Thermal Remote Sensing

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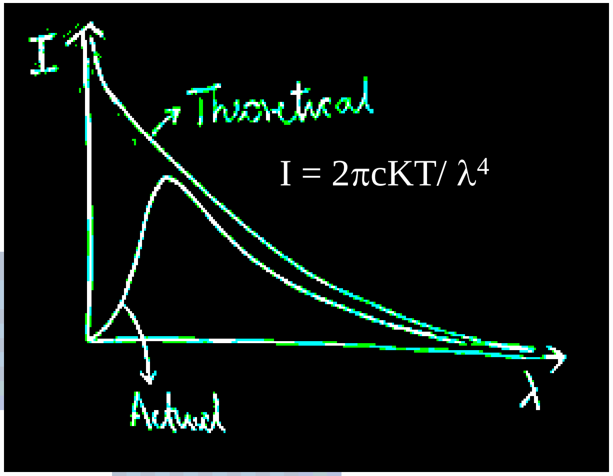
Fundamentals of TIR

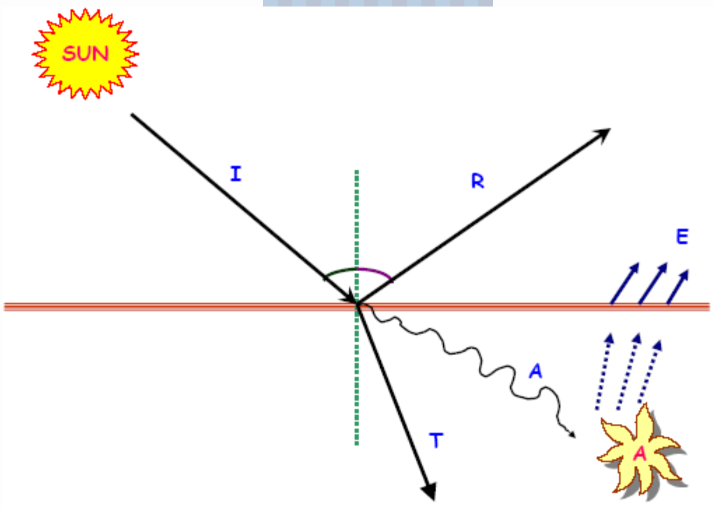
- Earth-Atmosphere derives its energy from sun
- For radiation – no medium is required

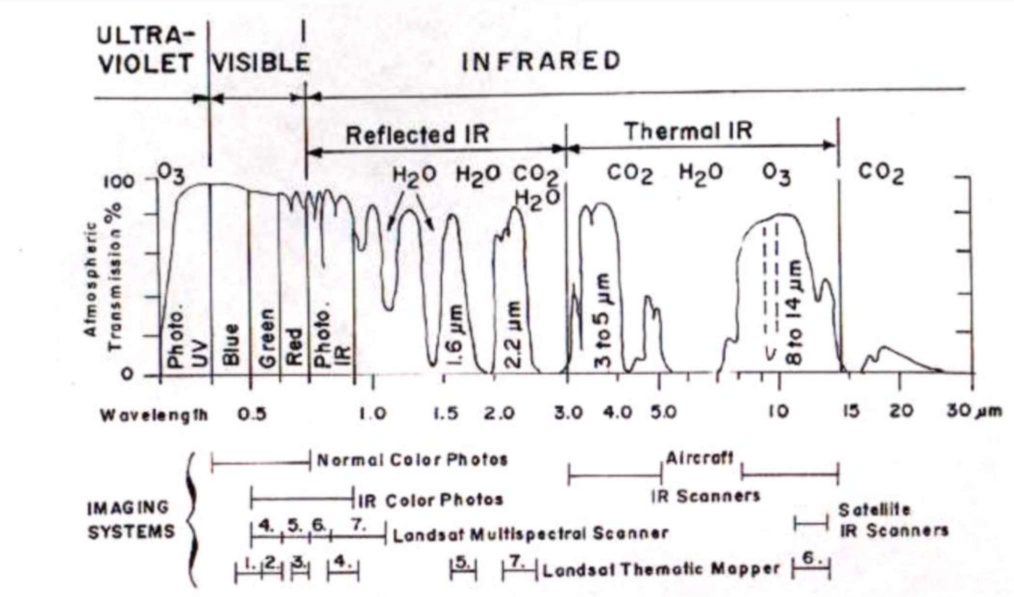


Heat Process: Conduction, Convection, Radiation

- Earth's surface & atmosphere radiate thermal energy outward owing to heating by solar irradiance.

- A thermal sensor picks up radiant emitted energy from a surface target heated through source.



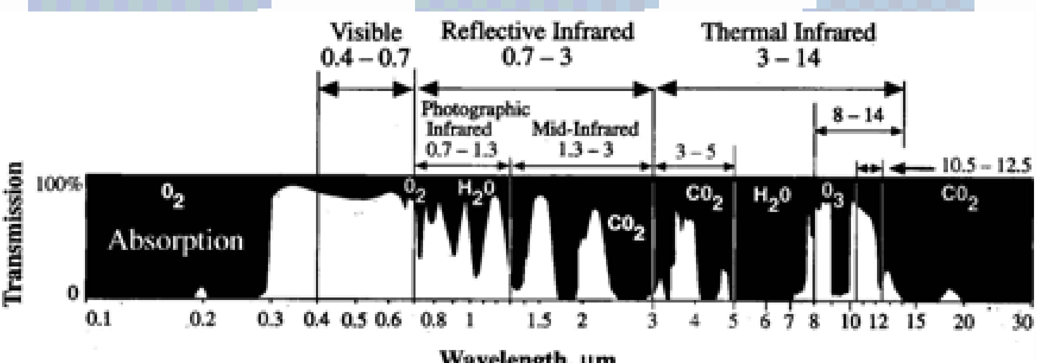


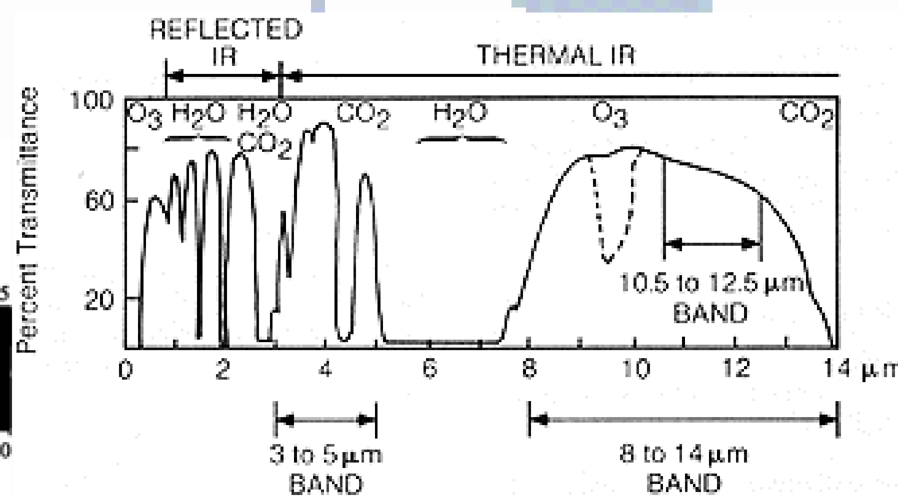
Near IR: 0.77 - 0.90 µm, 1.0 - 1.12 µm, 1.19 - 1.34 µm

