CEN 201
Geospatial Engineering - II

3. Remote Sensing

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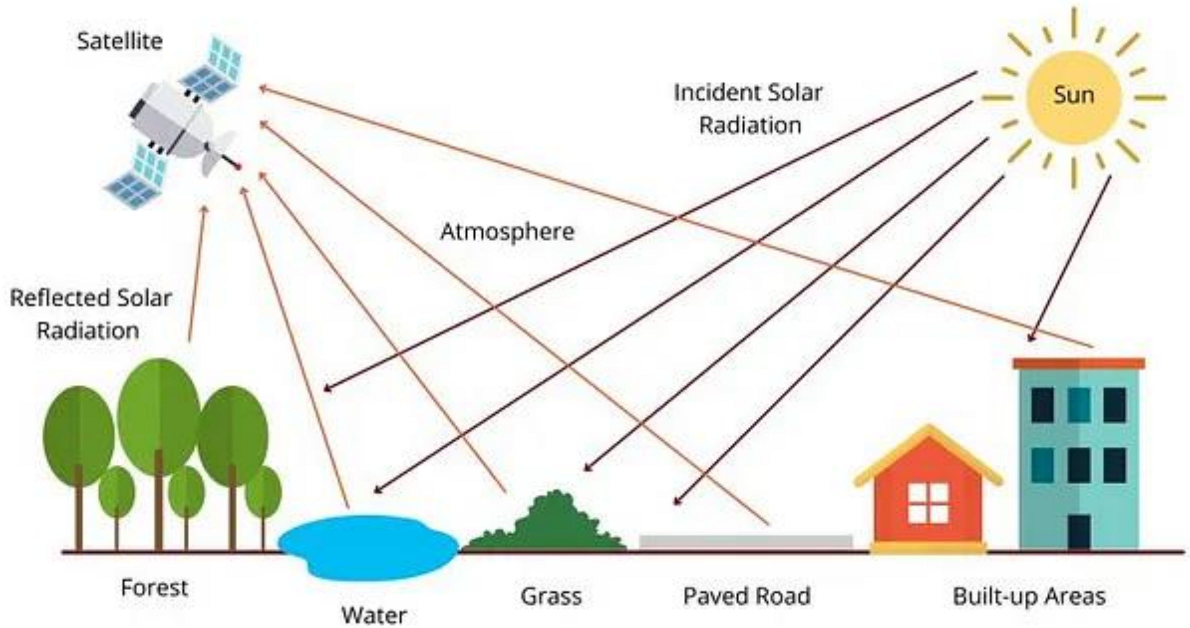
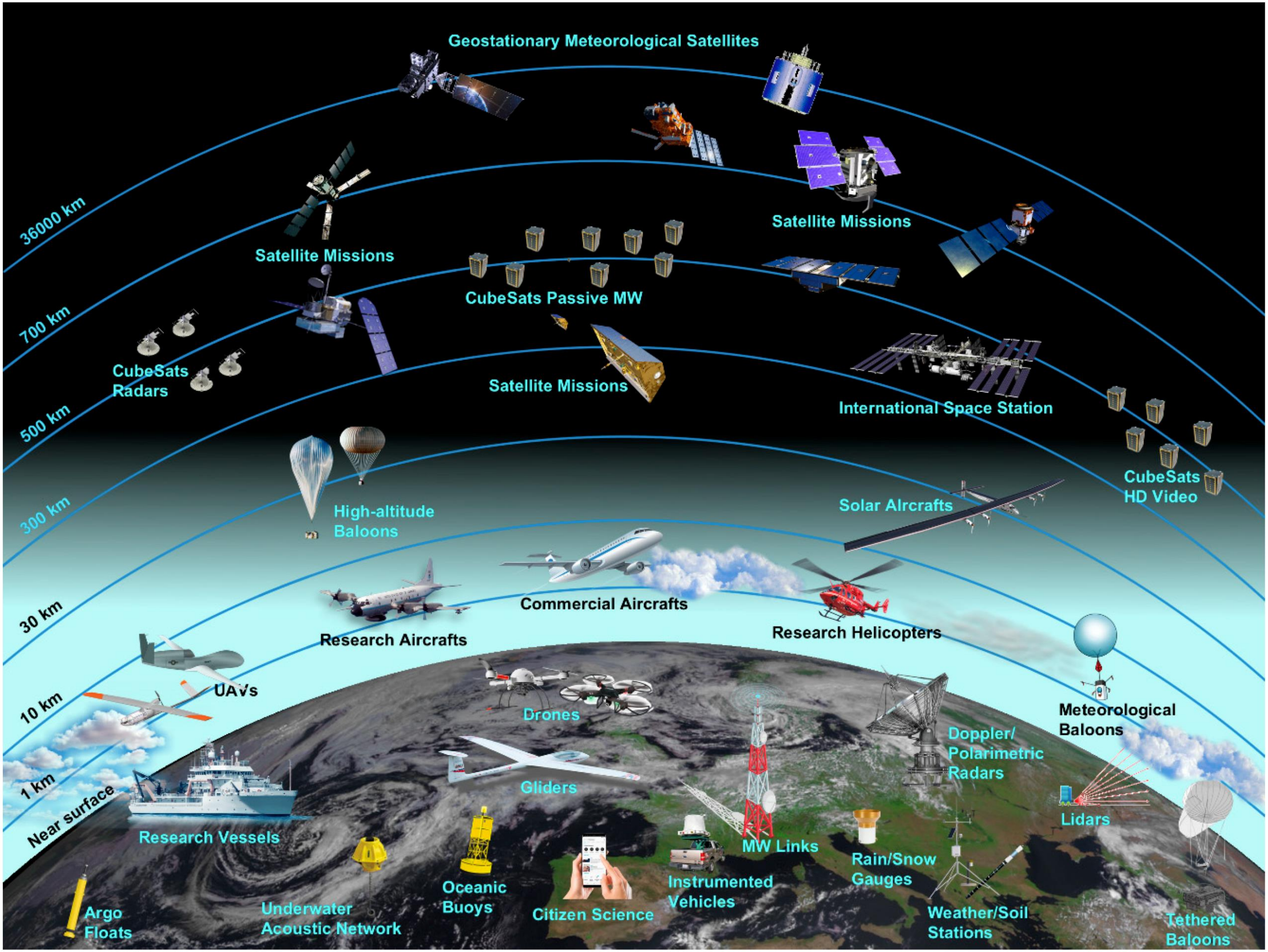
***CE4-6 Batch**

What is remote sensing

- "Science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation"
- We are concerned with aerial/space-borne remote sensing involving electromagnetic radiation (EMR)



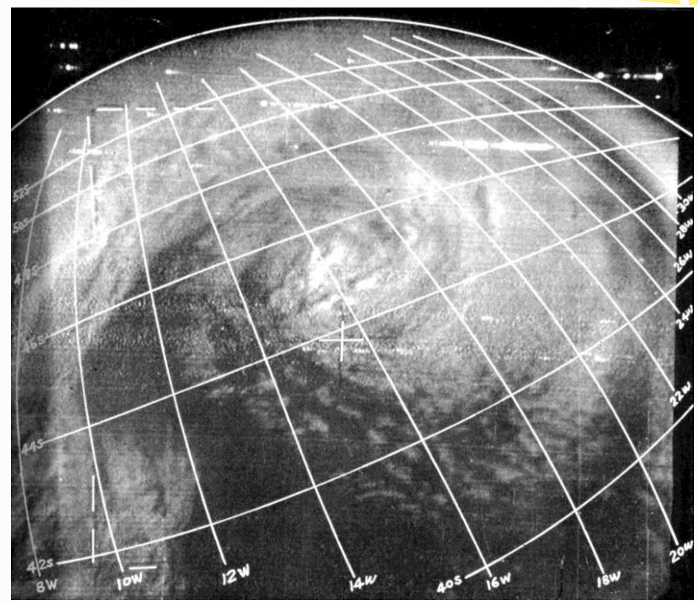
https://crisp.nus.edu.sg/~research/tutorial/optical.htm


Geostationary Meteorological Satellites
36000 km
Satellite Missions
Satellite Missions
700 km
CubeSats Passive MW
CubeSats Radars
500 km
Satellite Missions
International Space Station
CubeSats HD Video
300 km
High-altitude Baloons
Solar Aircrafts
30 km
Commercial Aircrafts
Research Aircrafts
Research Helicopters
10 km
UAVs
Drones
Meteorological Baloons
1 km
Doppler/ Polarimetric Radars
Near surface
Gliders
Lidars
Research Vessels
MW Links
Rain/Snow Gauges
Instrumented Vehicles
Oceanic Buoys
Weather/Soil Stations
Argo Floats
Underwater Acoustic Network
Citizen Science
Tethered Baloons

History of satellite remote sensing - TIROS

TIROS-1 (or **TIROS-A**) was the first full-scale weather satellite, launched in 1960. It had TV video cameras for taking earth cloud cover pictures. Weather forecasting was deemed the most promising application of space-based observations.

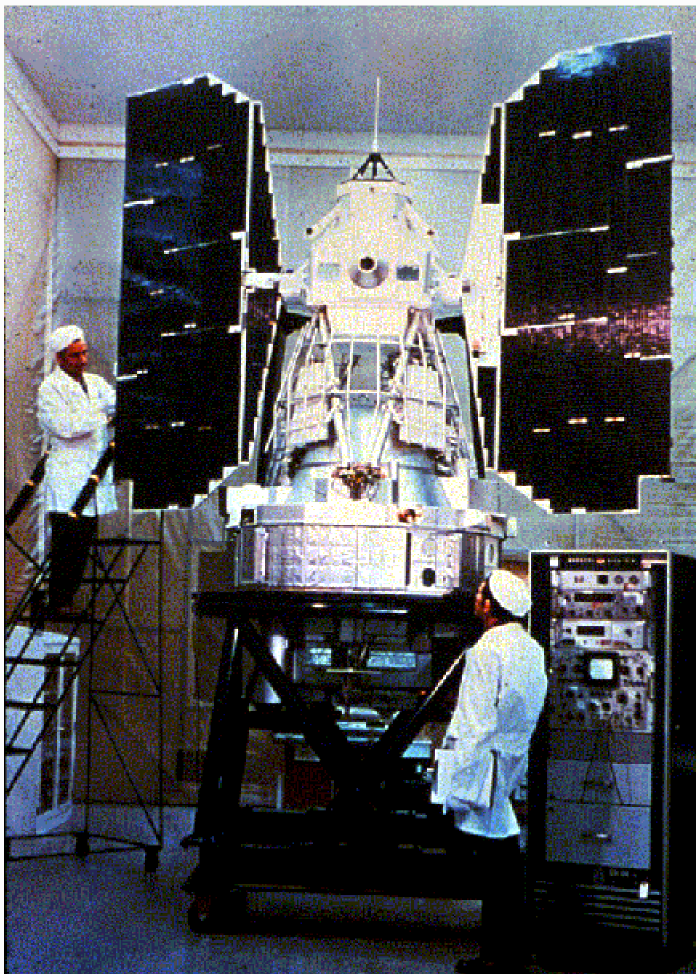
The TIROS-1 magnetic tape data recorder.

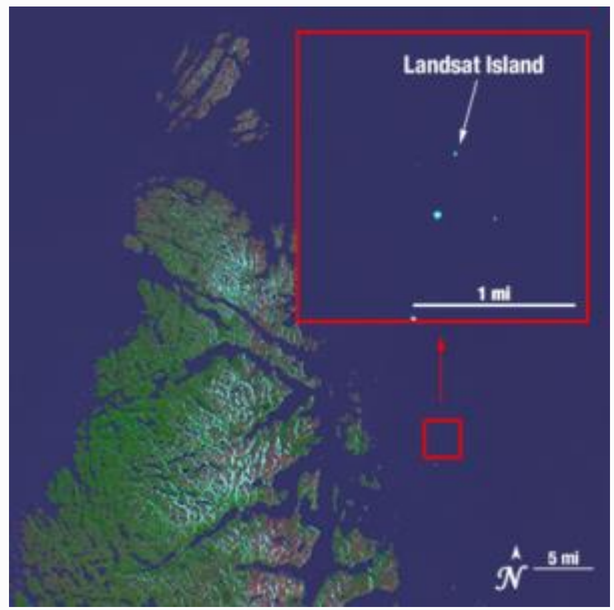


TIROS I image showing a cyclone in South Atlantic, taken on April 28, 1960

History of satellite remote sensing – Landsat1

It was the first Earth-observing satellite to be launched with the express intent to study and monitor our planet's landmasses.
Its overpass was at 9:42AM, with a revisit duration of 18 days.

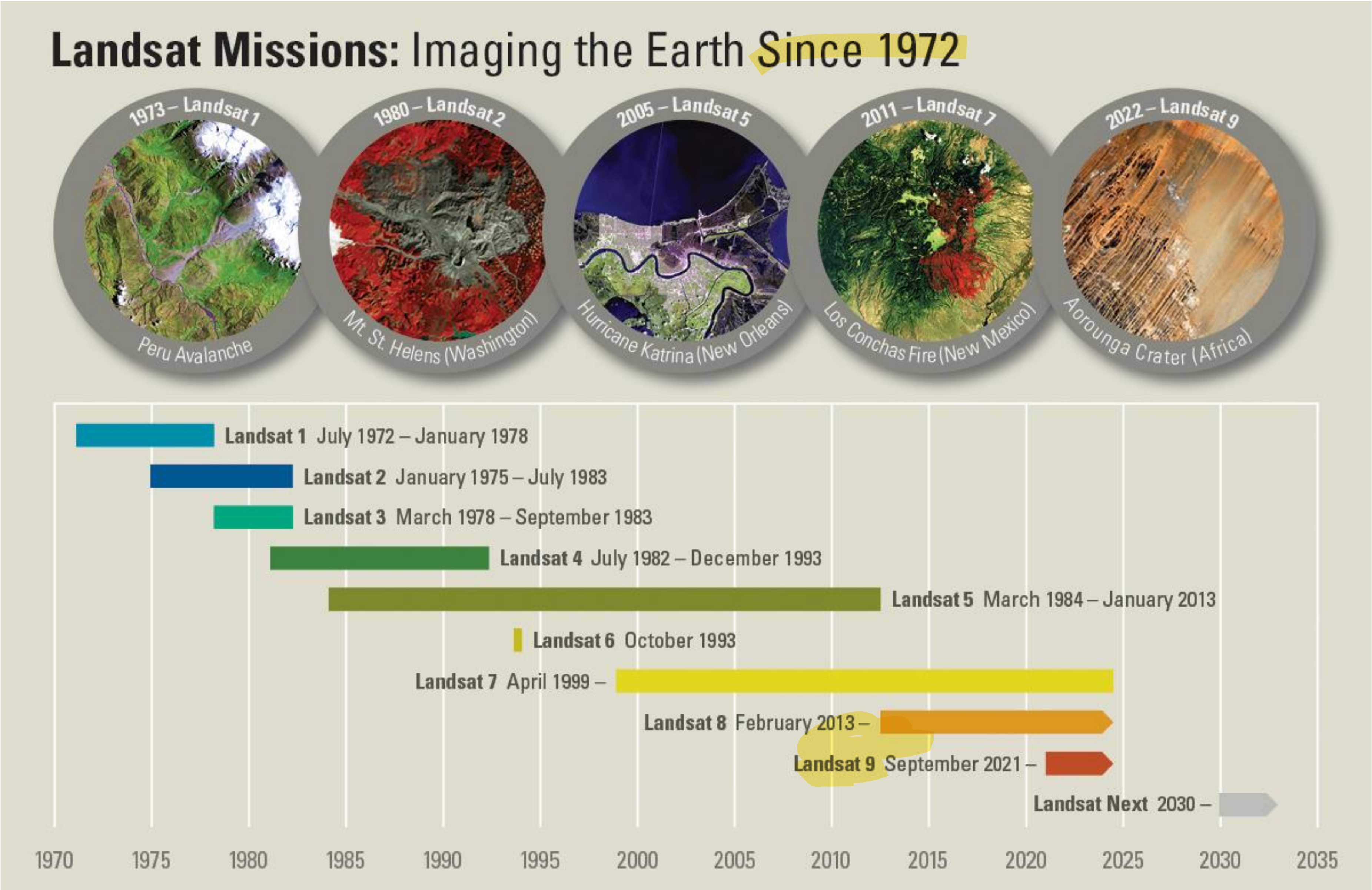




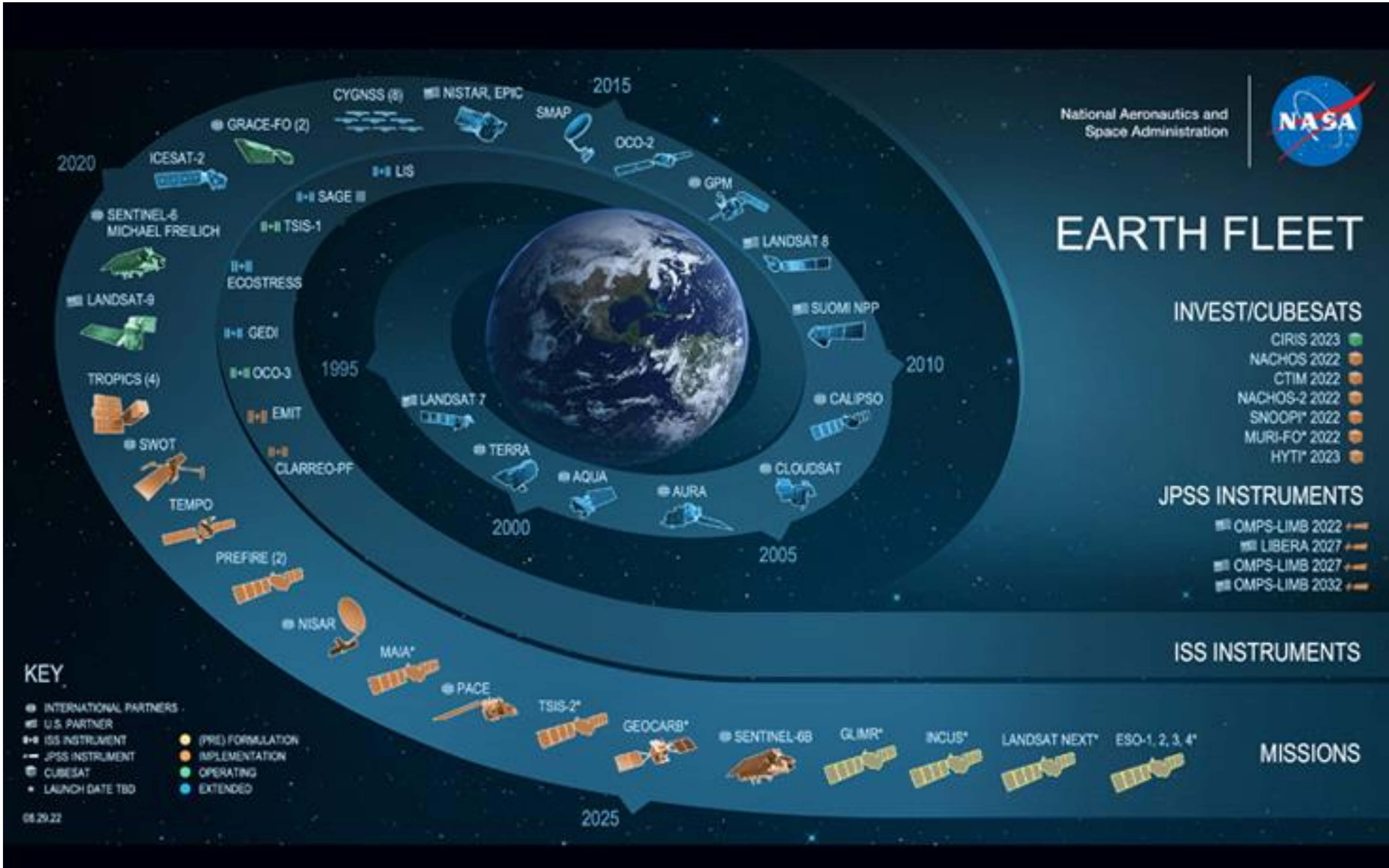
In 1976, Landsat data were used as part of a Canadian coastal survey. The Landsat images helped discover a number of uncharted features; the largest of these was a small island twenty kilometers off the northeast coast of Labrador.

NASA's Earth Resources Technology Satellite, later renamed as Landsat1, was launched on July 23, 1972

Landsat missions provide the longest archive of earth observation



Earth observation missions by NASA



Earth observation missions by ESA

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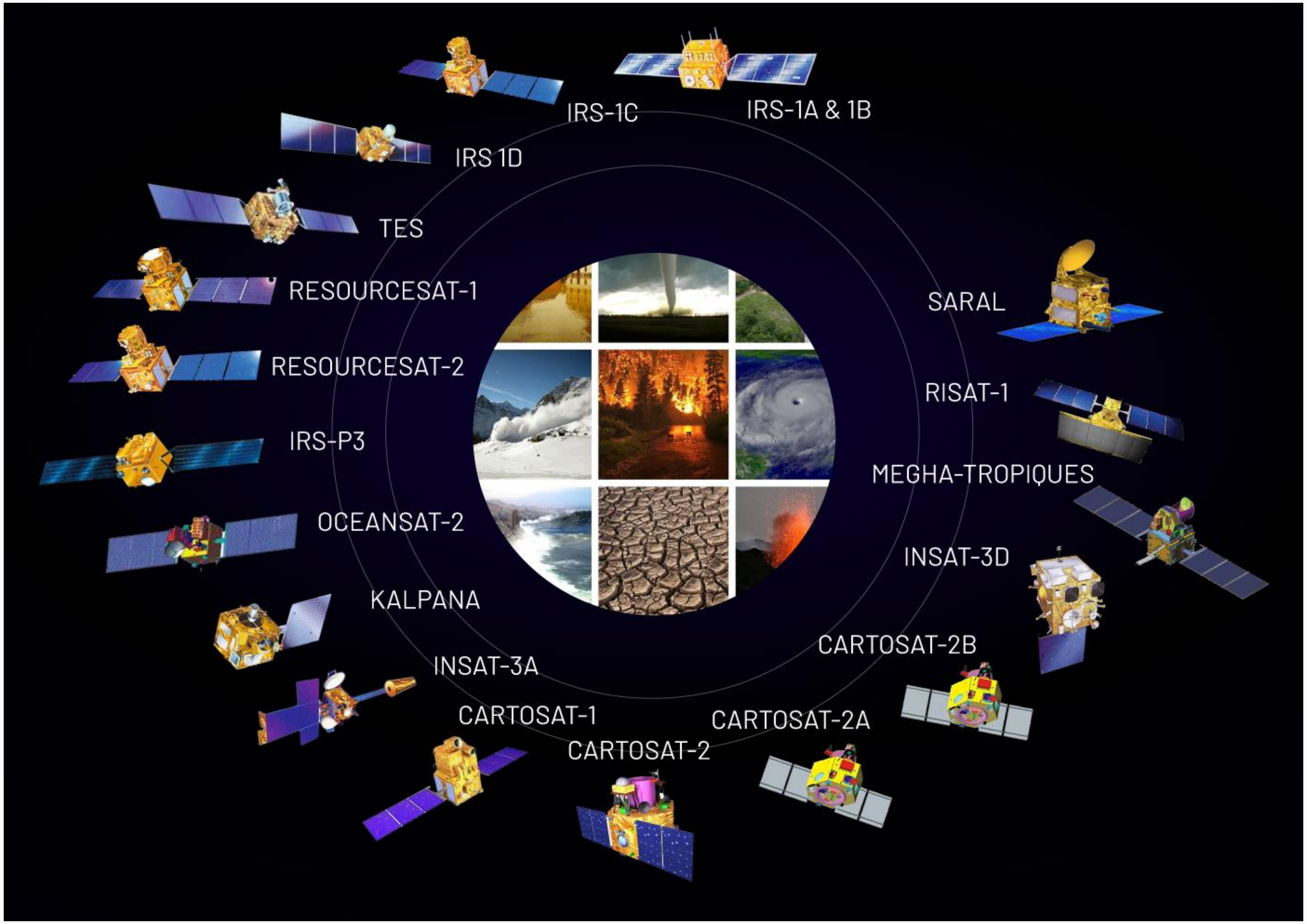
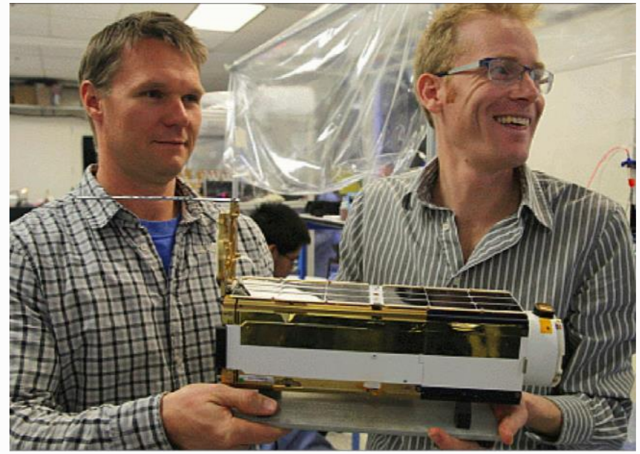
Earth observation missions by ISRO

