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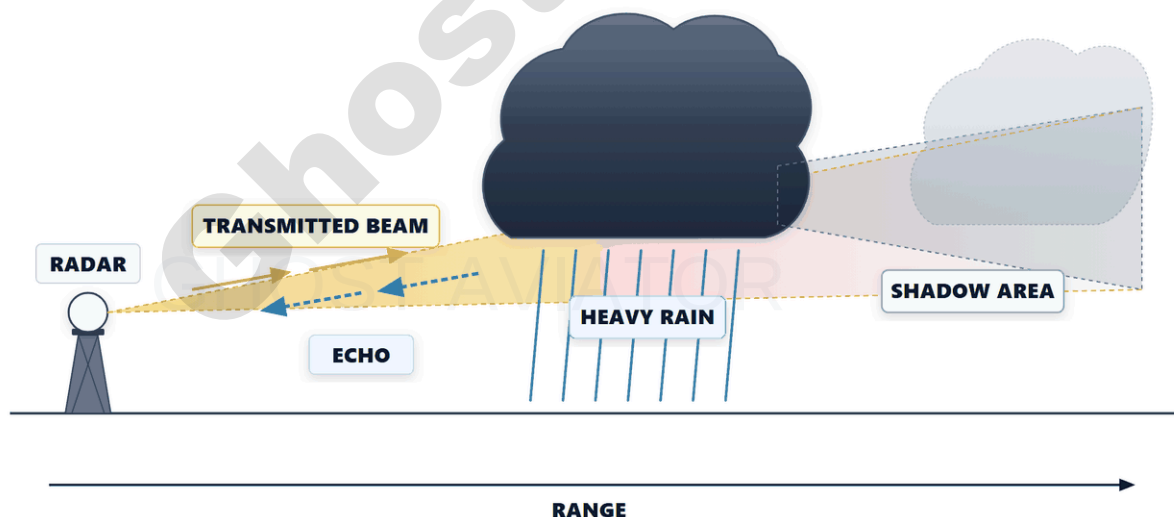
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1. Weather Radar — Introduction

Weather Radar (Radio Detection and Ranging): An important tool for detection of rain-bearing clouds, especially CU and CB, their speed, direction of movement, and vertical extent. Used for issuing timely weather warnings so that precautionary measures are initiated for parked and moored aircraft. Radars along the coast line of India detect storms and enable issuing of storm warnings.

- IMD has used X-Band weather-cum-wind finding Multi Met Radars and Radiosonde system since **1975**.
- Good network of S-band cyclone detection radars covering the Indian coast line.
- Operational network of digital X-band radars, including Doppler Weather Radars (DWR) for wind finding, storm detection, and dual capability — planned to be replaced by state-of-the-art DWR in a phased manner.



Radar beam, echo and shadow area

Range: Limited by 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.

2. Radar Scopes

Scope	Full Name	Function
PPI	Plan-Position Indicator	Presents a plan view of the echoes; provides the bearing and range of the echo
RHI	Range-Height Indicator	Enables direct reading of the altitudes of CB cells

3. Radar Wavelengths and Bands

Wavelength	0.75–2.5 cm	2.5–4 cm	4–8 cm	8–15 cm	15–30 cm
Band	K Band	X Band	C Band	S Band	L Band

Band Uses:

- **K and X Band:** Used for detection of clouds.
- **X Band:** Used for storm detection.
- **S Band:** Used for rain, precipitation, cyclones, and depressions. Also called **Cyclone Detection (and tracking) Radar**.