Mid IR: 1.55 - 1.75 µm, 2.05 - 2.44 µm

Thermal IR: 3.5 - 4.16 µm, 4.5 - 5.0 µm, 8.0 - 14.0 µm

- TIR radiation is absorbed by glass lenses of conventional cameras and can’t be detected by photographic films.
- Special optical-mechanical or electronic scanners are used to detect and record images in TIR region.





Fundamentals of TIR

- Sensor that measure emitted radiation in TIR can produce informative data of distinctive signatures & indirectly of properties of materials about earth surface.

- Thermal Remote Sensing can be defined as – Detection of remote objects by recording amount of thermal radiation emitted from various surfaces.

- All materials having temperature above absolute zero (0 K or -273 C) emit thermal energy both day and night.

Planck's formula for blackbody spectral exitance B_λ is given as,

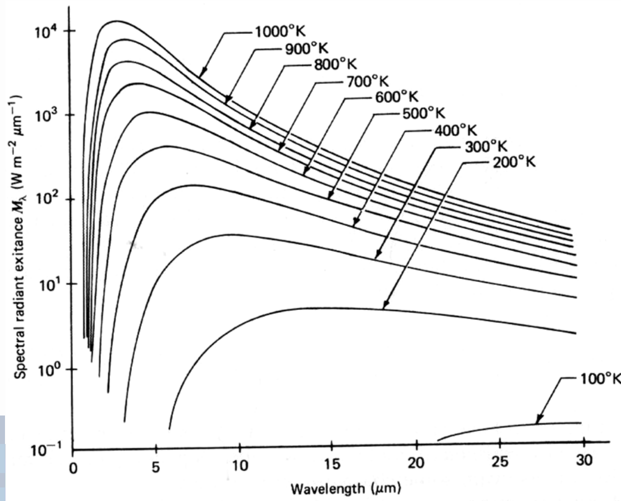
$$B_\lambda = \varepsilon C_1 \lambda^{-5} / [\exp (C_2/ \lambda T) -1]$$

where C_1 = 3.74151 x 10^{-8} W-m^{-2}-μm^4, C_2 = 1.43879 x 10^4 μm- K, T is the blackbody's temperature in kelvin (K).

The radiant exitance from sun and earth follows Planck's equation

$$M_\lambda = \frac{C_1}{\lambda^5\left[e^{C_2/\lambda T} - 1\right]}$$

λ_{max} = **2898 / T µm**

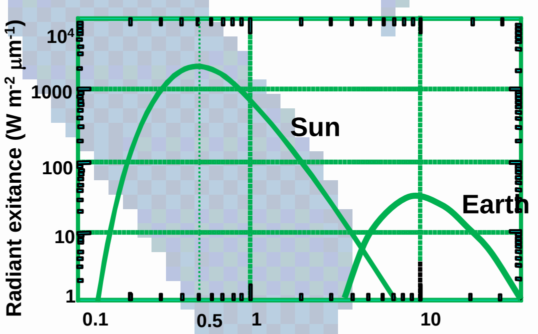


10.5 – 12.5 m is used for thermal imaging to avoid ozone absorption at ~9.5 mm

At microwave frequency $C_2/\lambda T << 1$ $M_\lambda \propto \varepsilon T \rightarrow$ Brightness Temperature

According to Weins displacement law

- λ_{max} = K / T, where K = 2898
- At 0 degrees C (272 degrees K), λmax = 10.65 µm
- At 50 degrees C, λmax = 9.00 µm
- At 25 degrees C, λmax = 9.76 µm



- Note, atmosphere absorbs all energy between 9 and 10 µm, therefore 10.5 is the best we can do

When the Planck radiation law is integrated over entire spectrum, one obtains the famous Stefan-Boltzmann law.

$$B = \int B(\lambda)\, d\lambda = \sigma T^4$$

$B(\lambda)$ = spectral radiant exitance ($W\ m^{-2}\ \mu m^{-1}$)
σ = Stefan-Boltzmann constant ($5.6697 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$)

The radiation obeys Planck's equation if the object is a perfect emitter or absorber *i.e,* Blackbody.

The efficiency with which real materials emit thermal radiation at different wavelengths is determined by their emissivity 'ε'

$$\varepsilon(\lambda) = B_\lambda\,(\text{material}, {}^0K) / B_\lambda\,(\text{blackbody}, {}^0K)$$

Values between 0 and 1.