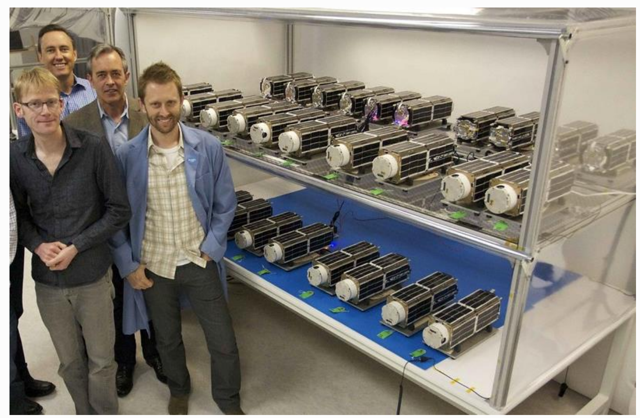


The Indian Remote Sensing (IRS) system is the largest constellation of remote sensing satellites for civilian use in operation today in the world, with 11 operational satellites. Available at https://bhuvan.nrsc.gov.in/home/index.php

Current trends

NASA's Landsat 8 satellite installed in payload fairing (2013)





Planet Lab's Dove nanosat (2013)

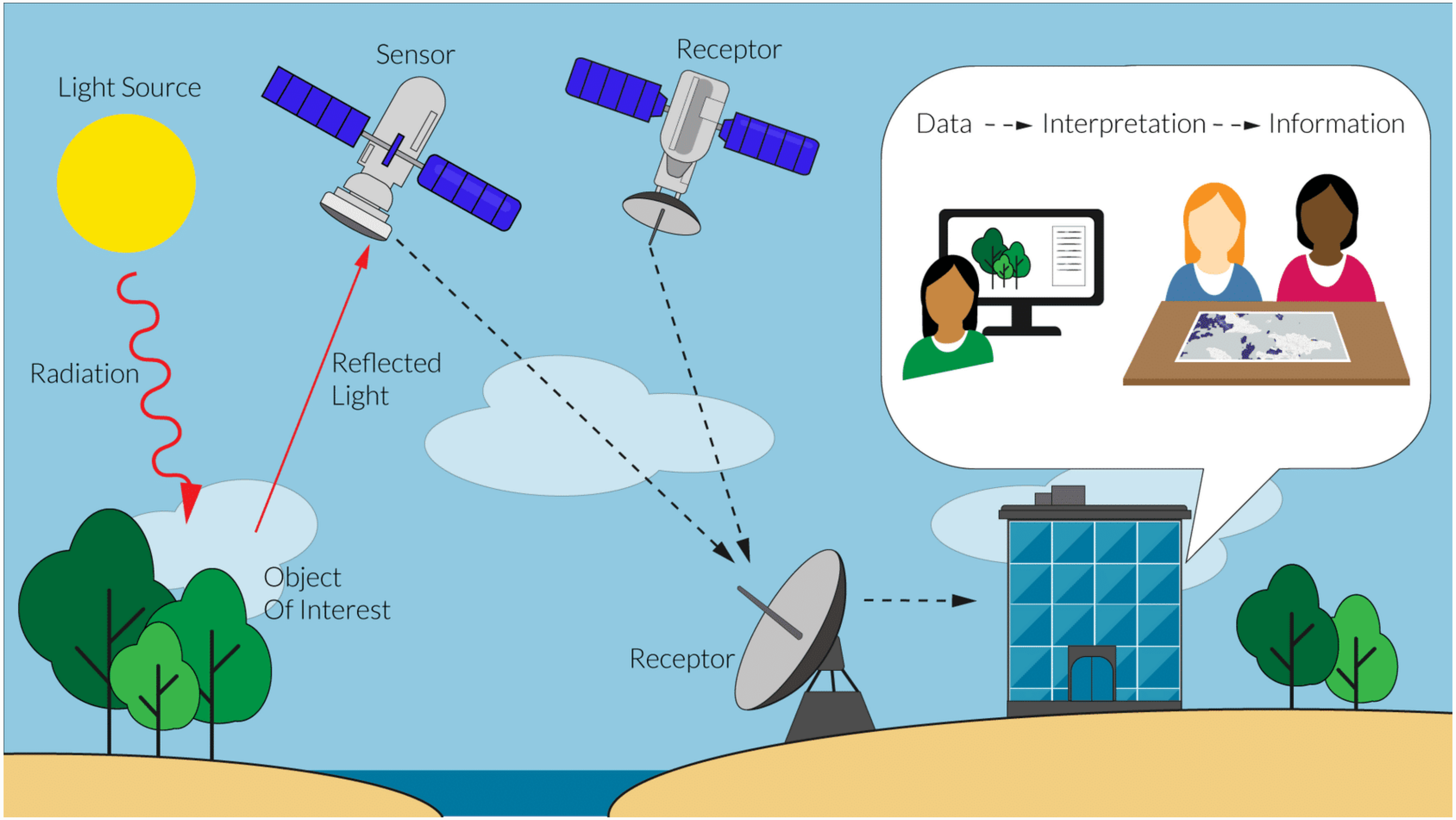
SatSure

GALAXEYE

pixxel

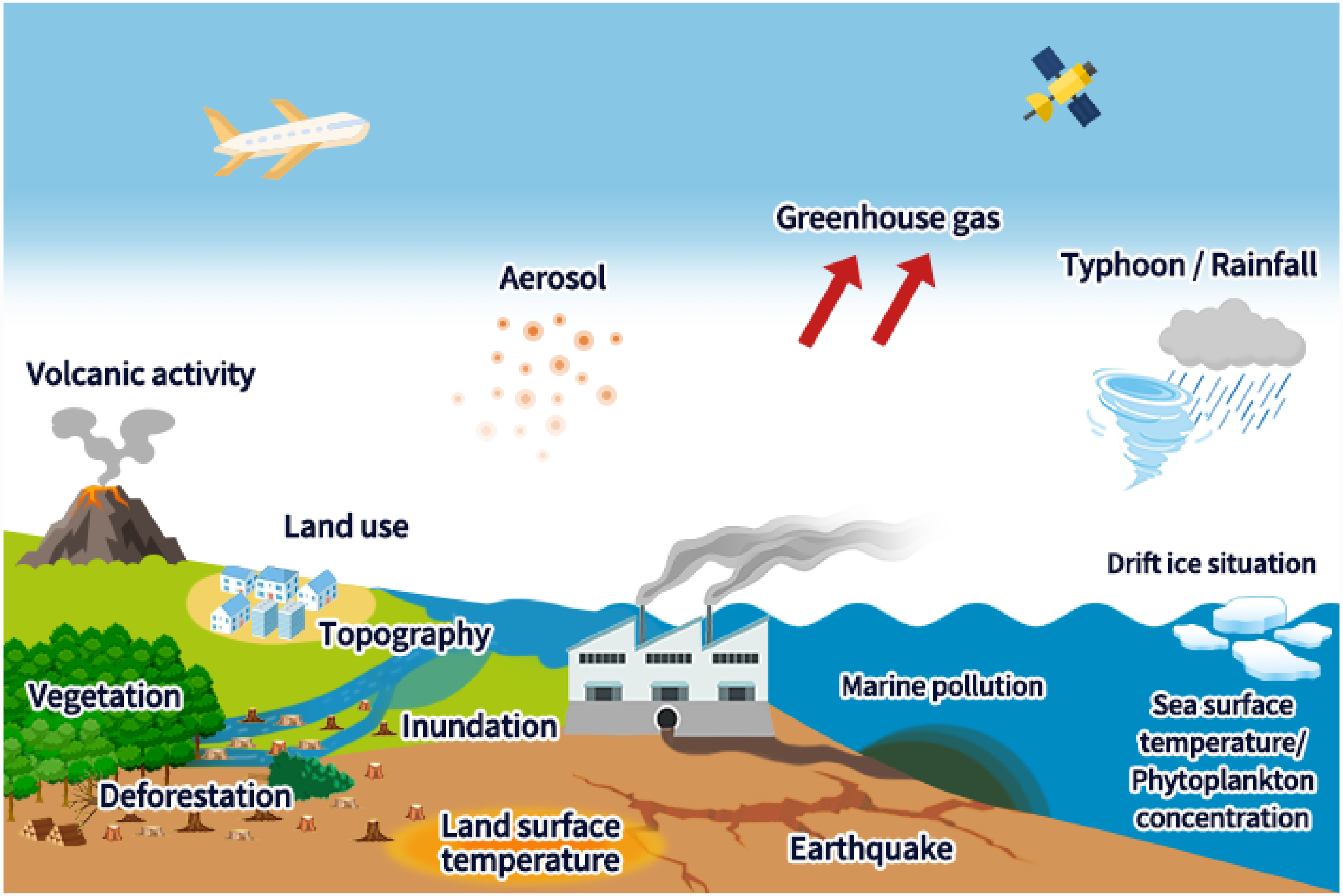
Indian small-sat startups

Components of remote sensing



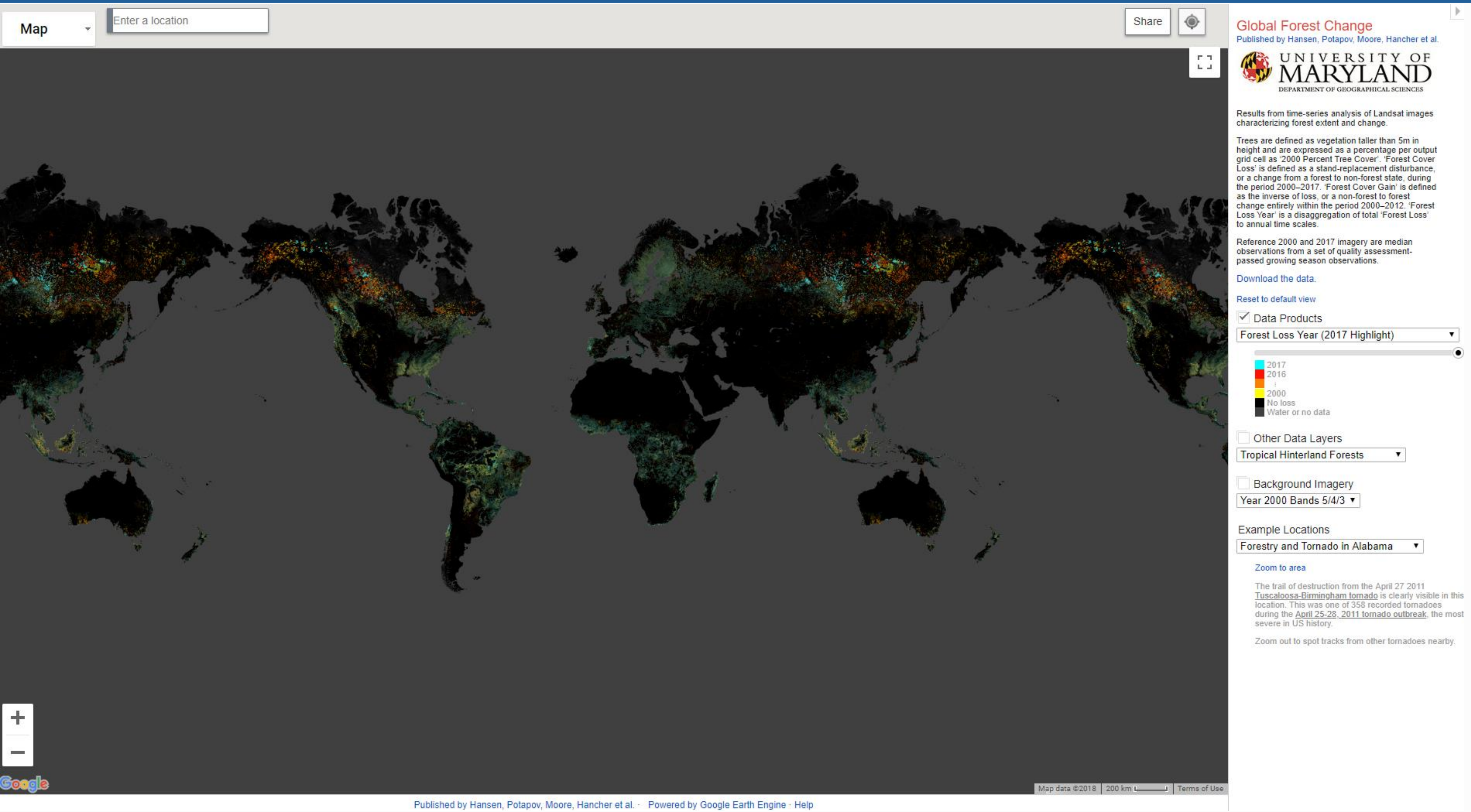
1. Energy source or illumination,
2. Radiation and atmosphere,
3. Interaction with object
4. Recording of energy by sensor,
5. Transmission, reception and processing,
6. Interpretation and analysis,
7. Application

Applications of satellite remote sensing



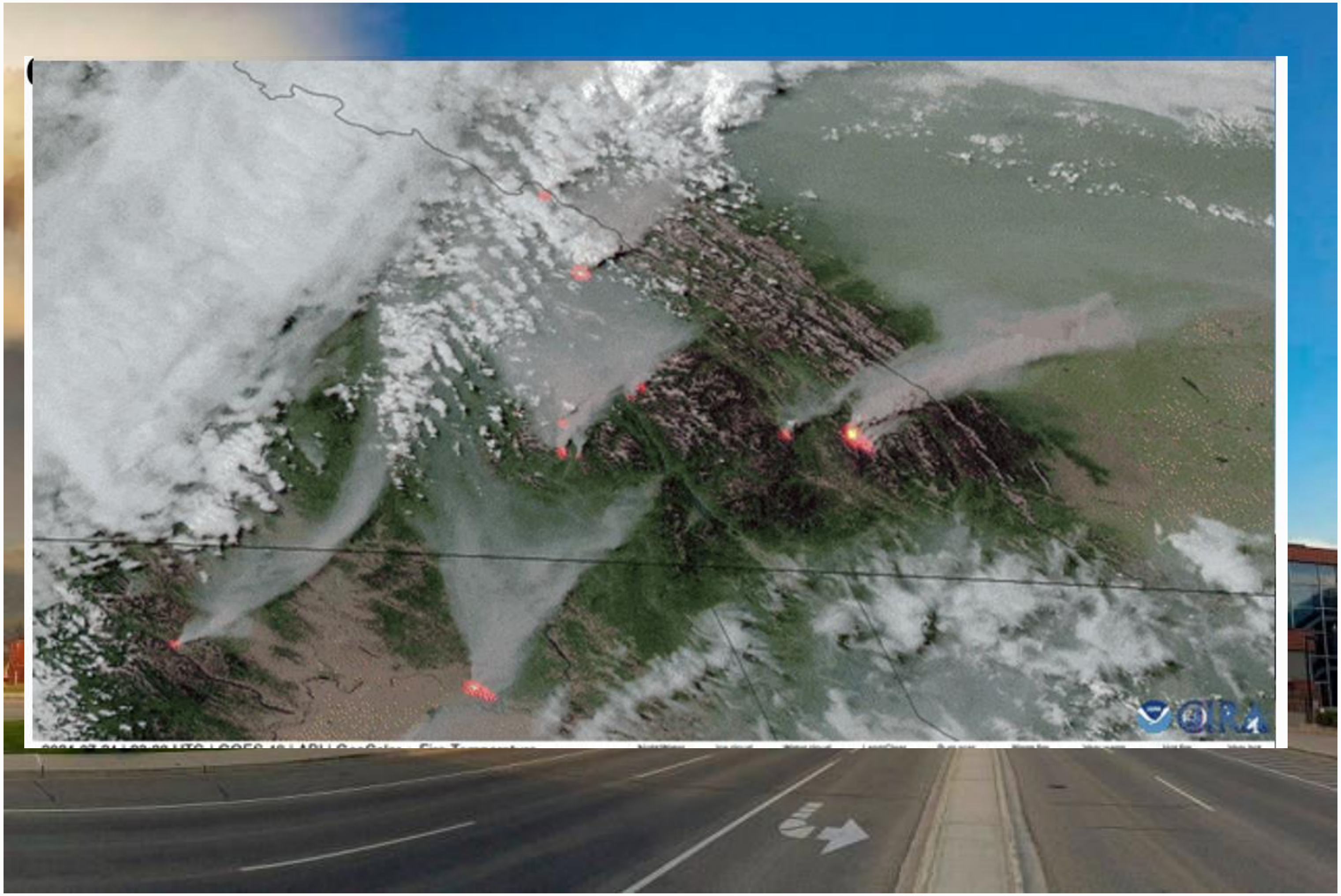
- https://earth.jaxa.jp/en/eo-knowledge/eosatellite-type/index.html

Application: Global forest change



- https://earthenginepartners.appspot.com/science-2013-global-forest
-

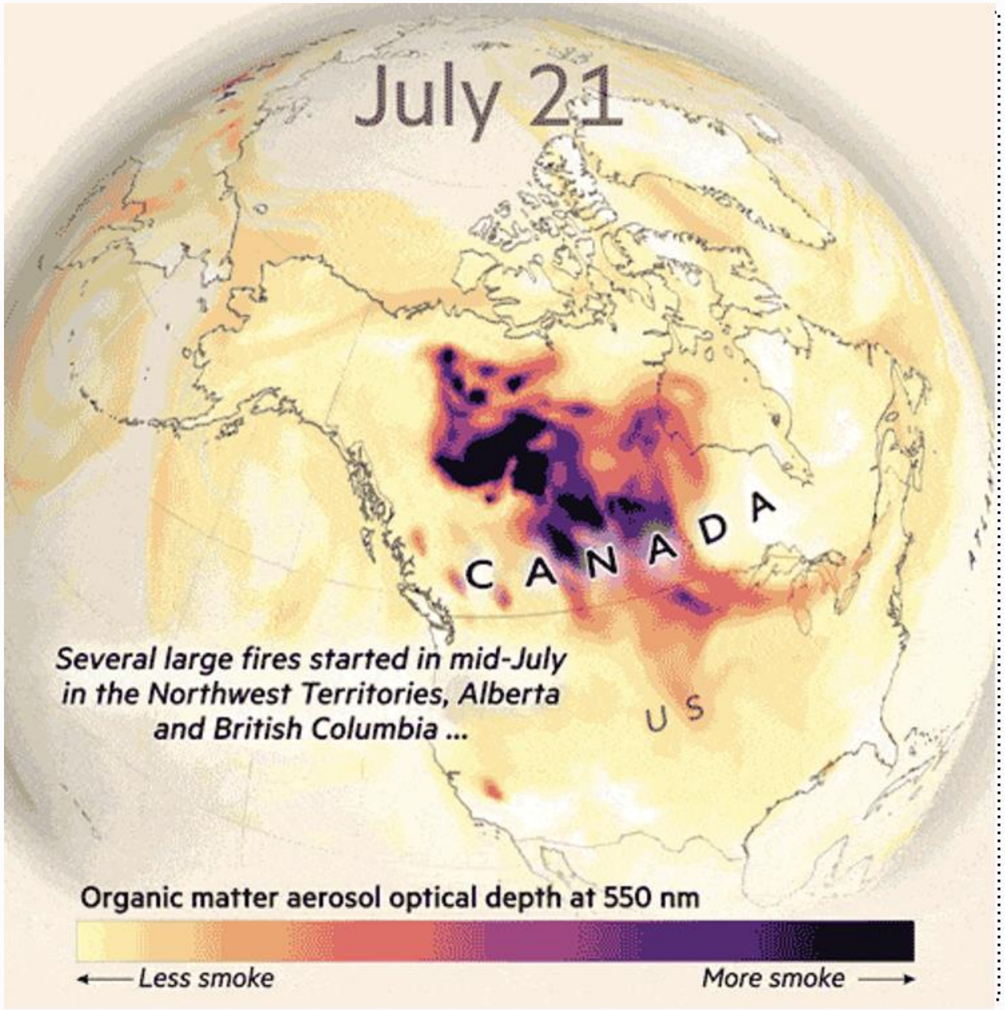
Application: forest fire



Wildfires in the Pacific Northwest, Canada (2024)

https://www.nesdis.noaa.gov/news/wildfires-rage-the-pacific-northwest

Application: forest fire and pollution



https://www.ft.com/content/8a63bec7-048c-40fb-b3ae-717419f4469f?emailId=706f2661-c3c8-42da-942f-940b9e539068&segmentId=ccee9840-6c9b-2776-04de-b87d446b96a1

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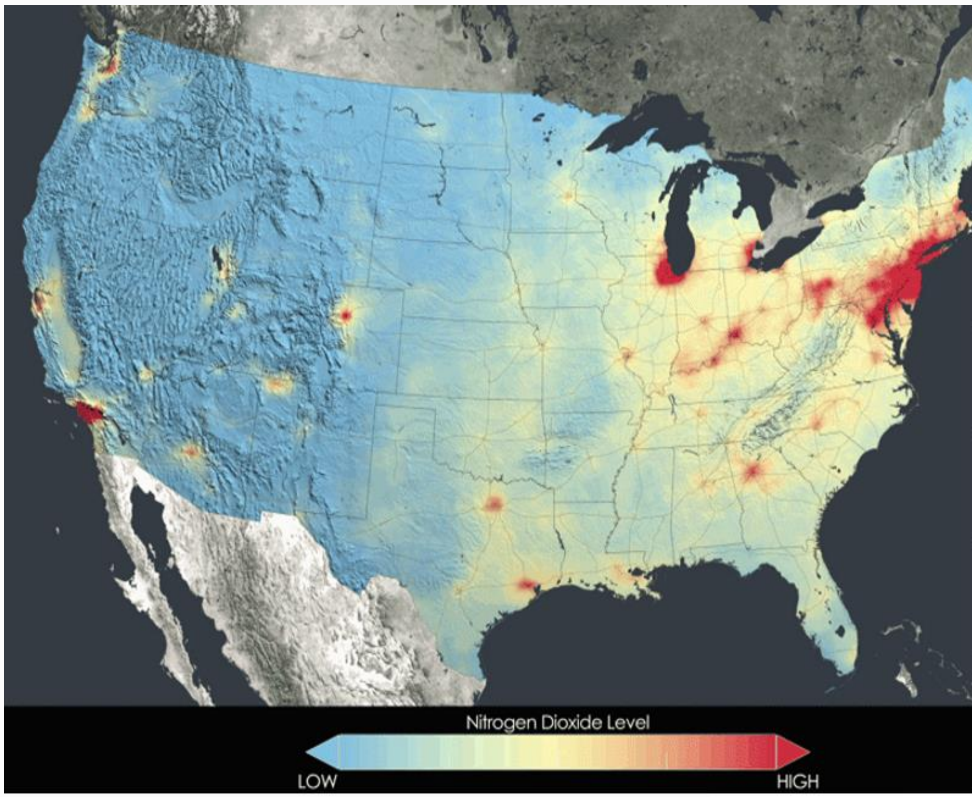
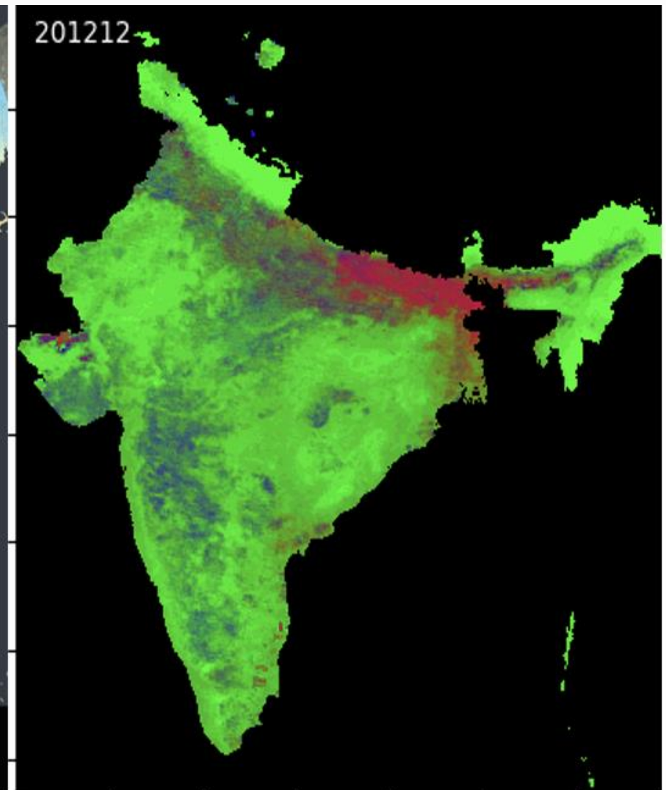
Application: air pollution