4. Types of Weather Radars

Type	Wavelength	Purpose
Quantitative Radar	10.0 cm	Quantitative measurement of rate of precipitation, total precipitation, intensity of precipitation, and snowfall measurements
Ultra Sensitive Radar	—	Detecting convection before and after cloud development; study CAT, gravity waves, and lee waves
Doppler Weather Radar (DWR)	—	State-of-art; Doppler Effect; wind finding, storm detection, dual capability

5. Doppler Weather Radar (DWR)

DWR is a state-of-art Radar that 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; rain drops are small but highly reflective.
- When snow falls through a layer above freezing temperature, it melts; snowflakes become coated with water and radar sees them as very large droplets — can be mistaken for stronger precipitation. On PPI: shows up as an intense ring of precipitation — **Bright Band** at the altitude where the beam crosses the melting level.
- Drizzle does not show up on radar — 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 structure of:** Clouds, Cyclones, TS, Hailstorm, Tornadoes
- **(d) Detection of:** Wind Shear and Turbulence, CAT, Gust Front, Microburst, Downburst and Tornadoes
- **(e) Genesis of:** Tornadoes
- **(f) Determination of:** Vertical Wind field and Horizontal Divergence field

Additional Radar Facts:

- Most modern weather radars utilise a **pulse-Doppler technique** for estimating precipitation rate, droplet motion with respect to the radar, and radial wind speeds.
- More recently, **dual polarized weather radars** have been developed that enable more accurate determination of precipitation types and sizes.

6. Cloud Echoes and Echo Characteristics

Stratiform Cloud Echoes

- Echoes from Stratiform clouds and steady rainfall are **diffused and ill-defined**; generally of **uniform intensity**.
- **Bright Band**: Appears in the RHI at **freezing level**; due to strong reflection of radio waves by ice crystals (snowflakes in initial stage of melting); seen only when updraughts are uniform and weak; band disappears with increasing convection. Bright Band is an indicator of **weak storm**; a few hundred metres thick; seen just below the freezing level in stratiform precipitation.

Convective Cloud Echoes

- Clearly defined **sharp edges**.
- **Blurring of edges** = first sign of decay.
- In RHI: consists of one or more sharp-edged vertical levels.
- Developing shower areas distinctly visible in the echo.
- Squall lines depicted by **line of echoes**.
- If echo is exceptionally intense OR top extends to about **-40°C** temperature level = **CB cloud**.

7. Echoes Associated with Severe Storms

Echo Type	Significance
Intense and Sharp Echoes	Updraughts strong; large number of precipitation particles; developing storm = sharp boundary near top; Anvils = fuzzy echoes near the top
Hooks, Appendages and Protuberances	Severe storms with hail; echo of figure '6' = indication of a tornado
Rapidly Moving Echoes	Strong winds associated with severe storms
Wind Shear	Showers seen as separate columns of rain; slant vertical columns represent vertical wind shear
Dry Holes	Echo-free areas embedded in very extensive and bright echo = severe storms with strong winds and heavy rain
Rapidly Developing Echoes	Indicate a vigorous storm
Large Horizontal Echoes	Large size strong echo = severe storm
Converging Echoes	Number of echoes appearing to converge = severe storm
Bright Band	A few hundred metres thick; indicator of WEAK storm; just below freezing level; in stratiform precipitation
Spiral Bands	Indicate tropical cyclones; last for a long time

Critical Distinction — Bright Band: Bright Band = WEAK storm indicator. This is counter-intuitive! It appears at the freezing level in stratiform (not convective) precipitation. It disappears with increasing convection. A Bright Band means the storm is NOT intense.

8. Airborne Weather Radar

- Light weight, generally **X-Band**, multi mode, digital with Alpha Numeric.
- Operate on super high frequency band; wavelength between X and S bands.
- Designed for: Weather detection and analysis, Ground mapping, Transponder beacon interrogation and reception.
- Radar beam: conical, approximately **3 degrees** wide, moving in azimuth **15 degrees** up and down.
- Radar screen covers **70 degrees** either side of aircraft heading.
- Large drops and hail adequately reflect at **3 cm** wavelength.
- **Four colors:** Green, Yellow, Red, Magenta (bright crimson).
- Colors show progressively stronger echoes; provision to flash red areas on and off every **½ sec** to emphasise areas of heavy precipitation.

