the W and S Pacific.

Generally, **El Nino and the Indian Monsoon rains are inversely related**. In most of the El Nino years the rainfall fell below the normal and many El Nino years brought droughts. During intense ESNO the SEly Trades become Wly and drive warm waters Eastwards and cause dry weather over a large area. This limits the moisture content, causing reduction and uneven distribution of rainfall across the Indian sub-continent.

Aviation weather Hazards

(a) **Low Clouds**. Very low clouds (150 to 200 m agl) and strong surface winds are common during the strong monsoon conditions and passage of Monsoon Depressions.

(b) **Poor Visibility**. Generally visibility is good. However, it may deteriorate during precipitation. Dust haze in the north during Break in Monsoon and monsoon haze along the west coast reduces visibility to a certain extent

(c) **CAT**. CAT is likely in the vicinity of TJ.

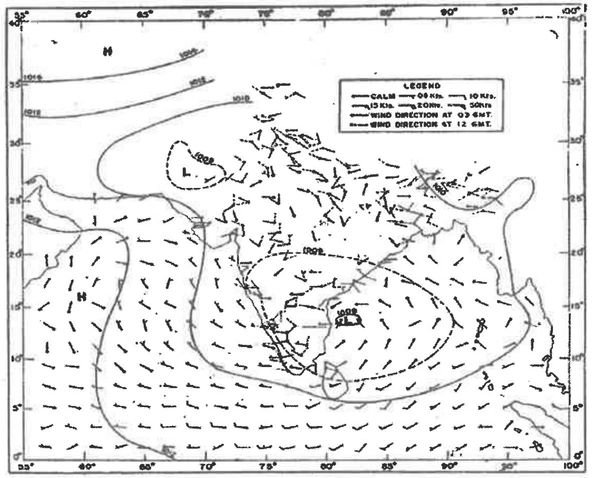
(d) **TS Activity**. During the onset of monsoon TS activity of a longer duration is a common feature, with its attendant hazards. During Break and then during revival of monsoon also TS are experienced.

Post Monsoon / NE Monsoon Season / Cool Season

This season is also called **Retreating SW Monsoon Season (Oct, Nov and Dec).** It is a transition season associated with the establishment of the NEly wind regime over the Indian subcontinent. **This is the major period of rainfall activity over coastal AP, Rayalseema and TN-Pondicherry (Puducherry). For TN this is the main rainy season accounting to about 48% of annual rainfall.** Rainfall mostly occurs between 2100 and 0300 hr in spells of 3 to 4 days duration. There are at times long spells of dry weather with little or no rain. Storms foming over the Bay of Bengal also cause rainfall. Large scale losses to life and property occur due to heavy rainfall, strong winds and storm surge in the coastal regions. (www.imdchennai.gov.in refers).

Pressure Pattern. The summer pressure and wind patterns undergo slow but steady modification to finally change to the winter pattern. One isobar (1010 hPa) surrounds the entire country including Bay Islands, Pakistan and parts of Myanmar. The monsoon trough shifts to the Bay of Bengal with its axis along 13° N. The pressure field is flat over the country. A weak low (1008 hPa) lies off Chennai coast and another over Baluchistan.

Surface Wind. With the withdrawal of monsoon from the N and Central India and the N Peninsula by the first half of Oct, the lower level wind pattern rapidly changes from SWly to NEly and hence the term **Northeast Monsoon.** Lower level winds cross diagonally from NE to SW and get humidified while travelling over Bay of Bengal before reaching Cape Comorin and rest of TN. Due to which TN and some parts of Kerala get significant rainfall. Parts of West Bengal, Orissa, Andhra Pradesh, Karnataka and Mumbai also receive minor precipitation. Due to a flat pressure distribution over the country, the surface winds are light and variable. The sea breeze effect is pronounced along the coasts in the afternoon hours and is felt up to 160 km inland.



Mean Pressure(hPa) and winds at surface level (OCTOBER)

Figure 19.7 Sea Level Pressure and Winds October

Surface Temperature. Temperatures are nearly uniform, 18° C, over the country. The diurnal range is 6-7° C. It is cool and pleasant at most of the places. The day temperatures start falling sharply all over the country. The mean temperatures over NW India show decline from about 38°C in Oct to 28°C in Nov.

Upper Winds. Gradually Wly winds start establishing at all levels and the pattern changes to that of Winters. The STJ reappears over J&K. Above 500 hPa level Ely remain confined to extreme S of the country, which weaken to 20 kt.

Weather

A few (1-2 per month) WDs affect N parts of the country. They cause clouding and precipitation over J&K and Punjab. **This is the best period for flying except over southern India.** Good visibility, and clear skies are the main features during the period. A few Tropical storms form over the central Bay and the Arabian sea and cause weather over the coastal areas. The retreating monsoon winds cause occasional showers along the east coast of TN, but rainfall decreases away from coastal regions. This is the major period of rainfall in S peninsula. In Tamil Nadu, this is the main rainy season, and accounts for nearly 60 % of annual rainfall in the coastal districts.

Maximum Cyclonic Storms occur in Oct over the Bay of Bengal and in Nov over the Arabian sea. SCS are more in Nov than in Oct. They usually form near Andaman Seas and move towards TN, AP and Orissa. They normally strike TN coast. Some of them move N and strike W Bengal or Bangla Desh . A few of them after crossing over the peninsula emerge over the Arabian Sea, revive, recurve and strike Maharashtra and Gujarat coasts.

Aviation weather Hazards

(a) **Poor Visibility.** Generally visibility is good. However, as the season progresses it starts deteriorating near industrial areas during dawn and dusk. After the passage of a WD there may be fog or mist. In the S poor visibility is during precipitation.

(b) **Low Clouds.** Low clouds, very strong winds, heavy rain and TS activity is experienced during the passage of a CS over S India.

(c) **CAT.** CAT may be experienced due to STJ in the north.

Note: January and July Upper Wind Maps are in later Pages

ROUTE WINDS

The general pattern of winds over various routes in India is summarised below:

From Oct to May (8 months)

1. **Above 3 km** : Winds all over India are Wly. They becoming stronger with height.STJ (Wly/ 80-150 kt) over DLH - CAL Route at 12 km.

   Below 3 km : NW- Wly over N India and NEly over S India

From June to September (4 months)

2. **Above 6 km:** Ely becoming stronger with height.

   TJ (Ely /60 – 100 kt) over MDS (Chennai) lat. at 15 km

   Below 6 km: W - SWly over S India and SEly N India

Present System of Forecasting SW Monsoon

Since 2007, the forecast for the South-West monsoon (Jun- Sep) rainfall over India is issued in two stages.

(a) The first stage forecast is issued in April and
(b) The second stage, its update forecast, is issued in June.

Along with the update, forecast for seasonal rainfall over four broad geographical regions of India (NW India, Central India, South Peninsula and NE India) and July rainfall over country as a whole are also issued.

For issuing the forecast a statistical forecasting system is used, by considering the following eight **predictors**:

S. No	*Predictor (Period)*	*Used for F/C in*
1	N Atlantic Sea Surface Temp (SST)(Dec + Jan)	April and June
2	Equatorial SE Indian Ocean SST (Feb + Mar)	April and June
3	East Asia MSL Pressure (Feb + Mar)	April and June
4	NW Europe Land Surface Air Temp. (Jan)	April
5	EquatorialPacificwarmWater Volume (Feb + Mar)	April
6	Central Pacific (Nino 3.4) SST Tendency (Mar Apr May –Dec Jan Feb)	June
7	N Atlantic MSLP (May)	June
8	North Central Pacific Wind at 1.5 Km ASL (May)	June

Table 19.2

The model error of April forecast system is 5% and of Jun forecast system, it is 4%.

For forecasting July rainfall over the country, a statistical model is used with the following **six Predictors**, (the error of the model is 9%) :

(a) N Atlantic SST - Dec of previous year

(b) NINO 3.4 SST - May + Jun

(c) N Pacific MSL pressure - Mar

(d) E Asia MSL pressure - Feb + Mar

(e) N Atlantic MSL pressure - May

(f) Equatorial Indian Ocean MSL pressure - Nov of previous year

For forecasting **seasonal rainfall over the four broad geographical regions** of India, multiple regression (MR) models based on separate set of predictors are used. All the four multiple linear regression models have model errors of 8%.

Since 2005, National Climate Centre also prepares an extended range forecast for onset of SW Monsoon over Kerala. The forecast is issued based on a statistical model with **six predictors**, (accuracy is a few days, plus minus). In addition, IMD prepares operational **long range forecasts for the Winter Precipitation** (Jan - Mar over NW India and NE Monsoon rainfall (Oct to Dec) over S Peninsula. For this purpose, separate statistical models have been developed.

QUESTIONS ON CLIMATOLOGY OF INDIA

Q1. During winters
(a) Advection fog occurs over northern & central parts of India
(b) Radiation fog occurs in southern parts of India
(c) Activity of Radiation fog increases after the passage of a WD over N India

Q2. Low Temperatures and low humidity is the characteristic of
(a) Post Monsoon (b) Summer (c) Monsoon (d) Winter

Q3. The Summer Season period is
(a) Jan-Feb (b) Mar-May (c) Jul - Sept (d) Oct – Dec

Q4. During Summer season
(a) WDs cause TS / DS over Punjab & Rajasthan
(b) No WD affect N-parts of country
(c) Track of WD is southern most

Q5. The monsoon current over the West coast of India is
(a) SWly (b) SEly (c) NEly (d) NWly

Q6. Monsoon period is
(a) Jan to Feb (b) March to May (c) Jun to Sep (d) Oct to Dec

Q7. The monsoon advances with
(a) Bay of Bengal current only (b) Arabian Sea current only
(c) Bay of Bengal and Arabian sea currents

Q8. The rainfall over India during monsoon depends on
(a) Low over Pakistan (b) Depression over Bay of Bengal
(c) The position of the axis of Monsoon Trough.

Q9. Rainfall occurs all over the country during monsoon when
(a) Axis of MT is in its normal position along Gangetic plains
(b) Axis of MT is along Himalayas
(b) Axis of MT is along Himalayas (c) Depression formed over Bay of Bengal

Q10. Break in monsoon occurs when the axis of monsoon trough is along the
(a) Gangetic plains (b) Foot hills of Himalayas (c) Bay of Bengal.

Q11. With a Depression over the Head Bay fair weather during monsoon occurs over
(a) Assam (b) W Bengal (c) Orissa

Q12. Monsoon is also called
(a) Pre monsoon (b) Rany Season (c) Post monsoon

Q13. Autumn Season period is
(a) Mar to May (b) Jun to Sept (c) Oct to Nov (d) Jan to Feb

Q14. During post monsoon, pressure gradient over India is
(a) weak (b) steep (c) same as winters

Q15. During monsoon season, low pressure lies over
(a) Bay of Bengal (b) NE India (c) Central India (d) Pakistan

Q16. During vigorous monsoon period the pressure gradient over west coast is
(a) Weak (b) Steep (c) Normal

Q17. Flying in Monsoon from Chennai to Kolkata at 14 km a/c will experience winds
(a) Easterly (b) Westerly (c) Nly (d) Southerly

Q18. An A/C flying in Winter season from Chennai to Kolkata at 12 km will experience
(a) Ely (b) Wly (c) Nly (d) Sly

Q19. An aircraft flying in Summer season from Delhi to Kolkata at 10 km will experience
(a) Easterly (b) Westerly (c) Northerly (d) Southerly

Q20. An A/C flying in Monsoon from Mumbai to Ahmadabad at 03 km will experience
(a) SEly (b) SWly (c) Nly (d) NWly

Q21. A/C flying in winter season from Delhi to Kolkata at 06 km will experience winds
(a) SEly (b) SWly (c) Nly (d) NW - Wly

Q22. An aircraft flying in winter season from Delhi to Kolkata at 06 km will experience
(a) Port drift (b) Starboard drift (c) Tail wind (d) Head wind

Q23. Flying in winter season from Kolkata to Nagpur at 02 km will experience
(a) Port drift (b) Starboard drift (c) Tail wind (d) Head wind

Q24. During break monsoon the pressures all over the country
(a) Rise (b) Fall (c) Do not change

Q25. During break monsoon sometimes surface winds over East UP and Bihar are
(a) very strong (b) weak (c) normal

Q26. Mid tropospheric cyclone occurs during
(a) Summer Season (b) Winters (c) Post monsoon (d) Monsoon

Q27. Mid tropospheric cyclone during monsoon form over
(a) Orissa (b) Punjab (c) Gujarat (d) Chennai

Q28. El Nino is
(a) Warm phase of ESNO (b) Cold Phase of ESNO
(c) Good for Indian Monsoon causing more rains

Q29. Maximum cyclones occur over India in
(a) Pre monsoon (b) Winters (c) Post monsoon (d) Monsoon

Q30. Tropical Jet stream occurs in India during
(a) Pre monsoon (b) Winters (c) Post monsoon (d) Monsoon

Q31. Pressure gradient over West Coast of India is steep during
(a) Pre monsoon (b) Winters (c) Post monsoon (d) Monsoon

Q32 During break monsoon more rain occurs
(a) along foot hills (b) NW India (c) S India

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**c**	**d**	**b**	**a**	**a**	**c**	**c**	**c**	**a**	**b**	**a**	**b**	**c**
Q.	14	15	16	17	18	19	20	21	22	23	24	25	26
A.	**a**	**d**	**b**	**a**	**b**	**b**	**b**	**d**	**a**	**a**	**a**	**a**	**d**
Q.	27	28	29	30	31	32							
A.	**c**	**a**	**c**	**d**	**d**	**a**							

20. GENERAL CIRCULATION

The surface and upper air charts show systems like highs, lows, cyclonic circulation etc., which change position and intensity with time. These systems are associated with distinct types of weather. The weather changes when these systems affect a locality. A study of the behaviour of these systems, known as **Synoptic Meteorology,** is of great importance in weather forecasting.

These moving systems are components of the large scale, static or semi-permanent, pressure and wind patterns over the globe. The knowledge of these provide an useful background in Aviation and Synoptic Meteorology.

The large scale, static or semi-permanent, pressure and wind patterns on the globe are termed as **General Circulation**, which is as a result from the following:

(a) Energy balance (b) Transport processes

Energy Balance. The Earth receives its energy from the sun as incoming short wave radiation and looses energy through the outgoing long wave radiation. Over the globe, when averaged over a year, the incoming energy nearly balances the outgoing energy. Latitudinally, the average radiation is surplus in the tropics and deficit in the polar regions (where the outgoing radiation is more than the incoming radiation).

Transport Processes. The surplus and deficit energy in different regions of the globe is transported and re-distributed equally around the earth by the atmospheric winds and oceanic currents.

Three Cell Model of General Circulation

This model represents the average circulation of the atmosphere and describes the atmospheric energy transport. Over the globe the energy balance is described in terms of three cells as follows.

Hadley Cell

The intense incoming solar radiation in the equatorial region heat up the surface and cause air to rise. The rising air forms convective clouds and heavy precipitation in the region. This area is called the Inter-Tropical Convergence Zone (**ITCZ**). In this zone NE Trades from the N hemisphere and SE Trades from S hemisphere converge, hence the name. ITCZ moves north and south following the sun during the year. Due to solar heating the heated air rises up to tropopause and, then stratosphere being stable region, can not rise further up, instead it moves polewards. By the time this air reaches about 30 N it becomes a **westerly wind** due to the Coriolis force. These winds are known as the Zonal Westerlies. Because of conservation of angular momentum and S – N temperature gradient, the westerly winds keep strengthening with height and establish as **Subtropical Jet** just below the tropopause. The polewards moving air piles up in the subtropical regions and forms high pressure belt at the surface, called the **subtropical high**. To compensate for the ascent of air near the equator, subsidence occurs over the subtropical highs. The subsidence inhibits cloud formation. This is the reason for the occurrence of large deserts near 30N and 30S.

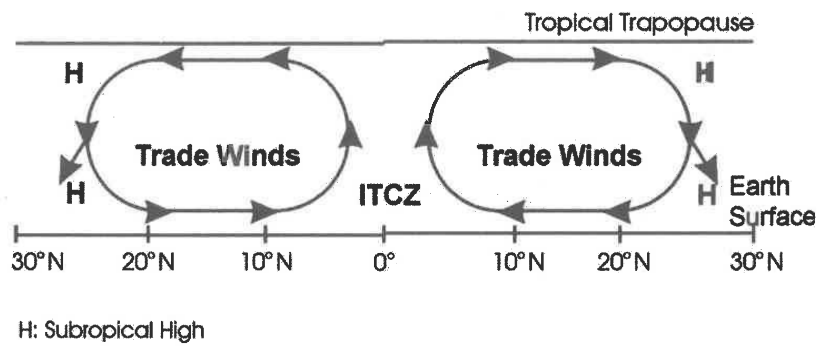
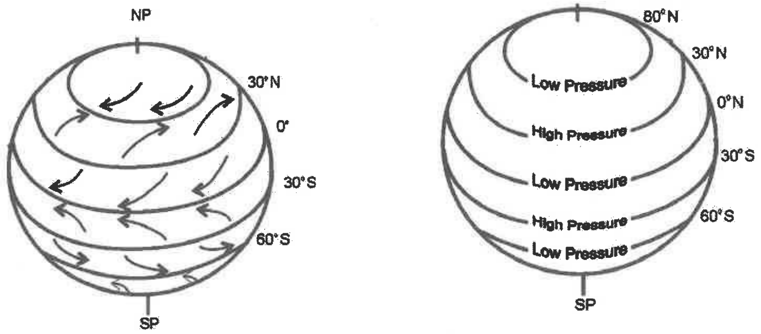


Figure 20.1 Hadley Cell

Once the sinking air reaches the ground, a part of it flows towards the equator, turning west (in the northern hemisphere) due to the Coriolis force. This surface air forms the **trade winds**, that blow steadily from the northeast in the northern hemisphere and southeast in the southern hemisphere. Thus a huge vertical circulation forms between the equator and 30N and another between equator and 30S, called Hadley Cells.



SURFACE WINDS

SURFACE PRESSURE BELTS

Figure 20.2 Global Surface Winds and Pressure Belts

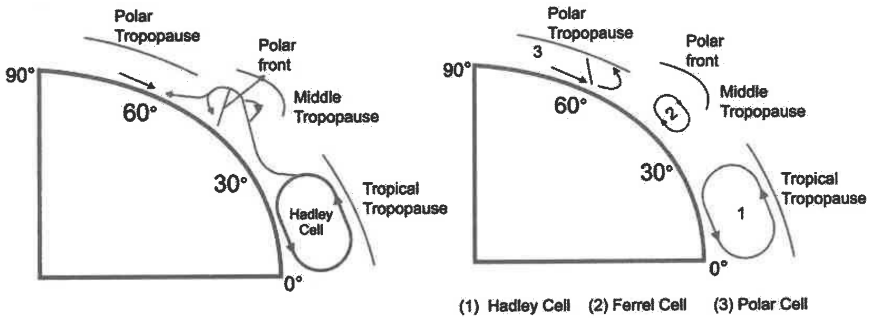


Figure 20.3 Three Cell Models

Ferrel Cell

Some of the diverging air at the surface near 30N moves polewards and is deflected to the east by the Coriolis force resulting in the westerly winds at the surface. At about 60N the air rises, cools and condenses and forms clouds and precipitation. This is the general region of the **polar front.** Some of this rising air returns equatorwards.

Polar Cell

The sinking air at the poles warms and results in a high pressure over the poles. At the surface, the polewards moving air gets pulled to the right by the Coriolis force (in the northern hemisphere) forming the **polar easterly winds.** This cold polar air meets the warm subtropical air moving polewards and forms the boundary between these two air masses known as the **polar front**. Due to the large temperature contrast, the polar front jet stream occurs in the vicinity of the polar front.

The major surface characteristics of the **Three Cell Model are:**

Equatorial Doldrums: Rising air creates calms or doldrums in the equatorial region.

ITCZ: Along the equator the rising air forms this zone of convection around the globe.

Trade Winds: Steady NE winds in the N hemisphere and SE winds in the S hemisphere.

Horse Latitudes (Lat 30-40°): The descending branch of the Hadley cell marked by calm winds and high pressure at the surface.

Roaring Forties: In both the hemispheres, Westerly winds blow between 35°and 60° lat. In Southern hemisphere these are of a very stormy nature S of 40°S.These continue almost throughout the year. In the olden days, sailors called them **Roaring Forties, Furious Fifties and**

Crying Sixties, as these winds were very noisy and were not favourable to sailors

. This is the major air flow pattern of the mid latitudes (35°to 60°).

Polar Front: Boundary between the cold polar air moving equatorwards and the warm subtropical air moving polewards.

Polar Easterly Winds: Cold polar air moving southwest (in the northern hemisphere) where it eventually meets with the prevailing westerlies to form the polar front. The sub-tropical highs are not of great vertical extent and their effect becomes negligible at higher levels. At these levels the temperature gradient is from S to N. Thus, except in a narrow belt near the equator, the winds in the upper troposphere are westerly, known as the **Zonal Westerlies**. In the **equatorial regions** the upper tropospheric winds are **Easterlies**.

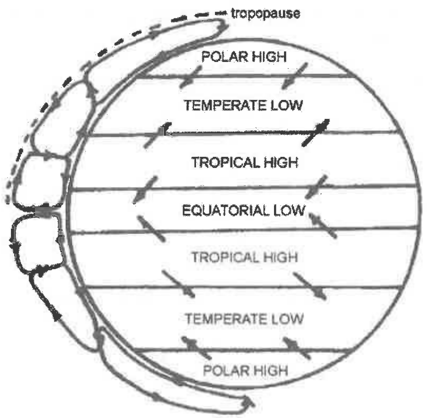


Figure 20.4 Idealised Global Pressure, Winds and three Cells

These zonal flows in the upper troposphere govern the movement of disturbances in the pressure and wind patterns. The disturbances of **middle latitudes move from west to east** in the westerly current and the tropical disturbances which form in the equatorial low pressure belt move in a **westerly** direction, being **steered** by the high level easterly flow. Tropical disturbance which reach the zone of transition in the upper level flow change course (or recurve) and begin to move in an opposite direction.

QUESTIONS ON GENERAL CIRCULATION

Q1. The polewards moving air piles up in the subtropical regions and forms high pressure belt at the surface, called
(a) Subtropical high (b) Polar High (c) Equatorial high

Q2. ……….. occurs over subtropical high
(a) advection (b) convection (c) subsidence

Q3. The occurrence of large deserts near 30N and 30S are due to large scale
(a) subsidence (b) convection (c) advection

Q4. A part of the sinking air over the subtropical highs flows towards the equator, turning west (in the northern hemisphere) due to the Coriolis force. This surface air is called
(a) Trade winds (b) Roaring forties (c) Doldrums

Q5. The huge vertical circulations, one between the equator and 30N and another between equator and 30S, are called
(a) Hadley Cells (b) Ferrel Cells (c) Polar cells

Q6. The descending branch of the Hadley cell marked by calm winds and high pressure at the surface are called
(a) Tropical Latitudes (b) Middle latitudes (c) Horse Latitudes

Q7. The winds in the upper troposphere are westerly. These are known as
(a) Natural Westerlies (b) Steady Westerlies (c) Zonal Westerlies

Q8. In the equatorial regions the upper tropospheric winds are
(a) Westerlies (b) Easterlies (c) Zonal Westerlies

Q9. The disturbances of middle latitudes move from
(a) W to E (b) E to W
(c) N to S (d) S to N

Q10. The tropical disturbances which form in the equatorial low pressure belt move in
(a) Easterly direction (b) Westerly direction (c) Southerly direction

Q11. Tropical disturbance which reach the zone of transition in the upper level flow change course and begin to move in a
(a) Perpendicular direction
(b) Opposite direction
(c) Southwards

Q12. Latitudinally, on the average there is radiation .... in the tropics than in the polar regions
(a) surplus (b) deficit (c) balance

Q13. The systems like highs, lows, cyclonic circulation etc are associated with distinct types of weather. A study of the behaviour of these systems, known as
(a) Synoptic Meteorology (b) Climatology (c) Physical Meteorology

Q14. Rising air creates calms or doldrums in the equatorial region.
(a) ITCZ (b) Horse Latitudes (c) Equatorial Doldrums

Q15. Steady NE winds in the N hemisphere and SE winds in the S hemisphere are called.
(a) Easterly winds (b) Trade Winds (c) Tropical Winds

ANSWERS

Q	1	2	3	4	5	6	7	8	9	10	11	12	13
A	a	c	a	a	a	c	c	b	a	b	b	a	a

Q.	14	15
A.	c	b

21. METEOROLOGICAL SERVICES FOR AVIATION

The objective of Meteorological Services is to contribute towards the safety and efficiency of air navigation. This objective is achieved by providing the required meteorological information to the operators, ATC, airfield management and others.