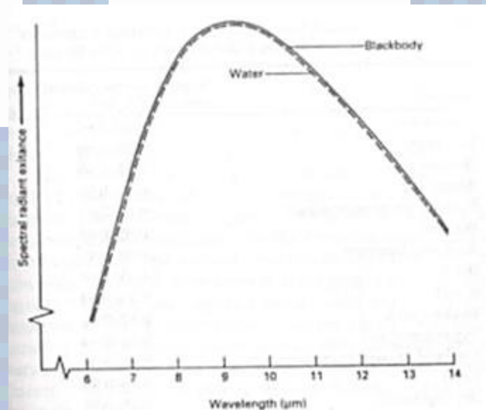
Thermal Basics

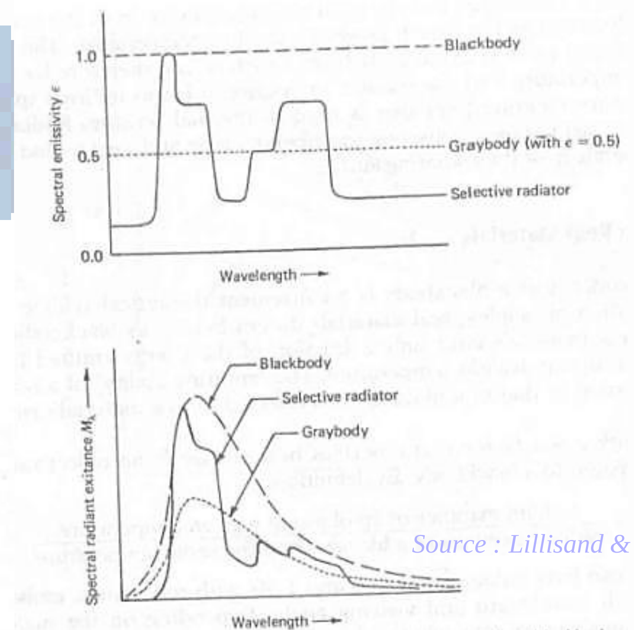
- All objects above absolute zero exhibit random motion of energy particles and energy of these particles is called **Kinetic Heat.**
- True kinetic Temperature can be measured using a Thermometer.
- Internal K.E. is also converted to **Radiant Energy** which is measured by RS.
- EM radiation exiting an object is called **Radiant Flux** (Watt).
- Amount of radiant flux is called **Radiant Temperature**.
- For most of the objects (expect glass, metal), there is high positive correlation between true **K.T** and amount of **radiant flux** radiated from an object.
- Therefore, we can use radiometers placed remotely to measure radiant temperature!!!!.
- This is basis of **Thermal Remote Sensing**.

- Unfortunately, the relationship between true K.T & Radiant Flux is not perfect.
- The radiant temperature is always less than the true K.T. (Emissivity)

Why Emissivity is Important ?

$$T_{rad} = \varepsilon^{1/4}\, T_{kin}$$





Source : Lillisand & Kiefer

Material	Emissivity
Water, distilled	0.99
Water	0.92-0.98
Concrete	0.71-0.90
Asphalt	0.95
Loamy soil, dry	0.92
Loamy soil, wet	0.95
Soil, sandy	0.90
vegetation	0.98
grass	0.97
Deciduous forest	0.97-0.98
Coniferous forest	0.97-0.99
Wood	0.90
Stainless steel	0.16
Polished metals	0.16-0.21
Aluminum, foil	0.05
Aluminum, polished	0.08
Aluminum, paint	0.55
snow	0.95
Human skin	0.98

For any object that intercepts EM radiant energy: $r_\lambda + \alpha_\lambda + \tau_\lambda = 1$

Natural earth objects are opaque: $\boxed{r_\lambda + \varepsilon_\lambda = 1}$

- most materials have an emissivity > 0.90
- Wet materials have higher emissivity than dry
- Metals have very low emissivity
- Some minerals have emissivity 0.7 to 0.9

At thermal IR wavelengths, $\tau_\lambda = 0$ **and** $\alpha_\lambda = \varepsilon_\lambda$

Therefore, $1 = r_\lambda + \varepsilon_\lambda$

This relationship describes why objects appear as they do on thermal imagery

If reflectivity increases, then emissivity must decrease

Thermal properties of materials

The primary objective of temperature measurements and related thermal response is to infer information about the nature, composition and other physical attributes at the earth's surface and its atmosphere.

The energy from sun is being given to all materials almost evenly but it is the internal characteristics of the earth materials that get heated differently.

- Emissivity
- Thermal Inertia (P)
- Heat Capacity (C)
- Thermal Conductivity (Γ)

Thermal properties of materials

The primary objective of temperature measurements and related thermal response is to infer something about the nature of the composition and other physical attributes of materials at the earth's surface and in its atmosphere.

Heat capacity (C)

The measure of increase in thermal energy content (Q) per degree of temperature rise. It denotes the capacity of a material to store heat. It is the ratio of the amount of heat energy in calories required to raise a given volume of a material by 1^0 C to the amount needed to raise the same volume of water by 1^0 C (unit: cal per cm^3).

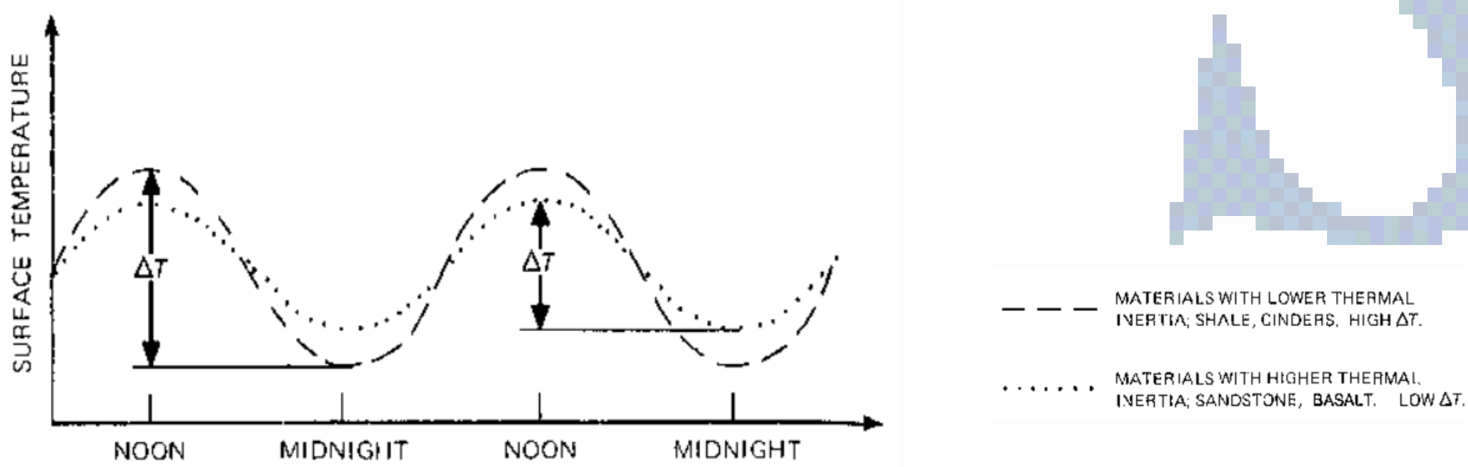
If C is more then, a material would take more energy to increase its temp. and in normal case its temp rise will be less than as compared to other body. Water has highest C =1.0

Thermal Conductivity (K) The rate at which heat passes through a specific thickness of a substance, measured as the calories delivered in one second across a 1 cm^2 area through a thickness of 1 cm at a temperature gradient of 1^0 C (Unit cal per cm per sec per deg C). Rocks & soils are relatively poor conductors of heat.

Thermal Interia (P)

measure of resistance offered by a substance in undergoing temp. changes.

In general, materials with high T.I have more uniform S.T throughout the day and night than material of low thermal inertia



Source: Sabins (1997)

Thermal Diffusivity

It governs the rate at which heat is conducted from surface to depth in the daytime and from depth to surface in the nighttime. (temperature change).