● **RED / MAGENTA:** Heavy precipitation, TS, hail, strong winds, tornadoes and severe turbulence. Aircraft should **ALWAYS AVOID**. Rainfall: **≥12 mm**

● **YELLOW:** Moderate precipitation, very low visibility, moderate turbulence, uncomfortable ride for passengers. Aircraft should **AVOID** going through. Rainfall: **4–12 mm**

● **GREEN:** Light precipitation, little to no turbulence, reduced visibility. Rainfall: **1–4 mm**

Rainfall Intensity Table

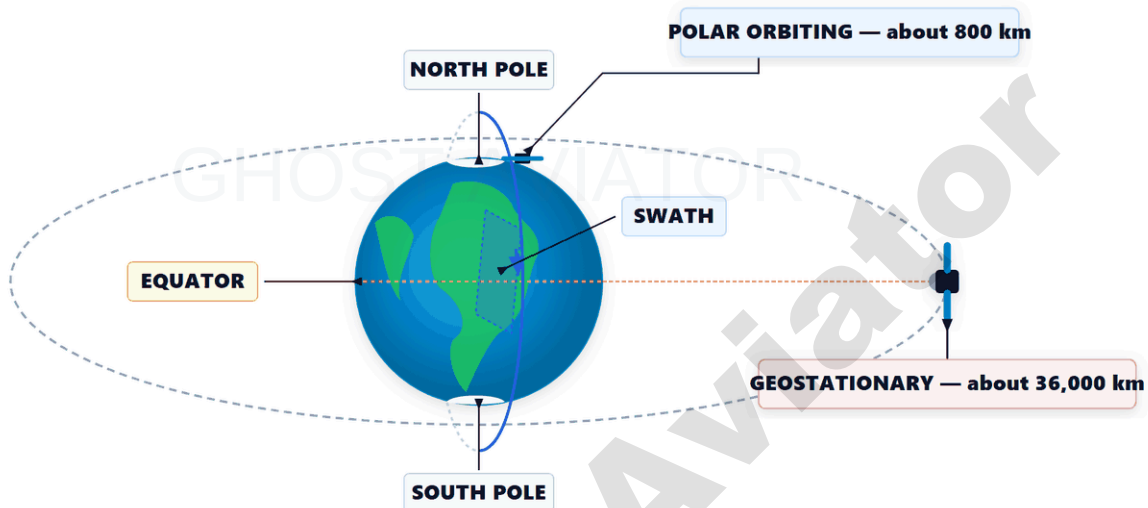
Colour	Storm Intensity	Rainfall in mm
Red (Magenta)	Severe (Very strong signal)	≥12
Yellow	Less severe (Mod intensity signal)	4–12
Green	Moderate (Low intensity signal)	1–4

9. Meteorological Satellites

flowchart LR

S["Met Satellites"] --> P["(a) Polar Orbiting\nAlt: 650–1500 km\nCovers earth twice in 24 hr\nSame place every 12 hr\nExample: NOAA"]

S --> G["(b) Geostationary\nAlt: ~36,000 km\nEarth's equatorial plane\nEarth synchronized\nSame spot always\n5 cover entire globe\nRound-the-clock weather\nExample: METEOSAT, INSAT"]



Geostationary and polar-orbiting satellites

Parameter	Polar Orbiting	Geostationary
Altitude	650–1500 km	~36,000 km
Earth coverage	Complete earth twice in 24 hr	Same spot always
Same point revisit	Every 12 hr	Continuous
Number for global coverage	Multiple	5 satellites
Weather info	Periodic	Round the clock
Examples	NOAA	METEOSAT, INSAT

Frequency of Satellite Imagery: Interval of observations = **30 min** ; however due to licensing and other restrictions, these satellites provide **three hourly** pictures.

10. Indian Meteorological Satellites

Satellite	Launch Date	Position	Key Features
Kalpana-1	12 September 2002	74°E	3 channel VHRR: VIS (0.55–0.75 μm), IR (10.5–12.5 μm), WV (5.7–7.1 μm); VIS res 2×2 km; ~48 images/day; 5 times during daytime only
INSAT-3A	10 April 2003	93.5°E	3 channel VHRR + CCD payload for VIS/Near IR/Short Wave IR; Resolution 1×1 km; 9 images/day; hydrometeorological data collection; Indian Area coverage 44.4°N to 10.3°S, 105.6E to 46.4E
INSAT-2E	—	—	Cloud imagery in panchromatic VIS band; 2×2 km WV map; TIR images; BV and IR 8×8 km; CCD board
METSAT	—	—	Satellite pictures every 3 hours commencing 0300 UTC; processed by SDUC in ~40 min; received at ~0415Z; In cyclones — hourly observations provided
INSAT-3D	25 July 2013	82°E	Advanced weather satellite of ISRO; launched from French Guiana Space Centre; 1 km MIR and Thermal IR; 4 km SWIR; 8 km WV; storm warning system; vertical profiles of temp/humidity
INSAT-3DR	08 September 2016	74°E	Operational Met satellite; images in VIS/IR/WV; resolution 1km, 4km, 8km