Meteorological Organisations for Providing Aviation Services

World Met Organisation (WMO) is a specialized agency of UN, which looks after the weather aspects of aviation in collaboration with ICAO. The purpose of WMO is to facilitate world wide cooperation in establishing networks of observatories, providing meteorological services, promoting rapid exchange of weather information, research, application of meteorology to human activities and training. Under the WMO, World Weather Watch (WWW), coordinates the world-wide weather activities utilising Global Observing System (GOS), Global Telecommunication System (GTS) and Global Data Processing System (GDPS).

There is a **World Area Forecast System (WAFS)**. The objective of WAFS is to provide, global aeronautical en-route weather forecasts to Met Offices.

Under WAFS there are **two World Area Forecast Centers (WAFC)**, located at Washington and London. In addition there are **19 Regional Area Forecast Centers (RAFC)** at various places in the world. One of them is at New Delhi.

WAFC prepares digital and grided global forecasts of Upper Winds and Temperatures and Humidity, FL of Tropopause and its Temperature, Max Wind, Icing, Turbulence and CB clouds. They also prepare SIGWX forecasts, accidental release of Radioactive material and Volcanic activity. These are prepared 4 times a day and issue within 6 hr of origin.

India Meteorological Department (IMD)

IMD is the National Met agency in India to caters to the weather needs. Its web site is www.imd.gov.in. It has 6 Regional Met offices (RMO) at Delhi, Mumbai, Kolkata, Chennai, Guwahati and Nagpur.

The following Met Offices have specifically been established to provide weather services for Aviation to the national and international flights:

- **Aerodrome Met Offices (AMO) (Total 18, including 4 MWOs)**. These are located at major National and International airports They maintain 24 h current weather watch, issue METAR/SPECI, RVR, weather forecasts, TAF, Landing Forecast, Aerodrome Warning, Briefing, VOLMET, ATIS, Radar and Satellite Pictures. They also provide forecasting cover to the associated Aeronautical Met Stations (AMS).
- **Aeronautical Met Stations (AMS) (Total 54)**. These take Current Weather observations and provide aeronautical forecast after obtaining from AMOs, during their watch hours.
- **Meteorological Watch Offices (MWO)(Total 4)**. These are located at Delhi, Mumbai, Kolkata and Chennai. They look after the meteorological needs of their FIR and issue SIGMET.
- **Tropical Cyclone Advisory Centre (TCAC)** of ICAO for monitoring development of Tropical Cyclones and issuing advisory about position, movement, central pressure and winds.
- **On-line Briefing System (OLBS).** AMOs also provide web-based OLBS and consultations to the registered operators and aircrew. The contents of OLBS are: Wind and temp. forecast for FL50 to FL530, 9 hr and 30 hr TAF, National and WAFC SIGWX charts, METARs of major airports, Satellite imagery, Radar products, Synoptic features, Route Forecast in T3 format for low level flights, Local/ Area forecasts for all the airports in the FIR, Take-off data and SIGMET Warnings.

Notification

To keep the required Met information ready for the user in time, it is essential that adequate Notice be given to the Met Office by the operators. They keep information for scheduled flights ready as a routine since for routine flights advance information is already available. For non-scheduled flights the following advance notice (before ETD) is essential :

(a) **National Flights**

AMOs	3 hr
AMSs	18-24 hr

(b) **International Flights**

(i) At New Delhi, Kolkata, Mumbai, Chennai, Nagpur, Banaras, Guwahati, Hyderabad, Thiruvananthapuram	3 hr
(ii) AMOs	12 hr
(iii) AMSs	18-24 hr

The notification is given in respect of time of departure, destination, route, level, type of met information required, time of briefing and other necessary details about the flights.

Routine Meteorological Observations

METAR – (Aerodrome Met Report, in aeronautical meteorological code). These are issued every half an hour by Met offices and are appended with trend type of landing forecast.

SPECI – (Aerodrome Special Met Report, in aeronautical meteorological code). SPECI is issued immediately for deterioration in weather to specified conditions. In case of improvement it is issued after 10 minutes, when conditions stabilise. Trend forecast is appended to each SPECI.

Aircraft Observations and Report (AIREP), also called **Pilot Report (PIREP)**

Arrangements exist with Indian Airlines, Air India and other Airlines operating through the Indian airspace to record and report meteorological observations, at specified points, as follows:-

- Routine aircraft observations during en-route and climb out phase. When air-ground data link is used, automated observations are made every 15 min during en-route phase and every 30 sec during the climb - out phase, during the first 10 min of the flight.

- Special observations are made by all aircraft whenever severe weather as for SIGMET criteria is encountered or observed.
- The other non-routine aircraft observations, e.g. when Wind Shear, Icing, Turbulence, are encountered, they are passed to ATS unit as soon as practicable. On arrival complete report on Volcanic Activity is submitted to AMO, who transmits it to the MWO of the region in which VA was observed.

Aircraft is exempt from making observation if:
- The aircraft is not equipped with RNAV equipment, or
- Flight duration is 2 hr or less, or
- Flight is one hr or less from the landing place, or
- Altitude of aircraft is below 1500 m (5000 ft).

Contents of Air Reports

Section 1 – Information on Identification, Position (Lat/Long), Time, FL or Altitude

Section 2 – Operational Information - ETA and Endurance.

Section 3 – **Met Information – Air Temp., Wind, TS, Turbulence, Icing and Humidity (if available)**

Example : AIREP IA120 BHP 1200 UTC FL350 MS54 270/40KT TS SCT CB TOP FL 400=

Types of Forecast

Nowcasting : The forecast is valid for less than 24 hr. (Example: TREND, TAF, SIGMET, Local Forecast, Aerodrome Warnings etc)

Short Range Forecast : The forecast has a validity of 1 to 3 days

Medium Range Forecast. The forecasts is of validity 4 to 10 days

Long range /Extended Range Forecast : Forecast having a validity period beyond 10 days. (Example: IMD Forecast of Monsoon, onset date etc).

Weather FORECASTS for Aviation

(a) **Aerodrome Forecast (TAF)**. Issued by AMOs for own and associated AMSs. TAF are valid for atleast 9 hr and a maximum of 30 hr. TAF valid for 9 hr are issued every 3 hr and of 12 - 30 hr validity every 6 hr, commencing at 0000 UTC.

(b) **Landing Forecast (TREND).** AMOs (except Jaipur and Safdarjung) issue trend forecast and append it to METAR or SPECI. Their validity is 2 hr. The term PROB is not used in TREND forecast. NOSIG means no significant change in weather.

(c) **Forecast for Take Off**. Are issued by AMOs, within 3 hr before ETD for:

- Surface wind (**averaged for the past 2 min only),** Temperature, QNH and any other element, as required.

(d) **ARFOR**. Area Forecast contains forecast in coded form or in Tabular form of Upper winds and Temperatures at various levels, Significant weather, Clouds, Freezing level, Turbulence, Icing, Jet stream, Tropopause, Maximum wind, Wind Shear data, Airfield Warning and Supplementary phenomena.

(e) **CODAR**. It is an Upper Air report from an aircraft (other than weather reconnaissance aircraft), in Figure Code.

(f) **WINTEM**. Forecast upper wind and temperature for aviation.

(g) **ROFOR**. Route forecast for aviation contains forecast in coded form of Upper winds and Temperatures at various levels, Significant weather, Clouds, Freezing level, Turbulence, Icing, Jet stream, Tropopause and Maximum wind.

(h) **Local/ Area Forecast**. These are issued three times a day, valid for 12 hr. They are issued at 0700 (valid 0730- 1930), 1300 (valid 1330- 0130), 1800 (valid 1830-0930) IST. Area forecast covers 100 NM or more and Local Forecast 50 NM around. These contain forecast of surface wind, visibility, weather, clouds, upper winds and temperature, and information on sun rise, sunset, warning, etc.

(i) **Global SIGWX Charts**. WAFC prepares **four** SIGWX forecasts of 24 hr validity based on 00, 06, 12 and18 UTC data. These are issued as :
- **High-level forecasts** for levels between **FL250 and FL630**
- **Medium-level forecasts** for levels between **FL100 and FL250**

National SIGWX Charts. In India all the four MWOs prepare SIGWX charts for their FIR, in respect of cloud areas and weather systems. On their basis MWO Chennai compiles a single SIGWX chart for Medium Level (between FL 100 and FL250), and one for High Level (between FL250 and FL630). These charts are based on 00, 06, 12 and 18 UTC data, and are valid for 24 hr.

(j) **SIGMET**. It is the information issued for **aircraft in flight** by MWOs at Mumbai, Kolkata, New Delhi and Chennai, for their FIRs, **for occurrence or expected occurrence of the following en-route weather which may affect safety of aircraft operations.** It is issued every 3 hr, commencing 010 UTC. The validity of SIGMET is not more than 4 hr. For Volcanic Ash and Tropical Cyclones it is issued up to 12 hr before the period of validity and is updated every 6 hr. SIGMET are passed to FIC/ACC for further communication to aircraft in flight.

- **Thunderstorm** — Obscured (OBSC TS), Embedded (EMBD TS), Frequent (FRQ TS), Squall line (SQL TS), Squall line with heavy Hail(TSGR)
- **Tropical Cyclone** — (10min mean Wind 34 kt or more + cyclone name)
- **SEV TURB** — (Turbulence associated only with low level strong surface winds, Rotor streaming, in cloud / not in cloud)
- **SEV ICING** — (Icing in clouds other than in convective clouds)
  - Severe icing caused by Freezing Rain (FZRA)
- **SEV MTW** — (Mountain Wave with down draught 3.0 m/sec or more, or SEV TURB observed or forecast)
- **Duststorm** — HVY DS
- **Sandstorm** — HVY SS
- **Volcanic Ash** — VA (+ Volcano name)
- **Radio Active cloud**

Note- **ISOL TS : individual TS, less than 50% area covered;**
OCNL TS- well separated TS, 50-75% area covered;
FRQ TS little or no separation between adjacent TS, > 75% area covered

Separate SIGMET are issued to local ATC in respect of Light or Mod Hail and MOD Icing for use of light aircraft. These are not disseminated outside the aerodrome of issue.

(k) **AIRMET Information.** AIRMET is **SIGMET for low level flights**, issued by MWO.

(l) **GAMET**. It is an **area forecast** in abbreviated plain language **for low-level flights** for a FIR or sub-area thereof, prepared by the AMOs and exchanged with Met offices in adjacent FIRs.

Warnings

- **Aerodrome Warning.**
  These are issued by AMOs for expected weather which could adversely affect aircraft on ground and aerodrome facilities and services to ensure safety, proper picketing and mooring of aircraft :
- The **validity** of these warnings is **not exceeding 4hr**.

Wind: Speed 30kt or more, or
Direction of 20 kt wind changes by 45 degrees.

Weather: Squall (also expected direction), TC, DS, SS, TS, GR, Frost, SN, Hoar Frost or Rime, FZ Precipitation, and Raising Sand or Dust, VA, Tsunami.

Warnings for gliders and light aircraft and helicopters are issued by AMOs, for own and AMSs, and appended to local forecast when **wind speed is expected to reach 17 kt or more** and are issued with the prefix **Warnings for Light Aircraft**.

The warnings are passed on to local ATS units for further dissemination over the aerodrome to the operators and others. These are not disseminated beyond the aerodrome of origin. Amendments and cancellations are done as applicable.

- **Wind Shear Warning (up to 500 m (1600 ft) above runway).**

It is issued by AMOs for the **observed or expected occurrence of wind shear** which could adversely affect aircraft on approach path, take off path, during circling approach or on the RW during landing and take off. WS above 500m due to topography is also included.

Wind shear warning is also included as supplementary information in METAR, SPECI and SPECIAL reports. It is prepared in abbreviated plain language. The microburst reported by pilots is also included in the warning, for example:

- WS WRNG MBST APCH RWY 30

Wind shear warning by an aircraft includes the type of aircraft in the text, for example:

- WS WRNG B747 REPORTED MOD WS IN APCH RWY 28 AT 1000

Exchange of Meteorological Messages

(a) **VOLMET**. It is a MET information for aircraft in flight. It is of two types:

- **Data Link VOLMET (D-VOLMET)**. It provides current METAR, SPECI, 9 hr TAF, SIGMET, Special AIREPS not covered by SIGMET, and where available AIRMET.
- **VOLMET Broadcast**. It provides METAR, SPECI, TAF, SIGMET by means of continuous and repetitive voice broadcasts. VOLMET Radio Telephony Broadcasts in India are made on HF Channel from Mumbai and Kolkata in turn every half an hour.
  - ~ Mumbai Broadcasts include METARs of Mumbai, Ahmadabad, Chennai, Colombo, Karachi and Male and TAFs of Mumbai, Male and Colombo.
  - ~ Kolkata Broadcasts include METAR s of Kolkata, Delhi, Dhaka, Yangon and Katmandu and TAFs of Kolkata, Delhi and Ho-Chi-Minh.

(b) **ROBEX (Routine OPMET Bulletin Exchange).** Routine METAR / SPECI of international aerodromes and their alternates are exchanged outside India under ROBEX scheme. Air Reports are also exchanged under ROBEX.

(c) **Automatic Terminal Information System (ATIS)**. ATIS facility is available at important aerodromes in India. One of the purposes of this facility is to continually broadcast half-hourly current weather information for general use of the operators.

(d) **Current Weather Display**. Computer based display systems are in use at Kolkata, Delhi and Mumbai and Chennai for current weather information in ATC and Met Offices.

QUESTIONS ON MET SERVICES FOR AVIATION

Q1. For non-scheduled National Flights an advance notice (before ETD) is required to be given to AMOs
(a) 3 hr (b) 18-24 hr (c) 6 hr

Q2. For non-scheduled National Flights an advance notice (before ETD) is required to be given to AMSs
(a) 3 hr (b) 18-24 hr (c) 6 hr

Q3. WAFS provides high quality en-route forecasts of ..... to Met Offices.
(a) high quality en-route forecasts of winds and temperature
(b) SIGMET
(c) TREND

Q4. IMD has .... Regional Met offices
(a) 4 (b) 5 (c) 6

Q5. There are .... Aerodrome Met Offices
(a) 17 (b) 18 (c) 19

Q6. There are .... Aeronautical Met Stations
(a) 56 (b) 54 (c) 52

Q7 In AIREP the Met Information is contained in Section
(a) 1 (b) 2 (c) 3

Q8. TAF are generally valid for
(a) 18 hr (b) 12 hr (c) 9hr

Q9. The validity of Landing Forecast (TREND) is
(a) 1 hr (b) 2 hr (c) 3 hr

Q10. Landing Forecast is append to
(a) METAR and SPECI (b) TAF (c) AIREP

Q11. Local/Area Forecast is issued three times a day valid for next
(a) 18 hr (b) 12hr (c) 9hr

Q12. Area Forecast covers an area
(a) 100 NM (b) 100 km (c) 50 NM

Q13 Global SIGWX Charts are issued by
(a) WMO (b) AMO (c) WAFC

Q14. Global SIGWX Charts are valid for
(a) 18 hr (b) 24 hr (c) 9hr

Q15. Global SIGWX Charts for high-level are issued for Flight Levels
(a) 250 & 630 (b) 460 & 100 (c) 460 & 260

Q16. CODAR is
(a) Radar Report
(b) Coded ARFOR
(c) Upper report from an aircraft, other than weather reconnaissance aircraft

Q17. WINTEM is
(a) Actual upper winds
(b) Forecast upper wind and temperature
(c) Actual temperature and upper winds

Q18. SIGMET is a notice of severe weather for
(a) actual (b) expected (c) both

Q19. SIGMET is issued for aircraft
(a) in flight (b) on ground (c) both

Q20. SIGMET is issued by
(a) WAFC (b) AMO (c) MWO

Q21. SIGMET is valid for
(a) 4 hr (b) 8 hr (c) 9 hr

Q22. SIGMET is not issued for
(a) Rain (b) Volcanic Ash (c) SEV Icing

Q23. AIRMET is SIGMET issued by a MWO for the safety of
(a) low-level aircraft (b) high -level aircraft (c) both

Q24. GAMET is an area forecast in abbreviated plain language for
(a) low level flights (b) high level flights (c) all level flights

Q25. The validity of Airfield warnings is not exceeding
(a) 3 hr (b) 4 hr (c) 6 hr

Q26. Airfield warning is issued for expected wind speed
(a) 30 kt (b) 24 kt (c) 15 kt

Q27. Airfield warning is issued for wind direction of 20 kt changes by
(a) 45° (b) 30° (c) 60°

Q28. Airfield Warning for gliders, light aircraft and helicopters is issued for expected wind speed
(a) 15 kt (b) 17 kt (c) 30 kt

Q29. Wind Shear Warning is issued for the observed or expected wind shear above runway
(a) up to 500 m (b) above 500 m (c) 300 m

Q30. VOLMET is a MET information for aircraft
(a) on ground (b) in flight (c) both

Q31. VOLMET Radio Telephony Broadcast made on HF Channel from
(a) Mumbai only
(b) Kolkata only
(c) both Kolkata and Mumbai

Q32. VOLMET consists of
(a)SIGMET (b) TAF only (c) TAF and METAR

Q33. In ROBEX the METAR/SPECI of international aerodromes and their alternates is exchanged
(a) within India (b) outside India

Q34. Global SIGWX Charts are issued ………. times a day
(a) Two (b) Three (c) Four

Q35. Global SIGWX Charts for Medium-level are issued for Flight Levels
(a) 150 & 200 (b) 100 & 250 (c) 100 & 150

Q36. In India who compiles a single National SIGWX chart:
(a) New Delhi (b) Mumbai
(c) Kolkata (d) Chennai

Q37. The Indian National SIGWX chart is made for Medium Levels between Flight Levels
(a) 150 & 200 (b) 100 & 250 (c) 100 & 150

Q38. The Indian National SIGWX chart is valid for
(a) 24 hr (b) 18 hr (c) 12 hr

Q39. In India the National SIGWX chart is issued
(a) 2 times a day (b) 4 times a day (c) 6 times a day

Q40. Individual TS which cover less than 50% area, is termed as
(a) FRQ (b) ISOL (c) OCNL

Q41. If TS cells have no separation between adjacent TS and cover an area more than 75%, it is termed as
(a) FRQ (b) ISOL (c) OCNL

Q42. If TS cells are well separated and cover an area 50 - 75%, it is termed as
(a) FRQ (b) ISOL (c) OCNL

Q43. The Indian National SIGWX chart is made for High Levels between Flight Levels
(a) 150 & 200 (b) 100 & 250
(c) 100 & 150 (d) FL250 and FL630

Q44. Local Forecast covers an area
(a) 100 NM (b) 100 km (c) 50 NM

Q45. Nowcasting forecast is valid for :
(a) 30 hr (b) 48 hr (c) less than 24 hr

ANSWERS

Q	1	2	3	4	5	6	7	8	9	10	11	12	13
A	**a**	**b**	**a**	**c**	**b**	**b**	**c**	**c**	**b**	**a**	**b**	**a**	**c**
Q.	14	15	16	17	18	19	20	21	22	23	24	25	26
A.	**b**	**a**	**c**	**b**	**c**	**a**	**c**	**a**	**a**	**a**	**a**	**b**	**a**
Q.	27	28	29	30	31	32	33	34	35	36	37	38	39
A.	**a**	**b**	**a**	**b**	**c**	**c**	**b**	**c**	**b**	**d**	**b**	**a**	**b**
Q.	40	41	42	43	44	45							
A.	**b**	**a**	**c**	**d**	**c**	**c**							

22. WEATHER RADAR AND MET SATELLITES

Weather Radar (Radio Detection and Ranging) is an important tool for detection of rain bearing clouds, especially CU and CB, their speed, direction of movement and vertical extent. Aircraft utilize radar information for avoiding hazardous clouds. On ground the information is utilized for issuing timely weather warnings so that precautionary measures are initiated for parked and moored aircraft. Radars installed along the coast line of India detect storms and enable issuing of storm warnings. To-day radar has become an integral part of aviation. It contributes a lot towards the flight safety.

In India an integrated upper air sounding system comprising indigenous X-Band weather-cum-wind finding Multi Met Radars and Radiosonde system, is in use since 1975. IMD has a good network of S-band cyclone detection radars covering the Indian coast line and an operational network of digital X-band radars, including Doppler Weather Radars (DWR), for wind finding, storm detection and with duel capability. All these are planned to be replaced by the state - of- art DWR in a phased manner.

Range . The observational range of radars is limited by the attenuation of radar waves by rain and earth curvature effect. Weather radars can detect up to a range of 500 km, but resolution is better up to a range of 250 km. Normally echoes from range within 25 nm are displayed. Echoes at long range up to 75 nm are also used.

Radar Scopes

The Plan-Position Indicator (PPI) scope presents a plan view of the echoes and provides the bearing and range of the echo. The Range-Height Indicator (RHI) enables direct reading of the altitudes of CB cells.

Wavelengths: Radars use the following wavelengths:-

Wavelengths	(0.75–2.5) 1 cm	(2.5- 4) 3cm	(4-8) 5cm	(8-15)10 cm	(15-30) 20cm
Nomenclature	K Band	X Band	C Band	S Band	L Band

Table 22.1

K and X band radas are used for detection of clouds, X band for storm detection and S band for rain, precipitation, cyclones and depressions. S band radar is also called Cyclone Detection (and tracking) Radar.

Types of Weather Radars

Quantitative Radar (10.0 cm). The quantitative measurement of rate of precipitation, total precipitation, intensity of precipitation and snowfall measurements are done by these radars.

Ultra Sensitive Radar. These are used for detecting convection before and after the development of the clouds and also to study CAT, gravity waves and lee waves.

Doppler Weather Radar (DWR)

DWR is a state-of-art Radar (Radio Detection and Ranging). It works on the principle of Doppler Effect and measures change of frequency of the return signal to determine if targets are moving towards or away from the radar station. It is a coherent radar, detects the pulse difference between outgoing and return pulses.

A radar beam's reflectivity depends on the diameter of the target and its capacity to reflect. Snowflakes are large but weakly reflective while rain drops are small but highly reflective.

When snow falls through a layer above freezing temperature, it melts into rain. During the melting process the snow flakes become coated with water and the radar sees them as very large droplets. This can be mistaken for stronger precipitations. On a PPI, this will show up as an intense ring of precipitation. at the altitude where the beam crosses the melting level.

An opposite problem is that drizzle does not show up on radar because radar returns are proportional to the sixth power of droplet diameter.

DWR is used for the following :

(a) Prediction of : TS/DS/SS, Hailstorm and Tornadoes, HVY rainfall and floods

(b) Tracking of : Cyclones and TS and estimation of associated winds

(c) Study of the structure of : Clouds, Cyclones, TS, Hailstorm, Tornadoes

(d) Detection of: Wind Shear and Turbulence, CAT, Gust Front, Microburst, Downburst and Tornadoes etc.