Nox concentration change 2005 to 2011



Fine aerosol monthly variation

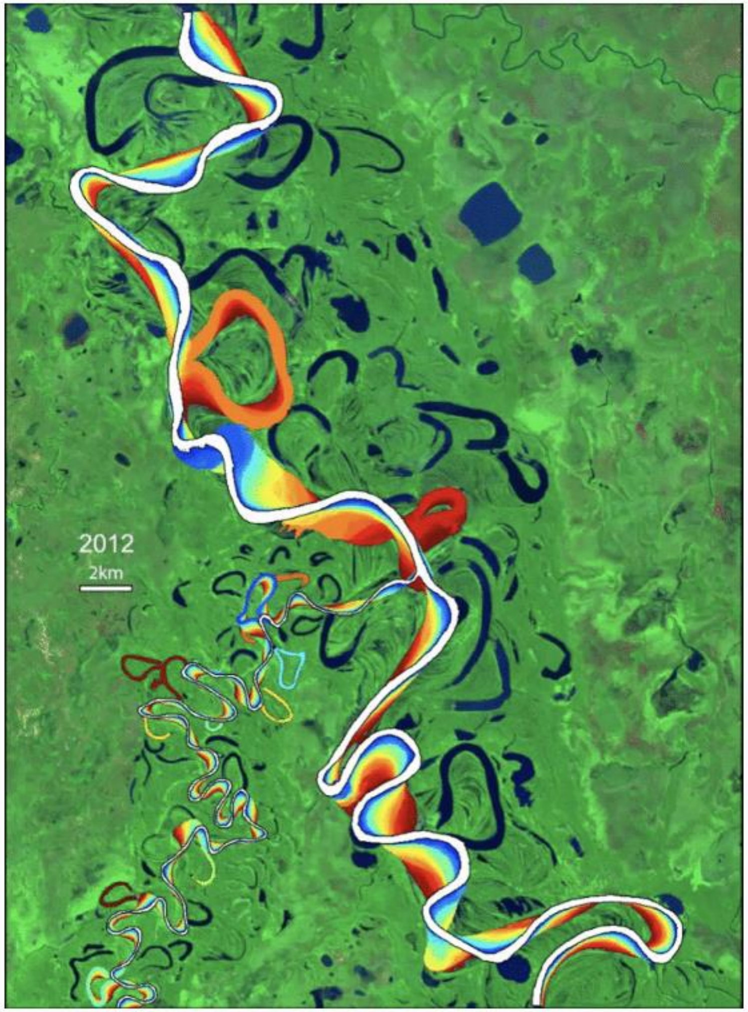
Misra, P.; Fujikawa, A.; Takeuchi, W. Novel Decomposition Scheme for Characterizing Urban Air Quality with MODIS. *Remote Sens.* **2017**, *9*, 812. https://doi.org/10.3390/rs9080812

Application: river morphology

River morphology

Bryk et al. UC Berkeley

Global Analysis of River Planform Change using the Google Earth Engine (2014)



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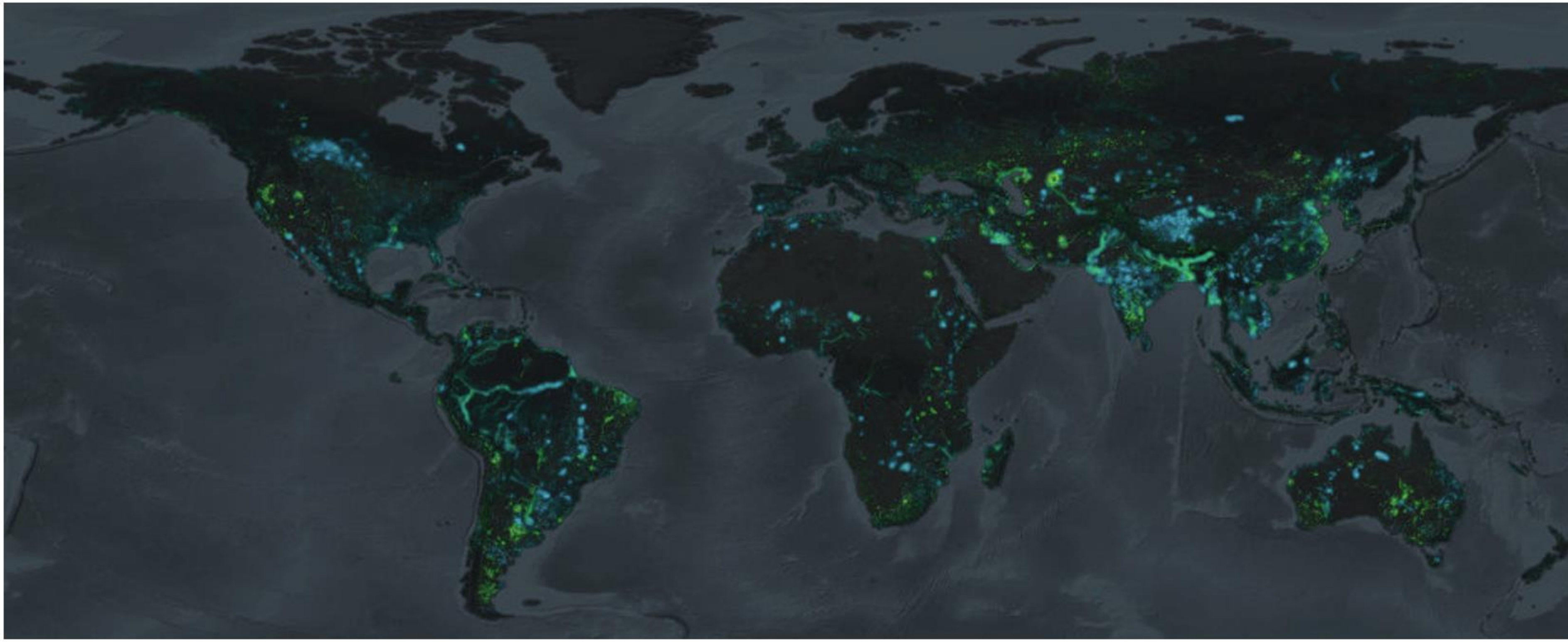
Application: surface water change



Blue lighting shows where land was converted into water over the period 1985–2015. Green lighting shows where water was converted into land over the same period. The intensity of the colours highlights the spatial magnitude of the change.

http://aqua-monitor.appspot.com/

Earth's surface water change over the past 30 years

Gennadii Donchyts, Fedor Baart, Hessel Winsemius, Noel Gorelick, Jaap Kwadijk & Nick van de Giesen

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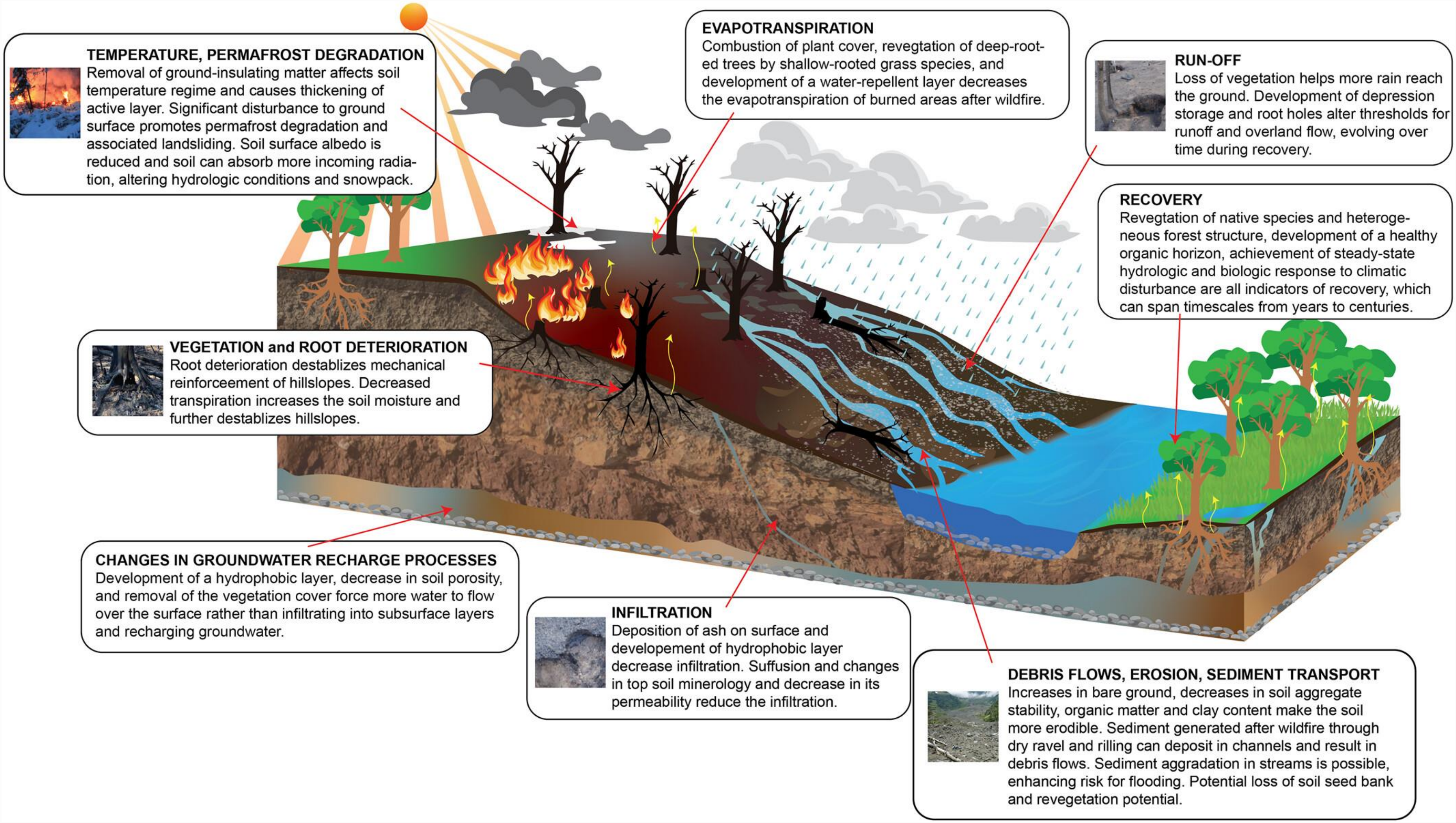
Application: fire and sedimentation



https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023EA003498

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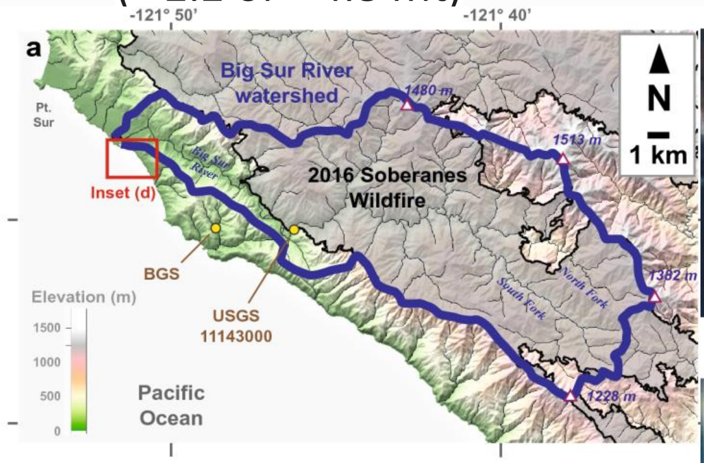
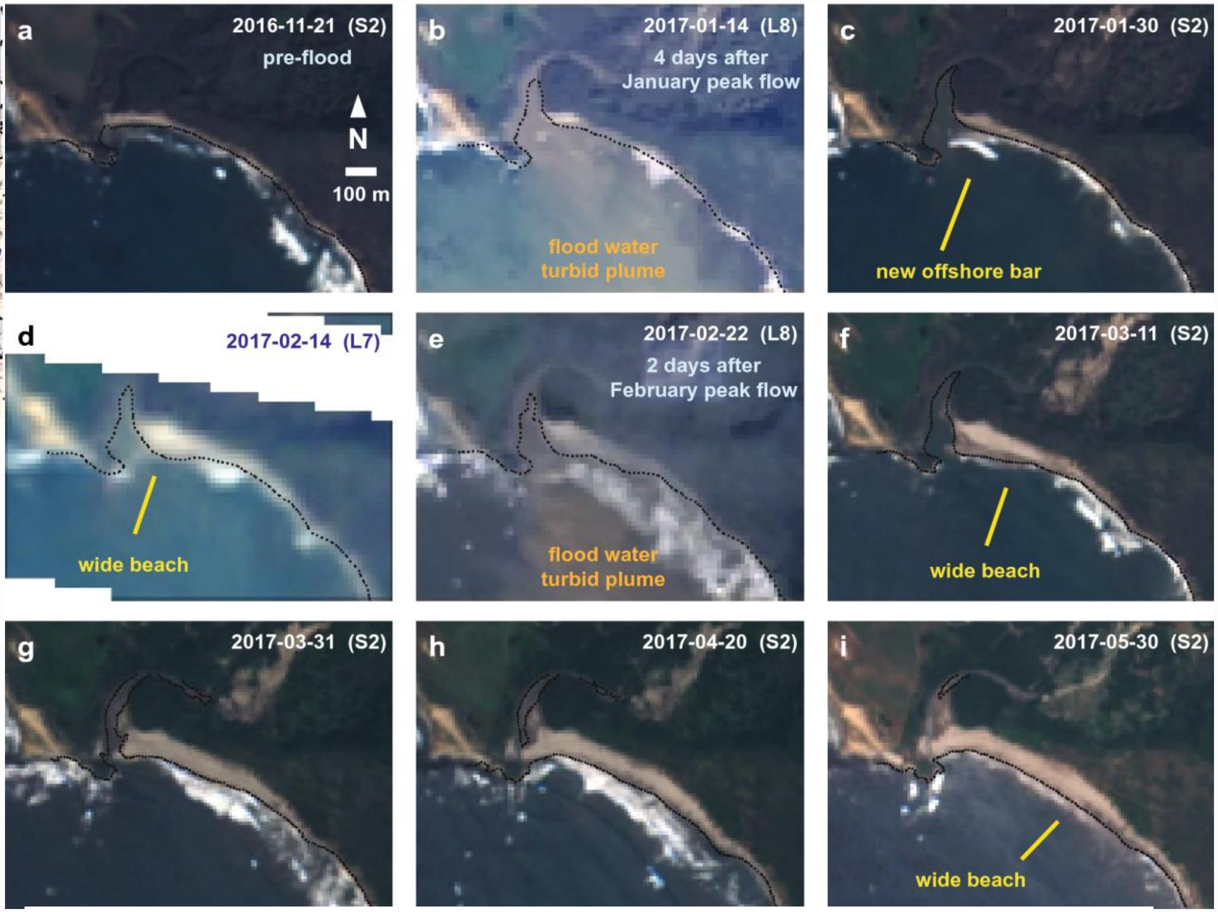
Application: fire, flood and sedimentation

A 2016 wildfire followed by record precipitation increased sediment discharge in the Big Sur River and resulted in almost half of the total river sediment load of the past 50 years (~ 2.2 of ~ 4.8 Mt)



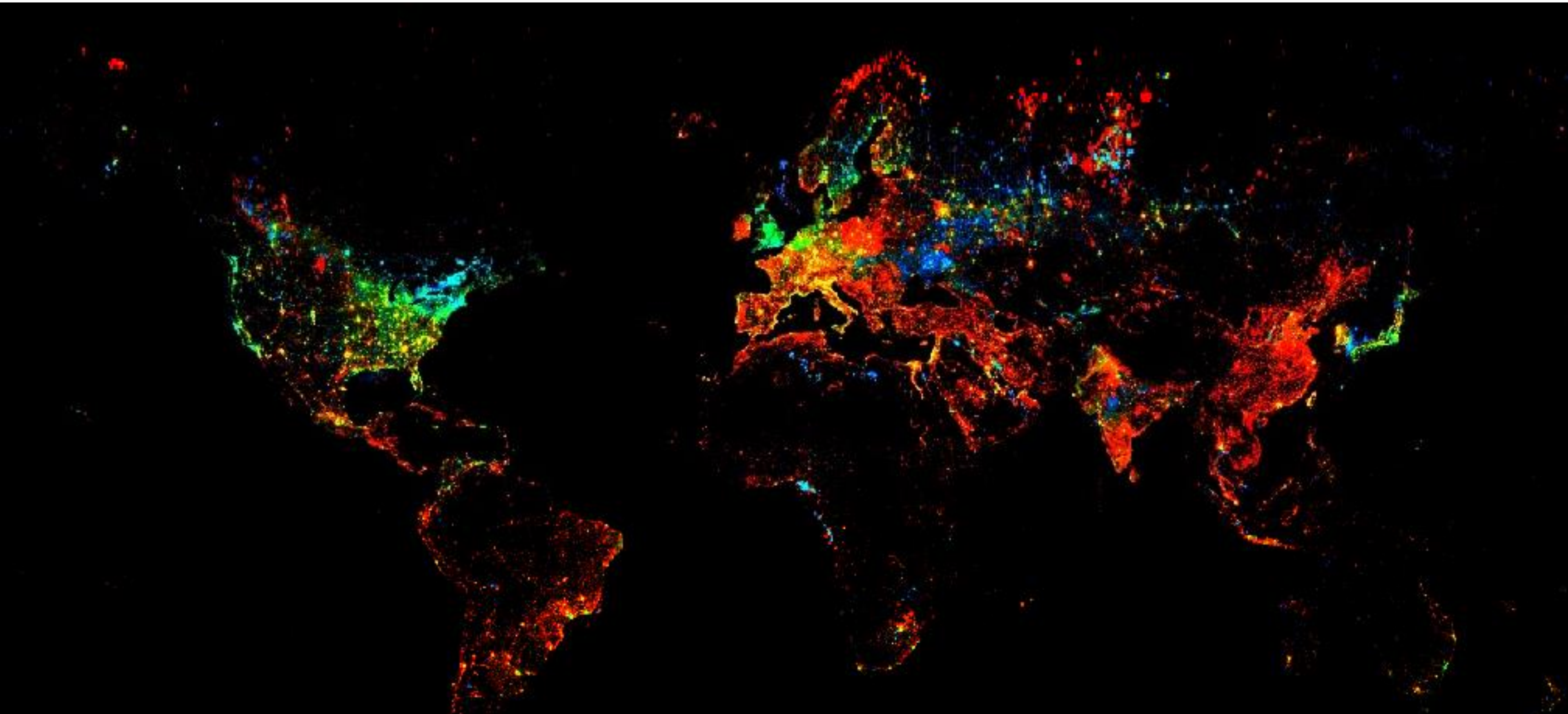
Watershed map of the Big Sur River watershed, including the boundaries of the 2016 Soberanes wildfire and sampling stations.



Sentinel-2 (S2) and Landsat (L7 and L8) imagery of the Big Sur River mouth highlighting coastal changes from river sediment contributions during the winter and spring of 2016–2017.

https://www.nature.com/articles/s41598-022-07209-0

Application: socio-economic development



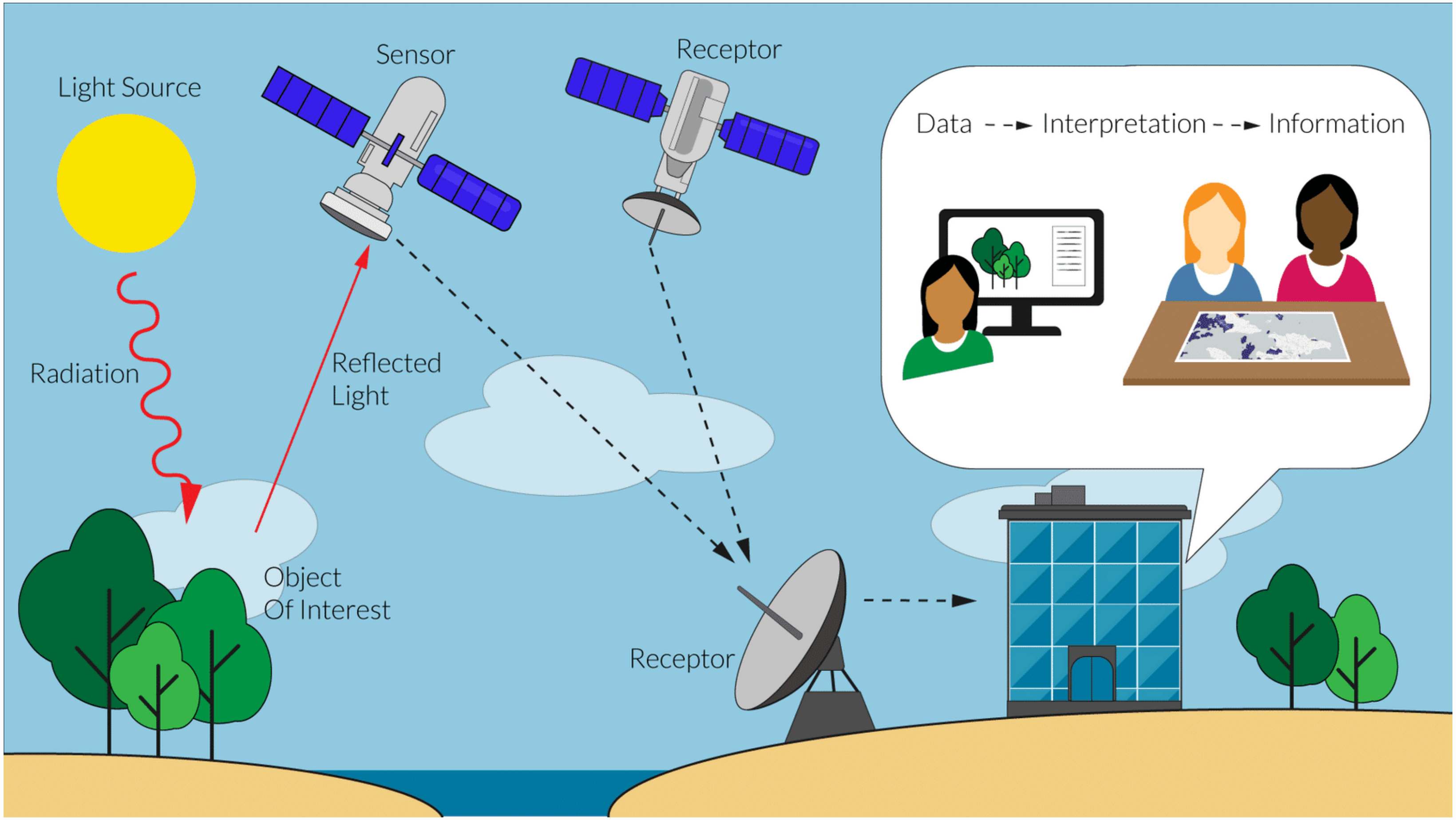
Global trend of night-time lights

(https://github.com/google/earthengine-api)
https://code.earthengine.google.com/7a2f8922437e3ba7c5ab2f871ccef4ca

Applications of remote sensing

- Land-use mapping
- Forest and agriculture applications
- Telecommunication planning
- Environmental applications
- Hydrology and coastal mapping
- Urban planning
- Infrastructural Planning
- Emergencies and Hazards
- Global change and Meteorology

Components of remote sensing



1. Energy source or illumination,
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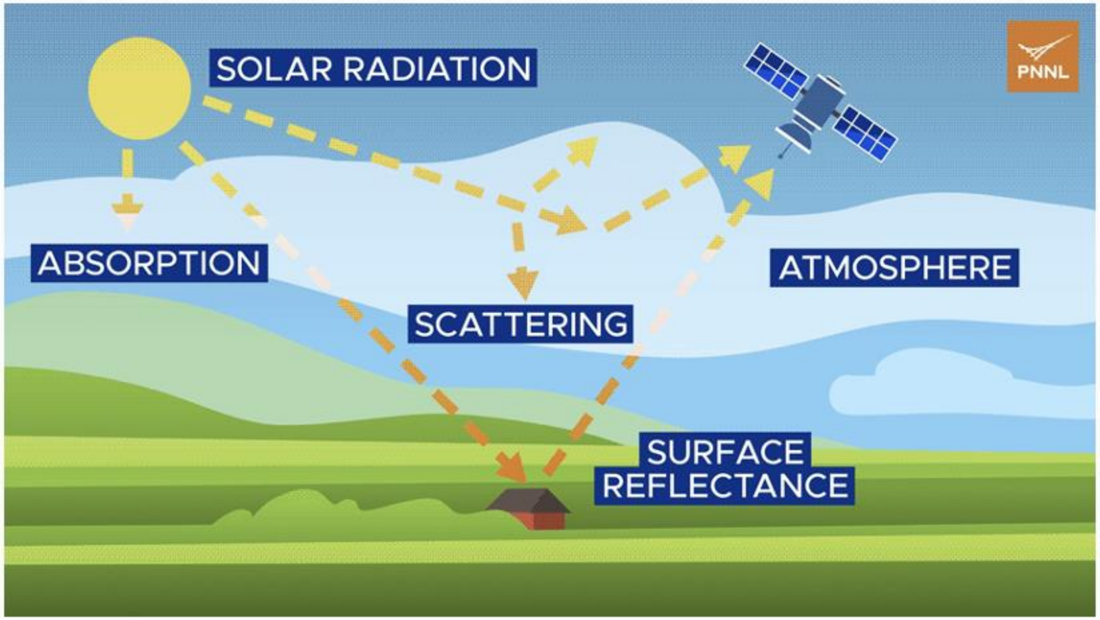
Ideal remote sensing components