INSAT-3D & INSAT-3DR (together):

- Two operational Met satellites; image earth in VIS, IR, and WV bands.
- Resolution: **1 km** VIS, **4 km** IR, **8 km** WV.
- Located at 74°E; provide **48 passes** daily.
- After every **15 minutes** a new set of images/products available to forecasters.
- Scan **Indian land region every hour**; scan **Indian Ocean region every 90 minutes**.
- Inter-change their scan areas after every **3-hour** interval to get temperature and humidity profiles.
- Processed data: Sea Surface Temperature (SST), Outgoing Long Wave Radiation, Rainfall Estimation, Cloud Motion Vectors, Water Vapour Vector, Upper Tropospheric Humidity.

METSAT: Receives and processes satellite pictures every **3 hours**, commencing **0300 UTC**. Processed by SDUC in about **40 min**. Imagery received after **1 hr 15 min** (i.e. 0300Z picture received by 0415Z). In event of cyclones: **hourly observations are provided**. Animation of hourly and 3-hourly satellite pictures also available on the website.

OCEANSAT-2 (ISRO): Data utilised for Tropical Cyclone genesis and NWP models.

Foreign Satellites

Satellite	Country/Org	Type	Key Info
NOAA (K, L, M)	USA / NOAA	Polar (POES)	Daily global coverage of clouds, storm location, temperature, heat balance; 3 ground processing systems at IMD New Delhi, RMC Chennai, RMC Guwahati
METEOSAT	EUMETSAT	Geostationary	Near 0° meridian; operated by EUMETSAT on behalf of European Met Agencies
GMS	Japan	Geostationary	At 130°E
INSAT	India	Geostationary	At 83° and 93°
GOES	USA	Geostationary (GOES)	2 satellites (East and West coast); provides temp data every hour; interval ~30 min

Computer-generated output from Indian Satellites:

- (a) Vertical temperature and humidity profile
- (b) Cloud top and SST (Sea Surface Temperature)
- (c) Upper winds
- (d) Convective clouds and Mesoscale systems

Quantitative Satellite Products: SST, Outgoing LW Radiation, Quantitative Precipitation Estimates, Cloud Motion Vectors, Water Vapour Winds, Land Surface Emissivity, Atmospheric moisture profile, Fog detection; Vertical profile of temp/humidity, Cloud top temp, Upper winds, Convective clouds and meso-scale systems.

11. Cloud Characteristics in Satellite Imagery

Feature	Appearance in Satellite Imagery
Clouds (general)	White and gray; cast dark shadows on ground; thicker clouds and water clouds are brighter than ice clouds
High clouds (detectable)	Detectable only by the shadow they cast
CU clouds	Great variety, organized into small regular lines or bands
Jet stream clouds	Very long streaks; high cirrus clouds
Smoke	Brown to grey; from oil fires = black
Haze	Featureless and pale gray or whitish
Dust	Slightly tan (like soil); can be white, red, dark brown, even black (due to mineral content)
Volcanic plumes	Steam and gas = white; ash = brown

In IR Imagery:

- **Lowest temperatures = Whitest** (high cold cloud tops appear bright white)
- **Warmest = Dark grey or black** (warm surface, clear areas)