(e) Genesis of : Tornadoes

(f) Determination of : Vertical Wind field and Horizontal Divergence field

Cloud Echoes

The echo characterization associated with Stratiform and Convective clouds are as follows:-

Stratiform Clouds. Echoes from Stratiform clouds and steady rainfall are diffused and ill defined. The echoes are generally of uniform intensity. In the RHI, at freezing level, a **Bright Band** appears because of strong reflection of radio waves by ice crystals snowflakes in the initial stage of melting. The Bright Band is, seen only when updraughts are uniform and weak. The band disappears with increasing convection.

Convective Clouds. The echoes of convective clouds have clearly defined sharp edges. A blurring of the edges can be regarded as the first sign of decay. In RHI-scope, the echo consists of one or more sharp-edged vertical level. The developing shower areas are distinctly visible in the echoes. The squall lines are depicted by line type of echoes. If the echo is exceptionally intense or if the top of the echo extends to great heights (to about -40° C temperature level), the echo is from a CB cloud.

Echoes associated with Severe Storms

Intense and Sharp Echoes. The echoes are sharp, well defined and intense when updraughts are strong and the size and number of precipitation particles is large. A developing storm depicts a sharp boundary near the top. Anvils are indicated by fuzzy echoes near the top.

Hooks, Appendages and Protuberances. These indicate severe storms with hail. A echo of figure '6' is an indication of a tornado.

Rapidly Moving Echoes. These indicate strong winds associated with severe storms.

Wind Shear. Showers in a TS can be seen as separate columns of rain. Such slant vertical columns represent vertical wind shear.

Dry Holes: Echo free areas embedded in very extensive and bright echo indicate severe storms with strong winds and heavy rain.

Rapidly Developing Echoes. These indicate a vigorous storm.

Large Horizontal Echoes. Large size strong echo indicate severe storm.

Converging Echoes. The area where a number of echoes appear to coverage indicates severe storm.

Bright Band. A Bright Band, a few hundred metres thick, is indicator of **weak storm**. It is seen just below the freezing level in stratiform precipitation.

Spiral Bands. These indicate tropical cyclones and last for a long time.

AIR BORNE WEATHER RADAR

These radars are light weight, generally X-Band multi mode and digital with Alpha Numeric. They operate on superhigh frequency band whose wavelength lies between X and S bands. These radars are designed for :- Weather detection and analysis, Ground mapping, Transponder beacon interrogation and reception.

The radar beam is conical, approximately 3 deg wide moving in azimuth 15 deg up down. Radar screen covers about 70 deg either side of aircraft heading. Large drops and hail adequately reflect at 3 cm wavelength.

Colors Used. Four colors viz. Green, Yellow, Red and Magenta (bright crimson) are used. These colours show progressively stronger echoes. Provision is also made to flash red areas on and off every ½ sec to emphasise areas of heavy precipitation.

These colours indicate :

- **Red/ Magenta** - Heavy precipitation, TS, hail, strong winds, tornadoes and severe turbulence. Aircraft should always avoid such areas.

- **Yellow** - Moderate precipitation, very low visibility, moderate turbulence and an uncomfortable ride for aircraft passengers. Aircraft should avoid going through.

- **Green** - Light precipitation, little to no turbulence and reduced visibility.

Rainfall Intensity indicated as follows:-

Colour	Storm	Rainfall in mm
Red (Magenta)	Severe(Very strong signal)	12
Yellow	Less severe (Mod intensity signal)	4-12
Green	Moderate (Low intensity signal)	1-4

METEOROLOGICAL SATELLITES

In the mid seventies the advent of Geostationary satellites revolutionized the satellite Meteorology. Now the NOAA (National Oceanic & Atmospheric Administration) series satellites of USA, Meteor series of USSR, INSAT series of India, METEOSAT of

European Met Agencies, Dundee satellite of UK and many others provide round the clock satellite cloud imagery and other useful weather information. These satellites carry radiometers for better resolution pictures, by day and by night.

The following two types of weather satellites are currently in orbit to provide weather information on global scale. They carry Very High Resolution Radiometers (VHRR) for better resolution.

(a) **Polar Orbiting Type.** These satellites orbit the earth at altitudes varying from roughly 650 km to 1500 km. They cover the complete earth twice in 24 hours, passing over the same place every 12 hours. NOAA is polar orbiting satellite.

(b) **Geostationary Type.** These satellites are placed in near circular orbit at an altitude of about 36,000 km in the plane of the earth's equator. They are earth synchronized and have the same period of rotation as that of earth. Therefore, they remain over the same spot on the earth's equator. The entire globe could be covered by five such Geostationary satellites. Geostationary satellite provides round the clock weather information. METEOSAT and INSAT are geostationary satellites.

Frequency of Satellite Imagery. The interval of observations of the satellite imagery is 30 min, however, due to licensing and other restrictions all these satellites provide **three hourly** pictures.

Indian Met Satellites: (web sites*: **www.imd.gov.in***) IMD is receiving and processing meteorological data from the following satellites:

Kalpana-1 was launched on 12 September, 2002 and is located at 74 E, and INSAT-3A was launched on 10 April, 2003 and is located at 93.5 E.

Kalpana-1 and INSAT-3A both have three channel Very High Resolution Radiometer (VHRR) for imaging the Earth in Visible (0.55-0.75 m), Infra-Red (10.5-12.5m) and Water Vapour (5.7-7.1m) channels having resolution of 2x2 km in visible and 8X8 km in WV and IR channels. In addition the INSAT-3A has a three channel Charge Coupled Device (CCD) payload for imaging the earth in Visible (0.62-0.69m), Near Infra Red (0.77-0.86m) and Short Wave Infra Red (1.55-1.77m) bands. The Resolution in all the three channels is 1x1 km. At present about 48 satellite images are taken daily from Kalpana-1 which is the main operational satellite and 9 images are taken from INSAT-3A. Imaging from CCD is done 5 times during daytime only. All the received data from the satellite is processed and archived in National Satellite Data Centre (NSDC), New Delhi.

INSAT-2E. It provides cloud imagery in a panchromatic visible (VIS) band with resolution of 2x 2 km, water vapour (WV) map of the moisture patterns in the atmosphere and thermal infrared (TIR) images of the earth and cloud patterns. Both these water vapour and IR imagery have a resolution of 8 x 8 km. The other instrument on-board provides images of the earth in visible, near infrared and short wave infrared regions. The resolution of these images is 1x1 km for all the three bands.

METSAT (India) receives satellite pictures every three hours, commencing at 0300 UTC. The satellite pictures are received by SDUC in about 40 min. They are then processed and transmitted in the IR, Visible, Colour composite and Water Vapour modes. On website the imagery is received after 1 hr 15 min (i.e. 0300Z picture is received by 0415Z). **In the event of cyclones hourly observations are provided.** Animation of hourly and three hourly satellite pictures are also available on the above web site.

INSAT-3A. It provides 3 hourly imagery with 2 km resolution in the visible band and 8 km resolution in infrared and water vapour bands. In addition, it provides imagery in the visible and short wave infrared bands with a spatial resolution of 1 km. It also collects real time hydrometeorological data from unattended platforms located on land and river basins. The data is then relayed to a central location. Indian Area coverage is 44.4ºN to 10.3° S 105.6E to 46.4E.

INSAT – 3D. Weather Satellite of ISRO, INSAT 3D, was launched on 25 Jul 2013 from Fench Guiana Space Centre. It is an advanced weather satellite. It was launched to provide an operational, environmental and storm warning system to protect life and property and also monitor earth's surface and carry out oceanic observations. It also provides vertical profiles of temperature and humidity. It has a resolution of 1 km in VIS and SWIR, 4 km in MIR and thermal IR, and 8 km in WV channels.

Characteristics of Clouds

The clouds are identified in the satellite imagery from the six general characteristics, viz. Brightness, Texture, Pattern, Shape, Structure and Size.

Thicker clouds and water clouds are brighter than the ice clouds. CU clouds occur in great variety and are organized into small regular lines or bands. Wave phenomena also produce distinctive features which make them easily identifiable. In IR images the lowest temperatures are the whitest and the warmest dark grey or black.

Temperature, Winds and other Weather Data

Radiometers are used for measuring radiation, temperatures of cloud tops and earth surface for global mapping of clouds by day and night.

The computer generated **output from the Indian Satellites** are:-

(a) Vertical temperature and humidity profile
(b) Cloud top and sea surface temperatures
(c) Upper winds
(d) Convective clouds and Mesoscale systems

The Quantitative Satellite Products are :

- Sea Surface Temperatures (SST), Outgoing Long wave Radiation (OLR), Quantitative Precipitation Estimates (QPE), Cloud Motion Vectors (CMVs), Water Vapor Winds (WVW), Land Surface Emissivity, Atmospheric moisture profile and Fog detection.
- Vertical profile of temperature and humidity, Cloud top temperature, Upper winds, Convective clouds and meso-scale systems.

NOAA/MODIS satellites payloads are also available on IMD website for use of forecasters and researchers.

Three Ground receiving and processing systems for NOAA/METOP and MODIS Polar orbiting satellites are installed at IMD New Delhi, RMC Chennai and at RMC Guwahati.

The OCEANSAT-2, Satellite of ISRO, data is utilised for Tropical Cyclone genesis and for NWP models.

American Meteorological Satellites

Polar Operational Satellites (NOAA, K, L, M). The POES satellite system provides daily global coverage, of clouds, storm location, temperature, and heat balance in the earth's atmosphere.

European Meteorological Satellites (EUMETSAT)

Satellite METEOSAT is operated by EUMETSAT on behalf of European Met Agencies near 0° meridian, GMS (Geostationary Met Satellite) by Japan at 130°E and **INSAT** at 83° and 93°. There are two Geostationary Operational Environmental Satellite System (GOES) of USA near its East coast and West coast. GOES provides temperature data of atmosphere every hour. Interval of observations is about 30 min.

23. MET INSTRUMENTS

S. No	Element	Instruments Used	Unit of Measure
1	Pressure	a. Mercury barometer b. Aneroid barometer c. Barograph (Self-recording)	Hectopascal (hPa) or Millibar (mb) or Inches (in) of mercury
2	Air Temp. (TT)	Dry, Max (Mercury) thermometer Min (Alcohol) thermometer	Degree Celsius °C
3	Dew Point Temp (TdTd)	Dry & Wet bulb (Mercury) thermometers	
4	Relative Humidity (RH)	a. Dry & wet bulb thermometer b. Hygrometers c. Hygrograph (Self – recording) d. Psychrometer	Percentage (%)
5	Humidity Mixing Ratio (HMR)	Hygrograph	gm/kg
6	Precipitation Rain Snow	a. Raingauge b. Self-recording rain-gauge c. Hyetograph d. Snowgauge	mm or cm depth, amount (by melting)
7	Surface Wind (Direction & Speed)	a. Wind Vane (for Direction) b. Anemometer c. Anemograph (Self-recording)	Direction in degree from True North in clockwise Speed in knots (KT).

S.No	Element	Instruments Used	Unit of Measure
8	Cloud Base	a. Search light /Laser beam b. Ceilometer / Ceilograph c. Ceiling Balloon d. Nephoscope (direction of movement) e. Alidade	Feet (ft) or m 8 points of compass
9	Visibility RVR	AVRA, Transmissometer or Scopograph Forward Scatterometer Manually – Visibility Landmarks	m m or km
10	Upper Winds	a. Optical Theodolite b. Hydrogen filled Pilot Balloon c. Radar Wind (RAWIN)	Direction: in degrees Speed: Knots (KT) or km per hour (KMH); or m per sec (MPS)
11	Upper Air Pressure, Temp and Humidity	Radio Sonde Dropsonde (used in cyclones)	Hectopascal (hPa) Degree Centigrade %
12	Clouds	Weather Satellites, RADAR	

Table 23.1

24. STATION MODELS

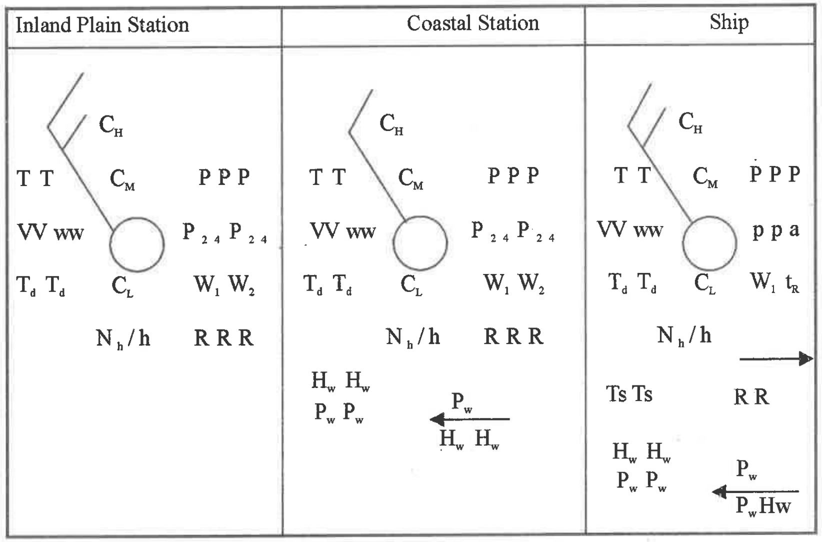
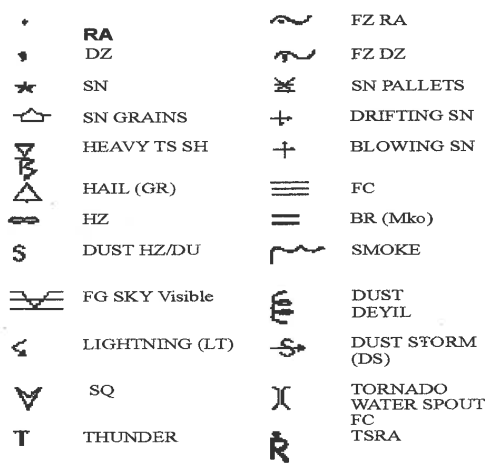


Table 24.1

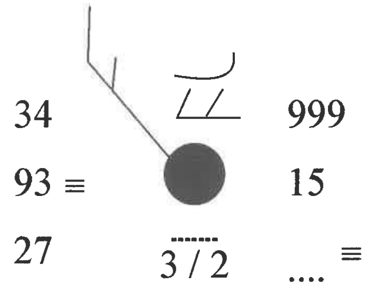
MEANING OF SYMBOLS

	Wind Direction and Speed	C_H	Type of High Clouds
TT	Temperature in ° C	C_M	Type of Medium Clouds
$T_d T_d$	Dew Point Temperature in ° C	C_L	Type of Low Clouds
VV	Visibility in Code 90 – 99	**N**	Total Cloud Amount
ww	Present Weather in Symbols	N_h	Amount of Low/Medium Clouds
$W_1 W_2$	Past Weather in Symbols	**h**	Height of base of C_L or C_M
PPP	Sea Level Pressure QFF	$P_{24} P_{24}$	Pressure Change in 24 hr
RRR	Rainfall since 03 UTC in Code	**a**	Pressure Tendency Symbol
p p	Pressure Change in 3 hr 1/10 of hPa	V_s	Average Speed of Ship(kt) in 3 hr
$t_R t_R$	Duration of Precipitation	**GG**	Time of observation (full Hr UTC)
$T_S T_S$	Difference in Sea Surface temperature and TT in ° C		
$H_{W1} H_{W1}$	(Height of first Wave (swell) repeated for subsequent waves)		
$P_{W1} P_{W1}$	Period of first Wave in Second (repeated for subsequent waves)		

MAIN SYMBOLS . ww



Example:



Interpretation of above Station Models	
Wind Direction and Speed **330/15 kt**	
Temperature **34° C**	Type of Low Clouds **Fracto Stratus**
Visibility **500m but not 1000 m**	Amount of Low Clouds **3/8**
Present Weather **Fog**	Height of base of Low Clouds **100 -199 m**
Dew Point Temperature **27° C**	Sea level Pressure QFF **999.8 hPa**
Type of High Clouds **CI**	Pressure change in 24 hr **1.5 hPa**
Type of Medium Clouds **AS/ NS**	Past Weather in Symbols **Fog**
Total Cloud Amount **8/8**	Rainfall since 03 UTC **Trace**

Past Weather (W_1W_2) W_1 for higher weather code and w_2 for lower weather code

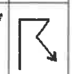
Coded	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
W_1W_2		C	0		≡	,	●	✱	▽	
	Cloud Cover <4/8	Cloud Cover >4/8 Part Period	Cloud >4/8 Throughout	DS	FG	DZ	RA	SN	SH	TS

Table 24.2

Sandstorm	Fog	Drizzle	Rain	Snow	Shower	Thunderstorm
						

Symbols of Low, Medium and High Clouds as plotted in the Station Model:

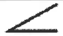
Code Fig	Kind of Low Clouds (CH)	Symbol	Kind of medium Cloud (CM)	Symbol	Kind of high Cloud (CH)	Symbol
0	No low cloud		No Medium cloud		No high cloud	
1	Fair weather CU		Thin AS		Cirrus in Filaments	
2	CU of large vertical development		Thick AS or NS		Dense Cirrus	
3	CB without anvil		AC at single level		Dense CI remnant of dissipated CB	
4	SC with CU with bases at same level		AC at different level		CI becoming denser	
5	Stratocumulus		AC in bands; Thickening and Spreading		CI and CS and progressively increasing	
6	ST of fair weather		AC resulting from spreading of CU		CI and CS progressively increasing covering most of the sky	
7	ST of bad weather		AC with AS or NS		CS covering entire sky	
8	SC and CU at different levels		AC with turreted structure		CS not covering entire sky	
9	CB with anvil		AC in chaotic sky		CC predominate	

Table 24.3

Meanings of Codes h, RRR, and VV

h code	Cloud Base m	RRR code	Rain Amount mm	VV code	Visibility m	
0	0-49			90	< 50	VERY THICK FOG
1	50-99	. . .	**Trace**	91	50 to <200	THICK FOG
2	100-199	—	**0.1-0.9 Trace**	92	200 to < 500	MOD FOG
3	200-299	**1**	**1 - 1.5**	93	500 to < 1000	FOG
4	300-599	**2**	**1.6 - 2.4**	94	1000 to < 2000	THICK MIST
5	600-999	**3**	**2.5 - 3.5**	95	2000 to < 4000	SLIGHT MIST
6	1000-1499	**4**	**3.6 - 4.4**	96	4000 to <10000	
7	1500-1999	**5**	**4.5 - 5.5**	97	10000 to < 20000	
8	2000-2500	**6**	**5.6 - 6.4**	98	20000 to < 50000	
9	No Cloud below 2500	**7** 8	**6.5 - 7.5** 7.6 - 8.4	99	50000 or more	
/	Base not known Or below hill Stn.	9 extrapolate	further values			

Table 24.4

Symbols for ww

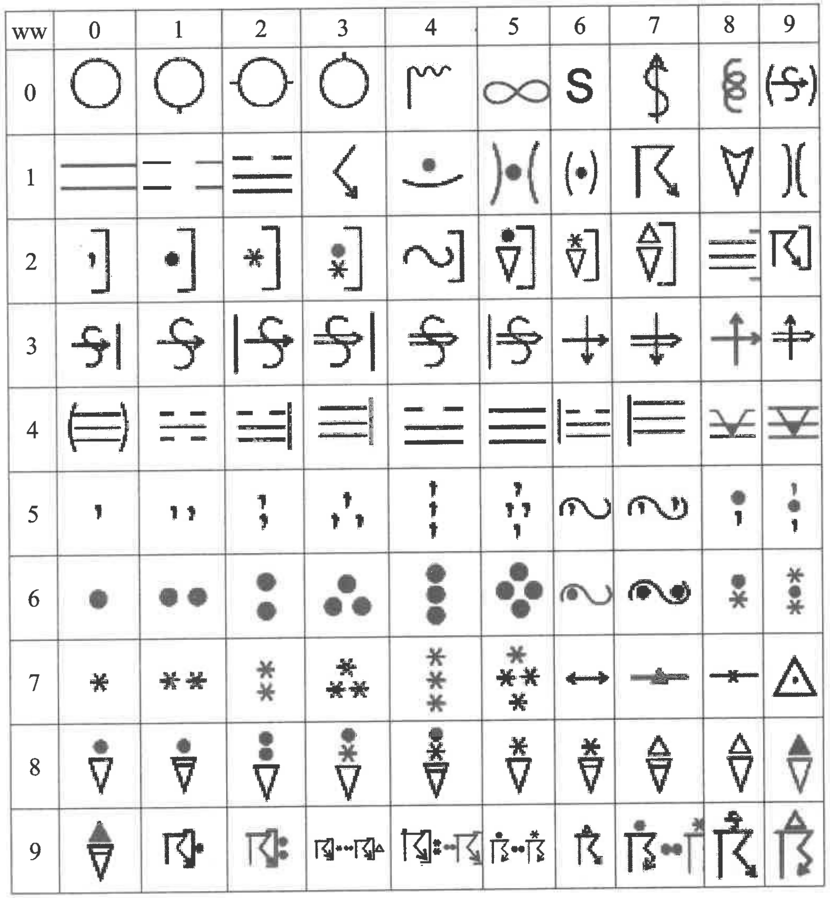


Table 24.5

Code Fig	Present Weather	Code Fig	Present Weather
00	No Cloud	**30-39 DS, SS or blowing SN at the time of observation**	
01	Clouds decreasing		
02	Clouds unchanged	30	Slight duststorm decreasing
03	Clouds increasing	31	Slight duststorm no change
04	Smoke haze	32	Slight duststorm increasing
05	Moist haze	33	Severe duststorm decreasing
06	Dust haze	34	Severe duststorm no change
07	Dust raising winds	35	Severe duststorm increasing
08	Dust devil	36	Slight drifting snow low level
09	Distant sandstorm	37	Heavy drifting snow low level
10	Mist	38	Slight blowing snow high level
11	Shallow fog in patches	39	Heavy blowing snow high level
12	Shallow fog		
13	Lightning	**40-49 Fog at time of observation**	
14	Rain not reaching ground	**40**	Distant fog
15	Rain at a great distance	**41**	Fog in patches
16	Rain close to station	**42**	Fog, sky visible-thinning
17	Thunderstorm without rain	**43**	Fog, sky invisible-thinning
18	Squall	**44**	Fog, sky visible no change
19	Funnel cloud	**45**	Fog, sky invisible no change
20-29 Weather during last one hour but not at the time of observation		**46**	Fog, sky visible-thickening
20	Drizzle	**47**	Fog, invisible-thickening
21	Rain	**48**	Fog, sky depositin rime, sky visible
22	Snow	**49**	Fog, depositing rime, sky invisible
		50-59 Drizzle at the time of observation	
23	Rain and snow	**50**	Slight intermittent drizzle
24	Freezing drizzle	**51**	Slight continuous drizzle
25	Shower of rain	**52**	Moderate intermittent drizzle
26	Shower of snow	**53**	Moderate continuous drizzle
27	Shower of hail	**54**	Heavy Intermittent drizzle
28	Fog	**55**	Heavy continuous drizzle

Code Fig	Present Weather	Code Fig	Present Weather
29	Thunderstorm	**56**	Heavy freezing drizzle
57	Moderate freezing drizzle	**80-89 Shower at time of observation**	
58	Slight drizzle and rain mixed	**80**	Slight shower
59	MOD or HVY DZ RA	**81**	MOD/HVY SH
60-69 Rain at the time of observation		**82**	Violent Shower
60	Slight intermittent rain	**82**	Violent shower
61	Slight continuous rain	**83**	Slight shower with snow mixed
62	Moderate intermittent rain	**84**	MOD or HVY SH with SN
63	Moderate continuous rain	**85**	Slight snow shower
64	Heavy intermittent rain	**86**	MOD/HVY snow shower
65	Heavy continuous rain	**87**	Slight shower of ice pellets
66	Slight freezing rain	**88**	MOD/HVY shower
67	Moderate or heavy FZRA	**89**	Slight SH of GR without TS
68	Slight rain and snow mixed		
69	MOD or HVY RA SN mixed		
70-79 Solid precipitation at the time of observation		**90-99 TS with precipitation**	
70	Slight intermittent snow	**90**	MOD/HVY SH GR after TS ceased
71	Slight continuous snow	**91**	Slight RA after TS ceased
72	Moderate intermittent snow	**92**	MOD/HVY Ra after TS ceased
73	Moderate continuous snow	**93**	Slight SN/ GRl after TS
74	Heavy intermittent snow	**94**	MOD/HVY SN/GR after TS
75	Heavy continuous snow	**95**	Light TS with RA
76	Ice prisms	**96**	Light TS with GR
77	Snow grains	**97**	HVY TS with RA/SN
78	Isolated star-like snow crystals	**98**	TS and DS
79	Ice pellets	**99**	HVY TS with GR

Table 24.7

Total Cloud Amount N

Octas	0	1	2	3	4	5	6	7	8	9	/
N											

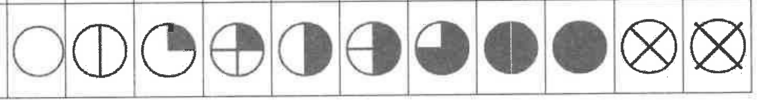
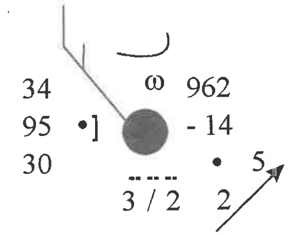


Table 24.8

Note : 9 Octas symbol indicates sky not discernible. /
symbol indicates data not available.