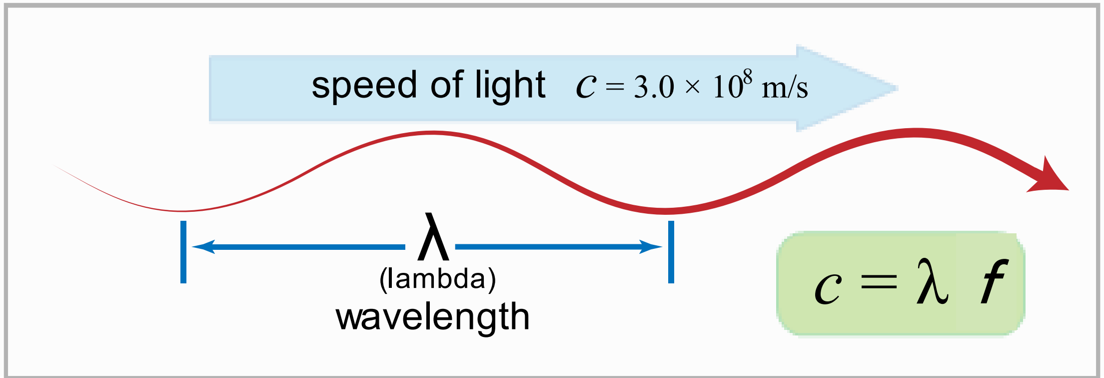


1. Source of EM energy (sun/**satellite**)
2. Non-interfering medium which with EM (atmosphere)
3. Matter on ground (objects)
4. Super-sensor to detect and record changes in EM

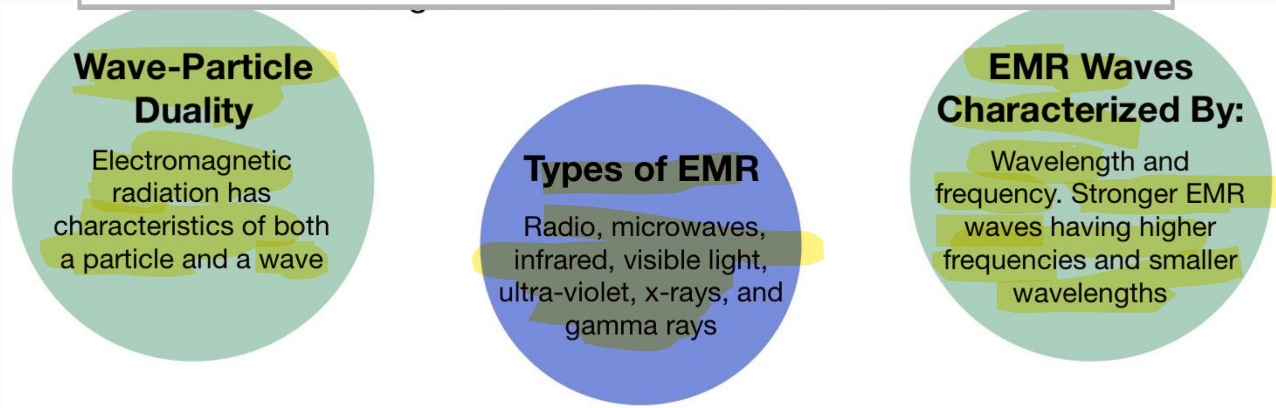
Light reaching sensor $I = I_o + I_s + I_d$

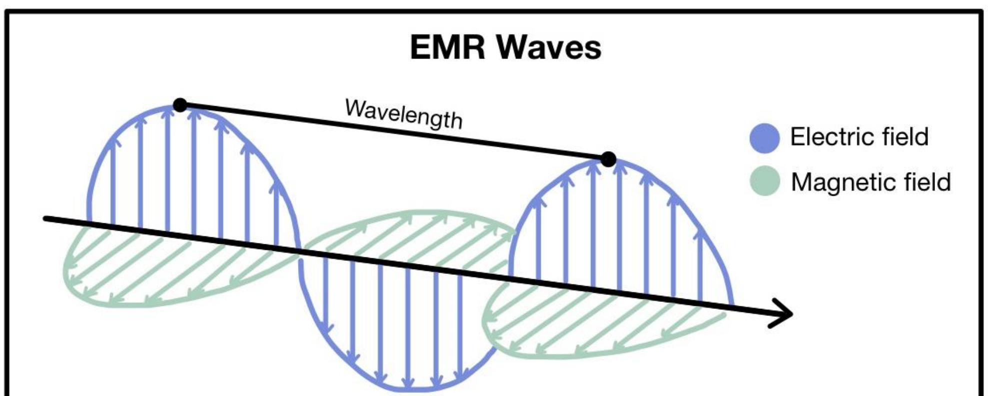
- I_o: scattered/absorb by the atmosphere directly to the sensor
- I_s: reflected from the ground
- I_d: diffuse light directed to the ground then to the atmosphere

All objects above 0K emit/radiate EM wave



$$E = hf = \frac{hc}{\lambda}$$

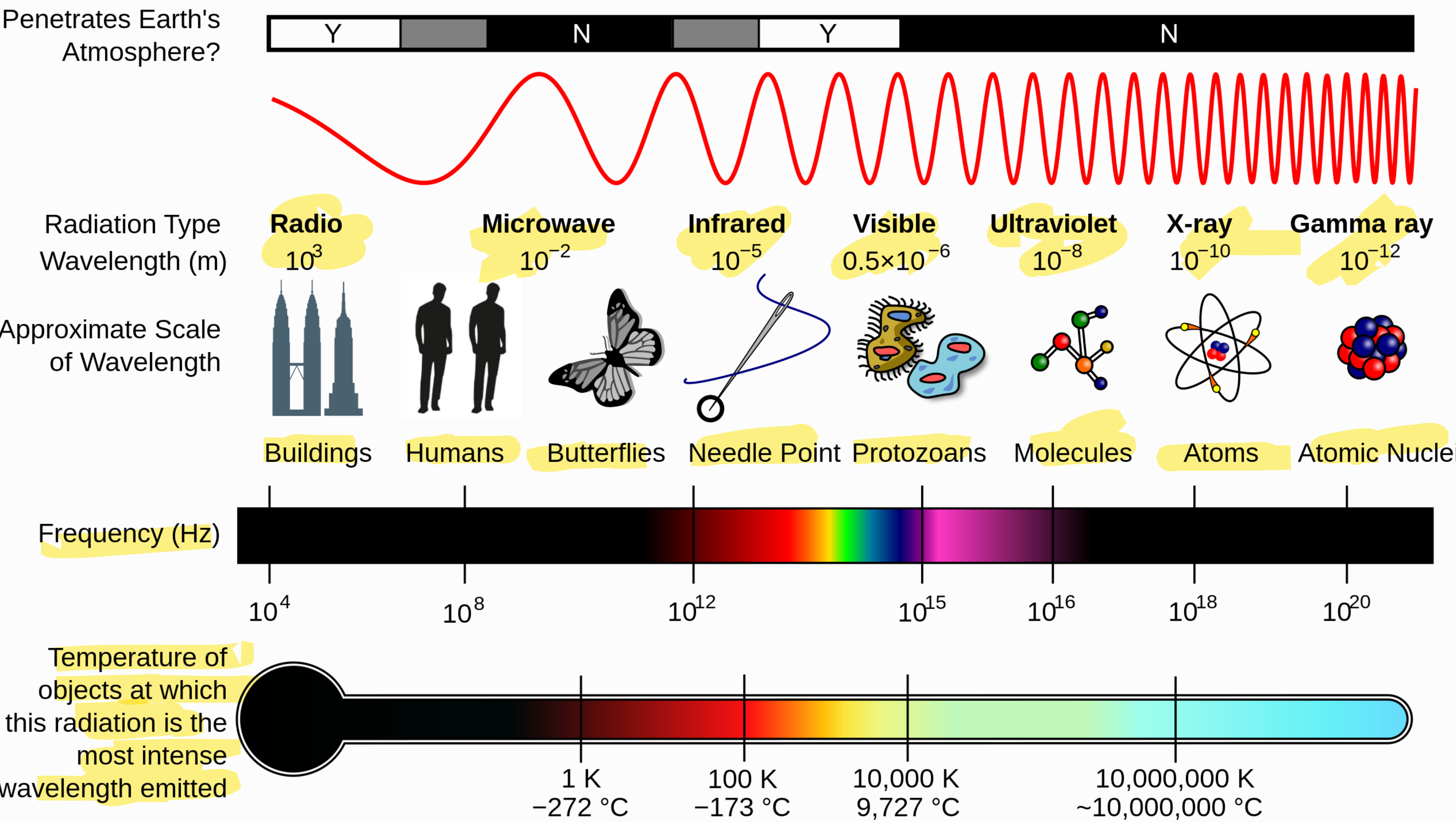




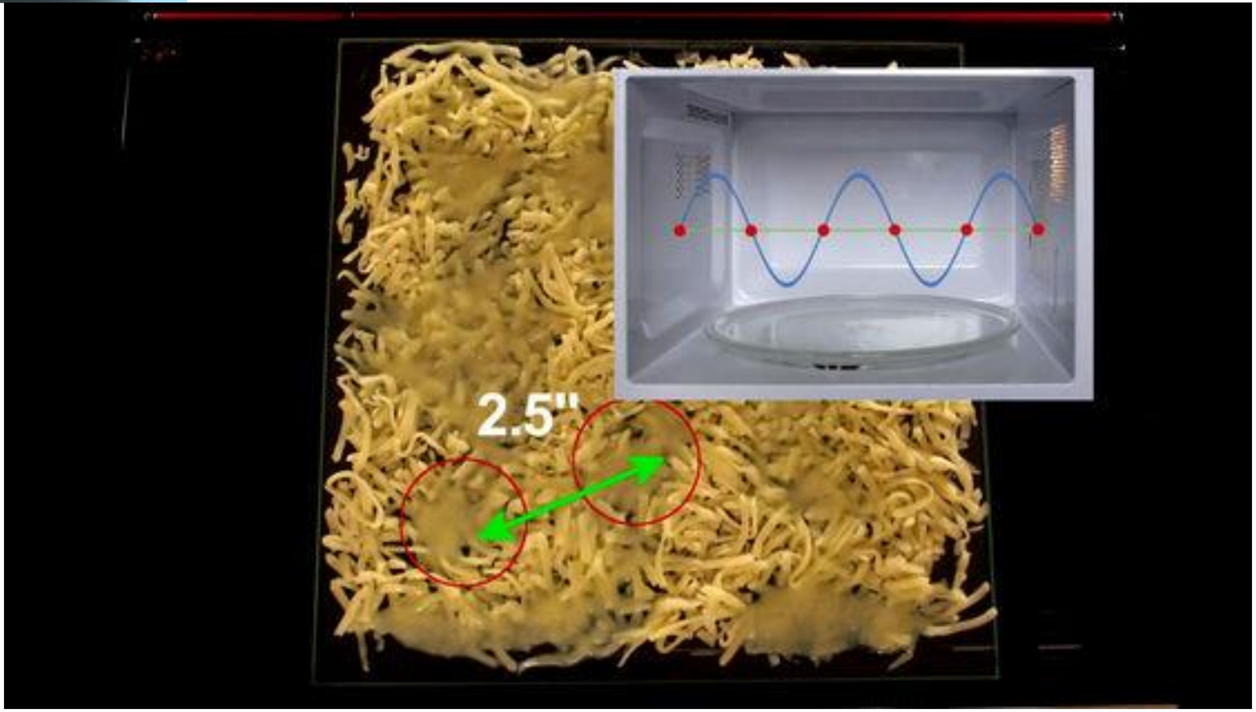
For Longer wavelength

- hence less energy
- hence requires larger area to be sensed
- hence lower resolution image

EM radiation



Measuring wavelength of a microwave



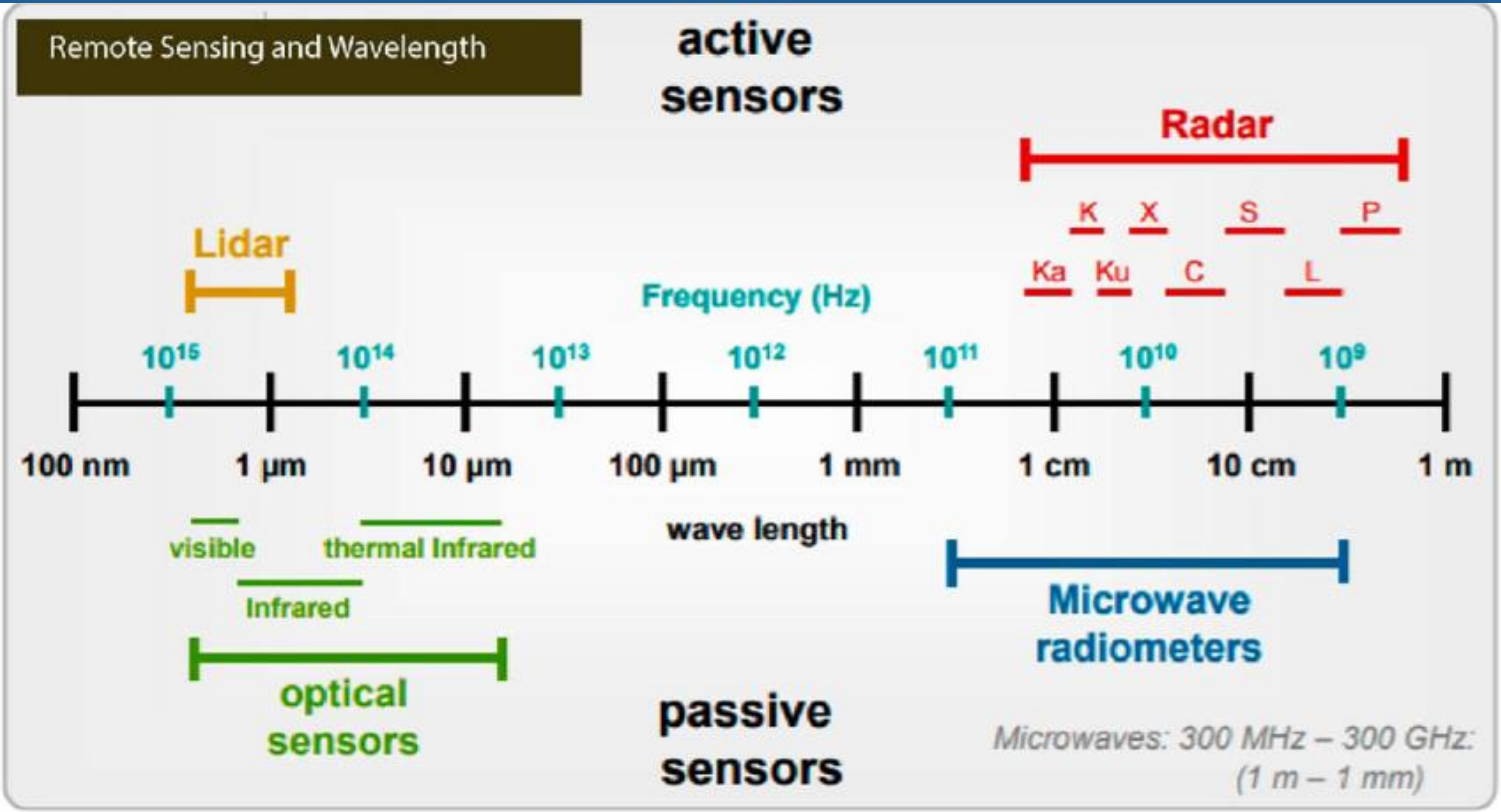
https://www.youtube.com/watch?v=kp33ZprO0Ck

EM spectrum

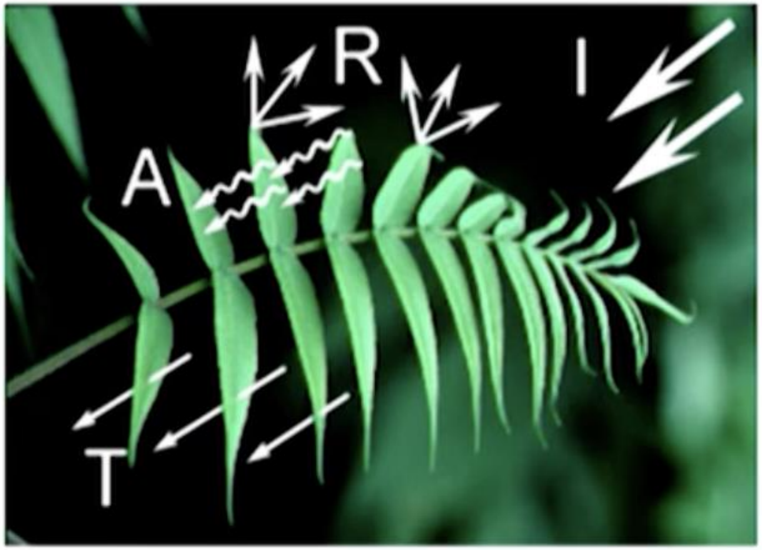
1.	γ & x Rays	Up to 10-8 m wavelength region
2.	Ultraviolet	From 10-9 to 10-7 m.
3.	Visible regions **Violet:** 0.4 - 0.446 μm **Blue:** 0.446 - 0.500 μm **Green:** 0.500 - 0.578 μm **Yellow:** 0.578 - 0.592 μm **Orange:** 0.592 - 0.620 μm **Red:** 0.620 - 0.7 μm	(0.4 - 0.7 μm) is only one of many forms of electro-magnetic energy and mostly used to acquire remotely sensed data for natural resource mapping. This wavelength interval is generally referred to a 'light'.
4.	Near-, Middle-Thermal, Far-Infrared,	From 0.7 - 20 μm is subdivided: (0.7 -1.3) μm - Near, 1.3 - 3.0 μm - Middle Infra-red regions 3.0 -14.0 μm - Thermal Infrared and 7.0 - 15.0 μm - Far Infrared). The sensors operating in this region of EMR are Spectrometers, Radiometers, Polarimeters and Laser-based active sensing systems.
5.	Microwave region	Down to a wavelength of 1 m. The sensors operating in this region are RADAR, Microwave Radiometer Altimeter, Scatterometer etc.
6.	Radio waves	Wavelengths longer than 1 m .

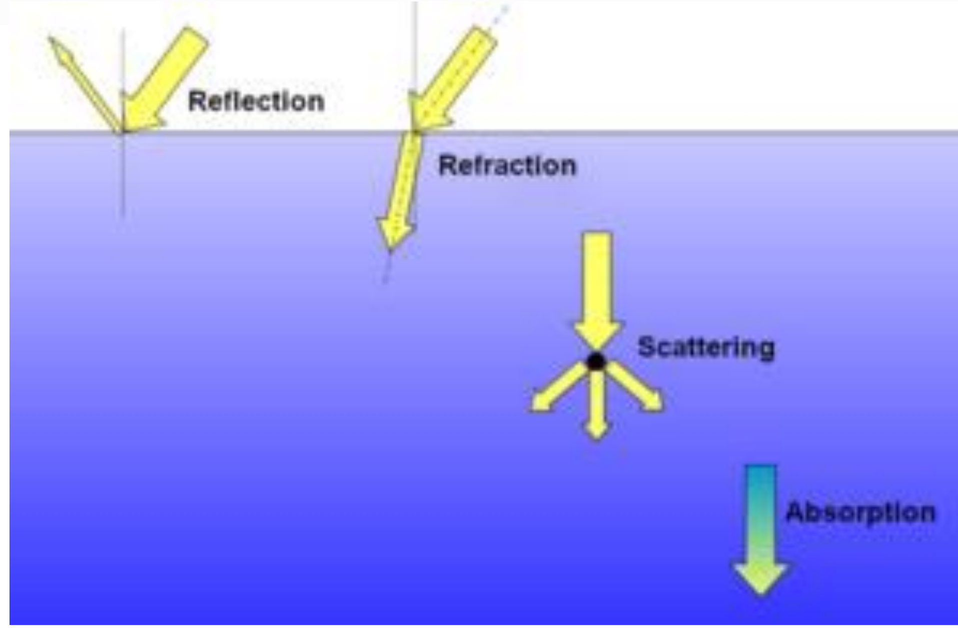
Gamma and X-rays completely absorbed by atmosphere. Visible, IR and MW are used in remote sensing of earth. UV is absrobed by ozone and used for studying atmosphere. GPS uses radio waves.

Types of remote sensing sensors



Energy interaction

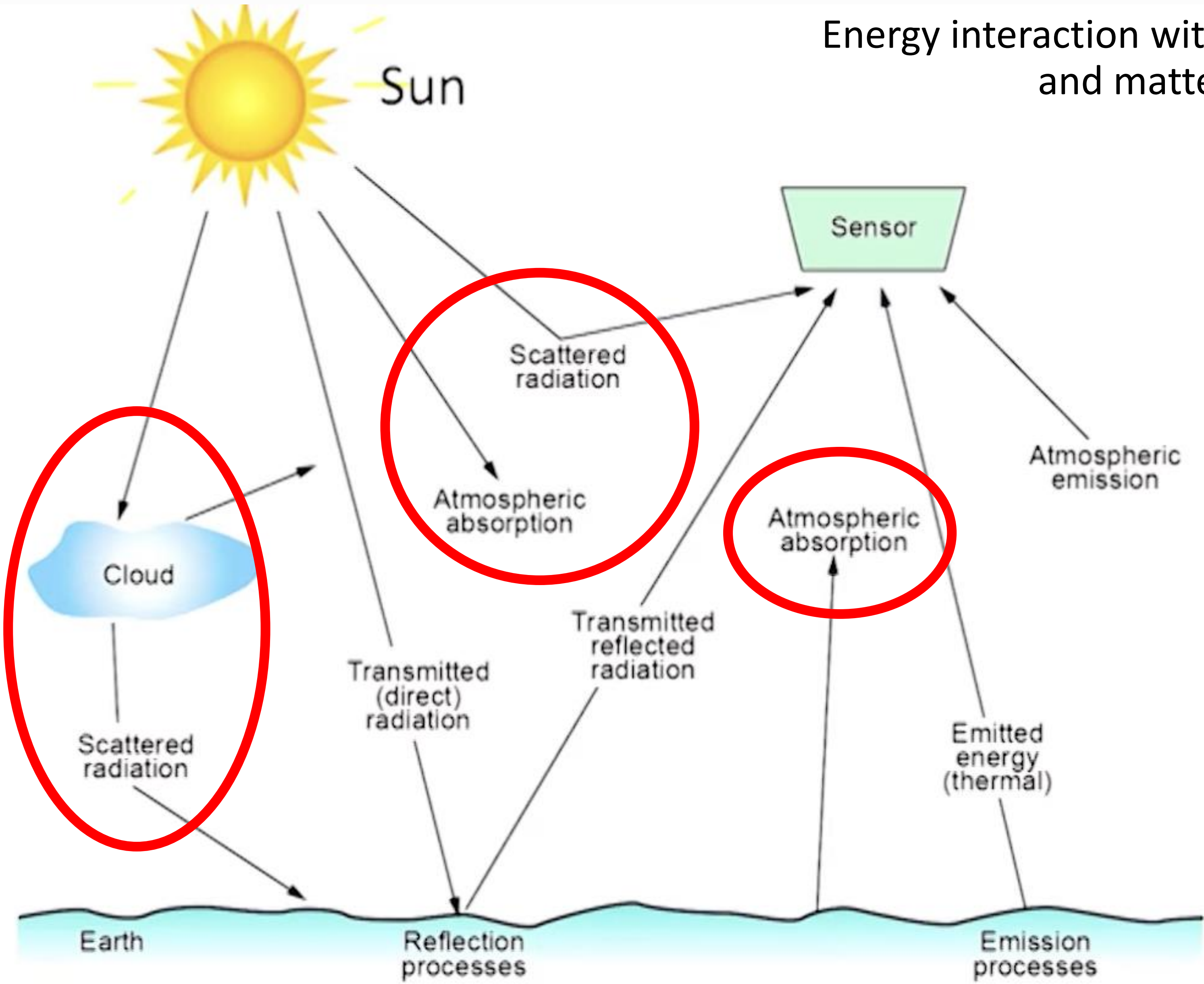




- Incident energy (I) on interaction is either scattered (S), reflected (R), absorbed (A) or transmitted (T)
- I = S+R+A+T
- Proportion of S, R, A, T is unique to combination of wavelength and the object's physio-chemical properties
- Most objects do S,R, A, T in varying proportions