Quick Revision Summary — Radar

- PPI = plan view (bearing/range); RHI = height view (CB altitude)
- Bands: K(0.75–2.5cm), X(2.5–4cm), C(4–8cm), S(8–15cm), L(15–30cm)
- K+X = clouds; X = storms; S = cyclone detection/tracking; Quantitative radar = 10 cm
- DWR = Doppler; measures frequency change; coherent radar
- Radar range: detect 500 km, best resolution 250 km, display 25 NM, long range 75 NM
- Bright Band = WEAK storm; at freezing level; stratiform only; disappears with convection
- Figure '6' echo = tornado; Spiral bands = tropical cyclone
- Dry Holes = severe storms (strong winds + heavy rain)
- Airborne: X-Band, 3° beam, 15° up/down, 70° coverage, 3cm wavelength, ½ sec flash
- Colors: Green=light(1–4mm), Yellow=moderate(4–12mm), Red/Magenta=severe(≥ 12 mm)
- Drizzle NOT shown on radar (returns $\propto$ 6th power of droplet diameter)

Quick Revision Summary — Satellites

- Polar: 650–1500 km; covers earth 2×/day; same spot every 12 hr; e.g. NOAA
- Geostationary: ~36,000 km; earth-synchronized; 5 cover globe; round-the-clock; e.g. INSAT, METEOSAT
- Satellite imagery interval: 30 min; but pictures provided: 3 hourly
- Kalpana-1: launched 12 Sep 2002 at 74°E; 48 images/day (daytime only)
- INSAT-3A: launched 10 Apr 2003 at 93.5°E; 1×1 km resolution
- INSAT-3D: launched 25 Jul 2013 at 82°E; INSAT-3DR: 08 Sep 2016 at 74°E
- INSAT-3D/3DR: 48 passes/day; new image every 15 min; land scan every 1 hr; ocean every 90 min
- METSAT: pictures every 3 hr from 0300 UTC; in cyclones: hourly
- IR imagery: coldest = whitest; warmest = darkest

Practice Q&A

Q1. PPI scope provides:

(a) Plan view of echoes — bearing and range (b) Height of echoes (c) Intensity of echoes

✓ **Correct Answer: (a) Plan view of echoes — bearing and range**

The Plan-Position Indicator (PPI) presents a plan (top-down) view of echoes and provides the bearing and range of the echo.

✗ (b) Height of echoes: This is the function of the RHI (Range-Height Indicator) scope.

✗ (c) Intensity: While colour-coded intensity may be shown, the defining feature of PPI is plan view with bearing/range.

🎓 PPI = Plan (horizontal) = Position = Bearing/Range. RHI = Range-Height = Altitude of CB cells. Easy: "RHI reads Height."

Q2. RHI scope enables direct reading of:

(a) Speed of echoes (b) Range of echoes (c) Altitude of CB cells

✓ **Correct Answer: (c) Altitude of CB cells**

The Range-Height Indicator (RHI) enables direct reading of the altitudes of CB cells — essential for aviation weather avoidance decisions.

🎓 RHI = Range-Height Indicator. Direct reading of CB cell altitude = pilots can decide if they can overfly the CB or need to deviate.

Q3. S band radar is used for:

(a) Detection of clouds (b) Storm detection (c) Cyclone detection and tracking (rain, precipitation, cyclones)

✅ **Correct Answer: (c) Cyclone detection and tracking**

S band (8–15 cm wavelength) is used for rain, precipitation, cyclones, and depressions. It is also called the Cyclone Detection (and tracking) Radar.

❌ (a) K and X Band = cloud detection. ❌ (b) X Band = storm detection. S Band is specifically the cyclone band.

🎓 "S for Sea/Storm/Cyclone" — S band covers the longest range for weather, best for cyclone tracking. IMD's cyclone detection network uses S-band radars along the coast.

Q4. Quantitative Radar measures rate of precipitation using wavelength:

(a) 5.0 cm (b) 10.0 cm (c) 3.2 cm

✅ **Correct Answer: (b) 10.0 cm**

Quantitative Radar (10.0 cm wavelength) is used for quantitative measurement of rate of precipitation, total precipitation, intensity, and snowfall.

🎓 Quantitative Radar = 10 cm. Remember: 10 cm is in the S-Band range (8–15 cm). Airborne weather radar = 3 cm (X-Band).