QUESTIONS ON STATION MODEL

Example:



Q1. The direction of surface wind is
(a) NW (b) NE (c) SE

Q2. The range of wind speed is
(a) 20-25 kt (b) 16-22 kt (c) 18-22 kt

Q3. The type of medium cloud is
(a) AC (b) AS (c) AC &AS

Q4. Low clouds are
(a) CU (b) SC (c) ST

Q5. High clouds are
(a) CC (b) CI (c) CS

Q6. Height of base of low clouds is
(a) 200 m (b) 250 m (c) 100 to 199m

Q7. Amount of lowest cloud is
(a) 2/8 (b) 4/8 (c) 3/8

Q8. Dew Point temperature range is
(a) 29.5 to 30.4°C (b) 29.1 to 30.4°C (c) 30.6 to 30.4°C

Q9. Temperature 34° C is
(a) Dry (b) Wet (c) Dew Point

Q10. 962 represents
(a) QFE (b) QFF (c) QNH

Q11. Pressure value in hPa is
(a) 996 (b) 996.2 (c) 1096.2

Q12. Pressure change of 1.4 hPa is in
(a) 6 hr (b) 3hr (c) 24 hr

Q13. Past weather is
(a) Moderate Light Rain (b) Continuous Rain (c) Heavy Rain

Q14. Rainfall amount is
(a) 2 mm (b) 1.5 mm (c) 1.6 to 2.4 mm

Q15. Rainfall reported is from
(a) 0300Z of yesterday to 0300Z of today
(b) 0100 to 2400Z
(c) 0530 to 0830 IST

Q16. Speed of Ship is
(a) 5 KMH (b) 5 MPS (c) 5 KT

Q17. Direction of movement of Ship
(a) NW (b) SW (c) NE

Q18. Speed of Ship reported is averaged for
(a) 3 hr (b) 6 hr (c) 12 hr

Q19. Surface visibility is
(a) 500 to <1000 m (b) 1000 to 2000m (c) 2000 to < 4000 m

Q20. Weather reported is
(a) Rain at the time of observation
(b) Rain during last one hour
(c) Rain not at station but within 5 km

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**a**	**c**	**a**	**c**	**b**	**c**	**c**	**a**	**a**	**b**	**b**	**c**	**a**

Q.	14	15	16	17	18	19	20
A.	**c**	**a**	**c**	**c**	**a**	**c**	**b**

25. AERODROME MET REPORTS AND CODES OF METAR SPECI AND TREND

AERODROME REPORTS: METAR AND SPECI

Met Offices take weather observations for aviation purpose. These are encoded in Aeronautical Meteorological Codes (Reference WMO Manual on Codes WMO 306). These reports are called METAR and SPECI and are widely used by the aircrew, operators and ATC staff, and for exchanging with other stations.

METAR is the code for **Aerodrome Met Report** and
SPECI is the code for **Aerodrome Special Met Report**.

Both METAR and SPECI have the **same code**. METAR is issued at **half hourly or hourly interval** and SPECI is issued **any time** as per the specified criteria.

Code:

METAR or SPECI CCCC YYGGggZ dddffGfmfmKT/MPS/KMH dndndnVdxdxdx
VVVVDv VxVxVxVxDv $RD_RD_R/V_RV_RV_RV_Ri$ w' w'
or or
CAVOK $RD_RD_R/V_RV_RV_RV_RV\ V_RV_RV_RV_Ri$
$N_S N_S N_S h_S h_S h_S$ T' T' /Td' Td' $QP_HP_HP_HP_H$ RE w' w' WS $RWYD_RD_R$
or
VV/// or WS ALL RWY

or
SKC or NSC

$(WT_ST_S\ SS)\ (R_RR_RE_RC_Re_Re_RB_RB_R)$

Reporting of Met Elements in Aviation Reports

(a) **Surface Wind**

- Direction and Speed are reported as: 27010 KT/MPS/KMH
- Variable wind is reported if wind is less than 3KT
  For example: VRB02KT
  Stronger wind if direction changed 180° or more:
  For example: VRB10KT
- Calm wind (less than 1 kt) is reported as: 00000KT
- Gusty Wind 30020 gusting 40KT is reported as: 30020G40KT
- Extreme directions are reported only if variation is 60° to 180° and wind ≥ 3KT e.g.: 270V050
- Wind ≥ 100 KT e.g. 240100KT is reported as: 24 0P99KT

(b) **Visibility** is reported in steps of:

- 50 m when visibility is 0 to 800 m e.g. 50, 100, 150,...,750, 800 m
- 100 m when visibility is 800 m to 5000 m e.g.,900, 1000, 1100...4900, 5000 m
- 1 km when visibility is 5000 m to 9000m e.g. 6000, 7000, 8000, 9000 m etc
- Visibility is reported as 9999 when it is 10 km or more

(c) **RVR**: Runway Visual Range observations, for Touch Down Zone, are made when visibility or RVR is < 1500 m. It is reported in steps of

- 25 m when RVR is 000 m to 400 m
- 50 m when RVR is 400 m to 800 m
- 100 m when RVR is 800 m to 2000 m

- RVR 1500 to 2000m is reported under RMK and not disseminated internationally.

(d) **Cloud base** is reported in steps of:

- 30 m up to 3000 m and 300 m above 3000 m

(e) **Clouds**: For reporting clouds the Terms used are: FEW (1 – 2 Oktas), SCT (3 – 4 Oktas), BKN (5 – 7 Oktas), OVC (8 Oktas) and SKC (clear sky).

(f) i. Lowest layer is reported regardless of amount (FEW, SCT, BKN or OVC).
ii. Next layer is reported when cloud amount is 3/8 or more (SCT, BKN or OVC).
iii. Next layer is reported when cloud amount is 5/8 or more (BKN or OVC).
iv. In addition CB is reported whenever observed.

(g) **Temperature** involving 0.5°C or more are rounded up to next higher value e.g. + 2.5°C reported as 03 and – 2.5°C as M 02.

(h) **Pressure** is rounded down to the nearest whole hectopascal lower value e.g. QNH 996.6 hPa is reported as QNH 996 hPa. In inches exact value is reported. (Range of pressure over the world is 0850 hPa to 1100 hPa)

(i) **Fog (FG)** is reported when visibility is < 1000 m due to water drops or ice crystals or both, except when prefixed by MI, BC, PR or VC.

(j) **Mist (BR)** is reported when visibility is 1000 m but not more than 5000 m.

(k) **HZ, SA, DU, FU, VA** are reported when visibility is 5000 m or less, except SA when specified by DR (Low Drifting).

(l) **Present Weather**

Drizzle (DZ), Rain (RA), Snow(SN), Snow Grain(SG), Ice Pallet(PE), Ice (IC), Hail (diametre 5 mm or more) (GR),Hail (diametre <5 mm) (GS), Fog (FG), Mist (BR), Sand (SA), Dust (DU), Haze (HZ), Smoke (FU), Volcanic Ash (VA), Dust Devil (PO), Squall (SQ), Funnel Cloud (FC), Dust Storm (DS), Sandstorm (SS), Shower (SH), Thunderstorm (TS).

(m) **Supplementary Information**. Recent significant weather information is also included in abbreviated plain language e.g. WIND 32010 KT, WIND AT 60 M 36025 KT IN APCH OR MOD TURB AND ICE IN CLIMOUT, WS RWY 12.

(n) **CAVOK**. CAVOK signifies Visibility, Cloud Ceiling and Present Weather better than the prescribed values or conditions (pronounced as KAV-OH-KAY). It is issued when the following conditions occur simultaneously:

i. Visibility 10 km or more
ii. No clouds of operational significance
iii. No weather of significance.

CAVOK replaces Visibility, RVR, Present weather and Clouds in METAR.

Minimum Sector Altitude

The lowest altitude which may be used which will provide a minimum clearance of 300 m (1000 ft) above all objects located in the area contained within a sector of a circle of 46km (25NM) radius centered on a radio aid to navigation.

Criteria for issue of SPECI

SPECI is issued when any of the following changes take place from the last report. SPECI for **deterioration is reported immediately** and for improvement after 10 minutes.

(a) **Surface Wind**

i. Change in wind direction by ≥ 60° and speed before and/ after change is ≥10 kt.

ii. Mean speed has changed by ≥ 10 kt

iii. Variation from mean speed by ≥ 10 kt (gust) and speed before and/ after change ≥ 15 kt

(b) **Visibility**: When passes 800, 1500, 3000 or 5000 m.

(c) **RVR** changes or passes 150m, 350m, 600 or 800 m.

(d) **Present Weather** – Onset, cessation or change in intensity of: FZ precipitation, FZFG, MOD or HVY precipitation, drifting and blowing snow, sand, dust, DS, TS, SS, squall and funnel clouds (tornado or waterspout).

(e) **Clouds**

i. BKN or OVC base at 30, 60, 150, 300, 450 m

ii. Cloud amount below 450 m changes:

From SKC/ FEW/ SCT to BKN / OVC
From BKN/ OVC to SKC/ FEW/ SCT.

(f) When sky is obscured and vertical visibility changes or passes 30, 60, 150 or 300 m (100, 200, 300, 1000 ft), where laser ceilometer is installed.

(g) When surface **temperature** has increased by 2°C or more from the last observation.

SPECIAL. In addition to the SPECI, Special Report (in abbreviated plain language) are issued for Height of Base of Clouds and Visibility in India as follows. These are passed to ATC only for their local use and not disseminated beyond the aerodrome of origin:-

i. Visibility 2000 or 4000 m

ii. Cloud base 90 or 120 m, where Ceilograph/Ceilometer exists.

Explanation of various groups of METAR and SPECI code:

Code		Meanings	Coded As
Identification Groups	METAR or SPECI CCCC YYGGggZ	Code Name ICAO location Indicator Date and time (UTC) of observation	METAR or SPECI VIDP (Delhi) 241130Z
Surface Wind Direction and Speed	dddffGfmfm KT/MPS/KMH dndndn Vdxdxdx	Wind 27010KT Variable 2 KT: Calm: Wind 32020 gusting 45KT: 240100KT: Direction varying between 170 deg and 050 deg:	27010KT VARB02KT 00000KT 30020G45KT 240P99KT 170V050

Code		Meanings	Coded As
Visibility	VVVVDv VxVxVxVxDv Or CAVOK	Min. Visibility 6000 m in South Visibility <1500 in one direction and >5000 in other then: Direction variation Dv: N, NE, NW: Visibility 10 km or more: CAVOK:	6000S 1400SW 6000E 3000NW 9999 CAVOK
Runway Visual Range (if available)	$RD_RD_R/V_RV_RV_RV_Ri$	R - RVR, D_RD_R - Runway, i - tendency of RVR in last 10 min: i as N - nil as D - decreased, as U - increased RVR 1200m, RWY 27, Decreased: RVR >1500m has Increased: RVR below the value assessable (e.g. 150m) by the instrument	R27/1200D R27P1500U R27/M0150
Present Weather	w' w'	Heavy Shower Shallow Fog	+ SHRA MIFG
Clouds Or Vertical Vis. Or SKC or NSC	$N_sN_sN_sh_sh_sh_s$ VV/// Or SKC or NSC	Cloud Amount and Base 3/8 at 1550 ft 1-2/8 CB at 2000 ft 3-4/8 at 10000 ft When Sky is Obscured: Sky Clear or No Sig. Cloud	FEW,SCT,BKN, FEW,SCT,BKN, OVC, SCT015 FEW020CB BKN100 VV/// SKC or NSC
AirTemp & Dew Point	$T'T'/T_d'T_d'$	Temp 24.3° C/ Dew Point 02.7° C	24/M02

Code		Meanings	Coded As
Pressure QNH	$QP_HP_HP_HP_H$ Or $AP_HP_HP_HP_H$	Rounded down to whole Number 999.9 hPa: 30.05 inches (reported as such):	 Q0999 A3005
Recent Wx Winde Shear Sea Surface Temp & State State of RWY	RE w' w' WS $RWYD_RD_R$ or WS ALL RWY (WT_ST_S SS) ($R_RR_RE_RC_Re_Re_RB_RB_R$	Recent Rain; Recent TS Wind Shear Runway 09: Wind Shear All Runway: Sea Surface Temp. 19 and Sea State: Moderate: (RWY covered with Snow, its depth etc information)	RERA; RETS WSRWY09 WS ALLRWY W19/S4

At the end of the report RMK (Remarks) may be added

Table 25.1

TREND FORECAST (LANDING FORECAST)

TREND forecast is a statement of expected significant changes in any one or more of the weather elements: surface wind, visibility, weather and clouds. In the TREND forecast only those elements are included for which significant change is expected. When no significant change is expected to occur it is indicated by the abbreviation NOSIG.

TREND forecast is **appended to** a METAR or SPECI and is **valid** for **TWO hours.**

Note: In case of significant change (SPECI criteria) in respect of:

(a) **Clouds**. All cloud groups, including cloud groups expected to change and those not expected to change are included in the TREND.

(b) **Visibility**. Phenomena causing reduction of visibility is indicated in the TREND.

TREND Code:

TTTTT or NOSIG   TTGGgg   dddffGfmfmKT/MPS/KMH   VVVV or CAVOK

w' w' or NSW   NSNS NS hS hS hS   or V///   or SKC or NSC   (RMK)

Explanation of various groups of TREND (Landing Forecast)

Change Group	TREND TTTTT or NOSIG	Code Name TTTTTT BECMG(Becoming), TEMPO (Temporary change of 1 hr or less) (Becoming - gradual and permanent change) No Significant Change
Time of expected occurrence of change	TTGGgg	TT: FM (From), TL (Until), AT (At) GGgg: Time in Hr and Min eg 0430, 0800 BECMG FM1230 TL1300 TEMPO FM0800 e.g. BECMG TL1230 OVC005 e.g. BECMG AT1030 OVC010
Surface Wind Direction and Speed	dddffGfmfm KT/MPS/KMH	29010KT OR if wind is gusty 27010G40KT; G for Gusting
Visibility	VVVV or CAVOK	Visibility 4000 m in Rain and Showers: 4000 RASH CAVOK: as in METAR
Weather Phenomena	w' w' or NSW (no sig wx)	FZRA,FZFG, Mod to Heavy (RA,SH), DS,SS,TS,SQ, FC, BLDU/SA/SN
Clouds or Vertical Visibility SKC or NSC	NS NS NS hS hS hS or VV/// Or SKC or NSC	FEW020 SCT100 BKN250 When sky obscured: VV/// SKC: Sky Clear, NSC: No Significant Cloud

Table 25.2

Note: TEMPO change lasts for less than one hour **and the aggregate of such repeated changes is less than half the period indicated by GGgg**

BECMG is a gradual permanent change, starts at.... UTC and completes at.... UTC.

W' W' Significant Present and Forecast Weather:

Qualifier	Description	Precipitation	Obscuratio	Other
- Light	MI Shallow	DZ Drizzle	BR Mist	PO Dust/ Sand Whirl (dust devil)
Moderate (no qualifier)	BC Patches (random coverage)	RA Rain	FG Fog	
		SN Snow	FU Smoke	SQ Squall
+ Heavy (well developed: dust/sand whirl, dust devil, funnel cloud)	PR Partial (substantial coverage)	SG Snow Grain	VA Volcanic Ash	FC Funnel Clouds (Tornado or Water Spout)
	DR Low Drifting	IC Ice Crystals, Diamond dust	DU Widespread Dust	
	BL Blowing	PL Ice Pellets		SS Sandstorm
VC In the Vicinity (not at station but within 8 km)	SH Shower	GR Hail	SA Sand	DS Duststorm
		GS Small Hail	HZ Haze	
	TS Thunderstorm			
	FZ Freezing			

Note: FZ (super cooled water droplets or precipitation) is used only with RA and DZ;
DR is used with DU,SA, or SN raised by wind to < 2 m agl;
BL is used with DU,SA or SN raised by wind to ≥ 2 m agl;
MI, BC and PR are used with FG only e.g. BCFG, MIFG, PRFG

Table 25.3

Explanation of hshshs Code:

hs hs hs Code	000	001	002	003	004	etc	011	009
Cloud Base m	<30	30	60	90	120	**....**	330	2970

Table 25.4

Example of SPECI:

SPECI VIDP 230300Z 30015G35KT 270V050 1200NW 6000S R27/P1500 +SHRA FEW020 FEW025CB SCT100 BKN250 34/27 Q1004 RERA WS RWY27 =

Interpretation:

SPECI VIDP	Aerodrome Special Met Report for Palam (New Delhi)
230300Z	for 23rd day at 0300 UTC
30015G35KT	Surface Wind 300/15 KT gusting to 35 KT
270V050	Wind direction varying from 270° to 050°
1200NW 6000S	Visibility 1200 m in NW direction and 6000m in the South
R27/P1500	Runway Visual Range for R/W 27 more than 1500m
+SHRA	Weather – Heavy shower and Rain
FEW020 FEW025CB SCT100 BKN250	Clouds 1-2/8 at 2000 ft, 1-2/8 CB at 2500 ft, 3-4/8 at 10,000 ft and 5-7/8 at 25,000 ft
34/27	Temperature 34° C and Dew Point 27° C
Q1004	QNH 1004 hPa
RERA	Recent Rain
WS RWY27	Wind Shear Warning for R/W 27

Example of TREND:

TEMPO FM0830 TL0900 24025G45KT 2000 RATS FEW020 FEWCB025 SCT100 BKN250 BECMG FM0930 27005KT 6000 NSW.

TREND forecast: From 0830 UTC Until 0900 UTC Surface Wind 24025 KT Gusting to 45KT Visibility 2000m in Rain and Thunder Shower, Clouds 1-2/8 at 2000 ft, 1-2/8 CB at 2500 ft,3-4/8 at10000 ft, 5-7/8 at 25,000 ft, Becoming from 0930 UTC, Wind 270/05 KT Visibility 6000 m and No Significant weather.

Examples of METAR with appended TREND:

METAR VIAM 211500Z 33010KT 6000 FEW040 FEW050CB 29/25 Q1004 NOSIG =

METAR VEGK 1600Z 09010KT 6000 LT FEW010 FEW020CB SCT025 24/22 Q1006 TEMPO FM 1630 TL 1725 30015G28KT 2500 TSSH SCT020CB OVC150 =

METAR VIJO 1230Z 23015KT 5000 SA SKC 37/18 Q1004 TEMPO 1314 24015G28KT -DS 1500 FEW015 SCT020CB BKN160=

METAR VIAR 1300Z 25015KT 2500 HZ SKC 39/19 Q1001 BECMG AT1400 25010KT CAVOK =

METAR VABB 0210Z 33005KT 3000 HZ SCT015 24/22 Q1011 TEMPO TL0310 1400 BR =

Examples of METAR and SPECI for various Weather elements with trend

1. Surface wind
METAR VIDP 0900Z 23015KT 8000 SCT015 FEW020CB SCT100 32/18 Q1010 BECMG FM0930 28025G35KT=

SPECI VIDP 0945Z 27025G40KT 0800 TSSH SCT010 SCT020CB BKN100 28/24 Q1012 BECMG FM1130 27010KT 8000 FEW025=

2. Visibility
METAR VAPO 0130Z 18005KT 6000 SCT015 26/24 Q1008 TEMO TL0300 2000 BR=

SPECI VAPO 0225Z 15005KT 4000 HZ SCT025 27/24 Q1008 BECMG AT 0300 2000 HZ =

3. Present weather
SPECI VABB 0845Z 32015KT 3000 TSRA SCT015 SCT020CB BKN120 26/25 Q1016 BECMG FM1000 NSW=

4. Clouds
METAR VOMM 0340Z 30005KT 6000 BKN012 OVC100 24/21 Q1008 TEMPO RA BKN008 OVC100=

SPECI VOMM 0400Z 30005KT 6000 -RA BKN008 OVC100 24/22 Q1008 TEMPO 4000 + RA=

International Location Indicators Code Names are at Appendix E

QUESTIONS ON AERODROME MET REPORTS METAR SPECI AND TREND

METAR VIDP 160230Z 30005KT 290V050 1500S 5000N R15/P1500U BR FEW020 FEW025CB SCT120 BKN300 32/29 Q1003 REFG TEMPO FM0330 22015G25KT 3000 + TSRA FEW010 SCT025CB BKN150 BECMG AT0415 27008KT CAVOK=

Q1. The METAR has been issued on ……….. day
(a) 15th (b) 16th (c) 17th

Q2. The METAR has been issued at
(a) 0630 IST (b) 0230UTC (c) 0230 IST

Q3. The surface wind speed is
(a) 2-6 kt (b) 3-7 kt (c) 4-6 kt

Q4. Wind direction is varying from
(a) 290 to 050° (b) 050 to 290° (c)200 to 050°

Q5. Visibility 1500 m is towards
(a) N (b) S (c) All over the airport

Q6. Visibility towards N is
(a) 1500m (b) 5000 m (c) 3000 m

Q7. Height of base of low clouds above station level is
(a) 2000 ft (b) 2500 ft (c) 2500 m

Q8. Runway Visual range is
(a) 1500 m (b) >1500 m (c) < 1500 m

Q9. Runway Visual range has
(a) Decreased (b) Increased (c) Remained same

Q10. The poor visibility is due to the Present weather, which is
(a) Fog (b) Brown Dust (c) Mist

Q11. Amount of lowest cloud is
(a) 1-2/8 (b) 2 -4/8 (c) 5-7/8

Q12. Amount of CB cloud is
(a) 1-2/8 (b) 2-4/8 (c) 5-7/8

Q13. Height of base of CB is
(a) 2500 m (b) 3000 ft (c) 2500 ft

Q14. The height of topmost layer of cloud is
(a) 3000 m (b) 30000 m (c) 30000 ft

Q15. The landing forecast appended to any METAR is valid for
(a) 1 hr (b) 2hr (c) 3 hr

Q16. The wind in TREND from 0330 UTC is valid up to ……….. UTC
(a) 0400 (b) 0430 (c) 0415

Q17. Expected visibility after 0415 UTC is
(a) 6000 m (b) 10 km (c) □ 10 km

Q18. The group Q1003 in the METAR indicates
(a) QFE (b) QFF (c) QNH

Q19. The difference between TT and TdTd is 3° C. The atmosphere is
(a) Very Dry (b) Moist (c) Saturated