Diffusivity Γ is then defined as,

$$\Gamma = K/\rho C$$

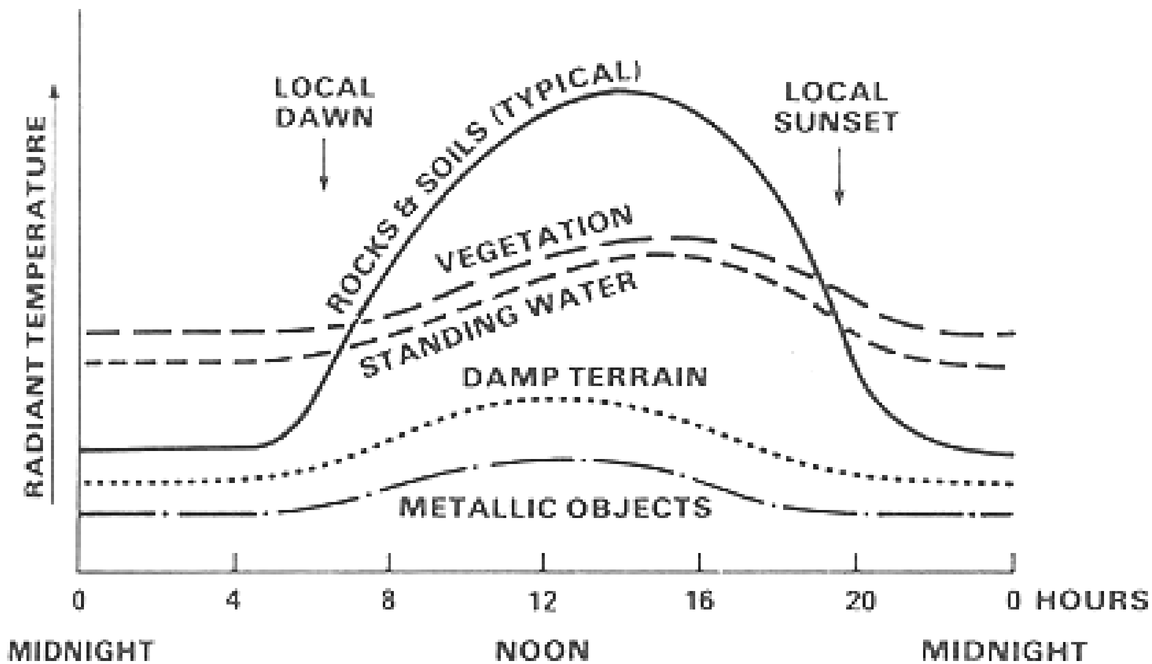
Water posses high specific heat and therefore minor changes in moisture content have significant effects on thermal diffusivity of soils.

Application of TIR Remote Sensing

The ability to record variations in TIR has advantage in extending our observation o many types of phenomena in which minor temperature variations may be significant understanding our environment.

- Identification of geological units and structures
- Soil moisture studies (state of crops, ET, soil moisture)
- Hydrology
- Oceanography/Coastal zones (SST, PFZ, oil spills, modeling, climatic change)
- Volcanology
- Forest fires (assessment, biomass burning)
- Coal fires
- Seismology
- Environmental modelling
- Meteorology
- Medical sciences
- Vetenary sciences
- Intelligence / military applications
- Heat loss from buildings
- Others

Interpretation Of Thermal Imagery



Temperature extremes and heating and cooling rates can often furnish significant information about the type of condition of an object e.g, temp. curve for water is distinctive.

Hence, acquisition should be known as the signature vary during day and night.

History of Thermal Infrared Remote Sensing

- The Astronomer Sir Frederick William Herschel (1738-1822) discovered the infrared portion of the EM spectrum in 1800.
- The single most important development in infrared technology was the development of the detector element by nations at war during World War-II. Early IR detectors were Lead salt photo detectors.
- Now-a-days, have fast detectors consisting of mercury-doped germanium (Ge:Hg), Indium antimonide (InSb) and other substances that are very responsive to infrared radiation.
- The first declassified satellite remote sensor data were collected by the U.S Television IR Operational Satellite (TIROS) launched in 1960. The coarse resolution TIR data were ideal for monitoring regional cloud pattern and frontal movement.
- NASA launched HCMM on April 26, 1978 with 600x600m spatial resolution TIR data (10.5-12.6 μm)at day (1:30pm) and night (2:30am). This was one of the first scientifically oriented (geology) TIR systems. 1986 launched TIMS- 6 channels for mineral signature information.
- NASA's Nimbus-7 launched on October 23, 1978 had a coastal Color Scanner (CZCS) that included TIR sensor for monitoring Sea Surface Temperature.

Thermal Infrared Data Collection

Thermal infrared remote sensor data may be collected by:

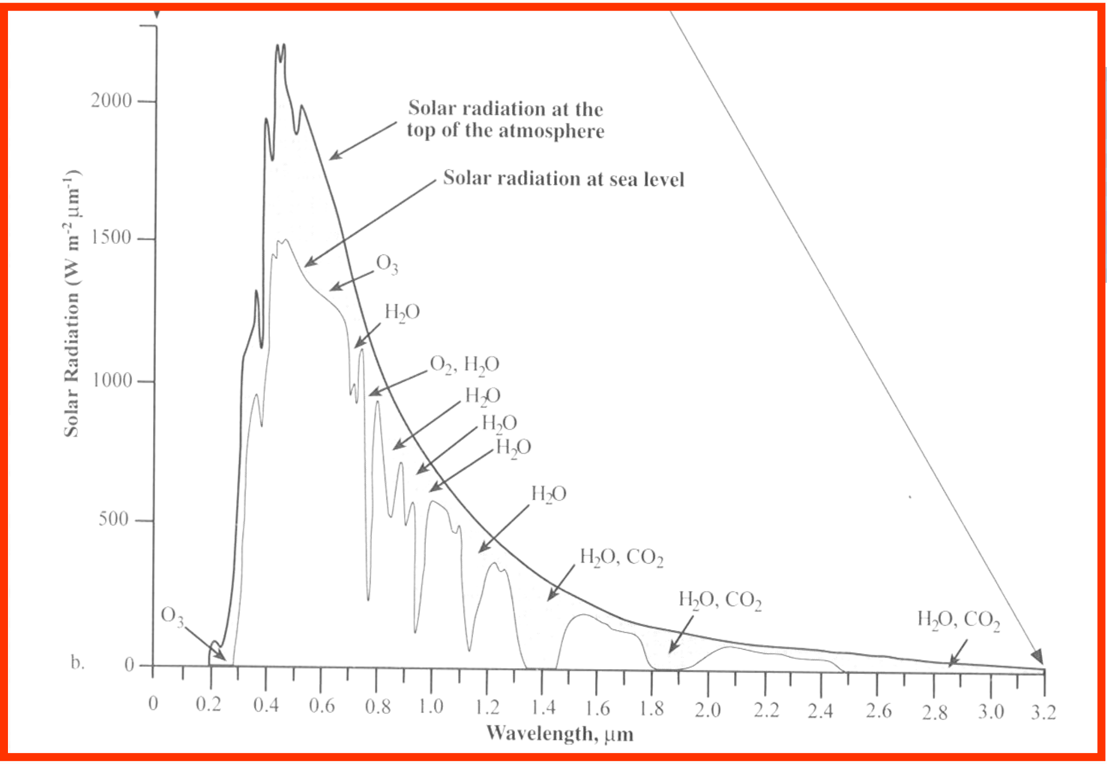
- across-track thermal scanners, and

- push-broom linear and area array charge-coupled device (CCD) detectors.

Atmospheric transmission

Not all of the energy emitted makes it through the atmospheric 'windows'

Atmospheric absorption causes temperatures recorded in space to be less than temperatures recorded at the Earth's surface



1. 'Ground-truth' method
2. Radiative Transfer Model
3. Multi-angle method
4. Split-Window Algorithm

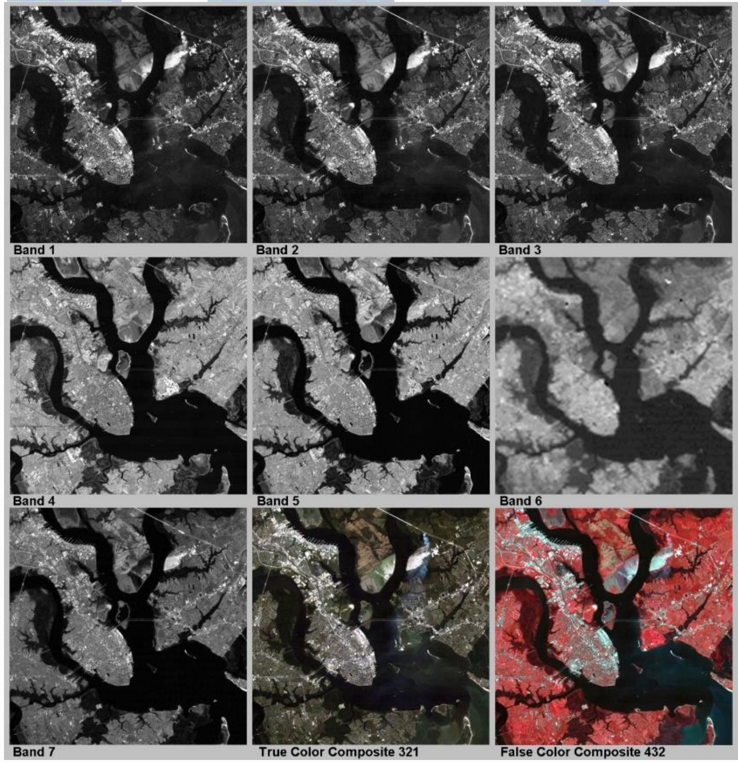
Need to correct for this effect to obtain true surface temperature

NOAA Advanced Very High Resolution Radiometer (AVHRR)

Wavelength		Spatial Resolution	Application
1	0.58 - 0.68 (red)	1.1 km	cloud, snow, and ice monitoring
2	0.725 - 1.1 (near IR)	1.1 km	water, vegetation, and agriculture surveys
3	3.55 -3.93 (mid IR)	1.1 km	sea surface temperature, volcanoes, and forest fire activity
4	10.3 - 11.3 (TIR)	1.1 km	sea surface temperature, soil moisture
5	11.5 - 12.5 (TIR)	1.1 km	sea surface temperature, soil moisture

Landsat Program

Spectral Band	Wavelength	Resolution
Band 1 - Coastal / Aerosol	0.433 - 0.453 µm	30 m
Band 2 - Blue	0.450 - 0.515 µm	30 m
Band 3 - Green	0.525 - 0.600 µm	30 m
Band 4 - Red	0.630 - 0.680 µm	30 m
Band 5 - NIR	0.845 - 0.885 µm	30 m
Band 6 – SW IR	1.560 - 1.660 µm	30 m
Band 7 – SW IR	2.100 - 2.300 µm	30 m
Band 8 - PAN	0.500 - 0.680 µm	15 m
Band 9 - Cirrus	1.360 - 1.390 µm	30 m
Band 10 -TIR	10.30 - 11.30 µm	100 m
Band 11 - TIR	11.50 - 12.50 µm	100 m



Advanced Spaceborne Thermal Emission Reflectance Radiometer (ASTER)

ASTER was successfully launched on 18th December, 1999 as a one of the sensors of the 'TERRA' satellite of EOS Flagship.

High resolution multispectral imager. The instrument has 3 bands in the VNIR (0.5 1.0 μm) with 15 m resolution, 6 bands in SWIR (1.0-2.5 μm) with 30 m resolution and 5 bands in TIR (8-12 μm) with 90 m resolution.

Moderate Resolution Imaging Spectroradiometer (MODIS)

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NE[delta]T(K)[4]
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2.00
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6.00	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in μm

[2] Spectral Radiance values are (W/m^2 -μm-sr)

[3] SNR = Signal-to-noise ratio

[4] NE(delta)T = Noise-equivalent temperature difference

Note: Performance goal is 30-40% better than required

Launched on the EOS Terra spacecraft on Saturday, December 18, 1999

Measurement of Pollution in the Troposphere (MOPITT)

MOPITT is an eight-channel gas correlation radiometer on board Terra since 2000.

MOPITT's spatial resolution is 22 km at nadir and it 'sees' the Earth in swaths that are 640 km wide. Moreover, it can measure the concentrations of carbon monoxide in 5-km layers down a vertical column of atmosphere, to help scientists track the gas back to its sources.

The MOPITT measures up welling radiation in three narrow infrared (IR) bands:

- 4.7 μm channels that have strong carbon monoxide (CO) absorption characteristics and are referred to as CO thermal channels because the dominant signals are from the thermal emission of the atmosphere and the Earth’s surface;

- 2.3 μm channels that have weak CO absorption and are referred to as CO solar channels due to the reflected sunlight being the dominant signal;

- 2.2 μm channels that have weak methane absorption for the band where reflected sunlight is the major signal source and are termed the methane solar channels.