Q5. DWR detects if targets are moving towards or away by measuring:

(a) Amplitude of return signal (b) Change of frequency of return signal (c) Time delay of return signal

✅ **Correct Answer: (b) Change of frequency of return signal**

DWR works on the principle of the Doppler Effect — measuring the change of frequency of the return signal to determine if targets (precipitation, wind, etc.) are moving towards or away from the radar station.

🎓 Doppler Effect = frequency change. Moving towards radar = higher frequency (blue shift). Moving away = lower frequency (red shift). This principle also used in airborne weather radar for wind shear detection.

Q6. Bright Band is an indicator of:

(a) Strong/severe storm (b) CB cloud (c) Weak storm

✅ **Correct Answer: (c) Weak storm**

Bright Band is an indicator of a WEAK storm. It appears at the freezing level in stratiform precipitation (not convective). It disappears with increasing convection.

❌ (a) Strong/severe storm: This is the OPPOSITE — Bright Band = weak storm. ❌ (b) CB cloud: CB echoes have sharp edges and may extend to -40°C — no Bright Band. Bright Band = stratiform (flat, weak) precipitation.

🎓 **Counter-intuitive DGCA trap!** Bright Band = WEAK storm. Formed by melting snowflakes at the freezing level in stratiform rain. Disappears when convection (strong storm) develops.

Q7. A figure '6' echo is an indication of:

(a) Hailstorm (b) Tornado (c) Severe turbulence

✅ **Correct Answer: (b) Tornado**

A radar echo of the figure '6' shape is an indication of a tornado. Hooks, Appendages and Protuberances indicate severe storms with hail.

🎓 Figure '6' = Tornado on radar. This is because the hook-echo structure (associated with tornado supercells) resembles the number 6. Classic DGCA question.

Q8. Spiral bands on radar indicate:

(a) Severe TS (b) Tropical Cyclone (c) Hailstorm

✅ **Correct Answer: (b) Tropical Cyclone**

Spiral bands on radar indicate tropical cyclones and last for a long time.

🎓 Spiral bands = TC signature. The spiral arms of precipitation are the classic visual structure of a tropical cyclone on radar imagery.

Q9. On airborne weather radar, Red/Magenta colour indicates:

(a) Light precipitation (b) Moderate precipitation (c) Heavy precipitation, TS, severe turbulence — AVOID

✅ **Correct Answer: (c) Heavy precipitation, TS, severe turbulence — aircraft should ALWAYS AVOID**

Red/Magenta on airborne radar = heavy precipitation, TS, hail, strong winds, tornadoes, severe turbulence. Aircraft must always avoid these areas.

🎓 Color code: Green=Go (light, 1–4mm), Yellow=Caution (moderate, 4–12mm), Red/Magenta=STOP/AVOID (severe, ≥ 12 mm). Never penetrate Red/Magenta areas.

Q10. Geostationary satellites are placed at an altitude of approximately:

(a) 650–1500 km (b) 36,000 km (c) 500 km

✅ **Correct Answer: (b) 36,000 km**

Geostationary satellites are placed in near circular orbit at about 36,000 km in the plane of the earth's equator. They are earth synchronized with same period of rotation as earth.

❌ (a) 650–1500 km: This is the altitude range for Polar Orbiting satellites. ❌ (c) 500 km: Too low — this would be LEO (Low Earth Orbit).

🎓 Geostationary = 36,000 km; 5 cover the globe; earth-synchronized. Polar = 650–1500 km; covers earth twice/day; same spot every 12 hr.

Q11. How many geostationary satellites are needed to cover the entire globe?

(a) 3 (b) 4 (c) 5

✅ **Correct Answer: (c) 5**

Five geostationary satellites are capable of covering the entire globe. METEOSAT, INSAT, GMS, and GOES (2) together provide global geostationary coverage.

🏠 5 geostationary satellites = global coverage. NOAA provides polar (LEO) global coverage with fewer satellites but periodic, not continuous, coverage.