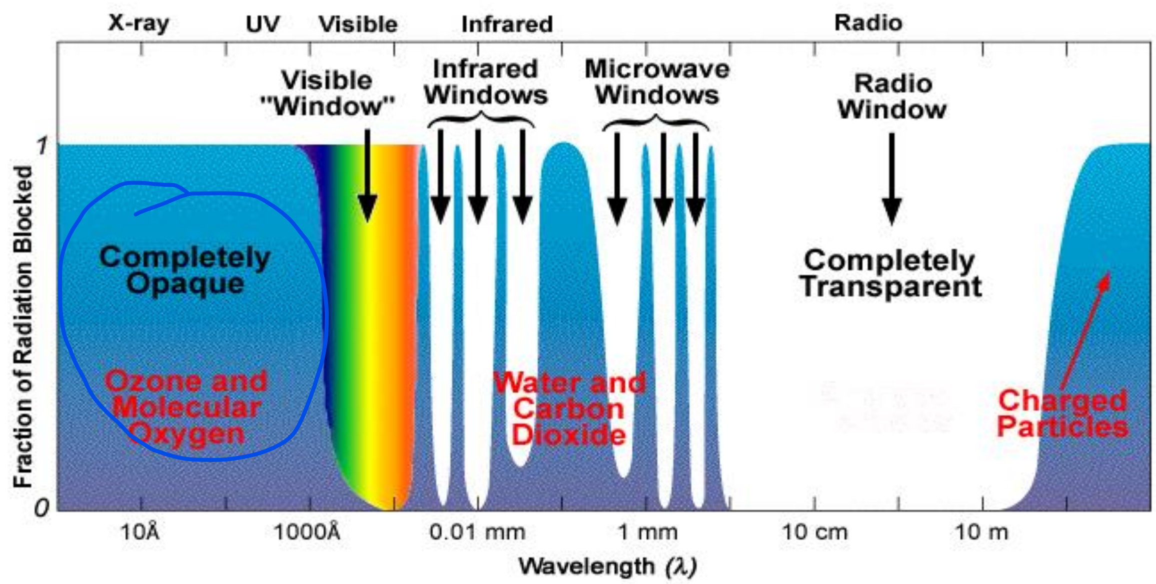
Energy received at sensor: interaction with atmosphere and surface

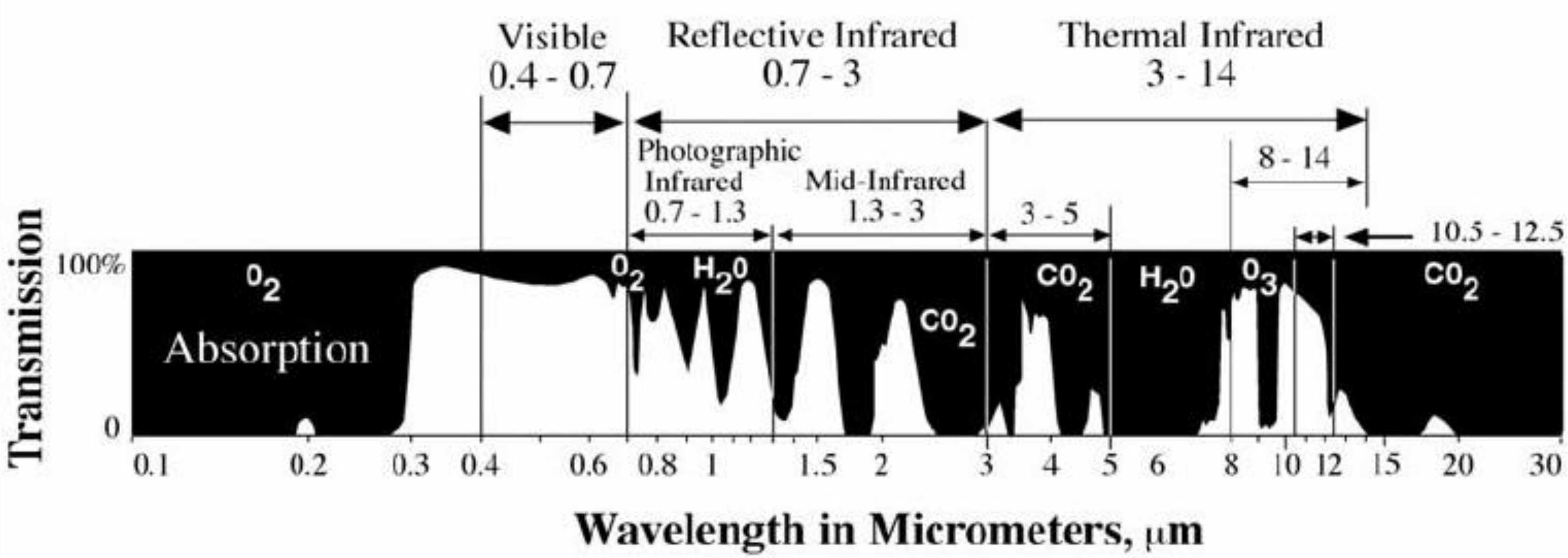
Energy interaction with atmopsh
and matter



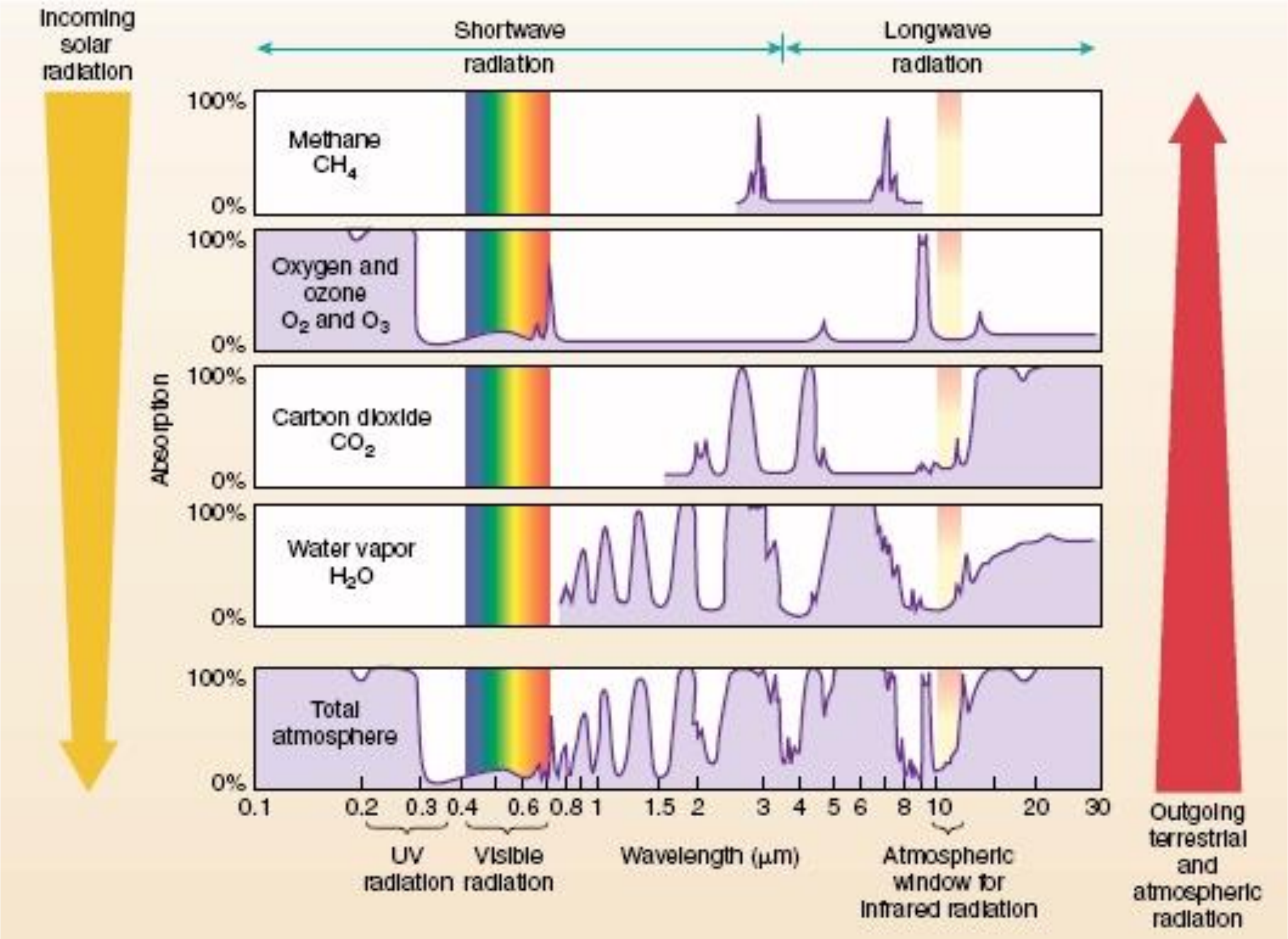
Atmospheric window

- Atmospheric window is a region of electromagnetic spectrum that can pass through Earth's atmosphere
- Ability of atmosphere to allow radiation to pass through it is referred to as its transmissivity, and varies with the wavelength/type of the radiation.
- It affects image quality



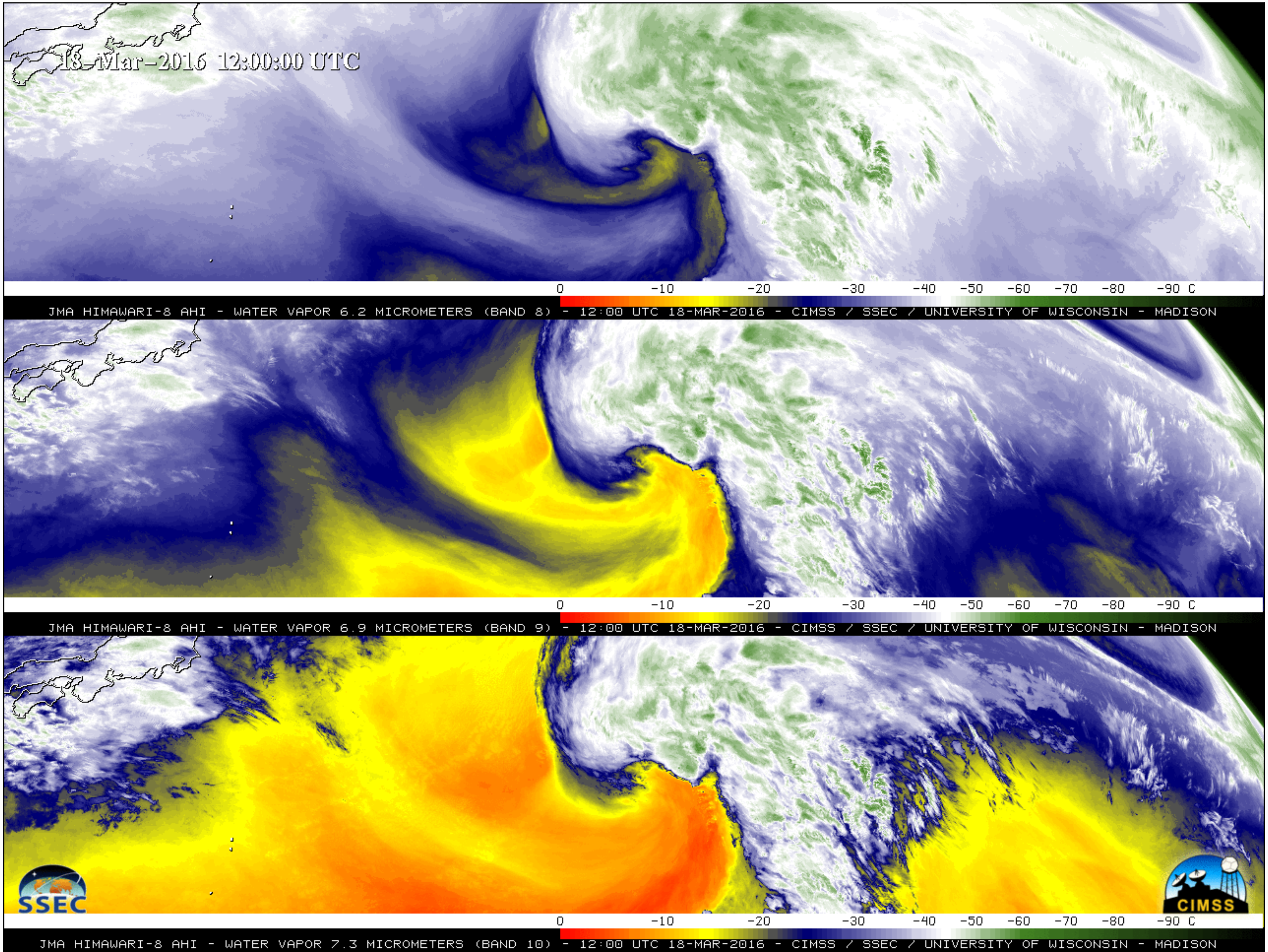


Atmospheric window



Can global warming be explained with atmospheric window?

Water vapor (clouds and moisture) at different atmospheric levels using JAXA's Himawari 8

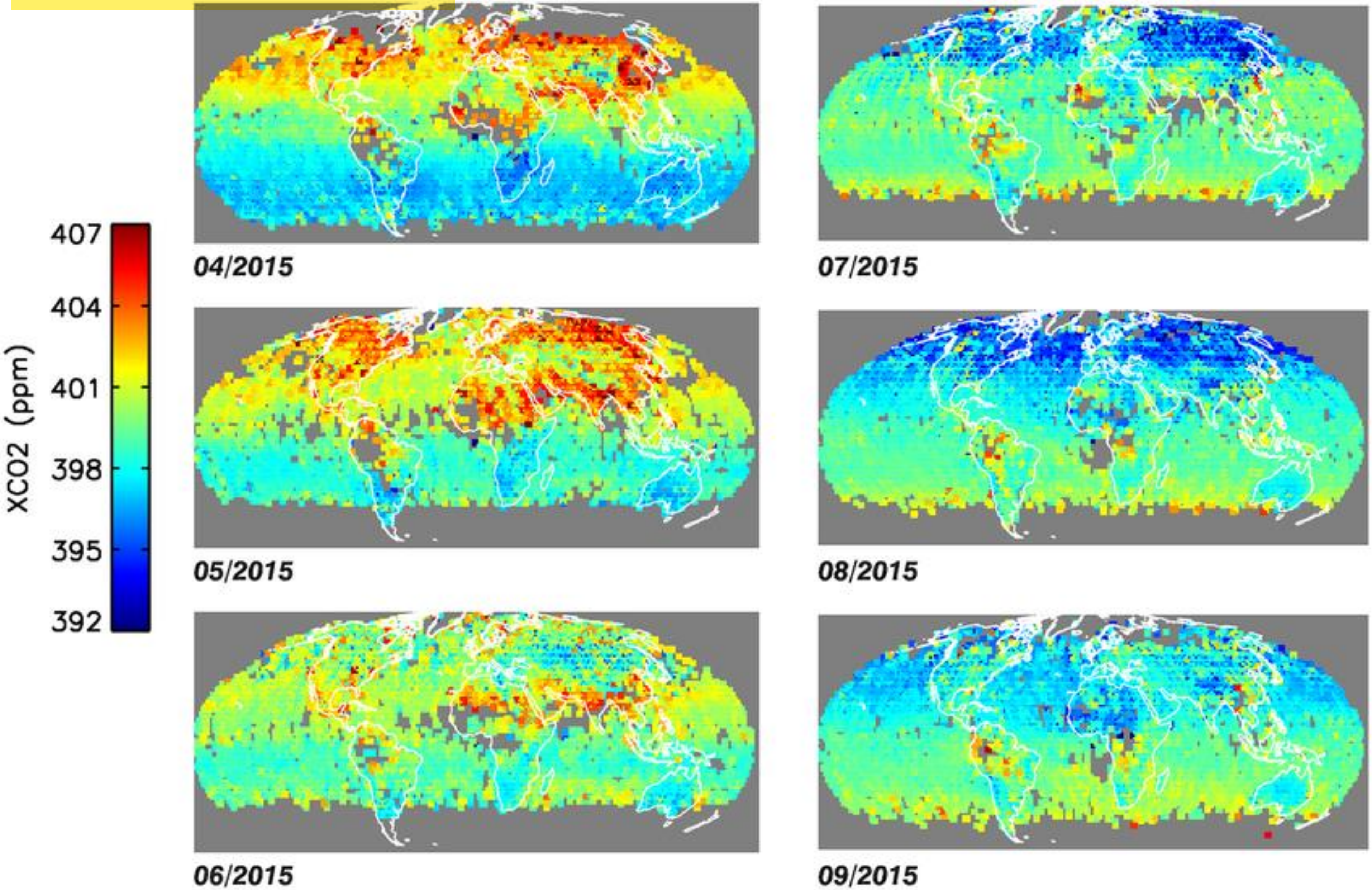


$6.2\mu m$ (high altitude)

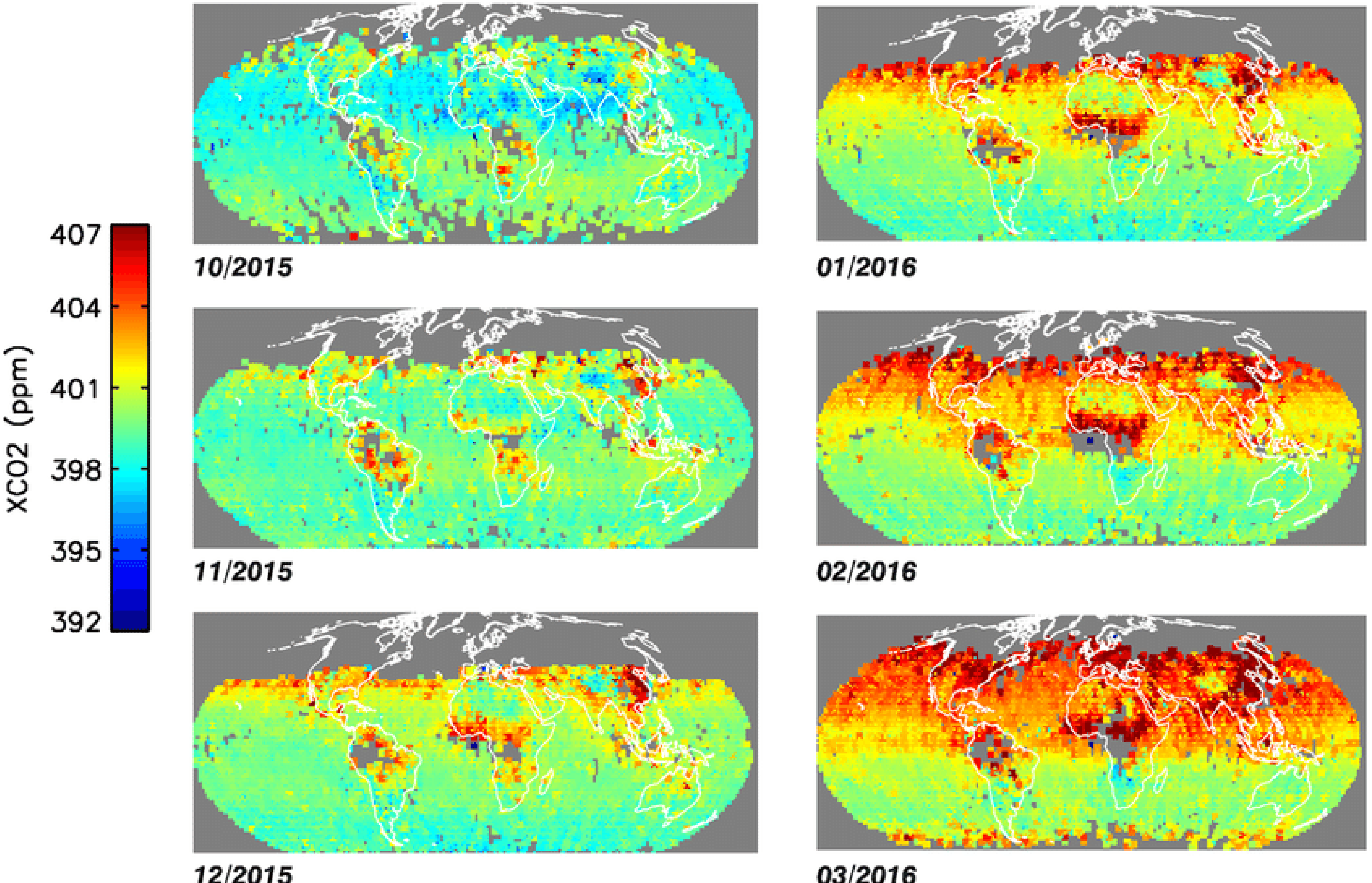
$6.9\mu m$

$7.3\mu m$ (low altitude)

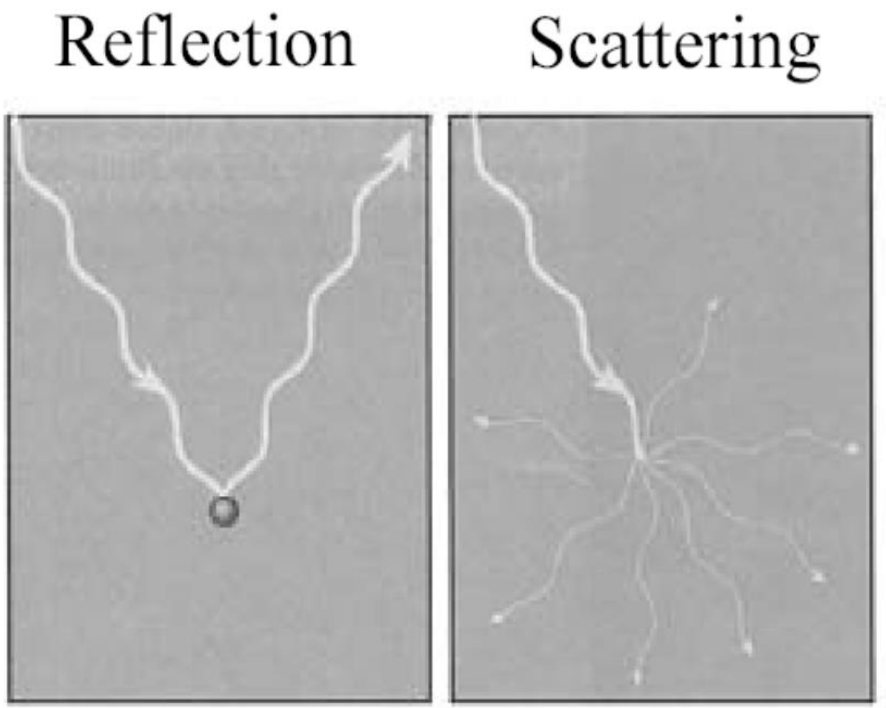
CO2 retrievals using NASA's OCO2 sensor (1.6μm, 2.1μm)



CO2 retrievals using NASA's OCO2 sensor ($1.6\mu m$, $2.1\mu m$)



Reflection and scattering



(from *The Atmosphere*)

- ❑ Reflection: light bounces back from an objective at the same angle at which it encounters a surface and with the same intensity.
- ❑ Scattering: light is split into a larger number of rays, traveling in different directions.
- ❑ Although scattering disperses light both forward and backward (backscattering), more energy is dispersed in the forward direction.

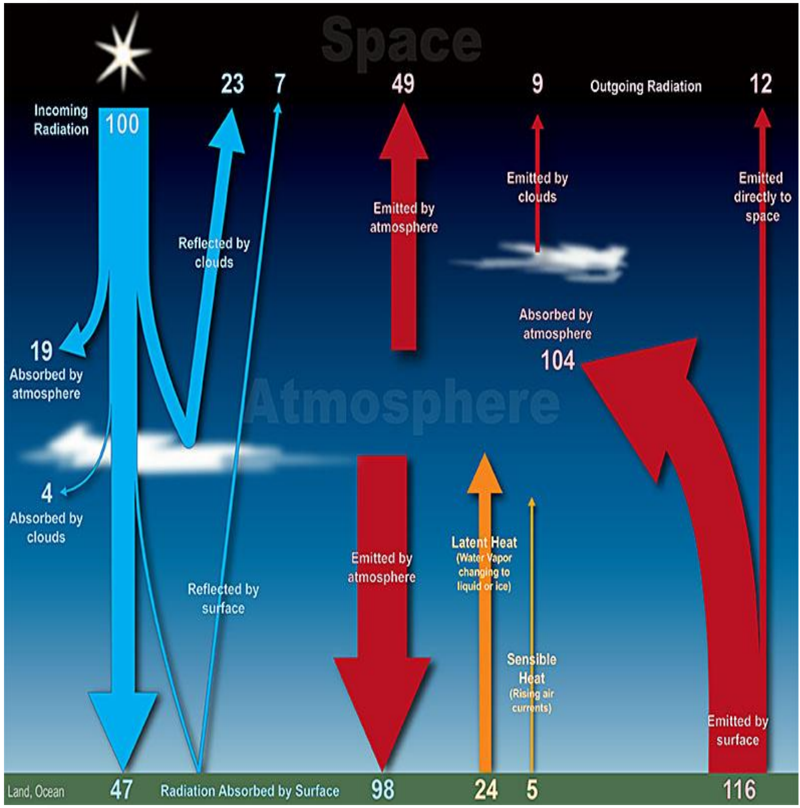
Reflection

Reflection is the process whereby radiation 'bounces off' an object such as top of a cloud, a water body, or the terrestrial earth.