Visible Infrared Imaging Radiometer Suite

VIIRS is one of five key instruments onboard Suomi NPP, launched on October 28, 2011. VIIRS collects imagery and radiometric measurements of land, atmosphere, cryosphere, & oceans in VIS, IR bands.

M-bands: 750 m (16 Moderate Resol'n channels)
I-bands: 375 m (5 High Resol'n channels)
Day/night DNB: 750 m

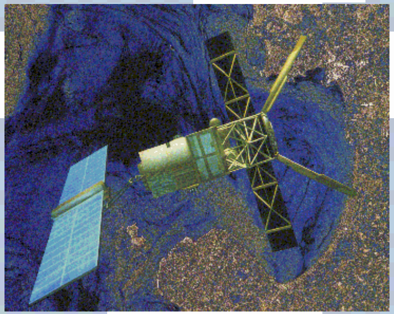
These are resampled to 500 m, 1 km, and 0.05 degrees in the NASA produced data products to promote consistency with the MODIS heritage.

Band	Spectral range (μm)	Primary uses
M1	0.402-0.422	Ocean Color Aerosols
M2	0.436-0.454	Ocean Color Aerosols
M3	0.478-0.498	Ocean ColorAerosols
M4	0.545-0.565	Ocean ColorAerosols
I1	0.600-0.680	Imagery
M5	0.662-0.682	Ocean ColorAerosols
M6	0.739-0.754	Atmosph. Correction
I2	0.846-0.885	NDVI
M7	0.846-0.885	Ocean ColorAerosols
M8	1.230-1.25	Cloud Particle Size
M9	1.371-1.386	Cirrus/Cloud Cover
I3	1.580-1.640	Binary Snow Map
M10	1.580-1.640	Snow Fraction
M11	2.225-2.275	Clouds
I4	3.550-3.930	Cloud Imagery
M12	3.660-3.840	SST
M13	3.973-4.128	SST, Fires
M14	8.400-8.700	Cloud Top Properties
M15	10.263-11.263	SST
I5	10.500-12.400	Cloud Imagery
M16	11.538-12.488	SST
DNB	0.5 - 0.9	Day/Night

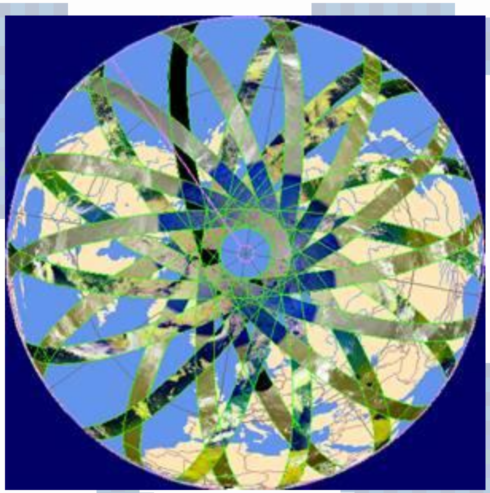
(ADVANCED) ALONG TRACK SCANNING RADIOMETER (ATSR)

Launched July 1991, April 1995 and March 2002

Launched aboard ERS-1, ERS-2 and Envisat (ESA)



1 day of data



MEASUREMENT TECHNIQUE:
Radiometer measuring @ 2 angles

- 7 channels in visible to microwave (0.55, 0.66, 0.86, 1.6, 3.7, 11 and 12 μm)

HORIZONTAL COVERAGE:
~1 km nadir footprint with 512 km cross-track scanning
→Global coverage 3-4 days

OVERPASS TIME:
~10:00 equator cross-over (on Envisat)

Atmospheric Infrared Sounder (AIRS) on board Aqua

Advanced sounder containing 2378 infrared channels and 4 visible/NIR channels, aimed at obtaining highly accurate temperature profiles within the atmosphere plus a variety of additional Earth/atmosphere products.

Band	Wavelength (μm)	Resolution (m)	Swath width (km)	Revisit time (days)
Band 5 (MWIR)	3.74 to 4.61	13500 (1000)	1800	0.5
Band 6 (TIR)	6.2 to 8.22	13500 (1000)	1800	0.5
Band 7 (TIR)	8.8 to 15.4	13500 (1000)	1800	0.5
Band 1 (VIS)	0.4	13500	1800	0.5
Band 2 (VIS)		13500	1800	0.5
Band 3 (VIS)		13500	1800	0.5
Band 4 (NIR)	to 1	13500	1800	0.5

CERES (Clouds and Earth's Radiant Energy System)

measure the Earth's total thermal radiation budget, and in combination with MODIS data, detailed information about clouds.
First CERES instrument was launched on TRMM satellite in November 1997; the second and third CERES instuments were launched on the Terra satellite in December 1999; and the fourth and fifth CERES instruments are on board the Aqua satellite.

Band	Wavelength (µm)	Bandwidth (µm)	Resolution (m)
Band 1 (SWIR)	0.3 to 5		20000 (10000)
Band 2 (TIR)	8 to 12		20000 (10000)
Band 3 (Other)	0.3 to 100		20000 (10000)

High Resolution Dynamics Limb Sounder (HIRDLS) on board Aura

tropospheric temperature and water vapor retrievals; momentum, energy, heat, and potential vorticity balances of the upper troposphere and middle atmosphere. Complete Earth coverage can be obtained in 12 hrs.

Band	Wavelength (µm)	Resolution (m)	Swath width (km)
Band 1-21 (TIR)	6 to 18	500 (1)	2000 (3000)

Tropospheric Emission Spectrometer (TES)

to monitor ozone in the lowest layers of the atmosphere. With very high spectral resolution, TES was capable of distinguishing concentrations of gases at different altitudes, a key factor in understanding their behavior and impact

Band	Wavelength (µm)	Resolution (m)	Swath width (km)
Band 1-12 (1A1-2B1) (TIR)	3.5 to 15.4	500 (5000)	5.3 (8.5)

Sentinel-3

is primarily an **ocean mission,** however, the mission is also able to provide atmospheric and land applications. The mission provides **data continuity** for the ERS, Envisat and SPOT satellites. Sentinel 3A: 2016; Sentinel 3B: 2018

Sentinel-3 makes use of multiple sensing instruments to accomplish its objectives; SLSTR (Sea and Land Surface Temperature Radiometer), OLCI (Ocean and Land Colour Instrument), SRAL (SAR Altimeter), DORIS, and MWR (Microwave Radiometer).