Q20. Just before the METAR was issued the weather was
(a) Rain (b) Mist (c) Fog

Q21. The range of pressure reported as Q1003 is
(a) 1002.5 to 1003.5 hPa
(b) 1003.0 to 1003.9 hPa
(c) 1003.1 to 1003.5 hPa

Q22. The range of temperature reported as 32° C is
(a) 31.4 to 32.3° C (b) 32.1 to 32.4° C (c) 31.5 to 32.4° C

General Questions on METAR and SPECI

Q23. Visibility is reported in steps of 50 m when visibility is
(a) 800 m to 5000 m (b) 0 to 800 m (c) 5000 m to 10 km

Q24. Visibility is reported in steps of 100 m when visibility is
(a) 800 m to 5000 m (b) 0 to 800 m (c) 5000 m to 10 km

Q25. Visibility is reported in steps of 1000 m when visibility is
(a) 800 m to 5000 m (b) 0 to 800 m (c) 5000 m to 9999

Q26. Visibility is reported 9999 when visibility is
(a) 800 m to 5000 m (b) 9000 to 9999 m (c) 10 km or more

Q27. Temperature + 2.5°C is reported as
(a) 02 (b) 03 (c) 2.5°C

Q28. Temperature – 12.5°C is reported as
(a) – 12 (b) – 13 (c) M 12

Q29. Pressure is rounded down to the nearest whole number in hectopascal
(a) exact value (b) upper value (c) lower value

Q30. QNH 1002.6 hPa is reported as
(a) Q1002 (b) Q1003 (c) Q1002.6

Q31. QNH 29.92 inches is reported as
(a) Q2900 (b) A2992 (c) A 3000

Q32. Fog is reported when visibility is
(a) < 1000 m (b) 1000 m (c) > 1000 m

Q33. Mist is reported when visibility is
(a) < 1000 m to 2000m (b) 1000 to 5000m (c) >1000 m

Q34. CAVOK signifies Visibility, Cloud ……….. and present weather better than the prescribed values or conditions
(a) ceiling (b) base (c) amount

Q35. CAVOK is issued when visibility is
(a) 9-10 km (b) 10 km or more (c) 10 km only

Q36. CAVOK is issued when
(i) Visibility 10 km or more
(ii) No weather of significance.
(iii) No clouds below 1500 m or below the highest minimum sector altitude, which ever is greater and no CB.
(a) Any one condition (b) Any two conditions (c) All the three conditions

Q37. SPECI is issued when
(i) Change in wind direction is □ 60° and speed before and/ after change □10 kt.
(ii) Mean speed has changed by □ 10 kt
(iii) Variation from mean speed by □10 kt and speed before and/ after change□ 15 kt
(a) Any two conditions (b) Any one condition (c) All the three conditions

Q38. SPECI is issued when Clouds are
(i) BKN or OVC base at 30, 60, 150, 300, 450 m
(ii) Cloud amount below 450 m changes:
From SKC/ FEW/ SCT to BKN / OVC OR
From BKN/ OVC to SKC/ FEW/ SCT.
(a) Any one condition (b) Any two conditions (c) All the above conditions

Q39. SPECI is issued for vertical visibility, by stations having Ceilograph, when sky is obscured
(a) True (b) False

Q40. SPECI is issued when surface temperature has increased by………. or more from the last observation.
(a) 3° C (b) 4° C (c) 2° C

Q41. WSRWY28 indicates that the wind shear has been reported for RW 28 in
(a) take off path
(b) approach path
(c) both take off and approach paths

Q42. R26/M0150 in a METAR indicates that
(a) maximum RVR is 150 m
(b) minimum RVR is 150 m
(c) 150 m is the lowest RVR instrument can measure and RVR is < 150 m

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**b**	**b**	**b**	**a**	**b**	**b**	**a**	**b**	**b**	**c**	**a**	**a**	**c**
Q.	14	15	16	17	18	19	20	21	22	23	24	25	26
A.	**c**	**b**	**c**	**c**	**c**	**b**	**c**	**b**	**c**	**b**	**a**	**c**	**c**
Q.	27	28	29	30	31	32	33	34	35	36	37	38	39
A.	**b**	**c**	**c**	**a**	**b**	**a**	**b**	**a**	**b**	**c**	**b**	**a**	**a**
Q.	40	41	42										
A.	**c**	**c**	**c**										

26. AVIATION WEATHER FORECASTS

Codes of Aerodrome Forecast, Area Forecast and Route Forecast

1. AERODROME FORECAST (TAF)

Code Form:

TAF CCCC YYGGggZ $Y_1Y_1G_1G_1/Y_2Y_2G_2G_2$
$dddffGf_mf_m$KT/KMH/MPS VVVV or CAVOK
w' w' or NSW $N_sN_sN_sh_sh_sh_s$ or VV/// or SKC or NSC
$PROBC_2C_2$ GGGeGe
TTTTT GGG_eG_e (TXT_FT_F / G_FG_FZ TNT_FT_F / G_FG_FZ)
or TTGGgg

Meaning of terms used is similar to those of METAR except for:

TAF is the name of the code for an Aerodrome Forecast. TAF are valid for atleast 9 hr and a maximum of 30 hr. TAF valid for 9 hr are issued every 3 hr and of 12 - 30 hr validity, every 6 hr, commencing at 0000 UTC. 9 hr TAF is not disseminated internationally but used for domestic flights and in VOLMET broadcast.

$Y_1Y_1G_1G_1/Y_2Y_2G_2G_2$ Valid on date Y_1Y_1 from time G_1G_1 to date Y_2Y_2 time G_2G_2 UTC

For example: 1200/1306 (TAF valid from day12 time 0000 to day13 time 0600 UTC) 1606/1615 (TAF valid on day 16 time 0600 to time 0600 UTC).

PROB C_2C_2 Probability of occurrence 30% or 40%: PROB30 or PROB40

YYGG/YYG_eG_e Change likely to occur between timings GG and G_eG_e (1809/1812 indicates change on 18th between 00900 and 1500 UTC).

(TXT_FT_F /G_FG_FZ TNT_FT_F / G_FG_FZ) Maximum temperature (TXT_FT_F) and minimum temperatures (TNT_FT_F) to occur at the time G_FG_F TX42 / 10Z (Max temperature 42° C at 1000Z) TN05 / 01Z (Min temperature 05° C at 0100Z).

Amended TAF is identified by TAF AMD

In the TAFs the date and time of issue of TAF is included after CCCC group. Letter **Z** is an indicator for time of issue in UTC and **KT** for wind speed.

Example:

TAF VECC 102100**Z** 1100/1109 09012**KT** 2500 BR FEW040 SCT150 BECMG 0204 16015KT 6 000 TEMPO 1107/1109 FEW030CB =

Interpretation:

TAF AERODROME FORECAST

VECC	FOR KOLKATA
102100**Z**	ISSUED ON 10TH DAY AT 2100UTC,
110009	VALID FOR 11TH DAY FROM 0000 TO 0900 UTC
09012**KT**	SURFACE WIND 09012 KT
2500 BR	VISIBILITY 2500 m DUE TO MIST
FEW040 SCT150	CLOUDS 1-2/8 AT 4000 FT, 3-4/8 AT 15000 FT
BECMG 0204	BECOMING FROM 0200 TILL 0400 UTC
16015KT 6000	SURFACE WIND 160/15 KT, VISIBILITY 6000 m
TEMPO 0709	TEMPORARILY FROM 0700 TILL 0900 UTC
FEW 030CB	1-2/8 CB AT 3000 FT

Sample TAFs:

TAF VOMM 031500Z 0318/0424 26005KT DZ/HZ SCT015 FEW025CB BKN080 TEMPO 0321/0403 1500 RA/BR SCT010 SCT015 FEW025CB OVC080 BECMG 0405/0406 07005KT 7000 TEMPO 0409/0415 2000 TSRA SCT008 FEW025CB BKN080 BECMG 0416/0417 00000KT 4000 HZ=

TAF VECC 031500Z 0318/0424 09005KT 5000 HZ SCT015 SCT080 TEMPO 0321/0322 3000 HZ SCT008 SCT250 PROB30 TEMPO 0400/0403 0800 FG BKN004 SCT010 BECMG 0403/0404 2000 +SHRA SCT008 SCT250 BECMG 0406/0408 6000 SCT015 BKN080=

TAF VILK 062100Z 0700/0709 27005KT 0500 FG TEMPO 0703/0708 35010G25KT 1500 DU FEW040 BECMG FM0800 FEW030CB =

TAF VOHS 030900Z 0312/0418 07010KT 5000 HZ NSC TEMPO 0400/0403 1500 BR FEW020 SCT200 BECMG 0405/0406 09010KT 6000 SCT020 SCT200 BECMG 0415/0416 09005KT 3000 HZ NSC=

TAF VABB 251200Z 2515/2524 07005KT 6000 SCT015 SCT020 BKN100 TEMPO 515/2518 4000 -TSRA/RA SCT015 FEW020CB OVC080 BECMG 2516/2517 00000KT 4000 HZ=

TAF VIDP 030900Z 0312/0418 VRB02KT 3000 HZ NSC BECMG 0316/0318 00000KT 1500 BR TEMPO 0400/0402 0800 FG BECMG 0403/0404 32005KT1000 BR FEW020 BECMG 0404/0406 33005KT 3000 HZ BECMG 0408/0410 4000 HZ NSC BECMG 0412/0414 30010KT 6000 =

TAF VEVZ 250600Z 2509/2518 12010KT 5000 HZ FEW018 SCT250 PROB40 BECMG 2516/2517 24010KT 7000=

TAF VOHS 251500Z 2518/2624 12010KT 6000 FEW015 SCT020 TEMPO 2521/2603 3000 DZ/HZ SCT008 SCT012 BKN080 TEMPO 2609/2618 24010G24KT 3000 RATS SCT015 SCT020 FEW025CB BKN080 BECMG 2621/2624 12005KT 3000 DZ SCT008 SCT012 BKN080=

TAF VOCB 251500Z 2518/2624 12010KT 3000 HZ SCT012 FEW025CB BKN100 TEMPO 2600/2603 1500 BR SCT010 FEW025CB OVC080 BECMG 2604/2605 27010KT 6000 TEMPO 2610/2615 2000 TSRA SCT012 FEW025CB BKN090 BECMG 2615/2616 14010KT 6000 =

TAF VOCI 141500Z 1418/1524 14005KT DZ/HZ SCT015 FEW025CB BKN080 TEMPO 1421/1503 1500 RA SCT010 FEW025CB OVC080 TEMPO 1509/1515 2000 TSRA SCT008 FEW025CB BKN080 BECMG 1516/1517 12010KT SCT120 7000=

QUESTIONS ON TAF

TAF VILK 241800Z 2500/2509 09008KT 0800 FG BECMG 2504/2505 09015KT 6000 SCT008 BKN120 TEMPO 2506/2508 12015G30KT 3000 TSRA FEW012 FEW025CB BKN100 BECMG AT 25/0800 09010KT 7000 FEW030 SCT120 BKN280 =

Q1. The TAF has been issued on ……….. day
(a) 23rd (b) 18th (c) 24th

Q2. The TAF has been issued at
(a) 2330 IST (b) 1830 UTC (c) 24 UTC

Q3. The expected surface wind speed is
(a) 09 kt (b) 06 kt (c) 08 kt

Q4. Initially expected wind direction is
(a) 120° (b) 090° (c) 050°

Q5. TAF is Valid for Date
(a) 23rd (b) 24th (c) 25th

Q6. Lowest forecast visibility in TAF is
(a) 1500m (b) 0800 m (c) 0200 m

Q7. Height of base of lowest clouds in TAF is
(a) 1000 m (b) 1000 ft (c) 0800 ft

Q8. Weather TSRA is expected after
(a) 0600 UTC (b) 0600 IST (c) 0800 UTC

Q9. Direction of gusty wind is
(a) 090° (b) 100° (c) 120°

Q10. Expected weather up to 25/0400UTC is
(a) Fog (b) TSRA (c) Mist

Q11. Amount of lowest cloud is
(a) 1-2/8 (b) 3-4/8 (c) 5-7/8

Q12. Amount of CB cloud is
(a) 1-2/8 (b) 2-4/8 (c) 5-7/8

Q13. Height of base of CB is
(a) 2500 ft (b) 3000 m (c) 2500 m

Q14. The height of topmost layer of cloud is
(a) 2800 m (b) 28000 m (c) 28000 ft

Q15. Period of validity of TAF is
(a) 23 to 00 IST (b) 00 to 09 UTC (c) 20 to 12 UTC

Other Questions

Q16. Group 1500/1509 in a TAF indicates
(a) TAF is issued on 15th at 0000 UTC
(b) TAF is valid from 15th 0000 to 0900 UTC
(c) TAF is valid from 1500 to 0900 UTC

Q17. What is true of a TAF
(a) 9 hr TAF is for international dissemination
(b) TAF valid for 9 hr is issued every 6 hr
(c) TAF valid for 12-30 hr is issued every 3 hr
(d) TAF for national use are valid for 9 hr and issued every 3 hr

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**c**	**a**	**c**	**b**	**c**	**b**	**c**	**a**	**c**	**a**	**b**	**a**	**a**

Q.	14	15	16	17
A.	**c**	**b**	**b**	**d**

2. AREA FORECAST FOR AVIATION (ARFOR)

ARFOR: It is the name of the code for an **Aviation Forecast in figure code for a specific Area**.

SECTION 1 ARFOR (YYGGggZ) $Y_1Y_1G_1G_1$ / $Y_2Y_2G_2G_2$ [KMH or KT or MPS]

AAAAA (VVVV) ($W_1W_1W_1$)

($N_sCCh_sh_sh_s$ or VV/// or SKC or NSC) $7h_th_th_th_fh_fh_f$ $6I_ch_ih_ih_it_L$ $5Bh_Bh_Bh_Bt_L$

($4h_xh_xh_xT_hT_h$ $d_hd_hf_hf_hf_h$) ($2h'_ph'_pT_pT_p$)

SECTION 2 (11111 $QL_aL_aL_oL_o$ $h'_jh'_jf_jf_jf_j$)

SECTION 3 (22222 $h'_mh'_mf_mf_mf_m$ (d_md_m VV))

SECTION 4 $9i_3nnn$

Explanation of terms:

AAAA – Description of area in plain language, e.g. VECC AND 50 NM AROUND.
VVVV – Forecast visibility e.g. 6000
($N_sCCh_sh_sh_s$ or VV/// or SKC or NSC) Cloud Group e.g. 2/8 AC at 10000ft reported as 2AC100

Criteria of reporting clouds:

1st Group: The lowest layer (N_s 1/8 or more)
2nd Group: The next higher layer (N_s 3/8 or more)
3rd Group: The next higher layer (N_s 5/8 or more)
In addition CB if not already included

$7h_th_th_th_fh_fh_f$	7 Indicator for altitude $h_th_th_t$ Altitude of cloud layer $h_fh_fh_f$ Altitude of Freezing Level
$6I_ch_ih_ih_it_L$	6 Indicator for Icing, I_c Type of icing, $h_ih_ih_it$ -Altitude of icing; t_L – Thickness
$5Bh_Bh_Bh_Bt_L$	5 Indicator for Turbulence
$4h_xh_xh_xT_hT_h$	4 Indicator for Wind and Temperature
$2h_{2p}h_{2p}T_pT_p$	2 Indicator for Tropopause level pressure and temperature

B	Type of Turbulence	I_c	Type of Icing	$W_1W_1W_1$	Reported as
0	Nil	0	Nil	111	Thunderstorm (TS)
1	Light	1	Light	222	Tropical cyclone (TRS)
2	Moderate CAT OCNL	2	Light Icing in Cloud	333	Severe Line Squall (LSQ)
3	Moderate CAT Frequent	3	Light Icing in Precipitation	444	Hail (HAIL)
4	Moderate in Cloud Occasional	4	Moderate Icing	555	Marked Mountain Waves (MTW)
5	Moderate in Cloud Frequent	5	Moderate Icing in Cloud	666	Widespread Sandstorm (SAND)
6	Severe CAT OCNL Occasional	6	Moderate Icing in Precipitation	777	Widespread Duststorm (DUST)
7	Severe CAT FREQ	7	Severe Icing	888	Freezing Rain (FZRA)
8	Severe in Cloud OCNL	8	Severe Icing in Cloud		
9	Severe in cloud FREQ	9	Severe Icing in Precipitation		

Code Figures and their Meanings for **Turbulence, Icing** and **$W_1W_1W_1$**

Table 26.2

Example:

ARFOR VIDP 091400 AREA FCST UPTO FL460 VALID 1000/1100 FOR AREA 28N72E 30N80E 20N90E 15N75E 28N72E SYNOPSIS TC CENTRED 23N74E AT 0300UTC MOV NW 20KT INTSF=

Interpretation

ARFOR VIDP	AREA FORECAST ISSUED BY DELHI PALAM
91400 UPTO FL460	ON 09TH DAY AT 1400 UTC AREA FCST UPTO FL460
100000	VALID ON 10TH DAY FROM 0000 UTC TO NEXT DAY 0000 UTC

FOR AREA	28N72E 30N80E 20N90E 15N75E 28N72E
SYNOPSIS	TC CENTRED AT 23N 74E AT 0300UTC
MOVE, INTSF	MOVE NW, SPEED 20 KT, AND INTENSIFY

WEATHER SYMBOLS USED IN FORECAST

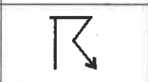
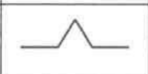
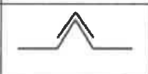
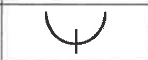
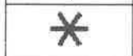
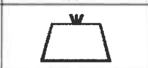
	Widespread Haze		Widespread Blowing Snow
	Widespread Smoke		Freezing Precipitation
	Widespread Mist		Thunderstorm
	Widespread Fog		Tropical Cyclone
	Freezing Fog		Severe Line Squall
	Severe Sand or Dust Haze		Moderate Turbulence
	Widespread Duststorm or Sandstorm		Severe Turbulence
	Drizzle		Marked Mountain Wave
	Rain		Light Ice Accretion
	Snow		Moderate Ice Accretion
	Hail		Severe Ice Accretion
	Shower		Volcanic Eruption

Figure 26.2

3. ROUTE FORECAST FOR AVIATION (ROFOR)

Code:

SECTION 1

ROFOR (YYGGggZ) $Y_1Y_1G_1G_1$ / $Y_2Y_2G_2G_2$ [KMH or KT or MPS] /

CCCC ($QL_aL_aL_oL_o$) CCCC Oi_2zzz

($\dot{V}VVV$) ($W_1W_1W_1$) $N_sCCh_sh_sh_s$ $7h_th_th_th_fh_fh_f$ $6I_ch_ih_ih_it_L$

$5Bh_Bh_Bh_Bt_L$ ($4h_xh_xh_xT_hT_hd_hd_hf_hf_hf_h$) ($2h'_ph'_pT_pT_p$)

SECTION 2 (11111 $QL_aL_aL_oL_o$ $h'_ih'_if_if_if_i$)

Jet Stream Data

SECTION 3 (22222 $h'_mh'_mf_mf_mf_m$ d_md_mVV)

Maximum Wind and Wind Shear

SECTION 4 $9i_3nnn$

Supplementary Weather Phenomena

Section 1 Contains Code identification and time group of ROFOR
Section 2 Contains Symbolic Figure: 11111, and Jet Stream Data (optional)
Section 3 Contains Symbolic Figure: 22222, and Data of Max wind and Vertical wind shear (optional)
Section 4 Contains Supplementary weather phenomena e.g. Lowest msl pressure, type of Front, Change at Lat/ Long, BECMG, FROM, TEMPO etc.

(For details refer to Aviation Weather Code Books of IMD or WMO)

Coded Message of ROFOR

ROFOR 060300Z 0606/0612 KT VIDP 12580 2AC120 4CI300 7///180 403028 27010 405020 28015 407015 30020 410010 33025 523306 631209 11111 12775 40120 22222 38150 27115=

Note: Height of winds and temperature are prefixed by **(INDICATOR 4)** followed by direction in 2 digits (eg 28 for 280) and speed in 3 digits (e.g. 20 kt is coded 020)

Interpretation **of the above ROFOR Coded Message:**

ROFOR	ROUTE FORECAST
060300Z	ISSUED ON 06 DAY AT 0300 UTC
060612	VALID ON 06 DAY FROM 0600 TO 1200 UTC
KT	WINDS SPEED IN KT
VIDP 12580	ROUTE PALAM (DELHI) TO (QUARDRENT 1) 25N 80E

2AC120 4CI300	CLOUDS 2AC10,000 FT 4CI30,000 FT
7///180	**(INDICATOR FIG 7)** FREEZING LEVEL 18,000 FT

WINDS AND TEMP. **(INDICATOR FIG 4)**

403028 27010	3000FT	TEMP 28ºC	WIND 270/10 KT
405020 28015	5000FT	20ºC	280/15 KT
407015 30020	7000 FT	15ºC	300/20 KT
410010 33025	10000 FT	10ºC	330/25 KT

523306	**(TURB. Group starts with Indicator 5)** MODERATE TURBULENCE IN CLEAR AIR AT 33,000 FT THICKNESS OF TURBULENCE 6000 FT (1800m)
631209	**(ICING Group starts with Indicator 6)** LIGHT ICING IN PRECIPITATION AT 12, 000 FT (THICKNESS tL 2700m or 9000 ft)
11111 12775 40120	JET STREAM **(INDICATOR 11111)** LOCATION (QUARQRENT 1) 27N 75E AT 40,000 FT WIND SPEED 120 KT
22222 38150 2715	MAX WIND **(INDICATOR 22222)** AT 38,000 FT SPEED 150 KT DIRECTION 270 DEG VERTICAL WIND SHEAR 15 KT PER 300m =

Interpret the ROFOR:

ROFOR 070530Z 070915 KT VECC VANP 4000 444 3CB020 7///170 641809 5416009 405016 16012 410006 24015 415003 28025 4200M04 27045 4300M25 28080 11111 12881 40150 22222 42160 28 25=

Hint: 444 stands for Hail, 64 (Moderate icing), 54 (Mod Turbulence in Cloud Occasional) (Note: See ARFOR for explanation of terms)

QUESTIONS ON ROFOR

ROFOR 010000Z 010610 KT VECC VILK 2SC030 2CB030 3AC100 2CI300 7///170 621800 541501 405022 28015 407010 28020 410005 29030 420M05 27045 440M41 27105 11111 12870 380120 22222 36140 2825=

Q1. Time of issue of ROFOR is
(a) 0610 UTC (b) 0000 IST (c) 0000 UTC

Q2. Period of validity of ROFOR is
(a) 0000 to 0000 IST (b) 0600 to 0100 IST (c) 0600 to 1000 UTC

Q3. Wind speed in ROFOR is in
(a) KT (b) MPS (c) KMH

Q4. Base of CB cloud is
(a) 300 m (b) 300 ft (c) 3000 ft

Q5. Height of Freezing level?
(a) 1700 m (b) 17,000 ft (c) 1.7 km

Q6. Icing group in the ROFOR is
(a) 7///170 (b) 621800 (c) 54//609

Q7. Type of Icing?
(a) Nil (b) Light (c) Light icing in cloud

Q8. Indicator figure for turbulence group in the ROFOR is
(a) 7 (b) 6 (c) 5

Q9. Height at which Icing is expected?
(a) 21,000 ft (b) 18,000 m (c) 15,000 ft

Q10. Thickness of Icing is expected to be?
(a) 300 m (b) 600 m (c) Up to Cloud Top

Q11. Height at which Turbulence is expected?
(a) 15,000 ft (b) 5,000 ft (c) 12,000 ft

Q12. Thickness of turbulence expected is?
(a) 2000 ft (b) 300 m (c) Up to Top of cloud

Q13. Wind at 5000 ft expected is?
(a) 280/10 kt (b) 280/15 kt (c) 280/20 kt

Q14. Wind at 20000 ft expected is?
(a) 270/45 kt (b) 270/45 KMH (c) 270/40 kt

Q15. Temperature at 20000 ft expected is?
(a) - 05 ºC (b) 05 ºC (c) 265 K

Q16. Temperature at 40,000 ft expected is?
(a) - 45 °C (b) - 41 °C (c) 233 K

Q17. Date of issue of forecast is?
(a)10 (b) 01 (c) 02

Q18. Indicator group for Jet stream in ROFOR is
(a) 22222 (b) 11111 (c) 111111

Q19. Indicator group for Maximum Wind in ROFOR is
(a) 22222 (b) 11111 (c) 111111

Q20 Maximum Wind speed expected is
(a) 120 kt (b) 130 kt (c) 140 kt

Q21. Maximum Wind speed expected at height
(a) 40000 ft (b) 36000 ft (c) 38000 ft

Q22. Jet stream is expected at Lat/Long
(a) 27 N/70 E (b) 28 N/75 E (c) 28 N/70 E

Q23. Vertical Wind Shear per 300 m expected is
(a) 25 kt (b) 30 kt (c) 38 kt

Q24. Jet stream core speed is expected to be
(a) 125 kt (b) 120 kt (c) 140 kt

Q25. Jet stream is expected at a height of
(a) 40,000 ft (b) 36,000 ft (c) 38,000 ft

Q26. Wind at 40,000 ft expected is ?
(a) 270/105 kt (b) 270/115 KMH (c) 270/140 kt

ANSWERS

Q	1	2	3	4	5	6	7	8	9	10	11	12	13
A	**c**	**c**	**a**	**c**	**b**	**b**	**C**	**c**	**b**	**c**	**a**	**b**	**b**

Q	14	15	16	17	18	19	20	21	22	23	24	25	26
A	a	a	b	b	b	a	C	b	c	a	b	c	a

27. RADAR REPORT, SIGMET MESSAGE AND SATELLITE BULLETIN

1. RADAR REPORT (RAREP)

Code:

RAREP	FEBB	Iiiii	YYGGg
CHARACTER	($b_1 b_1 b_1 / r_1 r_1 r_1$	$b_n b_n b_n / r_n r_n r_n$)	

Intensity Tendency

	$d_s d_s f_s f_s$	ALTD	($bbb/H_t H_t/rrr$)

Note:

RAREP is normally be reported only at synoptic hours. In the case of any break in observations or rapid development, additional message are transmitted as necessary.