Q12. Kalpana-1 satellite is located at:

(a) 74°E (b) 93.5°E (c) 82°E

✅ **Correct Answer: (a) 74°E**

Kalpana-1 was launched on 12 September 2002 and is located at 74°E. INSAT-3A is at 93.5°E. INSAT-3D is at 82°E.

🏠 Satellite positions: Kalpana-1 = 74°E; INSAT-3A = 93.5°E; INSAT-3D = 82°E; INSAT-3DR = 74°E (same as Kalpana-1). GMS (Japan) = 130°E.

Q13. In IR satellite imagery, the lowest temperatures appear:

(a) Black (b) Dark grey (c) White (brightest)

✅ **Correct Answer: (c) White (brightest)**

In IR images, the lowest temperatures (highest, coldest cloud tops) are the whitest (brightest). The warmest areas appear dark grey or black.

🏠 IR imagery rule: COLD = WHITE = High clouds. WARM = BLACK/DARK = Surface/warm areas. Useful for identifying deep convection (appears bright white in IR).

Q14. Drizzle does not show up on radar because radar returns are proportional to:

(a) Square of droplet diameter (b) Fourth power of droplet diameter (c) Sixth power of droplet diameter

✅ **Correct Answer: (c) Sixth power of droplet diameter**

Radar returns are proportional to the sixth power of droplet diameter. Since drizzle droplets are very small, their sixth power is tiny — making them virtually invisible to radar.

🎓 $Z = D^6$ (Z is radar reflectivity, D is droplet diameter). Sixth power means a tiny change in size = massive change in reflectivity. Drizzle droplets too small = near zero radar return.

Q15. INSAT-3D was launched from:

(a) Sriharikota (b) Baikonur (c) French Guiana Space Centre

✅ **Correct Answer: (c) French Guiana Space Centre**

INSAT-3D was launched on 25 July 2013 from French Guiana Space Centre (Ariane launch site). It is an advanced weather satellite for operational, environmental and storm warning.

🎓 INSAT-3D = French Guiana Space Centre, 25 Jul 2013, at 82°E. INSAT-3DR = launched 08 Sep 2016 at 74°E. Both are operational Met satellites.

Master Reference Tables

Radar Band Summary

Band	Wavelength	Use
K Band	0.75–2.5 cm	Cloud detection
X Band	2.5–4 cm	Storm detection; airborne WXR (~3 cm)
C Band	4–8 cm	—
S Band	8–15 cm	Rain, precipitation, cyclones, depressions; Quantitative radar ~10 cm
L Band	15–30 cm	Long range

Radar Echo Significance

Echo Type	Significance
Bright Band	WEAK storm; freezing level; stratiform; a few hundred metres thick
Figure '6' echo	TORNADO
Spiral bands	Tropical Cyclone
Hook/Protuberance	Severe storm with hail
Dry Holes	Severe storm — strong winds + heavy rain
Converging echoes	Severe storm
CB echo (top at -40°C)	Cumulonimbus
Slant vertical columns	Vertical wind shear
Separate rain columns	Wind shear in TS

Indian Satellite Summary

Satellite	Launch	Position	Resolution (VIS/IR/WV)
Kalpana-1	12 Sep 2002	74°E	2×2 km / — / 8×8 km
INSAT-3A	10 Apr 2003	93.5°E	1×1 km (CCD)
INSAT-3D	25 Jul 2013	82°E	1 km / 4 km / 8 km
INSAT-3DR	08 Sep 2016	74°E	1 km / 4 km / 8 km

Mnemonics

Mnemonic	Meaning
"PPI = Plan, RHI = Height"	PPI gives plan view; RHI gives altitude of CB cells
"S = Sea/Cyclone, X = Storm, K = Clouds"	Radar band applications
"Bright Band = Weak"	Counter-intuitive — Bright Band = weak/stratiform storm
"6 = Tornado"	Figure '6' radar echo = tornado indication
"Green Go, Yellow Caution, Red/Magenta STOP"	Airborne radar color action rule
"Cold = White (IR)"	In IR imagery, coldest (highest) clouds appear whitest
"5 Geosats cover globe"	Five geostationary satellites = global coverage
"36,000 km Geo, 650–1500 Polar"	Satellite altitude quick reference