Reflection differs from scattering in that the direction associated with scattering is unpredictable but in case of reflection it is predictable.

Reflection exhibits fundamental characteristics –

- The incident radiation, the reflected radiation, and a vertical to the surface from which the angles of incident and reflection are measured all lie in the same plane.
- The angle of incidence and the angle of reflection are approximately equal.



A considerable amount of incident radiant energy from the sun is reflected back from the top of clouds and other materials in the atmosphere.

Scattering

One very serious effect of the atmosphere is the scattering of radiation by atmospheric particles.

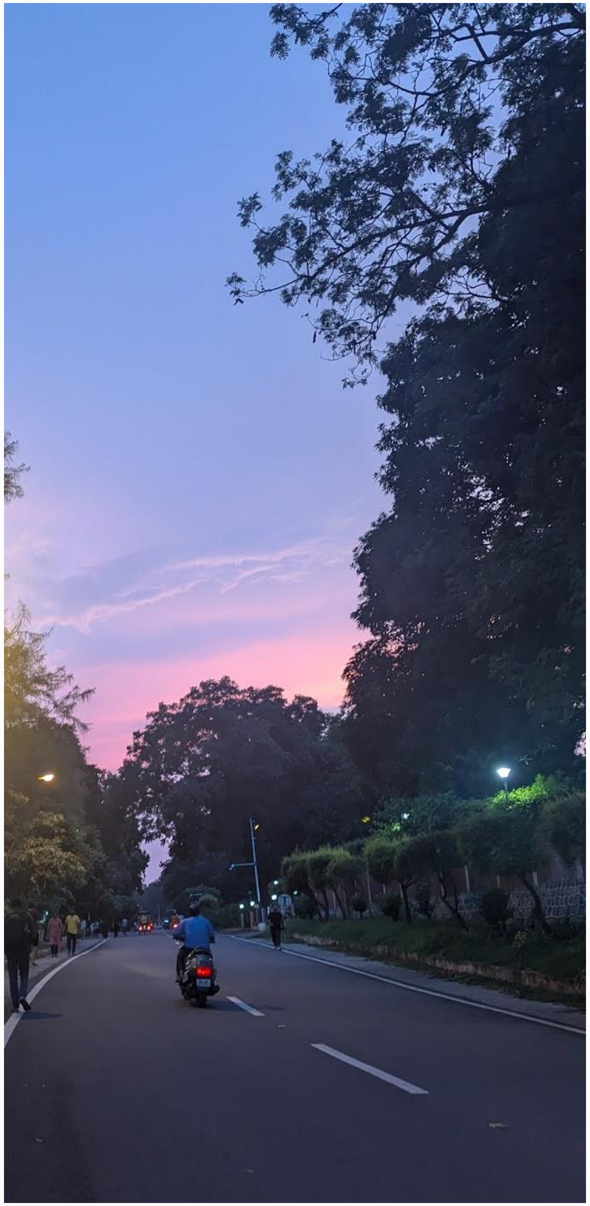
It occurs when particles or large gas molecules present in the atmosphere interact with EMR.

Scattering depends on several factors including the wavelength of the radiation, the diameter of particles or gases, and the distance the radiation travels through the atmosphere.

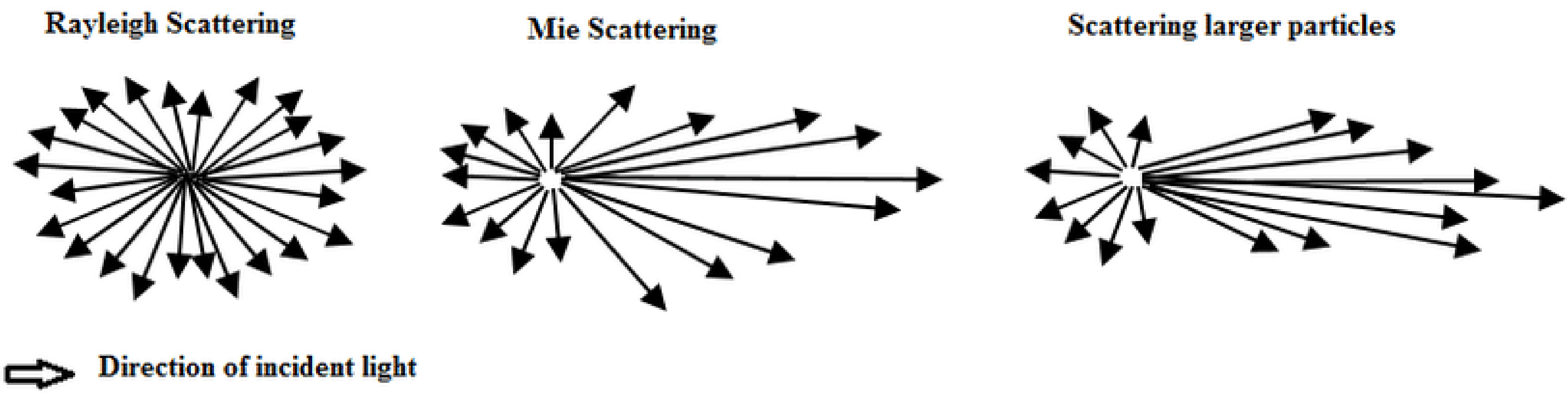
Shorter wavelength of visible light are scattered more effectively than are longer wavelengths (red, orange).

Therefore, when the Sun is overhead, the sky is predominantly blue due to scattering by the gases in the atmosphere.

At sunrise and sunset, the path of light is much longer through the atmosphere. Most of the blue light is scattered before it reaches an observer. Thus the Sun appears reddish in color.

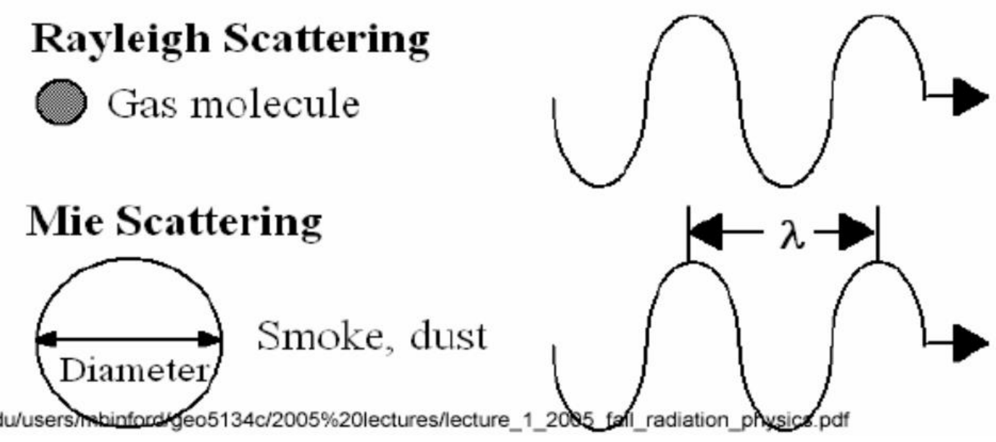


Types of scattering



- Selective
  - Rayleigh scattering
  - Mie scattering

- Non-selective



s.ufl.edu/users/mbinford/geo5134c/2005%20lectures/lecture_1_2005_fall_radiation_physics.pdf

Rayleigh scattering

Rayleigh scattering (sometimes referred to as molecular scattering) occurs when *effective diameter of the matter (usually air molecules such as oxygen and nitrogen in the atmosphere) is many times (usually <0.1 times) smaller than the wavelength of the incident EMR.*

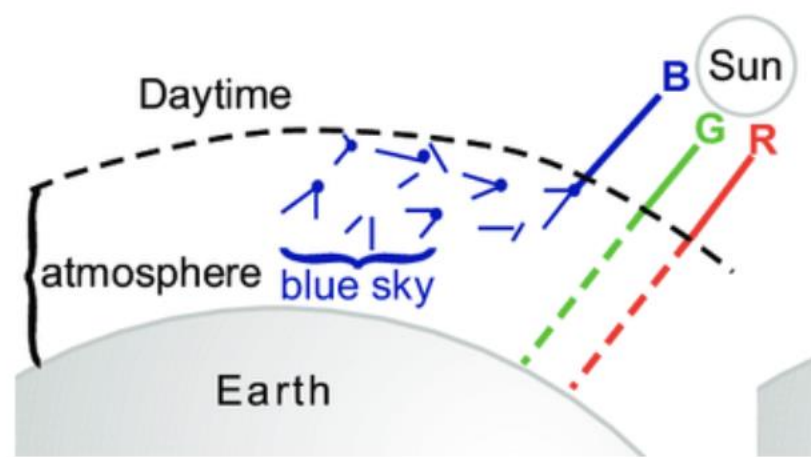
The amount of scattering is inversely related to the fourth power of wavelength of radiation.

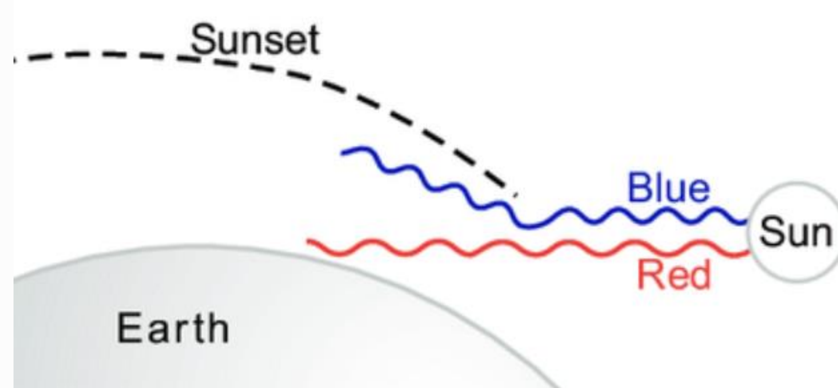
For example, ultraviolet light at 0.3 μm is scattered approximately 16 times more than red light at 0.6 μm.

Most Rayleigh scattering takes place in the upper 4.5 km of the atmosphere. It is responsible for the blue appearance of the sky. The shorter violet and blue wavelengths are more efficiently scattered than the longer green and red wavelengths.

That is why most remote sensing systems avoid detecting and recording wavelengths in the ultraviolet and blue portions of the spectrum.

$$I = a\, I_o\, \lambda^{-4}$$





Haze makes vegetation appear blue

Mie scattering

Mie scattering (also referred to as non-molecular scattering) takes place in the lower 4.5 km of the atmosphere.

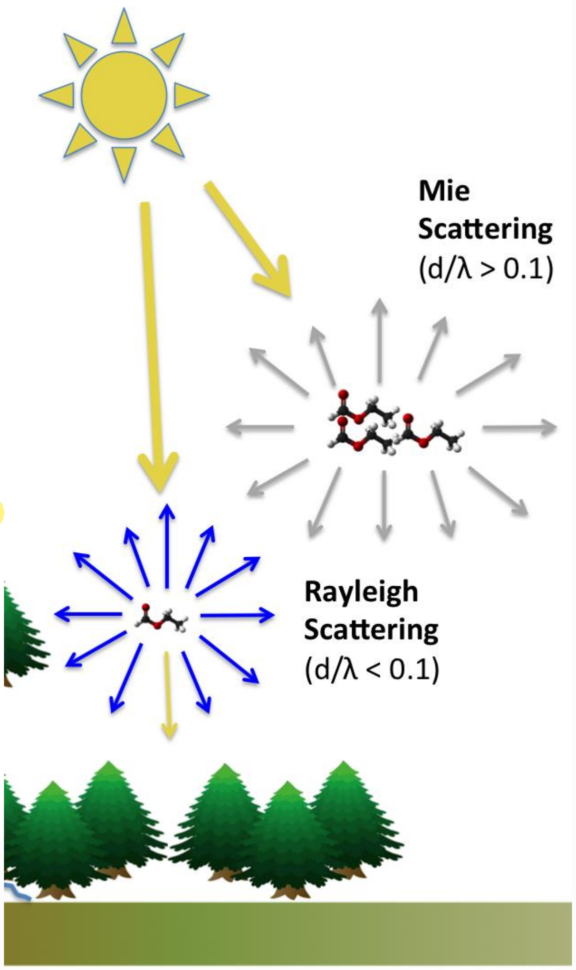
It takes place when the diameter of the particles present in the atmosphere is approximately equal to the size of the wavelength of the incident energy.

The actual size of the particles may range from 0.1 to 10 times the wavelength of the incident energy. For visible light, the main scattering agents are dust and other particles ranging from a few tenths of the micrometre to several micrometres in diameter.

Particle size ≈ λ of radiation e.g. dust, pollen, smoke and water vapour.

Affects longer λ than Rayleigh,

Mostly in the lower portions of the atmosphere



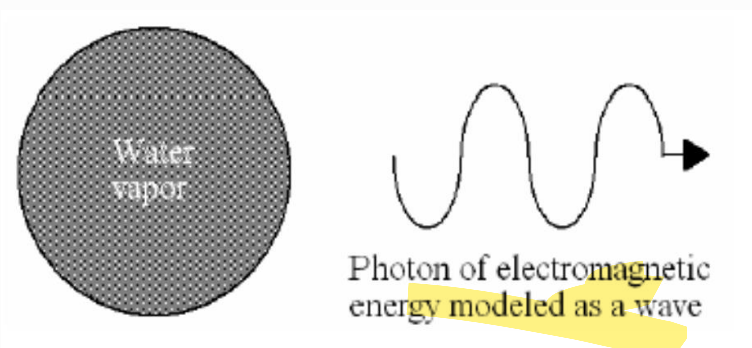
Non-selective scattering

Takes place in the lowest portions of the atmosphere when particles greater than 10 times the wavelength of the incident EMR are present in the atmosphere.

In non-selective scattering, all wavelengths of light are scattered, not just blue, green, or red.

Thus, the water droplets and ice crystals that make up clouds and fog banks scatter all wavelengths of visible light equally well, causing the cloud to appear white.

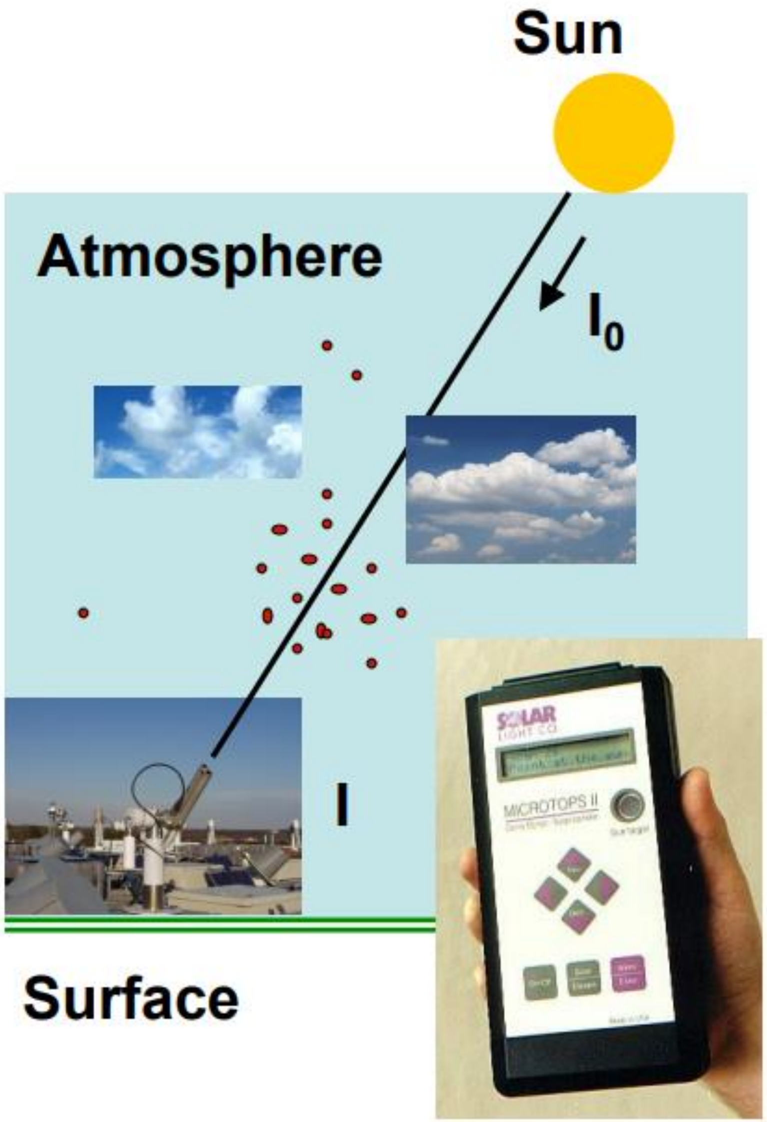
Non-selective scattering of approximately equal proportions of blue, green, and red light always appears as white light to the casual observer (blue + green + red light = white light)




Top of Atmosphere
(image at sensor)


Surface Reflectance
(image after removing
atmospheric effects)

Optical depth



Optical depth expresses the quantity of light removed from a beam by scattering or absorption during its path through a medium.