Iiiii	Station Index number
YYGGg	Date and time of RAREP
bbb	Azimuth in three digit degrees of points on the periphery of an echo area
r r r	Range three digit in kilometer

Character of Echoes:

EYE	AN ECHO OF EYE WALL OF A TROPICAL CYCLONE
SPRL BAND	A CONTINUOUS OR BROKEN CURVED LINE OF ECHOES OF SPIRAL BAND ASSOCIATED WITH A CYCLONE
SQL LN	SQUALL LINE HAVING LENGTH 60 KM OR MORE AND LENGTH TO WIDTH RATIO ABOUT 10 TO 1
BRKN LN	BROKEN LINE OF ECHOES

SLD	AN AREA FULLY COVERED WITH ECHOES
BRKN	AN AREA 4/8 TO 7/8 COVERED WITH ECHOES
SCT	AN AREA 1/8 TO 4/8 COVERED WITH ECHOES
WDLY SCT	AN AREA LESS THAN 1/8 COVERED WITH ECHOES
ISLTD	ISOLATED SOLID MASS OF ECHO
ECHO ALOFT	ECHOES SEEN ONLY AT ELEVATIONS HIGHER THAN THE BEAMWIDTH

Intensity Tendency

INCG	INCREASING
DEC	DECREASING
NO CHG	NO CHANGE
$d_s d_s$	DIRECTION IN TENS OF DEGREES IN WHICH ECHO IS MOVING
$f_s f_s$	SPEED IN KILOMETER PER HOUR OF THE ECHOES
ALTD	INDICATOR OF ECHO HEIGHT INFORMATION
$H_t H_t$	HEIGHT OF TOP OF ECHO amsl IN km (MAY BE REPEATED AS REQUIRED)

BRIGHT BAND AND ANOMALOUS PROPAGATION (AP) ARE REPORTED IN PLAIN LANGUAGE

Notes:

1. The groups within the brackets () are repeated as many times as necessary.
2. To define the shape of the line echoes, spiral bands and eye wall, as many bbb/rrr points as necessary are used. The points are given along the line in anticlockwise direction.
3. To define the shape of **areas**, as many bbb/rrr points as necessary to are given in the anticlockwise order starting from the northernmost point. The first point is repeated as the last point to indicate that it is a closed area.
4. If an echo system with a distinct characteristic is partly or wholly embedded in another, the two systems are reported in separate groups.
5. Reports of heights are restricted to a maximum range of 200 km from the station.

Example 1:

RAREP 42375 15030 270/050 300/060 350/025 280/ 010 SLD INCG 1525 ALTD 270/09/050 340/10/060 280/12/ 010 =

Explanation:

Radar Report for 42375 (International Identification No.) (say) Palam Date 15th at 0300 UTC Area of Solid echo from and 270 deg 50, 300 deg 60 km, 350 deg 25 km, 280 deg 10 km. Increasing Moving in 150 direction with speed of 25 KMH, Altitude of echoes in 270 direction 9 km at 50 km, in 340 direction 10 km at 60 km, in 280 direction 12 km at 10 km =

Example 2:

RAREP 43003 10143 270 / 030 330 / 040 050 / 020 MDT INCG RPD NW / 012 ALTD 260/ 15 / 030 BRIGHT BAND 280 / 30 AP 300/ 330 /150 Angles between the Azimuth 270 ° to 340 ° Range 15 to 20 nm (AP - Anomalous Propagation)

2. SIGMET MESSAGE

SIGMET messages is prepared in abbreviated plain language, using ICAO approved abbreviations and contains the following information as necessary and in the order indicated.

- Identification of the MWO originating the message, e.g. VECC
- Message Identification and sequence No. e.g. SIGMET 2 i.e. 2nd SIGMET
- Date-time group indicating the period of validity in UTC e.g. "VALID 221215/221600
- Description of the phenomenon, e.g. SEV, FRQ
- Phenomenon for which the message is issued, e.g. TURB, TS
- Indication whether the information is observed or forecast and expected to continue and related time, e.g. OBS AT 1150 UTC, FCST AT 1000 UTC
- Location (latitude and longitude and/or locations or well known geographic features) and level, e.g. FCST TOPS FL 390 S OF 54 DEG N or OVER KOLKATA AT FL250
- Movement or expected movement, e.g. MOVE E 25 KT
- Change in intensity using as appropriate the abbreviations INTSF, WKN or NC

- On the next line, an outlook providing information beyond the period of validity specified above, of the trajectory of the volcanic ash cloud and positions of tropical cyclone centre etc., e.g. VABB SIGMET 3 VALID 221600/222000 TC FCST 20.2N 89.2E AT 1800 UTC FRQ TS TOPS FL400 WI 100NM OF CENTRE MOV NW 15 KT OTLK TC CENTRE 230300 21N 87.9E 231200 21.5N 86.4E.

SIGMET for subsonic aircraft is identified as SIGMET, and those for supersonic aircraft during transonic or supersonic flight as SIGMET SST. Separate series of sequence number is used for SIGMET and SIGMET SST messages.

SIGMET information is disseminated to all the forecasting offices in India and also transmitted on AFTN under DD priority to MWOs in neighbouring countries within a distance of 1100 NM from the boundaries of local FIRs.

SIGMET information from other MWOs is also passed on to the local FIC.

Examples:

- VECC SIGMET 4 VALID 101200/101600 TC OBS 20.2N 89.2E AT 1130 UTC FRQ
- TS TOPS FL350 WI 150NM OF CENTRE MOV NW 10 KT OTLK TC CENTRE 110300 21N 87.9E 111200 21.5N 86.4E.
- VABB SIGMET 4 VALID 201200/201600 SEV TS OBS AT 1150 UTC TOPS FL 390 S OF 25 N W OF OR OVER MADRAS AT FL250 MOVE E 25 KT INTSF OR NC
- VECC SIGMET 3 VALID 151600/152000 TC OBS 20.2N 89.2E AT 1600 UTC FRQ
- TS TOPS FL500 WI 150NM OF CENTRE MOV NW 10 KT NC OTLK TC CENTRE
- 160300 21N 87.9E 161200 21.5N 86.4E.

3. SATELLITE BULLETIN

Weather Satellites

Satellite imageries are analysed and supplied as Bulletins in abbreviated form. An example is given below:

SAT BLTN BASED ON METSAT PIC OF 271200 UTC.

THE CONVTE CLOUDS CURVED BANDS OF VORTEX OVER EC BAY HAS REDUCED NOW CENTERED OVER 16.5 N/91.0E RPT 16.5N/91.0E(.) INTERSITY T 1.5 RPT T 1.5 (.) ASSTD BKN LOW MED CLOUDS EMBDD SCT MOD TO INT CONVTN (AT10.5N TO 14.0N LONG 85.5E TO 91.5E AND LAT 14.0N TO 18.5N EAST OF LONG 87.5E ARAKAN COT AND S MYANMAR(.) SCT M/LAYERED CLOUDS OVER NW JK AND AREA BET LAT 37.0N TO 16.0N LONG 60.0E TO 100.0E(.) SCT LOW /MED CLOUDS OVER SKM NE STATES BAY IDS KER(.) SCT MED/HIGHCLOUDS OVER AFSN PAK REST JK HP UTRCL PJB AND NW GUJ(.) SCT TO BKN LOW/MED CLOUDS EMBDD, MOD TO INT CONVTN OVER S ARESA BET LAT 5.0 N TO 14.8N LONG 60.0E TO 68.0E SE ARSEA ADJ INDIAN OCEAN BET LAT 2.0N TO 8.0N LONG 69.0E TO 76.0E S SRILANKA GULF OF MARTABAN SUMATTRA ADJ W COT BORNEO JAVA IDS AND SEA EXT. N MADAGASCAR(.) =

Interpretation of the Bulletin:

Satellite Bulletin based on METSAT satellite picture of 27th day at 1200 UTC. The connective clouds curved bands of vortex over East Central Bay has reduced. It is now centered over 16.5 N / 91.0E. Repeat 16.5 N / 91.0E. Intensity 1.5. Associated broken low and medium clouds embedded scattered moderate to intense convection at 10.5N to 14.0N long 85.5E to 91.5E and lat 14.0N to 18.5N east of long 87.5E, Arakan coast and S Myanmar. Scattered medium layered clouds over NW J&K and area bet lat 37.0N to 16.0N long 60.0E to 100.0E. Scattered low /medium clouds over Sikkim, NE states, Bay islands, Kerala. Scattered medium/high clouds over Afghanistan, Pakistan, rest J&K, HP, Uttaranchal, Punjab and NW Gujarat. Scattered to broken low/medium clouds embedded, moderate to intense convection over sea areas between lat 5.0N to 14.8N long 60.0E to 68.0E SE, Arabian sea, adjoining Indian ocean between lat 2.0N to 8.0N long 69.0E to 76.0E, S Srilanka, Gulf of Martban, Sumatra, adjoining W cost of Borneo, Java, islands and sea extending N of Madagascar. =

28. MET DOCUMENTATION AND BRIEFING

Aerodrome Met Offices provide meteorological information in the form of written/printed material, data in digital form, Briefing, Consultation or Display, to the following :

(a) **Operators** for - Pre-flight, In-flight and Re-flight Planning

(b) **Flight crew members -** before departure

(c) **Aircraft**, in flight

The Met information provided is as follows :

(a)	Winds	:	Upper Winds, Temperature, Maximum Wind, Jetstream and Tropopause height data
(b)	Reports	:	METAR, SPECI, TREND, AIREP, SIGMET, VA
(c)	Forecasts	:	En-route weather, TAF, for Take-off, WS Warning, Local/Area
(d)	Charts	:	SIGWX
(e)	Imagery	:	Satellite, and Ground based Radar

Briefing, Consultation and Display

The purpose of briefing is to provide the actual and forecast weather at the departing base, en-route, destination and alternate aerodromes. It is provided to the flight crew or operations personnel, in person, 3 hr prior to the scheduled departure. If not practical, it may be obtained through telephone or other telecommunication facilities.

Briefing for **Low Level flights**, and those under Visual Flight Rules, is given up to FL 100 (or up to FL 150 or above in mountains), poor visibility (5000m or less), any phenomena likely to lower widespread visibility to less than 5000 m, clouds which may affect flight, and SIGMET information.

Oral Briefing

Where adequate Notice (of 3 hr to AMOs and 12 hr to AMSs) has not been given to the Met Office for preparation of documentation, oral briefing is provided. It covers all the Met information as listed above. The details of briefing are recorded in the Briefing Register , with remarks " Briefed Capt/ Mr .... documentation not provided for want of adequate notice" and signature of the crew obtained. However, Oral briefings may be avoided as far as possible

Flight Documentation. It is issued as Charts, Tabular or Cross-section forms :

(a) Upper Wind and Temperature, and if relevant : Tropopause height, Maximum upper Wind, Jetstream data, Expected en-route WX

(b) SIGWX phenomena

(c) METAR, SPECI and TAF of Aerodromes of departure, destination, en-route and alternates, Area / local Forecast

(d) Relevant SIGMET, AIREP, Cyclone advisory, VA report.

Tabular Form (Met T-3) and Cross Section Form (Met T-4)

The following information is provided in these forms :

(a) Synoptic situation and Surface pressure data

(b) Outlook of en-route weather

(c) Amount and type of cloud (Pictorially depicted in T- 4 Form)

(d) Upper winds and temperatures, Height of Freezing Level

(e) Tropopause data

(f) Surface visibility (only for flights below FL100)

(Met T–3 is for flights up to 500 nm, and Met T-4 for flights beyond 500 nm)

The significant En-Route Weather Phenomena included in Met T-4 and T-3 are

For High Level Flights : TS, CS, SQ Line, Hail, MOD/SEV Turbulence, Icing, FZ Precipitation, Widespread DS/SS, Marked **Mountain Waves**

For Low Level Flights : In addition to the above : Fog, Precipitation and weather which reduce visibility below 5000 m.

Flight Documentation : Set of Charts provided:

International Flights - SIGWX charts (generated from WAFC forecast) between FL 250 and FL630 and a forecast 250 hPa wind and temperature charts.

National Flights - National SIGWX charts, WAFC upper wind and temp. charts and for LL Flights for altitudes 600, 1500 and 300 m (2000, 5000, 10,000 ft)

(Where Fax/internet facilities are not available- Met T-3 or Met T-4 form is provided)

National Significant Weather Charts

All the four MWOs prepare SIGWX charts for their respective FIR and transmit to MWO Chennai, where these are compiled for making a single SIGWX chart. One single SIGWX chart is made for the medium level (between FL 100 and FL 250) and one for high level (between FL 250 and FL630). Zero degree isotherm is included for medium level chart. SIGWX charts are made four times a day based on 00, 06, 12 and 18 UTC data and issued 09 hr after the observation time and are valid for 24 hr.

Contents of National SIGWX Charts

(a) Tropical Cyclone (wind 34 kt or more)

(b) CB associated with TS, TC, Line squall, Hail, MOD/ SEV Icing and Turbulence, CAT, Marked Mountain Waves, Widespread DS/ SS.

(c) Height of Freezing Level, FL of Tropopause

(d) Location of Volcanic eruption, and of accidental release of radioactive material significant for air operations

(e) Jetstream

Height Indications in the Flight Documentation

In all en-route Met conditions : eg Upper winds, turbulence, cloud base/top
- Flight Levels

In all aerodrome Met conditions : eg base and top of clouds
- Above aerodrome elevation

Information for Aircraft in Flight

It is supplied through VOLMET/ D-VOLMET broadcast by Mumbai and Kolkata.

For in-flight planning by Operators, and for aircraft in-flight, the information supplied is : METAR, SPECI, TAF, SIGMET, AIREP and upper winds and temperature, VA and TC advisory

QUESTIONS ON METEOROLOGICAL AND BRIEFING

Q1. Who prepares National SIGWX Charts
(a) AMOs (b) WAFC (c) MWOs

Q2. Flight Level of freezing Level is included in ……….. SIGWX Charts
(a) Medium level charts (b) High level charts (c) Low level charts

Q3. Fog, Precipitation and weather which reduce visibility below 5000 m is considered Significant weather for
(a) All level flights (b) High level flights (c) Low level flights

Q4. Briefing and Consultation are generally provided to the aircrew ……. hours prior to the scheduled departure
(a) 3 hr (b) 5 hr (c) 6 hr

Q5. SIGMET information is provided to
(a) Low level flights (b) All level flights (c) High level flights

Q6. For Low Level flights, and those under Visual Flight Rules, briefing is given up to
(a) FL150 or above in mountains
(b) FL110 above the sea
(c) FL 120 or over the plains

Q7. The height indications in the Flight Documentation in all en-route Met conditions : eg upper winds, turbulence, cloud base/top etc is
(a) Above aerodrome elevation
(b) Flight Levels
(c) As requested by the Pilot

Q8. The height indications in the Flight Documentation **in all aerodrome Met conditions** : eg base and top of clouds
(a) Above aerodrome elevation
(b) Flight Levels
(c) As requested by the Pilot

Q9. For National Flights the Documents provided are -
(a) National SIGWX charts only
(b) WAFC upper wind and temp. charts only
(c) both WAFC upper wind and temp. charts and National SIGWX charts

Q10. For National Flights the winds and temperatures are provided for LL Flights for altitudes
(a) 600, 1500 and 300 m
(b) 3000 ft, 5000 ft, 10,000 ft
(c) 600, 1000 and 500 m

ANSWERS

Q	1	2	3	4	5	6	7	8	9	10
A	c	a	c	a	b	a	b	a	c	a

29. FLIGHT FORECAST (TABULAR FORM) AND CROSS SECTION FORECAST OF ROUTE CONDITIONS

(Samples are in next Pages)

1. FLIGHT FORECAST (TABULAR FORM) (MET - T3)

DATE 04 APRIL 06 Heights in Feet amsl

Route From VECC To VIDP Via VILK
Valid For Departure Between 0300 UTC and 0500 UT C
Valid For Arrival Between 0600 UTC and 0800 UT C

Special Features of MET Conditions (Surface and Upper Air)

A WD LIES OVER W RAJASTHAN WITH UPPER AIR CYCIR UP TO 20,000 FT

ROUTE (Zone, Lat, Long. or Geographical Indicators)			**KOLKATA**	**LUCKNOW**	**DELHI**
Upper Winds(Deg/KT) Temperature (°C)	30,000 ft	M 33	300/60	270/70	M30
	20,000 ft	M 20	330/45	260/55	M18
	10,000 ft	12	050/15	120/25	14
	5,000 ft	22	050/10	160/15	24
Clouds (Top/ Base)		SCT ST 1000 FEW SC 2500 SCT AC 12000 ISOL EMBD CB 2000/35000 BKN CS 35000 3000 M IN RAIN AND			
Surface Visibility		6 KM 1500 M IN THUNDERSTORM			
Significant Weather		ISOL THUNDERSTORM ICING, TURB IN CB 25000/15000			
Height of 0 ° Isotherm		15000 14000			
Forecast QNH (hPa)		1006 1008			

Issued by Met Office ……….. at ……… UTC on ……… by ……….. Forecaster

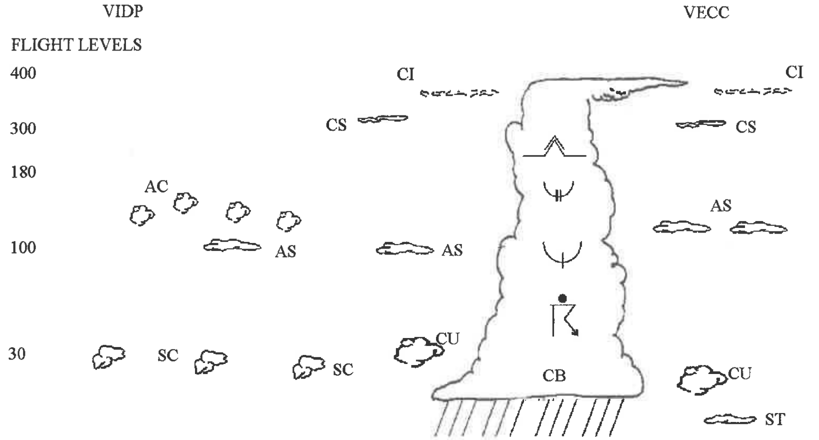
Abbreviations: SKC – 0 Oktas, FEW – 1 to 2 Oktas, SCT – 3-4 Oktas, OVC – 8 Oktas,

ISOL – Isolated (<50% area covered), OCNL(50 – 75% area) – Occasional, FRQ –(>75% area)Frequent, EMBD – Embedded, MOD – Moderate, HVY – Heavy, M – Minus LOC- Locally,

Table 29.1

2. CROSS SECTION - ROUTE FORECAST MET – T 4

HEIGHTS IN FLIGHT LEVELS



Remarks :	VIS 8-10 km , 2000 m in Scattered TS					
LOWEST	MSL PRESSURE		1002 hPa			
flight levels	400	M 38°C	270/80KT	WEAKNING	300/60KT	M39°C
	300	M32°C	270/45KT	VEERING	300/35KT	M35°C
	200	M15°C	260/30KT	VEERING	300/25KT	M16°C
	150	05°C	210/20KT	VEERING	300/15KT	08°C
	100	18°C	140/10KT	BCKING	300/20KT	20°C

Table 29.2

Appendix A

SYNOPTIC SYSTEMS

Depression. Intense low pressure system represented by two or three closed isobars at 2 hPa interval and wind speed at surface level 17 to 27 kt.

Deep Depression (DD). Intense low pressure system with two or three closed isobars at 2 hPa interval and wind speed at surface level 28 to 33kt.

Cyclonic Storm (CS). Intense low pressure system with more than four closed isobars at 2 hPa interval and wind speed on surface level 34 – 47 kt.

Severe Cyclonic Strom (SCS). Intense low pressure system with more than four closed isobars at 2 hPa interval and wind speed on surface level 48 – 63 kt.

Very Severe Cyclonic Storm (VSCS). Intense low pressure system having more than four closed isobars at 2 hPa interval and wind speed on surface level 64 – 119 kt.

Super Cyclonic Storm (SuCS). Intense low pressure system having more than four closed isobars at 2 hPa interval and the wind speed on surface level is 120 kt or more.

Trough in Westerlies. A wave, in mid latitudes, which moves from W to E over the globe. These systems generally affect the northern parts of India.

Trough in Easterlies. A wave in the equatorial easterlies moving from East to West.

Western Disturbance (WD). Low pressure area on the surface or cyclonic circulation/trough in the mid and lower tropospheric levels, which originate over the Mediterranean Sea, Caspian Sea and Black Sea and move across N India. Systems on the surface with two or more closed isobars are called **Western Depressions.**

Induced Low

Under the influence of the WD, sometimes a low develops to the South of the system. It is called as an **Induced Low** and a cyclonic circulation in the upper air developed to the south of the system is called **Induced Cyclonic Circulation.**

Easterly Wave. A shallow trough in the Easterly current of tropics, more evident in upper level winds than in surface pressure pattern. It moves from E to W and causes clouds and showers. It affect S peninsular India.

Trough in Easterlies. A wave in the equatorial easterlies moving from East to West.

High/High pressure area

Area in the atmosphere in which the pressures are higher than those of the surroundings at the same level and is represented on a synoptic chart by, at least, one closed isobar.

Shear line

A line or narrow zone across which there is an abrupt change in the horizontal wind component. It is a line of maximum horizontal wind shear.