Band	λ centre (μm)	Width (μm)	Function	Comments	Res. (m)	
S1	0.555	0.02	Cloud screening, vegetation monitoring, aerosol	Visible Near IR	Solar reflectance bands	500
S2	0.659	0.02	NDVI, vegetation monitoring, aerosol			
S3	0.865	0.02	NDVI, cloud flagging, Pixel co-registration			
S4	1.375	0.015	Cirrus detection over land			
S5	1.61	0.06	Cloud clearing, ice, snow, vegetation monitoring	Short-Wave IR		
S6	2.25	0.05	Vegetation state and cloud clearing			
S7	3.74	0.38	SST, LST, Active fire			
S8	10.85	0.9	SST, LST, Active fire	Thermal infra-red Ambient bands (200 K - 320 K)		
S9	12	1	SST, LST			1000
F1	3.74	0.38	Active fire	Thermal infra-red fire emission bands		
F2	10.85	0.9	Active fire			

Source: Sentinel Users Guide

- Measuring sea-surface topography, SSH, S
- Measuring SST and LST
- Measuring ocean and land-surface colour
- Monitoring sea and land ice topography
- Sea-water quality and pollution monitoring
- Inland water monitoring, rivers and lakes
- Aid ocean forecasts with acquired data
- Climate monitoring and modelling
- Land-use change monitoring
- Forest cover mapping
- Fire detection
- Weather forecasting
- Measuring Earth's thermal radiation for atmospheric applications

Spectral characteristics of GOES-16 (GOES-R)

Advance Baseline Imager (ABI)

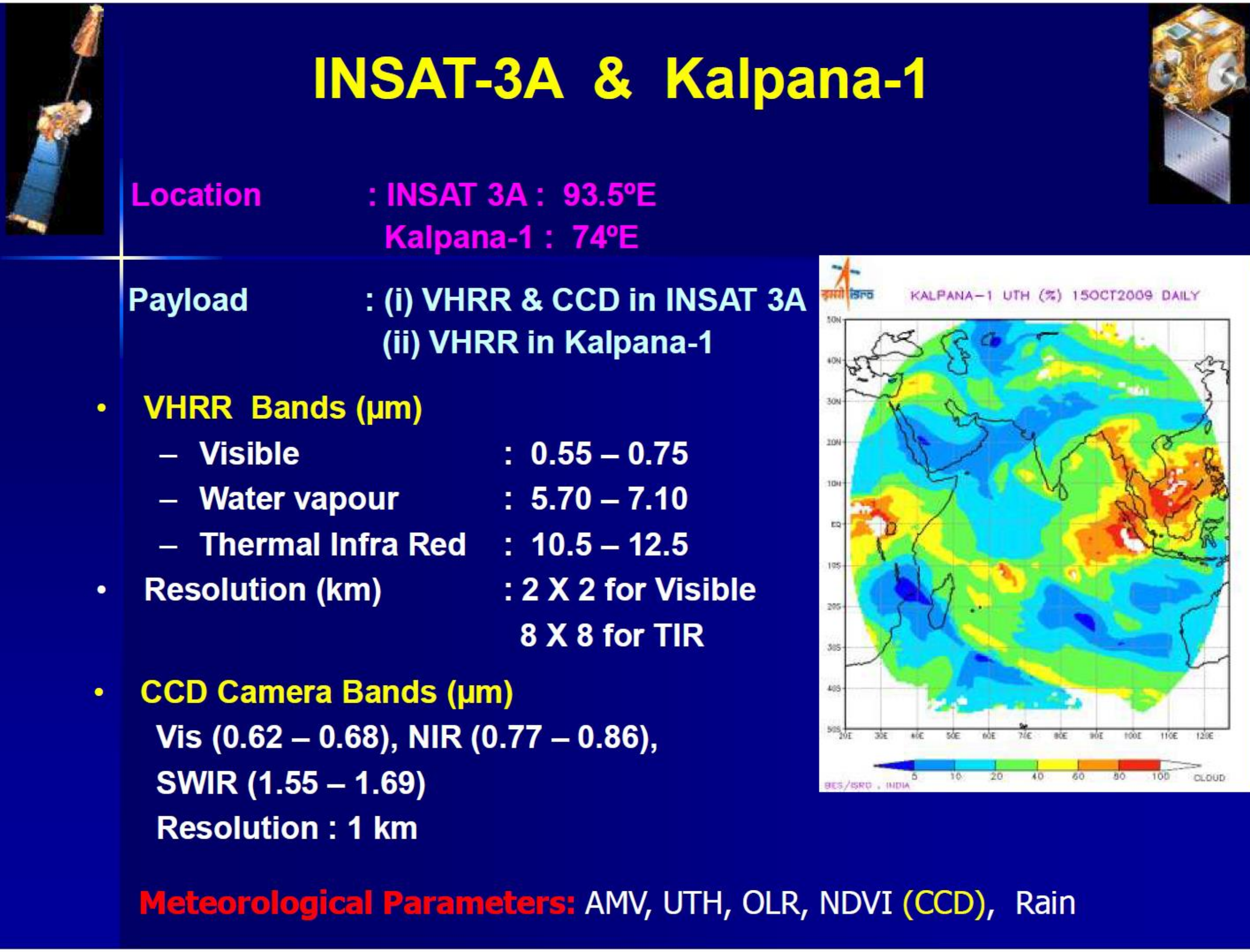
Band	λ (µm)	Central λ (µm)	Pixel spacing (km)	Nickname	Classification	Primary function
1	0.45–0.49	0.47	1	Blue	Visible	Aerosols
2	0.59–0.69	0.64	0.5	Red	Visible	Clouds
3	0.846–0.885	0.865	1	Veggie	Near-infrared	Vegetation
4	1.371–1.386	1.378	2	Cirrus	Near-infrared	Cirrus
5	1.58–1.64	1.61	1	Snow/Ice	Near-infrared	Snow/ice discrimination, cloud phase
6	2.225–2.275	2.25	2	Cloud Particle Size	Near-infrared	Cloud particle size, snow cloud phase
7	3.80–4.00	3.90	2	Shortwave Window	Infrared	Fog, stratus, fire, volcanism
8	5.77–6.6	6.9	2	Upper-level Tropospheric Water Vapor	Infrared	Various atmospheric features
9	6.75–7.15	6.95	2	Mid-level Tropospheric Water Vapor	Infrared	Water vapor features
10	7.24–7.44	7.34	2	Lower-level Tropospheric Water Vapor	Infrared	Water vapor features
11	8.3–8.7	8.5	2	Cloud-Top Phase	Infrared	Cloud-top phase
12	9.42–9.8	9.61	2	Ozone	Infrared	Total column ozone
13	10.1–10.6	10.35	2	Clean Infrared Longwave Window	Infrared	Clouds
14	10.8–11.6	11.2	2	Infrared Longwave Window	Infrared	Clouds
15	11.8–12.8	12.3	2	Dirty Infrared Longwave Window	Infrared	Clouds
16	13.0–13.6	13.3	2	CO_2 Longwave Infrared	Infrared	Air temperature, clouds