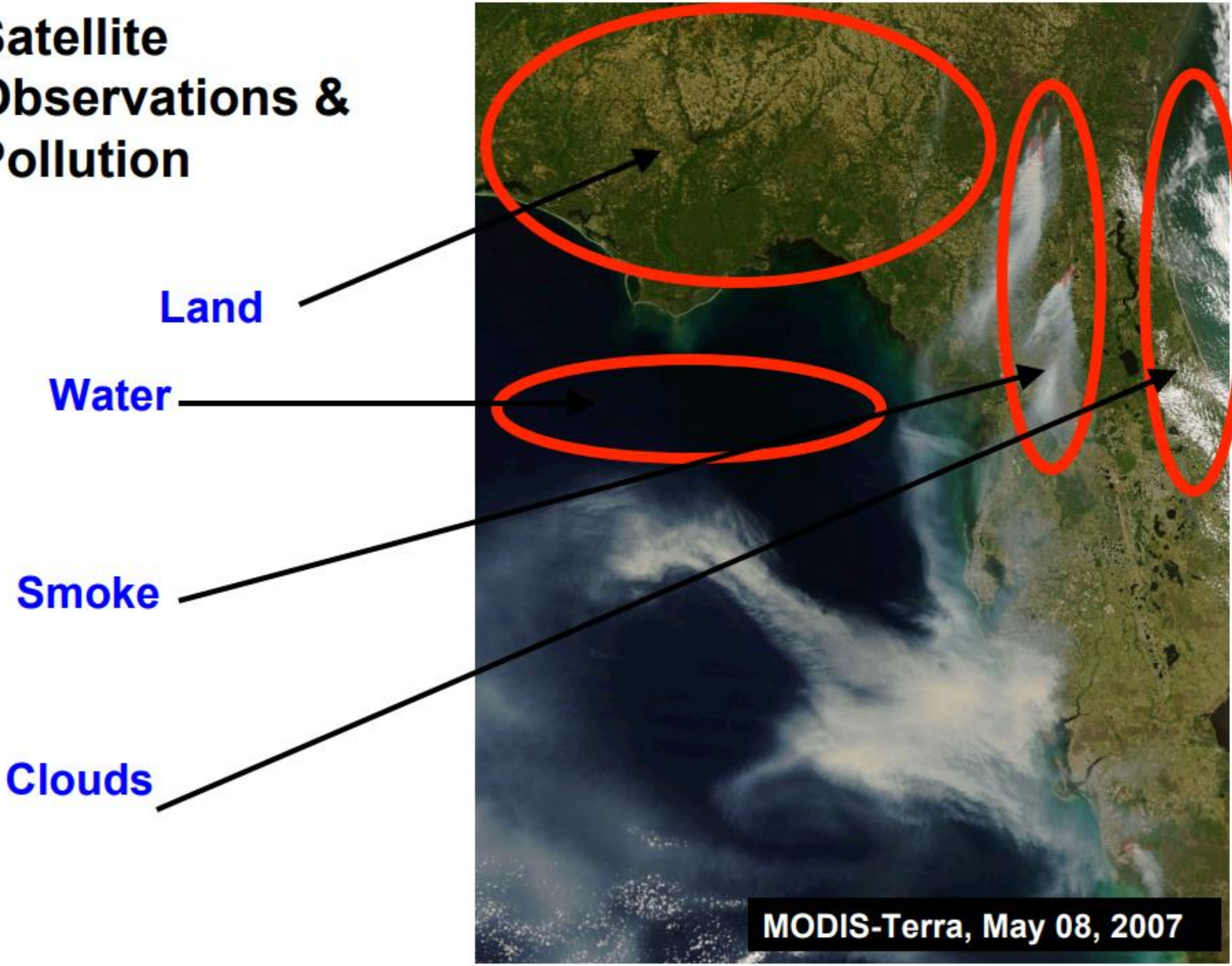
optical depth τ as

$$I = I_0 e^{-m\tau}$$

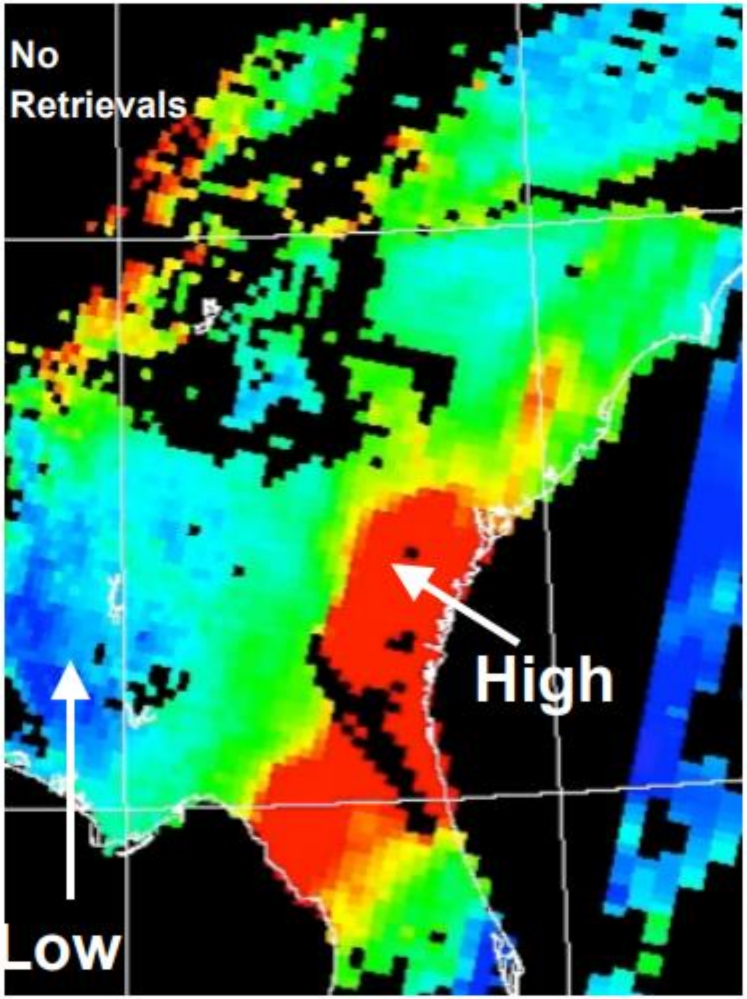
$$m = \sec\theta_0$$

$$\tau = \tau_{Rayl} + \tau_{aer} + \tau_{gas}$$

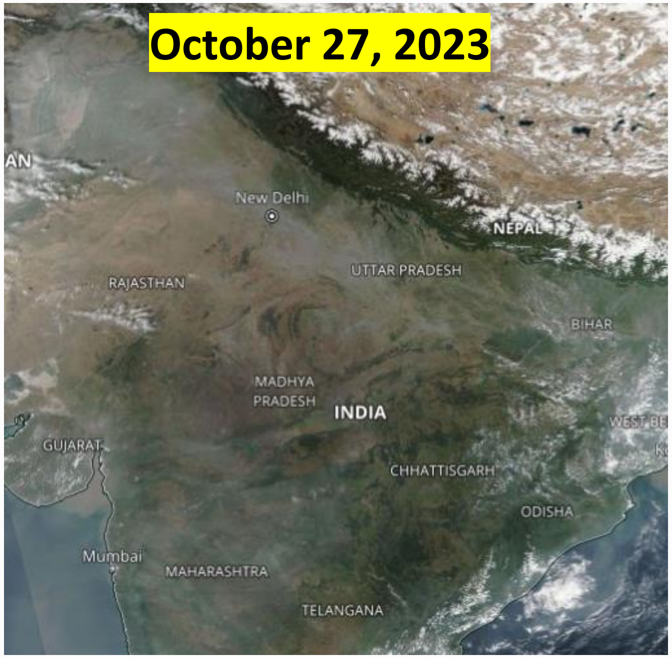
Satellite Observations & Pollution



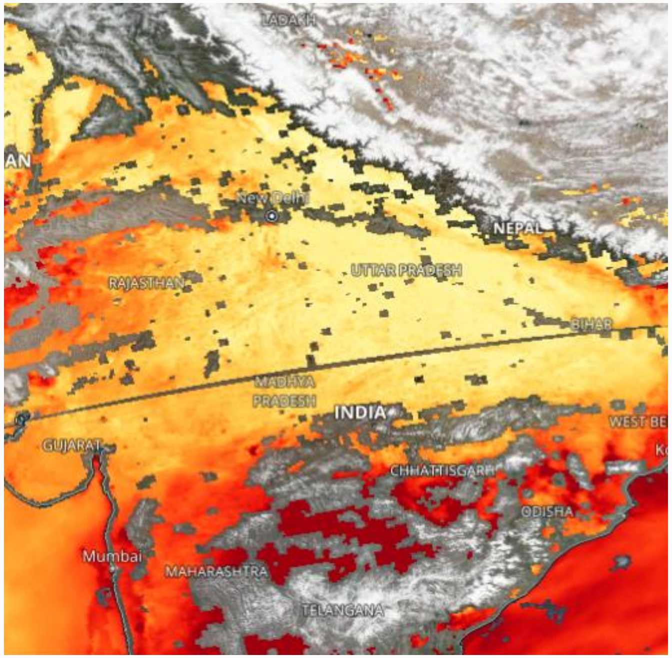
Radiance -to- Aerosol Products

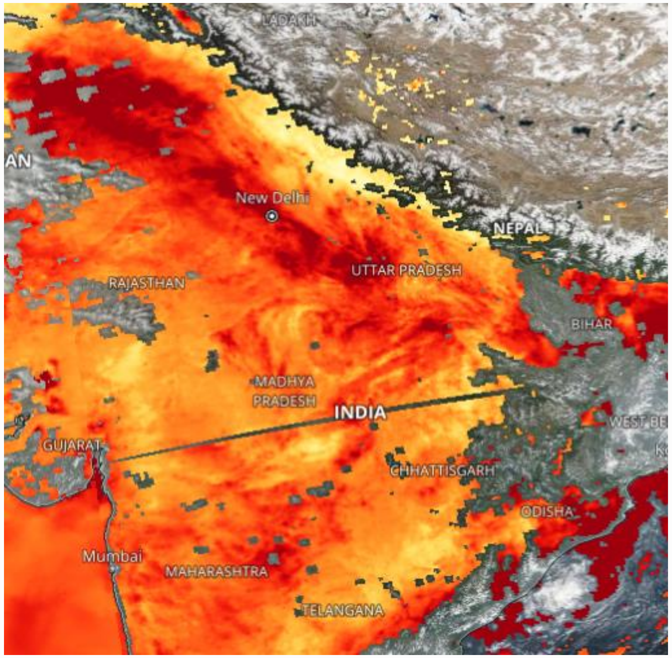


Aerosol optical depth from NASA's Suomi NPP sensor on VIIRS satellite



Top of atmosphere reflectance



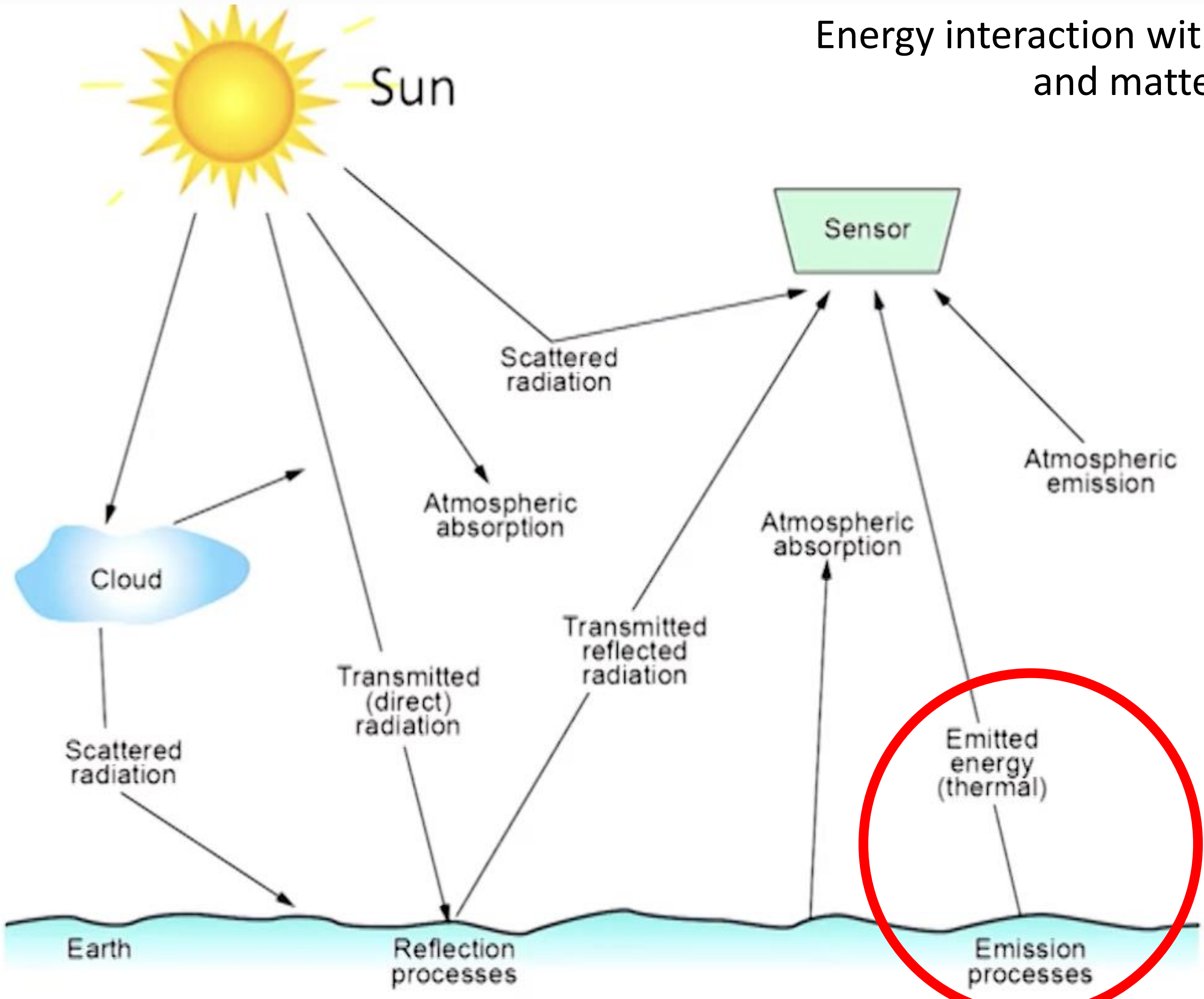


Aerosol optical depth

https://worldview.earthdata.nasa.gov/?v=56.740098219413696,-10.675765271109729,94.83844365331412,52.29233343214234&l=Reference_Features_15m(hidden),Reference_Labels_15m,Coastlines_15m,VIIRS_SNPP_AOT_Deep_Blue_Best_Estimate,OMI_SO2_Lower_Troposphere(hidden),AIRS_Prata_SO2_Index_Night(hidden),AIRS_Prata_SO2_Index_Day(hidden),OMI_Aerosol_Optical_Depth(hidden),MODIS_Aqua_AOD_Deep_Blue_Land(hidden),MODIS_Aqua_Angstrom_Exponent_Land(hidden),MODIS_Aqua_Aerosol_Optical_Depth_3km(hidden),MODIS_Aqua_Aerosol(hidden),MODIS_Combined_Value_Added_AOD(hidden),MODIS_Terra_Angstrom_Exponent_Land(hidden),MODIS_Terra_AOD_Deep_Blue_Land(hidden),MODIS_Terra_Aerosol_Optical_Depth_3km(hidden),MODIS_Terra_Aerosol(hidden),MODIS_Combined_Thermal_Anomalies_All(hidden),MODIS_Terra_Thermal_Anomalies_All(hidden),MODIS_Aqua_Thermal_Anomalies_All(hidden),VIIRS_SNPP_CorrectedReflectance_TrueColor,MODIS_Aqua_CorrectedReflectance_TrueColor(hidden),MODIS_Terra_CorrectedReflectance_TrueColor(hidden)&lg=false&t=2020-04-03-T08%3A47%3A36Z

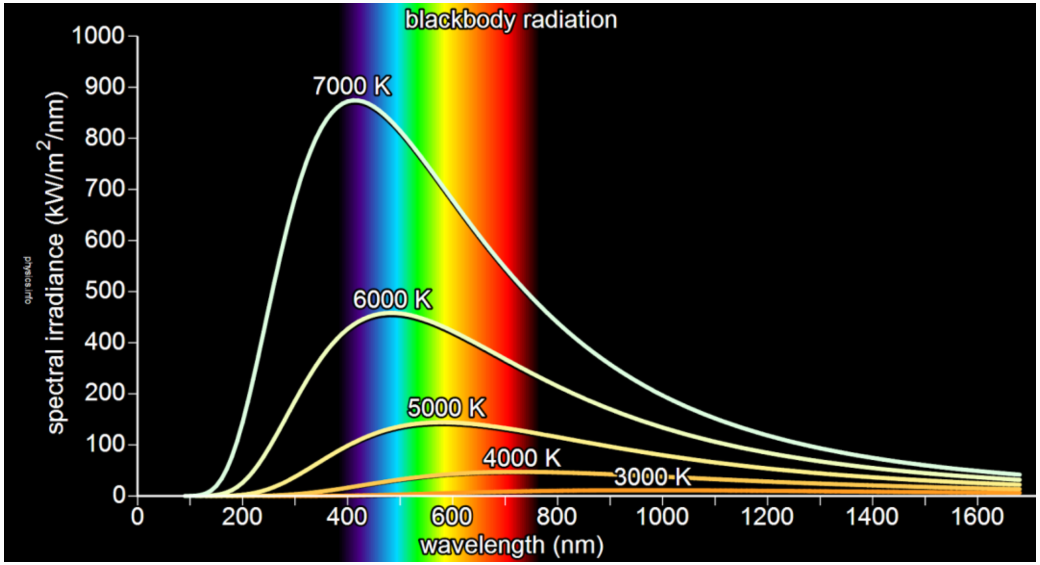
Energy received at sensor: interaction with atmosphere and surface

Energy interaction with atmopsh
and matter



Planck's law of black-body radiation

- Planck's law (1900) describes the spectral density of electromagnetic radiation emitted by a black body in thermal equilibrium. Blackbody is a theoretical object acting as a perfect absorber and emitter of radiation.
- Emitted by all matter above 0 kelvin
- Intensity and peak emission wavelength are function of temperature
- As T increases, total intensity increases, and shifts to higher energies (lower wavelengths)

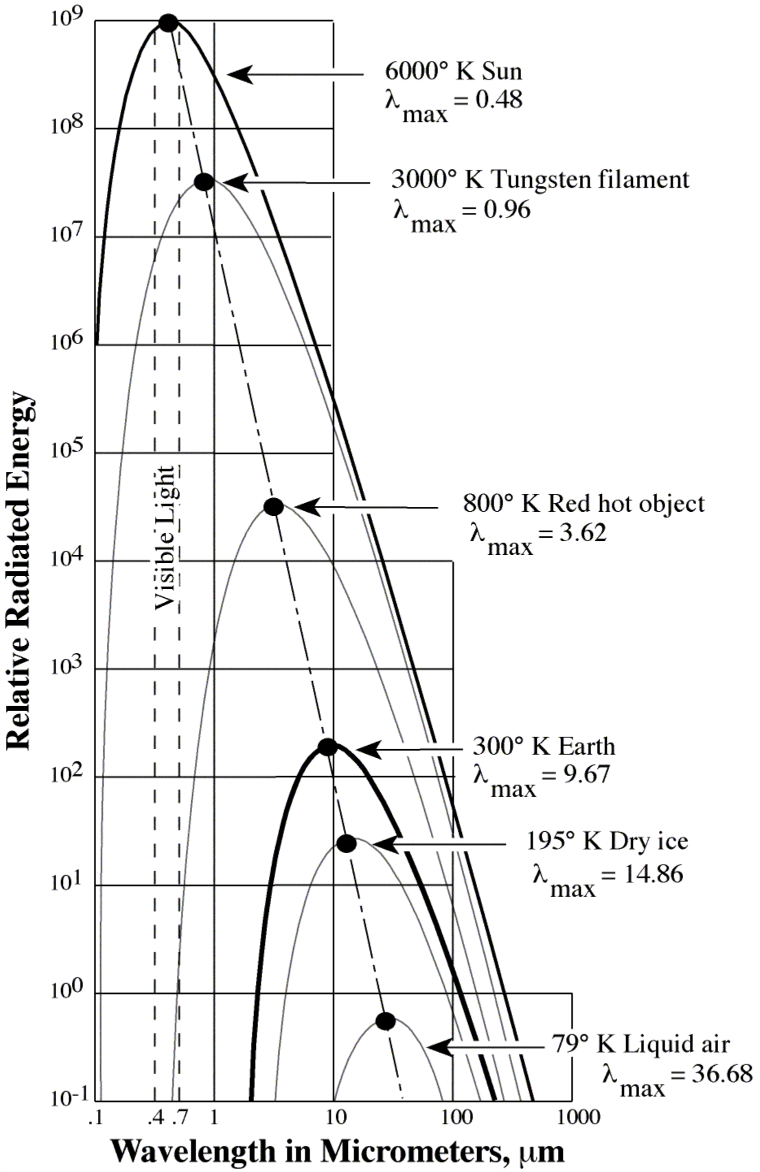


$$B(\lambda) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

B(λ) is spectral radiance density (power per unit solid angle per unit of area normal to the propagation) of wavelength λ at thermal equilibrium at temperature T

Wien's displacement law

- Wien's law (1893) relates an object's maximum emitted wavelength of radiation to the object's temperature
- Wavelength of the maximum emitted radiation by an object is inversely proportional to the objective's absolute temperature
- The hotter the radiating body, the greater is its radiance (intensity) over its range of wavelengths, and the shorter is its peak emission wavelength.



$\lambda_{max} = k / T$

(where $k = 2898 \mu mK$)

T: temperature of target,

λ_{max} : wavelength at which emitted energy is maximum.

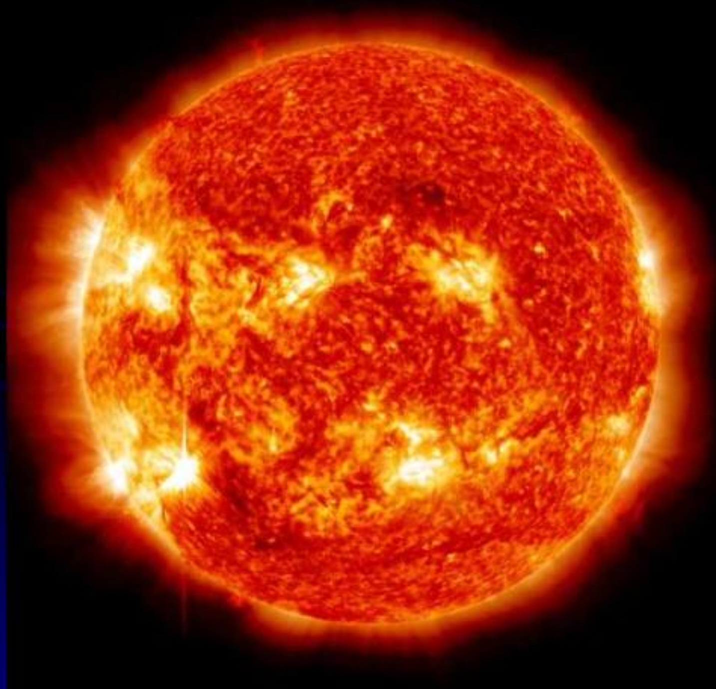
Wien's Displacement Law

$$\lambda_{MAX} = 2{,}987 / T \; [\mu m]$$

$T \sim 6000$ K

$\lambda_{MAX} = 2{,}987 / 6000$

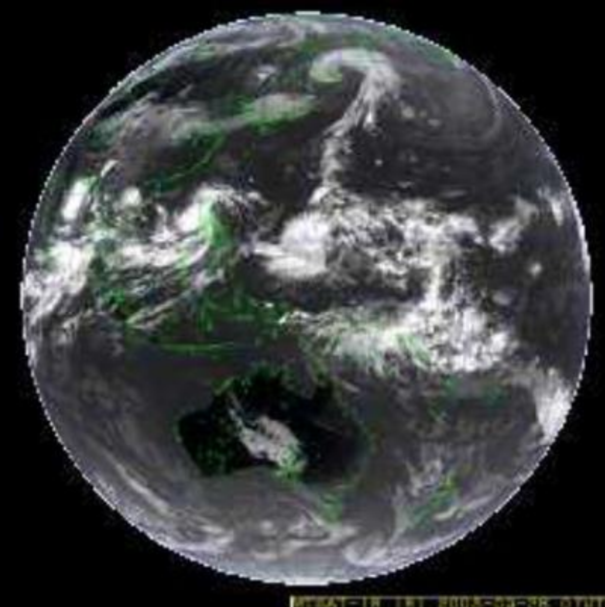
~ 0.5 [μm] (Visible)



$T \sim 300$ K

$\lambda_{MAX} = 2{,}987 / 300$

~ 10 [μm] (Infrared)



Source: http://www.nasa.gov/images/content/706436main_20121114-304-193Blend_M6-orig_full.jpg

Stefan-Boltzmann Law

- Stefan-Boltzmann's law (1876): the total radiation energy *E* per unit of a black body in unit time. (known as the black-body irradiance, energy flux density, radiant flux, or the emissive power)
- *E* is directly proportional to the fourth power of the black body's thermodynamic temperature *T* (also called absolute temperature).
- Sun emits about 160,000 times more radiation/area compared to Earth

$$E = \varepsilon\sigma T^4$$

*σ=5.67*10^{-8} (W/m^2/K^{-4}) [Stefan-Boltzmann constant]*
ε: emissivity, E: emitted energy

Emissivity

- Emissivity is a dimensionless number that expresses the ratio of thermal radiation emitted by a surface M to that of a blackbody M_b
- It is defined at particular wavelength and temperature for an object

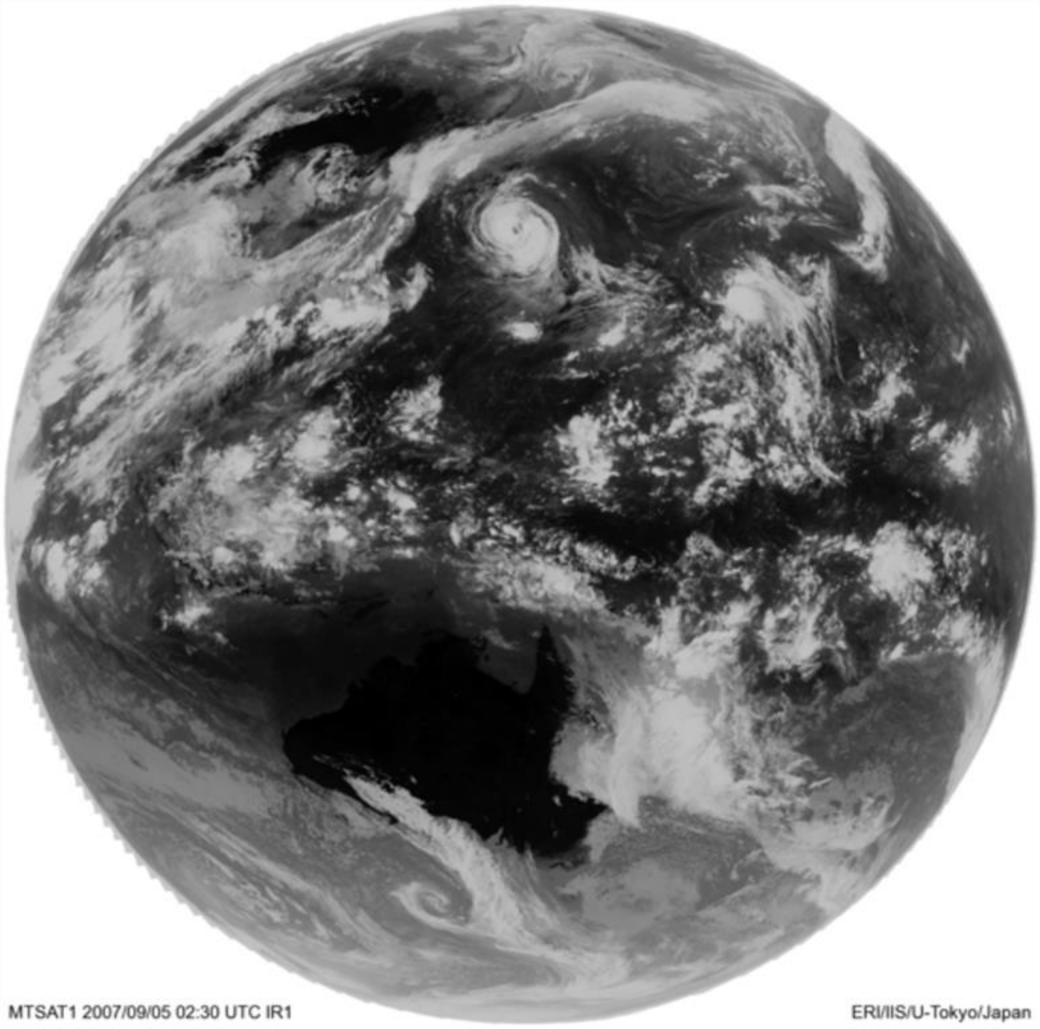
$$\varepsilon = M/M_b$$

ε: emissivity
M: emittance(radiant flux/area) of a given object
M_b=that of blackbody

Emissivity of common materials

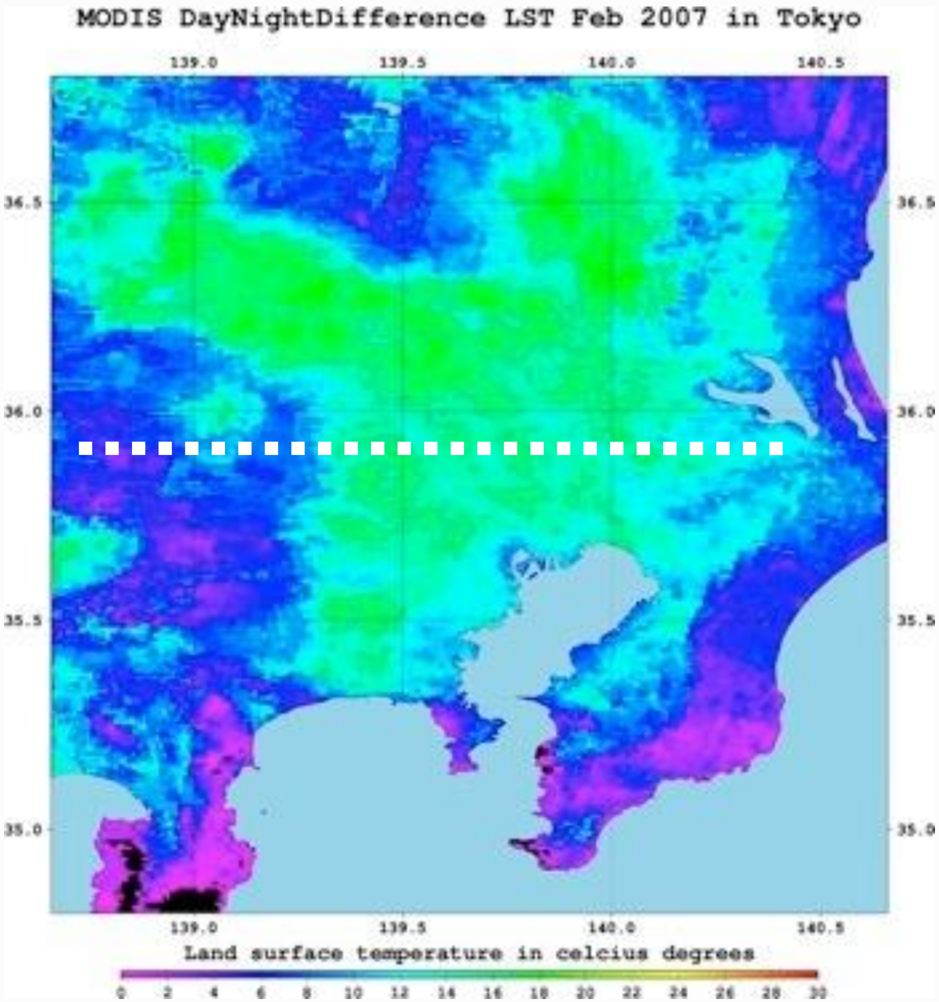
Material	Temperature (℃)	Emissivity
Polished copper	50-100	0.02
Snow	-10	0.85
Sand	20	0.9
Wood	20	0.92
Concrete	20	0.92
Glass	20	0.94
Human skin	35	0.95
Water	20	0.96
Ice	-10	0.96