Wind-discontinuity

A line across which there is an abrupt change in wind direction.

METEOROLOGICAL SCALES

Microscale (≤10 min). Phenomena of 1 km or less, e.g. local turbulence, gust etc

Mesoscale (5 hr). These range horizontally from 5 to 500 km and have lifetime of a day or less. e.g. TS, squall lines, fronts, cyclones, mountain waves and land & sea breezes.

Synoptic Scale (1day). Synoptic scale generally covers large area, e.g. extratropical cyclones, troughs and ridges, frontal zones, and jet streams.

Global/Macro/ Planetary Scale. (≥ 5 days)Systems which transport heat from the tropics to the poles. These have time periods longer than annual and seasonal cycle. e.g. ENSO, ITCZ, Rossby Waves.

Fujita Damage Scale Number for Tornadic Winds

F0	35–62 kt	:	light damage
F1	63–95 kt	:	moderate damage, cars pushed off the roads
F2	96–135 kt	:	considerable damage, roofs off, large trees uprooted
F3	136–180 kt	:	severe damage, heavy cars lifted and thrown
F4	181–225 kt	:	devastating damage, well constructed houses leveled
F5	226–275 kt	:	incredible damage, strong timber houses lifted

Saffir-Simpson Damage-Potential Scale of Cyclones

Category (damage)		**Central Pressure**	**Winds**	**Surge**
1.	(Minimal)	> 980 hPa	64 to 83 kts	4 to 5 feet
2.	(Moderate)	965 to 979 hPa	65 to 96 kts	6 to 8 feet
3.	(Extensive)	945 to 964 hPa	97 to 113 kts	9 to 12 feet
4.	(Extreme)	920 to 944 hPa	114 to 135 kts	13 to 18 feet
5.	(Catastrophic)	< 920 hPa	> 135 kts	> 18 feet

T Classification of Cyclonic Storms

Disturbance	L	D	DD	CS	SCS	VSCS	SuSC
T/ CI Number	T1.5	T2.0	T2.5	T3.0	T3.5	T4.0-6.0	T6.5-8.0

WEATHER ASSOCIATED WITH FRONTS

WARM FRONT

	Before	**At**	**After**
Temperature	Steady	Rise	Little change
Pressure	Falls	Arrested	Slight Rise
Wind	Backs (N Hem.) Veers (S Hem)	Veers (N Hem.) Backs (S Hem)	Steady Steady
Clouds	CI,CS,AS,NS, ST,SC,OCNL CB	ST,NS	ST, SC
Precipitation	- RA becoming +RA	RA/+RA, DZ,FG	- RA/DZ
Visibility	Reducing to Poor	Very Poor	Poor

COLD FRONT

	Before	**At**	**After**
Temperature	Warm	Abrupt Fall	Cold
Pressure	Falls	Fall Arrested	Rises
Wind	Backs (N Hem.)	Squally	Veers (N Hem.)
	Veers (S Hem)	Squally	Backs (S Hem)
Clouds	CI, CS, CB	CU, CB, NS Isolated CB, CU	Rapid Clearing,
Precipitation	Brief SH May be Hail	+TSSH Isolated SH	SH cease then
Visibility	Good	Very Poor in SH	Very Good

MISCELLANEOUS TERMS

Iso Lines	
Isobar	A line of constant (atmospheric) pressure.
Isohyet	A line of constant rainfall amount.
Isotach	A line of constant wind speed
Isogon	A line of constant wind direction
Isotherm	A line of constant temperature
Isallobar	A line of constant (atmospheric) pressure change
Isopicnic	A line of constant density
Isohel	A line of constant sunshine
Isomer	A line of constant % of average annual rainfall in a month
Isopleth	A line of constant, any quantity, a generic term
Isohypse /Contour	A line of constant (atmospheric) height
Streamline	A line tangential to the wind direction)

METEOROLOGICAL SUB-DIVISIONS OF INDIA (Map at page 250)

NW India	Jammu &Kashmir(J&K), Himanchal Pradesh. (HP), Punjab, Haryana, Delhi, E & W Uttar Pradesh (UP), Rajasthan, Uttarakhand
East India	Jharkhand, Bihar, Orissa, West Bengal (WB) and Sikkim
NE India	Arunachal Pradesh; Nagaland, Mizoram, Manipur, Tripura, Assam, Meghalaya
South India	Tamil Nadu (TN), Andhra Pradesh, Kerala, Karnataka, Lakshadweep, Andaman & Nicobar
West India	Konkan & Goa, Madhya Maharashtra, Marathawada, Gujarat, Saurashtra & Kutch
Central India	Madhya Pradesh (MP), Chhattisgarh, Vidarbh

Spatial Distribution of Rainfall (stations of a Met Division reporting at least 2.5 mm rainfall)

Widespread	**(Most Places)**	75 % or more number of stations
Fairly widespread	**(Many Places)**	51% to 74 % number of stations
Scattered	**(A few Places)**	26 % to 50% number of stations
Isolated	**(Isolated Places)**	25% or less number of stations

Intensity of Rainfall (Rainfall amount in a day is)

Trace	0.01 to 0.04 mm
Light Rain	2.5 to 7.5 mm
Heavy Rain	64.5 to 124.4 mm
Very Heavy Rain	124.5 to 244.4 mm
Rainy Day	2.5 mm or more
Mainly Dry	Very light rain
Dry Day	No rain

Description of CB/TS in Forecasts

Isolated	**(ISOL)**	Individual feature which affects < 50% area
Occasional	**(OCNL)**	Well separated features which cover 50 - 75% area
Frequent	**(FRQ)**	TS /CB with little or no separation between adjacent cells, covering >75% area

Part of the Day

Early hours	0000 – 0400 hrs. IST
Morning	0400 – 0800 hrs. IST
Forenoon	0800 – 1200 hrs. IST
Afternoon	1200 – 1600 hrs. IST
Evening	1600 – 2000 hrs. IST
Night	2000 – 2400 hrs. IST

INTERNATIONAL LOCATION INDICATORS

Agartala	VEAT	Jammu	VIJU
Agra	VIAG	Jodhpur	VIJO
Ahmadabad	VAAH	Khajuraho	VAKJ
Allahabad	VIAL	Kochi	VOCI
Amritsar	VIAR	Kolkata	VECC
Aurangabad	VAAU	Kozhikode	VOCL
Bangalore	VOBL	Leh	VILH
Baroda	VABO	Lucknow	VILK
Bhopal	VABP	Madurai	VOMD
Bhubaneswar	VEBS	Male	VRMM
Bhuj-Rudra	VABJ	Mohanbai	VEMN
Chandigarh	VICG	Mumbai	VABB
Chennai	VOMM	Nagpur	VANP
Coimbatore	VOCB	Patna	VEPT
Colombo	VCBI	Pune	VAPO
Delhi	VIDP	Ranchi	VERC
Guwahati	VEGT	Siliguri	VEBD
Goa	VAGO	Sri Nagar	VISR
Gorakhpur	VEGK	Tezpur	VOTZ
Hyderabad	VOHS	Thiruvananthapuram	VOTV
Jaipur	VIJP	Vishakhapatnam	VEVZ

Appendix F

METEOROLOGICAL CHARTS

1. National SIGWX Charts

These fixed time forecast charts are made for High Level (FL250 - FL630) and Middle Level (FL100 – FL250). The following is shown in these charts :

- Forecast positions of Synoptic systems and their movement (direction and speed, in KT).
- FL of base and top of Significant clouds (within scalloped boundaries).
- CB implies MOD or SEV Turbulence, Ice and Hail
- Symbols of TS, Cyclone, MOD and SEV Icing and Turbulence.
- Freezing Level is indicated by dotted line and its FL is indicated within boxes
- In high level SIGWX chart, FLs of Jet stream, Maximum Winds, CAT and Tropopause heights, are also indicated within boxes.

(see High Level India SIGWX chart in the next page)

2. WAFC Wind and Temperature Charts

- IMD Chennai prepares these charts for South Asia on the basis of raw data from WAFC London.
- In these charts period of validity of forecast and FL/hPa (eg 340 hPa/FL 250) are indicated. Winds at selected grid position are depicted by use of shaft for direction and feathers and pennants for speed. Temperatures are indicated close to wind shaft. Positive temperature are prefixed by PS (eg 12°C is indicated as PS12).

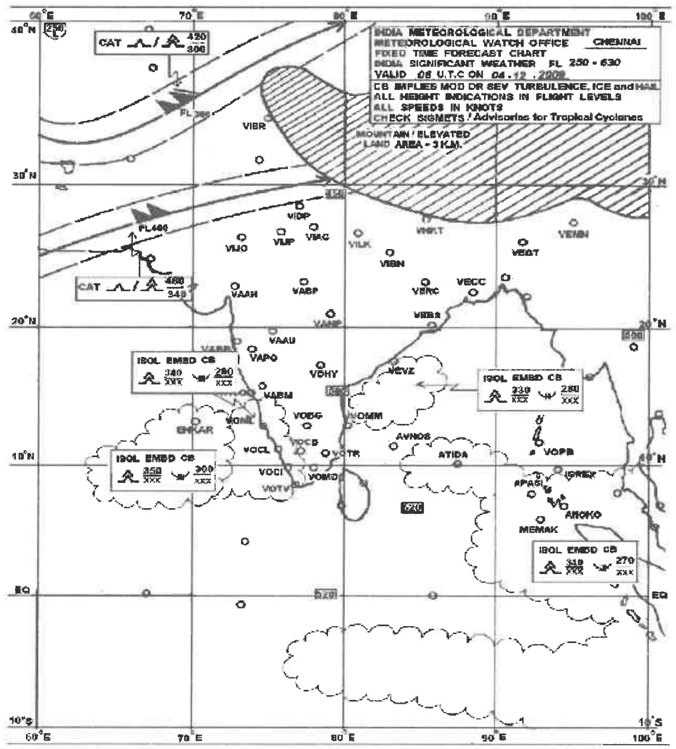
3. Tropopause and Maximum Wind Chart

- Tropopause heights are shown in boxes in FL e.g. FL400
- The maximum wind is shown by bold arrows indicating path of Jet stream, with FL.
- 0°C Isotherm is shown by a broken line of short dashes (- - - - - - - 0° e.g. FL150)

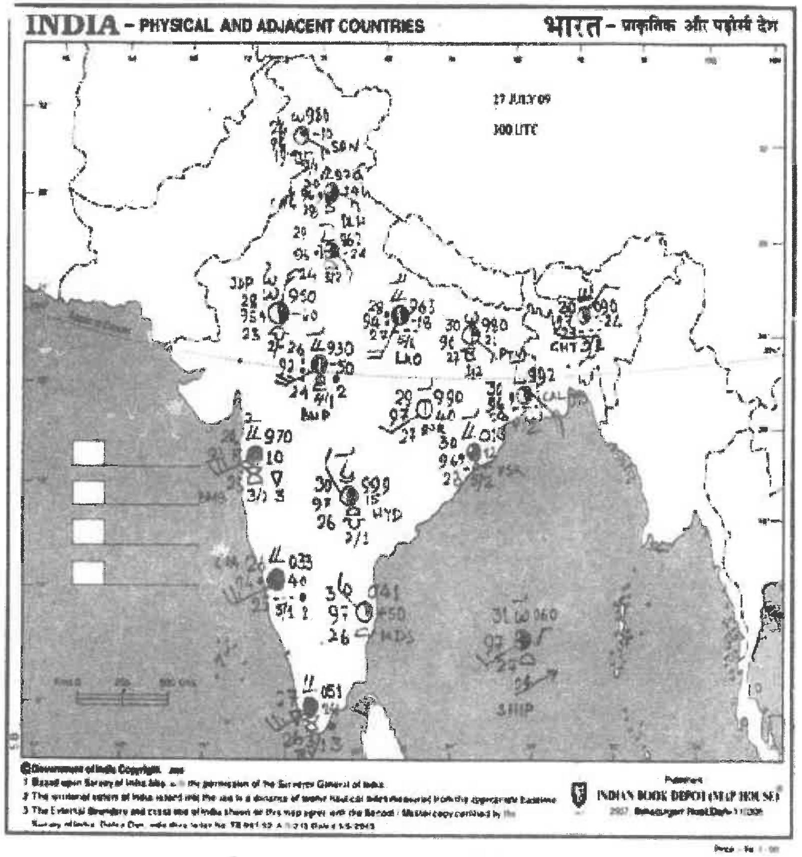
4. Spot Wind and Temperature Chart

- Forecast Wind and Temperature data is provided for various positions across the chart for various FL Altitudes (at an interval of 1000 ft). Forecast altitude of Freezing Level is also indicated, as follows :

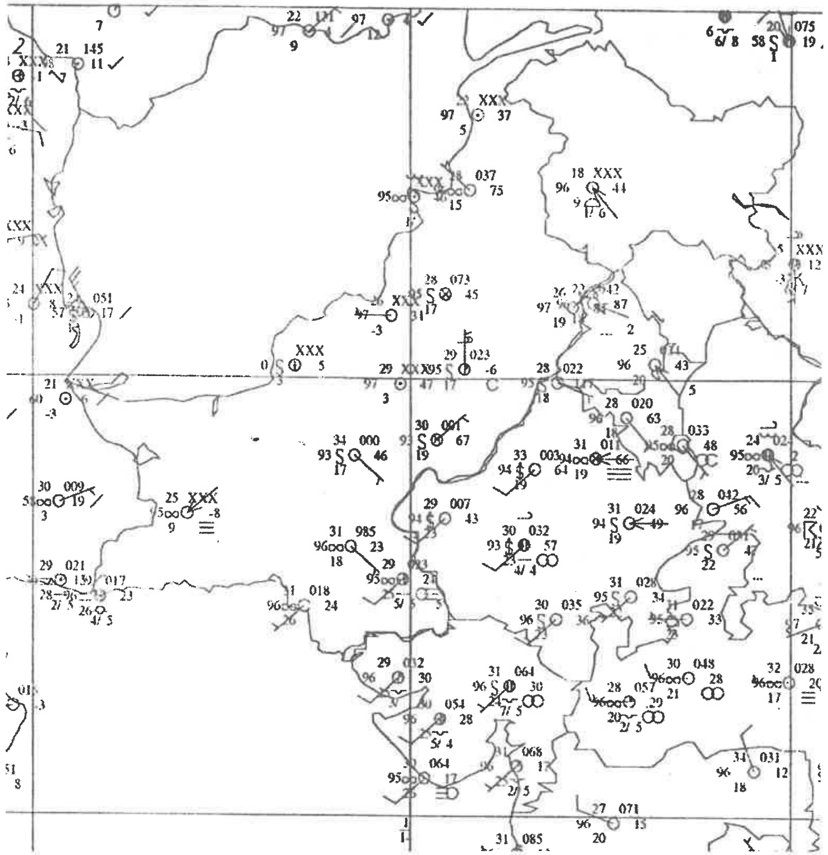
30	280100	- 32
20	290070	- 08
15	300040	02
10	300025	10
05	330020	18
17		0°C



PLOTTED STATION MODELS



SYNOPTIC CHART (COMPUTER PLOTTED)



Appendix H

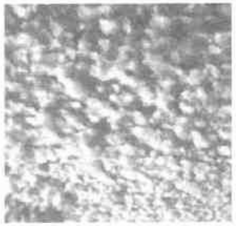
CLOUDS

STRATOCUMULUS

CUMULUS

NIIMBOSTRATUS

CUMULONIMBUS



ALTOCUMULUS

ALTOSTRATUS

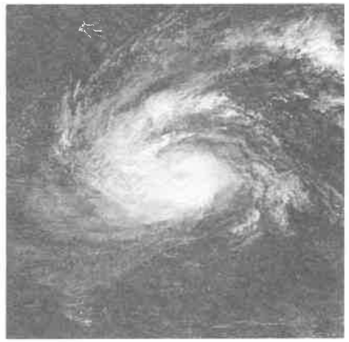
CIRRUS

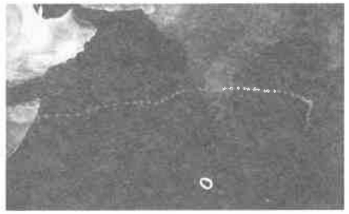
CIRROCUMULUS

CIRROSTRATUS

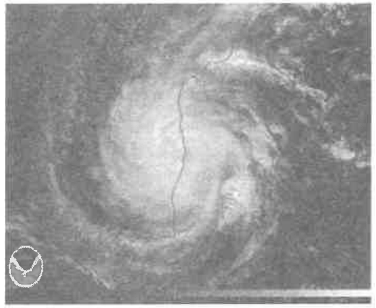
Appendix I

VERY SEVERE CYCLONIC STORM VARDAH





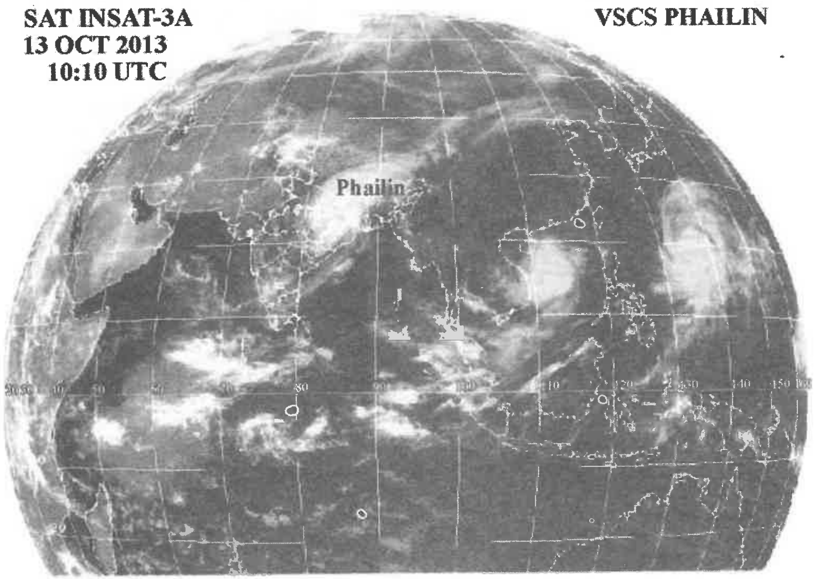
Track of VSCS Vardah 6 Dec to 19 Dec 2016



Vardah making a landfall over Chennai, TN on 12 Dec 2016

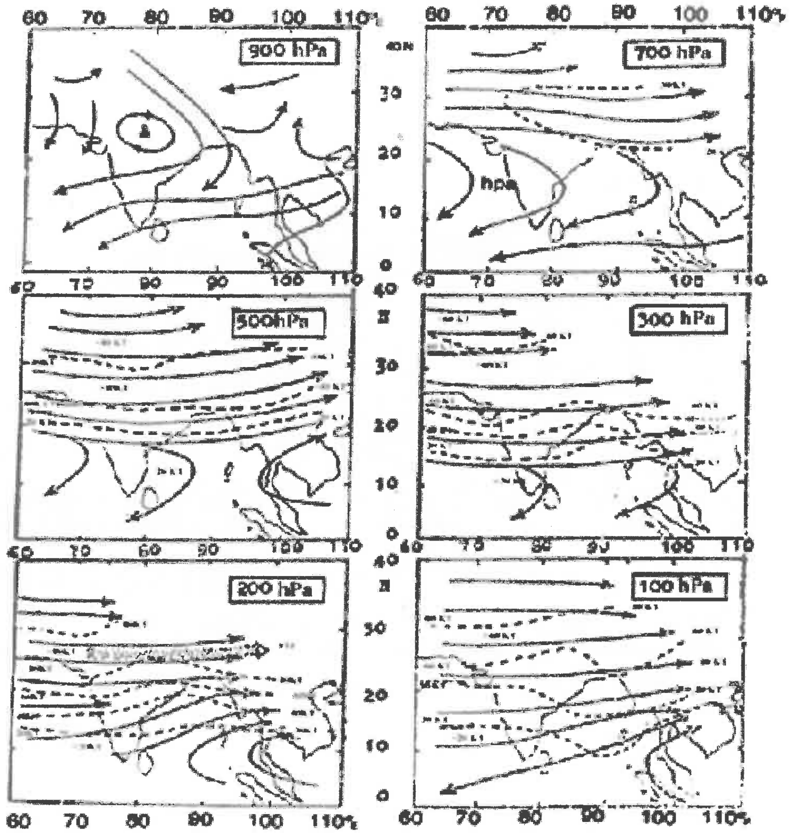
INSAT– 3A SATELLITE IMAGERY

10:00 UTC 13-10-2013
WD OVER J&K, VSCS (PHAILIN) OVER ODISHA AND AP
ITCZ NEAR EQUATOR



NORMALS

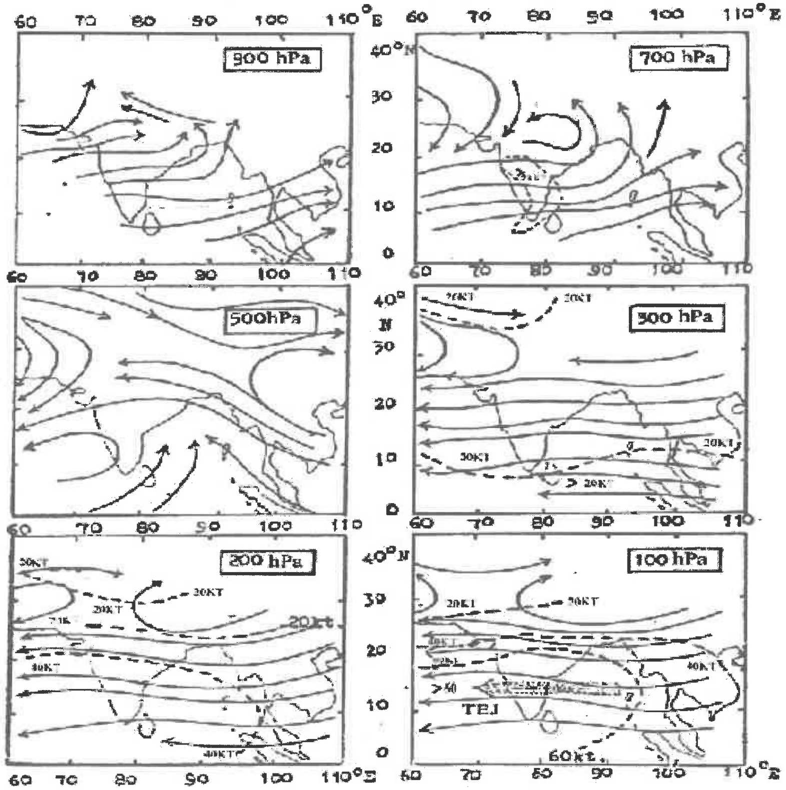
UPPER WINDS - JANUARY



Appendix J(Continued)

NORMALS

UPPER WINDS - JULY



MISCELLANEOUS QUESTIONS

Q1. Translucent rime ice forms due to
- (a) Melting of large snow particles
- (b) Freezing of large supercooled water drops
- (c) Freezing of small supercooled water drops
- (d) Sublimation of large hail

Q2. Advection fog occurs due to …….. air moving over ……………… surface over ………
- (a) Dry, wet, land only
- (b) Moist and cold, warm, land only
- (c) Warm & moist air, cold, both land & sea.