GMS- HIMAWARI-9

Band	Wavelength (μm)	Bandwidth (μm)	Resolution (m)
Band 1 Blue (VIS)	0.47		1000
Band 2 Green (VIS)	0.51		1000
Band 3 Red (VIS)	0.64		500
Band 4 (NIR)	0.86		1000
Band 5 (SWIR)	1.6		2000
Band 6 (SWIR)	2.3		2000
Band 7 (MWIR)	3.9		2000
Band 8 (TIR)	6.2		2000
Band 9 (TIR)	6.9		2000
Band 10 (TIR)	7.3		2000
Band 11 (TIR)	8.6		2000
Band 12 (TIR)	9.6		2000
Band 13 (TIR)	10.4		2000
Band 14 (TIR)	11.2		2000
Band 15 (TIR)	12.4		2000
Band 16 (TIR)	13.3		2000

METEOSAT SEVIRI MSG satellite

Channel no.		Characteristics of spectral band (μm)			Main gaseous absorber or window
		λcen	λmin	λmax	
1	VIS0.6	0.635	0.56	0.71	Window
2	VIS0.8	0.81	0.74	0.88	Window
3	NIR1.6	1.64	1.50	1.78	Window
4	IR3.9	3.90	3.48	4.36	Window
5	WV6.2	6.25	5.35	7.15	Water vapor
6	WV7.3	7.35	6.85	7.85	Water vapor
7	IR8.7	8.70	8.30	9.10	Window
8	IR9.7	9.66	9.38	9.94	Ozone
9	IR10.8	10.80	9.80	11.80	Window
10	IR12.0	12.00	11.00	13.00	Window
11	IR13.4	13.40	12.40	14.40	Carbon dioxide
12	HRV	Broadband (about 0.4 – 1.1)			Window/water vapor



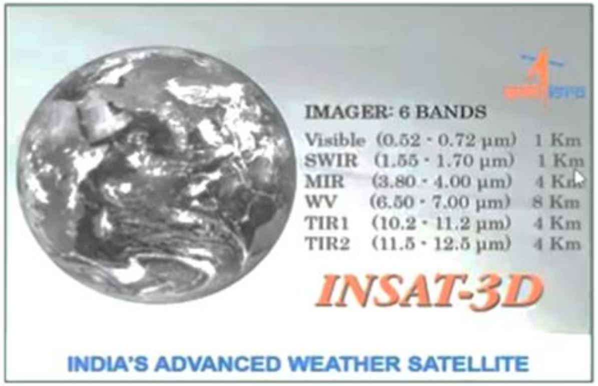
INSAT-3A, a multipurpose satellite launched in April 2003. It provides communication, weather and search & rescue services.

Communication payload: 12 Normal C-band transponders; 6 uppe extended C-band transponders; 6 Ku-band transponders.

Meteorological Payload VHRR (VIS, TIR, WV) at 2x2, 8x8, 8x8 km respectively; CCD (VIS, IR, SWIR) 1x1 km

Kalpana-1 is the first dedicated meteorological satellite launched in Sept, 2002. The satellite features a Very High Resolution scanning Radiometer (VHRR), for three-band images and a Data Relay Transponder (DRT) payload.

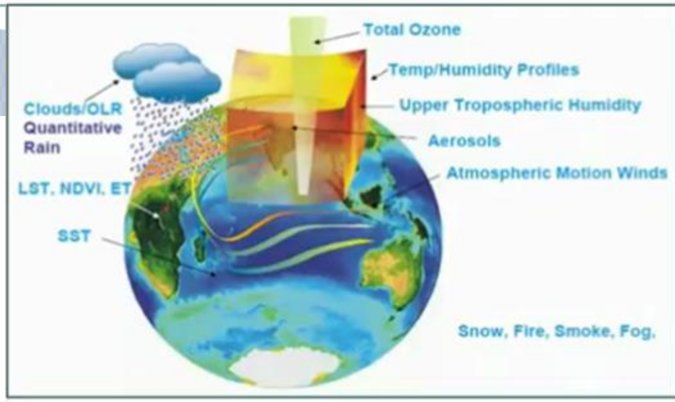
INSAT-3D/3DR Meteorological Satellites



Parameter	Imager	Sounder
Telescope Aperture	310 mm	310 mm
No. of Channels	6	19 (18 infrared + 1 Visible)
IFOV	1 km (Visible and SWIR) 4 km (MIR, TIR-1 & TIR-2) 8 km (Water Vapor)	10 km
Frame Time	~27 minutes	160 minutes for 6000x 6000km area
Signal Quantization	10 bits	14 bits

- Round the clock imaging from 36K Km
- Imaging every 15 min with INSAT-3D & INSAT-3DR
- 6-channel imager and 19-channel sounder
- Photodiodes as detector
- Filter wheel for sounder channel selection
- E-W scanning & N-S stepping for coverage of Earth disk
- More than 20 Geophysical parameter extraction
- Weather monitoring and forecasting

INSAT-3D: 82^0 E
INSAT-3DR: 74^0 E



Sounder Products

T/Q- profile, integrated Ozone

Derived products: Geopotential height, layer ppt water, TPW, Lifted Index, Wind Index, Dry microburst Index

Imager Products

Precipitation, AMV , OLR, UTH, Fire, smoke, Fog, SST

Geophysical parameters from Imager INSAT-3D/INSAT-3A/Kalpana-1

No.	Parameter	Input Channels/Data
1	Cloud Mask (CM)	MIR, TIR-1, TIR-2
2	Outgoing Longwave Radiation (OLR)	WV, TIR-1, TIR -2
3	Quantitative Precipitation Estimation (QPE) GPI, IMRSA and HE	TIR-1, TIR- 2
4	Sea Surface Temperature (SST)	SWIR, MIR, TIR – 1, TIR – 2
5	Snow Cover	VIS, SWIR, TIR – 1, TIR – 2
6	Fire	MIR , TIR -1
7	Smoke	VIS, MIR, TIR –1, TIR –2
8	Aerosol	VIS, TIR –1, TIR -2
9	Cloud Motion Wind Vector (CMV)	VIS, TIR-1, TIR –2
10	Water Vapor Wind Vector (WVWV)	WV, TIR-1,TIR –2
11	Upper Tropospheric Humidity (UTH)	WV, TIR-1, TIR –2
12	Fog	SWIR, MIR, TIR-1, TIR-2

Thank You

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