Q3. ELR 6.5° C and SALR 7°C on lifting a saturated parcel of air the atmosphere would be
- (a) Stable
- (b) Absolutely stable
- (c) Absolutely unstable
- (d) Indifferent

Q4. Gradient wind is weaker than geostrophic wind around a low because
- (a) Centripetal force is provided by pressure gradient force
- (b) Centripetal force is added to the pressure gradient force
- (c) Coriolis force is added to the pressure gradient force
- (d) Coriolis force is opposite to Centripetal

Q5. The altimeter of an aircraft is set to QFE before landing, on landing it will indicate
- (a) Height of A/C wheels above runway
- (b) Flight Level
- (c) A/C altitude AMSL
- (d) Height of A/C above ARP in ISA

Q6. TAF generally has a validity of ……… hr and TREND …….. hr
- (a) 9 hr; 2 hr
- (b) 24 hr; 3 hr
- (c) 12 hr; 2 hr
- (d) 24 hr; 9hr

Q7. CAT is most pronounced on which side of a subtropical jet stream
- (a) About 3 km above the core
- (b) Cold side of core
- (c) South side of core
- (d) at core

Q8. Hail forms by collision with super-cooled water drops by
(a) Condensation (b) Deposition
(c) Evaporation (d) Transpiration

Q9. Thermal wind blows parallel to .... keeping .... to the left
(a) Isotherms, low temperature (b) Isobars, low temperature
(c) Isobars, low pressure (d) Isallobars, high temperature

Q10. Roaring Forties are ...... winds blow throughout the year and are of very stormy nature in
(a) Wly, N hemisphere (b) Ely, S hemisphere
(c) Wly, S hemisphere (d) Ely, S hemisphere

Q11. Temperature in the troposphere decreases from equator to poles. The thermal wind throughout troposphere is therefore .... and .... as height increases
(a) Wly, increases (b) Wly, decreases
(c) Wly, remains same (d) Ely, increases

Q12. A Cold Front passes a station, the pressure
(a) Changes are very small (b) first increases and then decreases
(c) First decreases and then increases (d) rises continually

Q13. Flying conditions associated with CB during pre monsoon are
(a) Continuous rain, poor visibility, light turbulence
(b) Good visibility, drizzle, turbulence
(c) Hail, gusts, shower, and severe turbulence
(d) Rain, poor visibility, and turbulence

Q14. Which is true of a cold front
(a) Less steeper than a warm front
(b) Associated with continuous rain and ST clouds
(c) Heavy convective weather and squall line
(d) Similar slope as warm front

Q15. The observed temperature is - 40 deg C at FL 300 (10 km). It is termed as
(a) 10 deg C warmer than ISA (b) 10 deg C colder than ISA
(c) 15 deg C warmer than ISA (d) 15 deg C colder than ISA

Q16. Aquaplaning may occur in
(a) - GR (b) +RA
(c) -TS (d) Thick Fog

Q17. CAT is most likely to be encountered in
(a) A high close to a Dust Storm
(b) After the passage of a severe Sandstorm
(c) A sharp trough aloft with winds of jet stream speed
(d) A ridge aloft

Q18. What are Norwesters
(a) Warm dry winds coming from NW (b) Severe Duststorm from NW
(c) TS affecting NW India in premonsoon (d) TS of E and NE India in premonsoon

Q19. Example of non frontal stability is
(a) Squall line (b) Inversion
(c) Frontogenesis (d) Occlusion

Q20. If temperature initially is constant and then increases with height, the atmosphere is
(a) Stable (b) Unstable
(c) Indifferent (d) Adiabatic

Q21. Under what conditions severe icing is encountered
(a) temperature 0 deg C
(b) rain and temperature below -10 deg C
(c) visible vapour and temperature -5 deg C
(d) rain at temperature -20 deg C

Q22. (a) The level from ground to freezing level is more susceptible for icing
(b) Most potent area for dangerous icing is freezing level to about 25,000 ft
(c) Icing may be severe in the temperature range – 20 to – 40 deg C
(d) Severe icing may form in the temperature range – 10 to 30 deg C

Q23. Ice accretion
(a) increases drag but reduces stalling speed
(b) alters aerodynamics, reduces weight, and decrease lift
(c) alters aerodynamics, increases weight and lift
(d) increases drag and weight and stalling speed

Q24. The wind 260102 KT, is reported in a METAR / SPECI as:
(a) 26010 KT + 26002 KT
(b) 260P99 KT only
(c) Only in remark column
(d) 260P99 KT and complete wind in remark column

Q25. Will SPECI be issued if

(a) Wind changes from 27010 KT to 29018KT
(b) RVR changes, from 1400 m to 1600 m
(c) Visibility changes from 6000 m to 4000 m
(d) Temperature changes from 15 to 16 deg C

Q26. CAVOK in a METAR replaces

(a) Visibility, cloud and Wx groups
(b) Wind, visibility & cloud groups
(c) Wind, temp & pressure groups
(d) Visibility, temp & cloud groups

Q27. The calm and clear night is cooler than cloudy night because :

(a) Clouds prevent terrestrial radiation from escaping
(b) Clouds radiate heat towards sky
(c) Due to CO2 and H2O present in the air
(d) Terrestrial radiation skip through clouds

Q28. Diurnal variation of temperature is least

(a) When sky is clear
(b) During land breeze over the coastal areas
(c) When sky is overcast
(d) When winds are weak over the land surface

Q29. Density altitude is

(a) Higher if atmosphere is warmer than ISA
(b) Lower if atmosphere is warmer than ISA
(c) Higher if atmosphere is colder than ISA
(d) Higher if atmosphere is isothermal

Q30. The temperature to which air should be cooled to saturate it is ………… temperature

(a) Wet bulb
(b) Dew point
(c) Dry bulb
(d) Ambient

Q31. No cyclonic storm or high pressure systems form within 5° of the equator because

(a) Pressure gradient force is negligible
(b) Frictional force is minimal
(c) Coriolis force is negligible
(d) Geotropic force is maximum

Q32. Gradient wind

(a) Is due to the balance between Pressure gradient force and Friction
(b) Is super geostrophic in a low and subgeostrophic in a high
(c) Is due to the balance between Pressure gradient, Coriolis and Centripetal forces
(d) Blows parallel to straight isobars

Q33. Effect of Wind Shear

(a) Decreasing head wind increases lift
(b) Increasing tail wind increases lift
(c) Decreasing tail wind increases lift and a/c rises above the glide path
(d) Weakening head wind raises aircraft above the flight path

Q34. Due to friction the wind

(a) Strengthens and backs during landing
(b) Decreases and backs during landing
(c) Strengthens and backs during take off
(d) Decreases and veers during landing

Q35. The term 'monsoon' means

(a) Seasonal reversal of winds and rainfall
(b) Rains all over India
(c) One of the four seasons with maximum rain in the N
(d) Monsoon circulation

Q36. The two main seasons in India are

(a) Pre monsoon and SW monsoon
(b) Winters and Hot season
(c) Hot season and Rainy season
(d) Winter and SW monsoon

Q37. The main cause of seasons in India is

(a) Oscillation of sun 23½ N to 23 ½ S
(b) Advection of air from Arabian sea
(c) Thermal equator at equator whole year
(d) Earth rotating around its own axis

Q38. The axis of monsoon trough runs

(a) In the Bay of Bengal
(b) Along the Gangetic plains
(c) Along 22 deg East to West of India
(d) Along central peninsula

Q39. During monsoon season the low level winds are

(a) SEly along E coast
(b) NEly over Tamil Nadu
(c) SEly over Bay of Bengal
(d) SEly North of Monsoon Trough

Q40. During SW monsoon the winds above 500 hPa are

(a) Ely over S and weak Wly over N India
(b) Wly over S and strong over N India
(c) Wly over S and weak Wly over N India
(d) Strong Ely over S and weak over N India

Q41. Which is not true of post monsoon
(a) Pressure gradient is weakest of all seasons
(b) Frequency of tropical cyclones is max.
(c) Monsoon withdraws from the country
(d) Worst period for flying expect S India

Q42. The months during which Tamil Nadu gets most of its rainfall are
(a) Oct - Nov (b) Jul - Sep
(c) Apr - Jun (d) Dec - Mar

Q43. ITCZ affects weather over India during
(a) Winters only (b) Pre – monsoon only
(c) Monsoons only (d) All the four seasons

Q44. ESNO is the name given to
(a) El - Nino only (b) Southern oscillations and La- Nino
(c) El - Nino and Southern oscillations (d) El - Nino and La - Nino combined

Q45. Friction causes winds to get deflected …………
(a) Parallel to isobars (b) Towards low
(c) Perpendicular to isobars (d) Towards high

Q46. Station level pressure at ARP is reduced to MSL as per
(a) ISA is QFF (b) ISA is QFE
(c) Isothermal is QNH (d) ISA is QNH.

Q47. A/C moving from west to east and is drifting northwards. Its altimeter will
(a) Under read (b) Over read
(c) Reading will remain unchanged

Q48. Wind Shear in a TS is maximum
(a) Below the anvil (b) all sides of a CB
(c) Beneath the cloud (d) in SW sector

Q49. Difference between Airmass TS (AM TS) and Steady State TS (SS TS) is
(a) SS TS duration is more (b) AM TS duration is more
(c) SS TS duration is less (d) AM TS occur in fronts

Q50. In a line of TS there is a hole in the Radar echo, what would you infer
(a) No precipitation (b) Strong convective activity
(c) Area free of clouds (d) A gap between two CB

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	**c**	**c**	**b**	**a**	**d**	**a**	**b**	**b**	**a**	**c**	**a**	**c**	**c**
Q.	14	15	16	17	18	19	20	21	22	23	24	25	26
A.	**c**	**a**	**b**	**c**	**d**	**b**	**a**	**c**	**b**	**d**	**d**	**c**	**a**
Q.	27	28	29	30	31	32	33	34	35	36	37	38	39
A.	**a**	**c**	**a**	**b**	**c**	**c**	**c**	**b**	**a**	**d**	**a**	**b**	**d**
Q.	40	41	42	43	44	45	46	47	48	49	50		
A.	**d**	**d**	**a**	**d**	**c**	**b**	**d**	**a**	**c**	**a**	**b**		

ADDITIONAL QUESTIONS

1. The main cause of occurrence of weather over the earth surface is
   (a) Changing pressure (b) Advection of moist air
   (c) Variation in insolation (d) Movement of air mass

2. Thermal lows are generally located over
   (a) Polar region (b) Equatorial region
   (c) Temperate region (d) Movement region

3. The main cause of ground inversion is
   (a) Release of latent heat (b) Incident Solar radiation
   (c) Convection (d) Terrestrial radiation on calm and clear night

4. Above the friction layer winds mostly blow parallel to isobars due to balance of
   (a) Coriolis force and Geostrophic force
   (b) Coriolis force and Pressure Gradient force
   (c) Coriolis force and Gravitational force
   (d) Coriolis force and Centripetal force

5. Wind at 1 km height is 320/20 kt whereas surface wind is 260/05 kt because of
   (a) Subsidence (b) Convection
   (c) Friction (d) Thunderstorm

6. The amount of water vapour which air can hold depends on
   (a) Dew point temperature (b) Wet bulb temperature
   (c) Dry bulb temperature (d) Virtual temperature

7. In General circulation over the globe the Equatorial Low Pressure Belt is at the junction of which cells?
   (a) Hadley Cells (b) Polar cell
   (c) Ferrel and Hadley Cells (d) Ferrel Cell

8. The dew point temperature
   (a) is higher if air contains more water vapour
   (b) changes by cooling or warming
   (c) is equal to the air temperature during mist
   (d) is always higher than Wet Bulb temperature for unsaturated air

9. What controls the movement of most TS?
   (a) jet stream (b) wind at 400 hPa
   (c) wind at 700-500 hPa (d) wind at 30,000 ft

10. Isohyets are the line of equal
   (a) Humidity (b) Sunshine (c) Rainfall amount (d) Density

11. How much in advance of departure a pilot must notify the Aeronautical Met Station (AMS) requiring Met Forecast for a National flight ?
   (a) 3 hr (b) 6 hr (c) 12 hr (d) 18 to 24 hr

12. An a/c cruising at FL500 in July from Chennai to Trivandrum will generally experience
   (a) Weak Sly wind (b) Subtropical Wly wind
   (c) Tropical Ely wind (d) Tropical Jet stream

13. The sun is highest at noon, but two/three hours later the earth receives more radiation. Hence maximum temperature is around 1500 hr. It is due to
   (a) Angular Momentum (b) Thermal cooling
   (c) Thermal Inertia (d) Rotation of the Earth

14. Which of the following Indian month corresponds to Grishm Ritu
   (a) Jyeshtha and Asadha (b) Shravana (c) Phalguna (d) Paush

15. Due to Coriolis force an Ely wind blowing over the equator will
   (a) get deflected to the left (b) become Wly
   (c) weaken (d) remain unchanged

16. The surface wind at coastal stations on West coast of India during late night/early morning in Pre-monsoon season is
   (a) Nly (b) Ely (c) Wly (d) Sly

17. Convective clouds develop at a place when the atmosphere is
   (a) absolutely stable (b) conditionally stable
   (c) neutrally stable (d) none of the above

18. In a SPECI report the QNH 1005.8 hPa is reported as
   (a) 1016 hPa (b) 1015.8 hPa (c) 1005 hPa (d) 1016.8 hPa

19. Stability of atmosphere is determined by
   (a) Inversion (b) DALR (c) ELR (d) SALR

20. The characteristics features, good visibility and turbulence, are of
   (a) high pressure area (b) stable air mass
   (c) unstable air (d) cold Polar air mass

21. Extreme turbulence in a TS can be assessed from
   (a) heavy Ice accretion (b) frequent lightning
   (c) Hail (d) appearance of Anvil

22. Jet streams are strongest when temperature gradient are greatest
   (a) True (b) False

23. While planning to land during TS, which is the most expected serious aviation hazard
   (a) Hail storm (b) Downdraught
   (c) WS and Turbulence (d) Heavy rain

24. In an arid area the cloud which is capable of causing Dust Storm is
(a) CI (b) CU (c) CB (d) NS

25. If after the issue of a SPECI, conditions continue to be below the prescribed limit then the next routine report will be a
(a) METAR (b) SPECIAL
(c) SPECI (d) could be METAR or SPECI

26. Fronts are characteristics of
(a) Tropical cyclones (b) Monsoon depression
(c) TS (d) Extra Tropical Depressions

27. In India in a VOLMET broadcast
(a) SIGMET is excluded (b) METAR,SPECI,SIGMET and TAF are included
(c) only SPECI is included (d) only TAF are included

28. In a SPECI the lowest layer of clouds , regardless of amount, is reported as
(a) FEW, SCT, BKN or OVC (b) SCT, BKN or OVC
(c) BKN or OVC (d) FEW, SCT, or OVC

29. The atmospheric pressure at an aerodrome is equal to the MSL pressure then
(a) QNH > QFE (b) QNH < QFE
(c) QNH = QFE (d) None of the above

30. An a/c at FL180 in July from Kolkata to Mumbai will generally experience
(a) Wly wind (b) Ely wind (c) Nly wind (d) Sly wind

31. Isopicnic are the line of constant
(a) Height (b) Insolation (c) Geopotential heights (d) Density

32. The minimum notice required to be given to an Aerodrome Met Office (AMO) by an aircraft operator needing Met data for an National flight is
(a) 3 hr (b) 6 hr (c) 12 hr (d) 18 to 24 hr

33. METAR VIAG 250300Z 27005KT 1200 + SHRA FEW008 SCT025 BKN080 28/25 Q1004 TEMPO 0405 0800 + TSRA FEW020 CB OVC300 = In the METAR surface visibility in TS is
(a) 800 m (b) 1200 m (c) 4050 m (d) 0300 m

34. The upper air report from an a/c other than weather reconnaissance a/c has the identification code as
(a) WINTEM (b) VOLMET (c) RAWIN (d) CODAR

35. 'TAF AMD' covers validity period
(a) the remaining validity period of original TAF
(b) half the validity period of the TAF
(c) the validity starting 2 hr prior to the end period of original TAF
(d) full validity period of the TAF

36. RVR is a measure of
(a) Atmospheric transsmissivity and background illumination
(b) Atmospheric transparency, intensity of R/W lights and background illumination
(c) Intensity of background illumination
(d) Atmospheric transsmissivity, intensity of R/W lights

37. SPECI is issued when the visibility changes from
(a) 800 to1500 m (b) 8km to 6km
(c) 300m to 400m (d) 300m to 150m

38. During pre- monsoon the pressure gradient in the S parts of East coast of India is from
(a) N to S along the coast (b) S to N along the coast
(c) E to W across the coast (d) W to E across the coast

39. During SW monsoon the wind at FL400 over Bangaluru is generally
(a) Strong Ely (b) Strong Wly
(c) Fluctuates between Ely and Wly (d) Weak Sly

40. The lapse rate of temperature in a low level inversion is
(a) Positive (b) negative (c) insignificant (d) 6.5° C

41. Which of the following Indian month corresponds to Rainy Season/Varsha Ritu
(a) Kwar (b) Kartic (c) Magha (d) Shravana Bhadrapad

42. The Code Name for an aviation forecast in figure code for a specific area is
(a) ROFOR (b) ARFOR (c) TAFOR (d) GAMET

43. SIGMET message is
(a) Occurring or expected, enroute weather, which may affect safety of the air operation.
(b) Aerodrome forecast in plain language.
(c) Special Reports to local ATC unit and concerned operators
(d) Trend type of landing forecast passed to operators

44. Which of the following Indian month corresponds to Winter/ Shishira Ritu
(a) Kwar (b) Pausha (c) Magha and Phalguna (d) Shravana

45. The variable surface wind speed refers to
(a) < 03 KT (b) 04 KT or less (c) $\geq$ 02 KT (d) Calm

46. Which of the following Indian month corresponds to Sharad Ritu (Post monsoon)
(a) Jyeshtha (b) Asauj and Kartika (c) Phalguna (d) Shravana

47. TAF VECC 2203000 2400KT 3000 FU SCT030 BECMG 0406 6000 SCT030 BKN100 TEMPO 0708 2000 TSRA SCT20CB OVC080=
The above TAF forecasts TS and RA between
(a) 0400 and 0600 UTC (b) 0400 and 0600 IST
(c) 0700 and 0800 UTC (d) 0700 and 0800 IST

48. The hailstones occur from
(a) both warm and cold clouds (b) cold clouds only
(c) warm clouds only (d) NS clouds

49. SPECI is issued when the height of base of the lowest cloud layer ≥ 5/8 changes to or passes
(a) 500m, 300m, 150m, 50m, 25m (b) 450m, 350m, 150m, 50m, 30m
(c) 400m, 300m, 150m, 90m, 30m (d) 450m, 300m, 150m, 60m, 30 m

50. Fog is produced in Fronts by
(a) evaporation and precipitation (b) frequent Rain
(c) adiabatic cooling (d) freezing Rain

51. Over the earth deserts are located in the regions of
(a) Equatorial trough (b) Subtropical high (c) Polar Front (d) ITCZ

52. The air can hold more moisture at MSL over the
(a) Temperate latitudes (b) 20° Latitude
(c) Equator (d) Poles

53. With altitude in an isothermal atmosphere the density of the air
(a) does not change (b) increases with height
(c) first decrease and then decrease (d) decreases

54. The Fronts associated with WDs over NW India in winters are mostly
(a) Warm Occlusion (b) Cold Occlusion
(c) Cold Fronts (d) Warm Fronts

55. In a Cold Occlusion the
(a) Cold air of Cold Front is not the coldest
(b) Cold air of Cold Front is the coldest
(c) Cold air of Warm Front is the coldest
(d) Cold air of Warm Front is warmer than that of Cold Front

56. A day is called Rainy Day when the amount of Rainfall in a day is
(a) 7.5 mm or more (b) 10 mm or more
(c) 2.5 mm or more (d) at least 1.0 mm

57. A cold front is defined as the
(a) advancing cold airmass undercutting the warm airmass
(b) warm airmass over riding the cold airmass
(c) retreating cold pool of air
(d) leading cold gust front

58. In a METAR the third layer of clouds is reported when amount is
(a) 3/8 or more SCT, BKN or OVC (b) 5/8 or less SCT, BKN
(c) 5/8 or more BKN or OVC (d) 3/8 or more FEW, SCT

59. SPECI is issued for RVR when it changes or passes
(a) 150m (b) 200 m (c) 400 m (d) 900 m

60. Above which datum the cloud base is reported at airports ?
(a) above mean sea level (b) above the aerodrome level
(c) above standard pressure level (d) above pressure level in ISA

61. For International Flight documentation, the following data is provided
(a) SIGWX charts between FL 250 and FL 600
(b) SIGWX charts between FL 250 and FL 630 and forecast 250 hPa wind and Temp. data
(c) SIGWX charts and Upper wind and temperature charts
(d) WAFC generated SIGWX forecast chart only

62. When visibility is 800 m to 5000 m, in a METAR it is reported in steps of
(a) 100 m (b) 200 m (c) 500 m (d) 1000 m

63. The Polar Front is
(a) Continuous (b) Not continuous
(c) A transition Zone between Polar and Arctic Westerlies
(d) Boundary between Arctic and Polar Air masses

64. Most of the weather occurring in India is due to
(a) Fronts (b) Cyclones (c) TS (d) Monsoon Trough

65. The Doppler Weather Radar works on the Principles of
(a) Frequency amplification (b) Change in frequency of return echo
(c) Comparison of drop sizes (d) Wavelength modification

66. Flight forecast in "Chart from of Documentation" supplied in India consists of
(a) Synoptic charts 03 and 12 UTC and U/A charts for 00 and 12 UTC
(b) Latest surface synoptic chart and upper air charts
(c) SIGWX chart and upper air charts for 850, 500 and 300 hPa
(d) SIGWX chart and prognostic charts for 300,250 and 200 hPa

67. SIGMET message contains weather information which is
(a) Actual and not a forecast (b) Forecast only
(c) Both actual and forecast (d) Actual only

68. Veering of geostrophic wind at a station with height indicates
(a) Warm air advection (b) Cold air advection
(c) Subsidence of cold air (d) Convection of warm air

69. The wind Bora is a
(a) warm Anabatic wind (b) cold Katabatic wind
(c) violent Wly wind (d) light maritime Ely wind

70. Will a SPECI be issued when the mean speed has changed by
(a) < 09 kt (b) 10 kt or more (c) less than 10 kt (d) > 08 kt

71. Highest annual rainfall over the earth occurs the regions ?
(a) Temperate regions (b) Tropical regions
(c) Polar regions (d) Equatorial regions

72. The most hazardous area for aviation in a cyclone is
(a) about 400 km from eye (b) eye of the cyclone
(c) wall cloud around the eye (d) allover the cyclone

73. The ITCZ
(a) is a region of calm winds and layer type of clouds
(b) affects only N hemisphere in winters
(c) usually lies along the Equatorial Trough
(d) affects S hemisphere in monsoon

74. The strong Wly winds which blow in both the hemispheres between 35° and 60° Lat are called :
(a) Roaring Forties (b) Trades (c) Jetstreams (d) Polar Wly

75. Cold core low pressure system
(a) intensifies with height (b) weakens with height
(c) does not change with height (d) veers with height

ANSWERS

Q.	1	2	3	4	5	6	7	8	9	10	11	12	13
A.	c	b	d	a	c	c	a	a	c	c	d	d	c
Q.	14	15	16	17	18	19	20	21	22	23	24	25	26
A.	a	d	b	b	c	c	c	b	a	c	c	a	d
Q.	27	28	29	30	31	32	33	34	35	36	37	38	39
A.	b	a	c	b	d	a	a	d	a	b	a	c	a
Q.	40	41	42	43	44	45	46	47	48	49	50	51	52
A.	b	d	b	a	c	a	b	c	b	d	a	b	c
Q.	53	54	55	56	57	58	59	60	61	62	63	64	65
A.	a	a	b	c	a	c	a	b	b	a	b	c	b
Q.	66	67	68	69	70	71	72	73	74	75			
A.	d	c	a	b	b	d	c	c	a	a			

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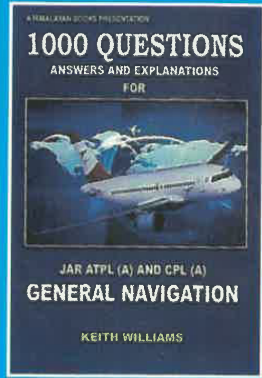

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