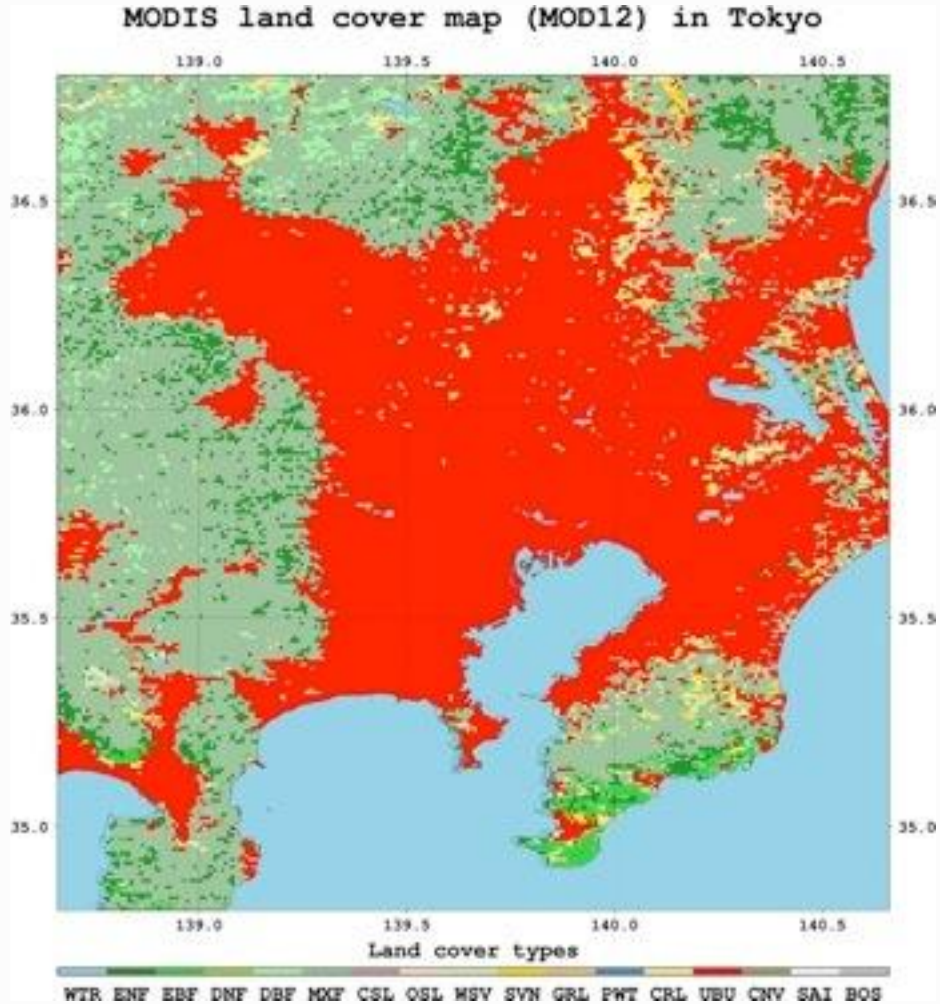
Application: MTSAT Thermal (geostationary)



Credits: Wataru Takeuchi, Utokyo (https://wtlab.iis.u-tokyo.ac.jp/wataru/publication/pdf/mtsat_lst2.pdf)

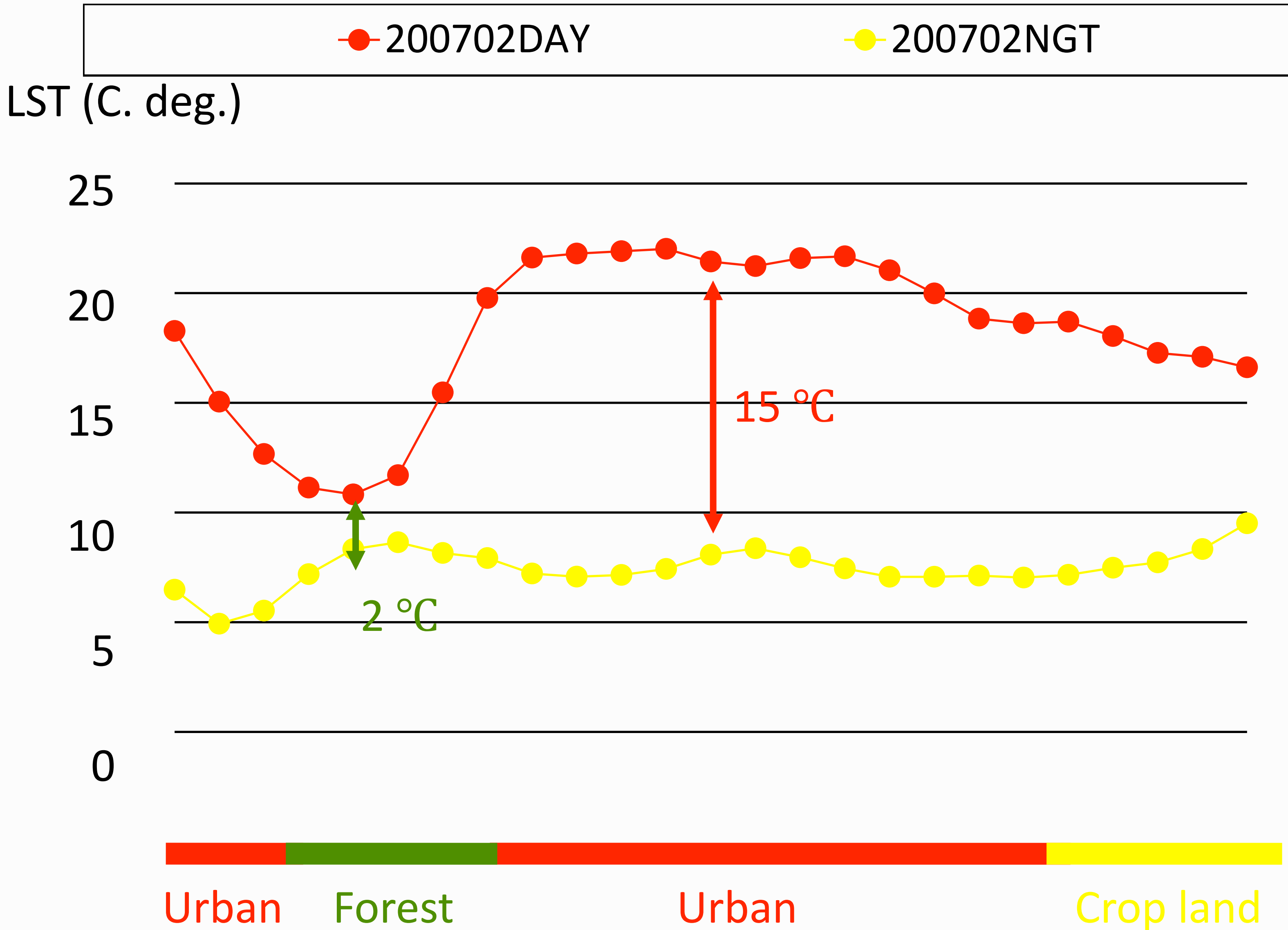
Application: urban heat





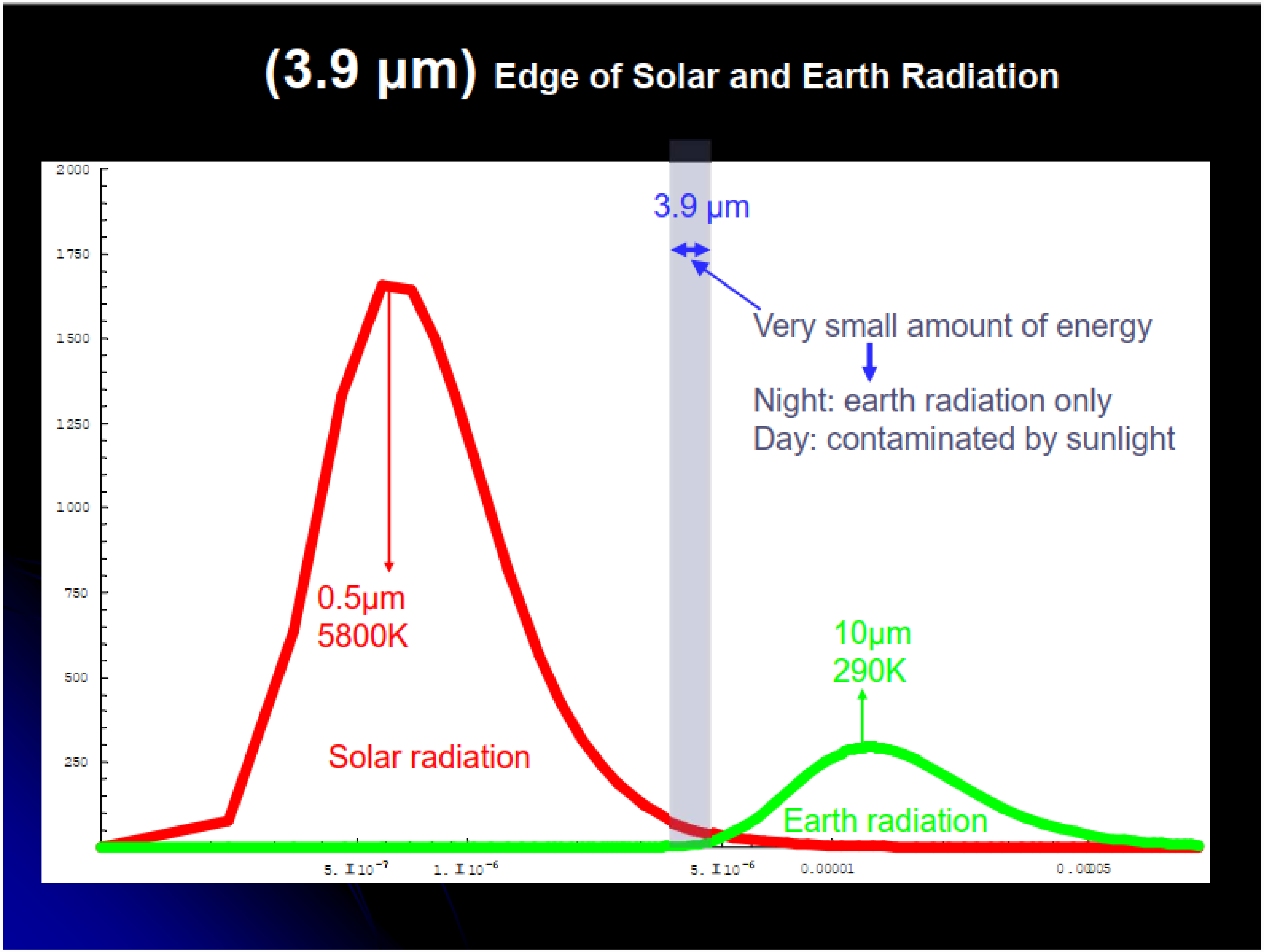
Credits: Wataru Takeuchi, Utokyo (https://wtlab.iis.u-tokyo.ac.jp/wataru/publication/pdf/mtsat_lst2.pdf)

Application: urban heat

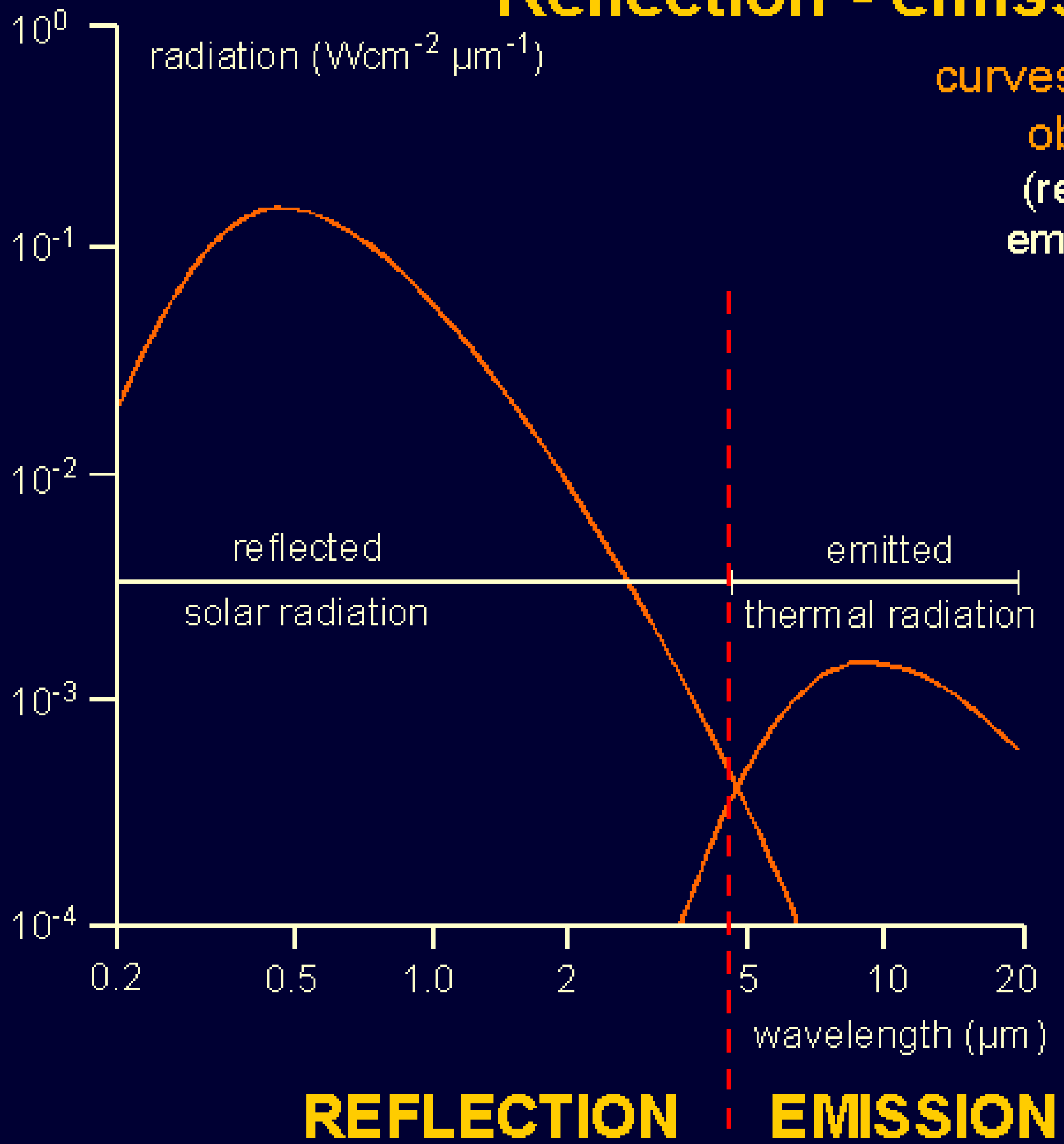


Credits: Wataru Takeuchi, Utokyo (https://wtlab.iis.u-tokyo.ac.jp/wataru/publication/pdf/mtsat_lst2.pdf)

Application: detecting active fire sites



Reflection - emission



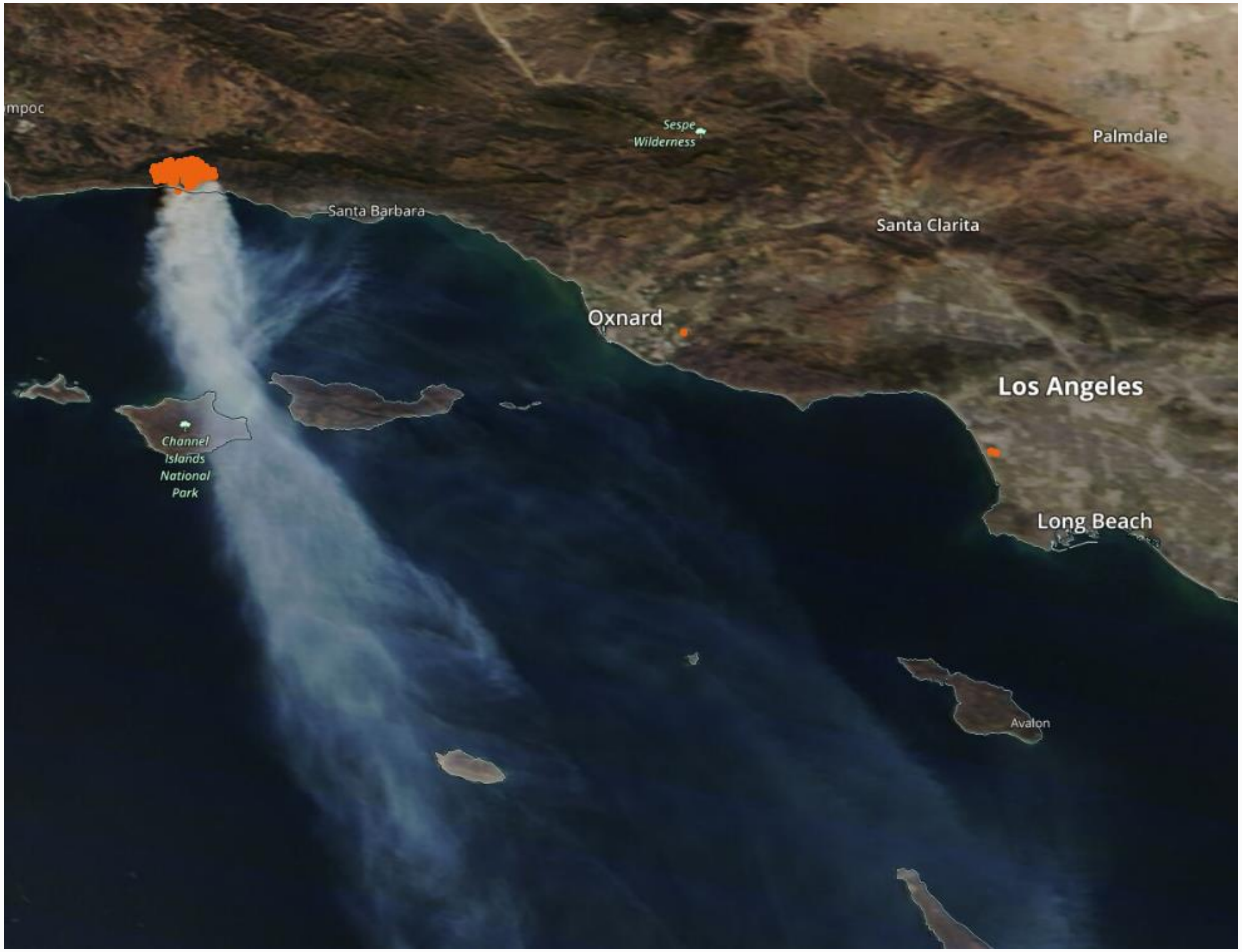
curves for an "average" object on earth

(refl. factor ≈ 0.6
emis. factor ≈ 0.6)

P.S.:

The theoretical intersection of the curves at maximal reflection ($\rho = 1.0$) and maximal emission ($\varepsilon = 1.0$) occurs at $\lambda \approx 4.5$ µm

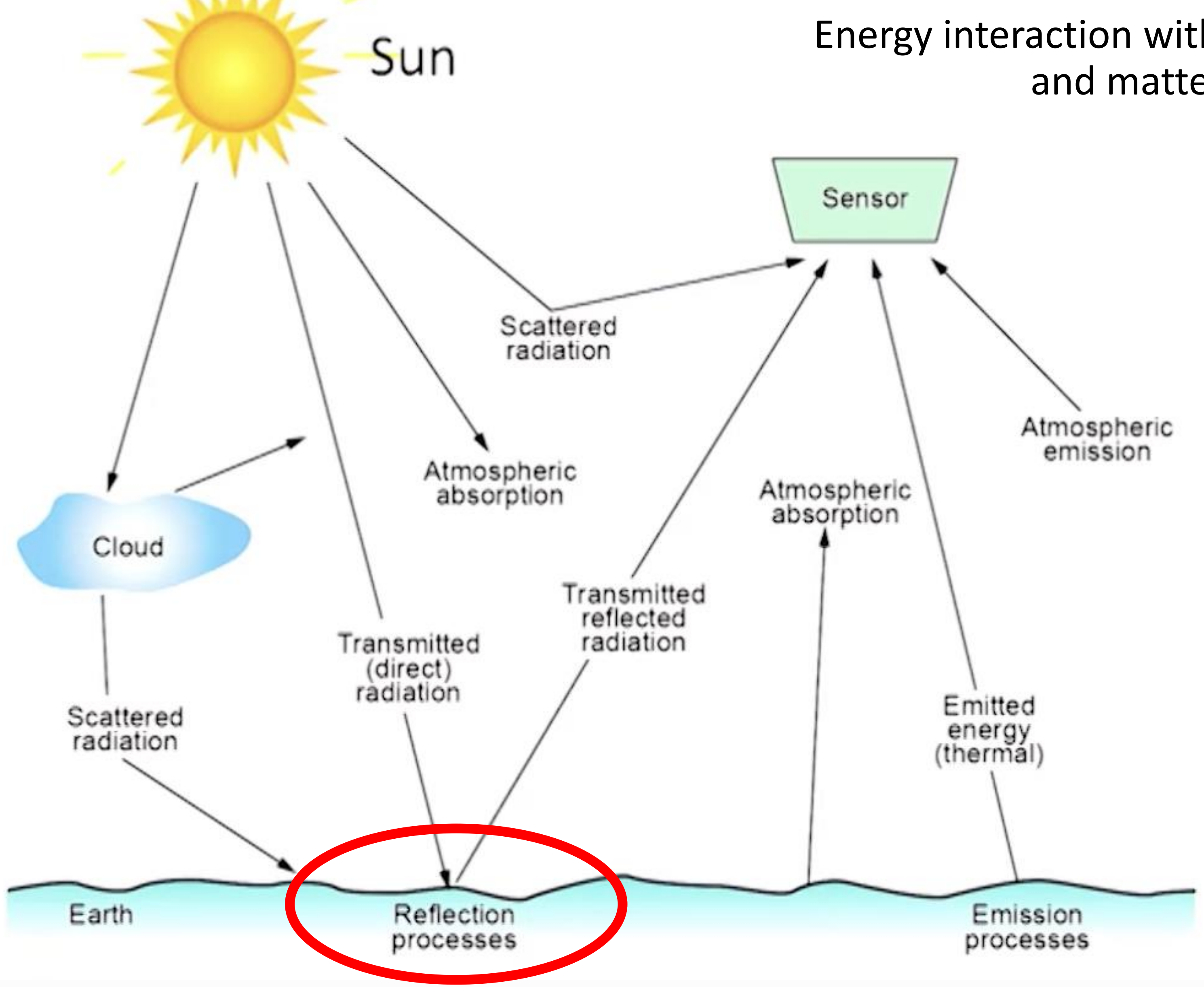
Santa Barbara fire, California on October 12, 2021



- https://worldview.earthdata.nasa.gov/?v=-121.6716600524833,32.52537592166272,-116.60490135585667,35.01917121765863&l=Reference_Features_15m(hidden),Reference_Labels_15m,Coastlines_15m,OMI_SO2_Lower_Troposphere(hidden),AIRS_Prata_SO2_Index_Night(hidden),AIRS_Prata_SO2_Index_Day(hidden),OMI_Aerosol_Optical_Depth(hidden),MODIS_Aqua_AOD_Deep_Blue_Land(hidden),MODIS_Aqua_Angstrom_Exponent_Land(hidden),MODIS_Aqua_Aerosol_Optical_Depth_3km(hidden),MODIS_Aqua_Aerosol(hidden),MODIS_Combined_Value_Added_AOD(hidden),MODIS_Terra_Angstrom_Exponent_Land(hidden),MODIS_Terra_AOD_Deep_Blue_Land(hidden),MODIS_Terra_Aerosol_Optical_Depth_3km(hidden),MODIS_Terra_Aerosol(hidden),MODIS_Combined_Thermal_Anomalies_All,MODIS_Terra_Thermal_Anomalies_All,MODIS_Aqua_Thermal_Anomalies_All,MODIS_Aqua_CorrectedReflectance_TrueColor(hidden),MODIS_Terra_CorrectedReflectance_TrueColor&lg=false&t=2021-10-12-T13%3A22%3A11Z

Energy received at sensor: interaction with atmosphere and surface

Energy interaction with atmopsh
and matter



Spectral signature

Any remotely sensed parameter, which directly or indirectly characterizes the nature and/or condition of the object under observation

Spectral Variation: Variation in reflectivity and emissivity as a function of wavelength. *{unique pattern of wavelengths radiated by an object}*

Spatial Variation: Variation of reflectivity and emissivity with spatial position (i.e. shape, texture and size of the object).

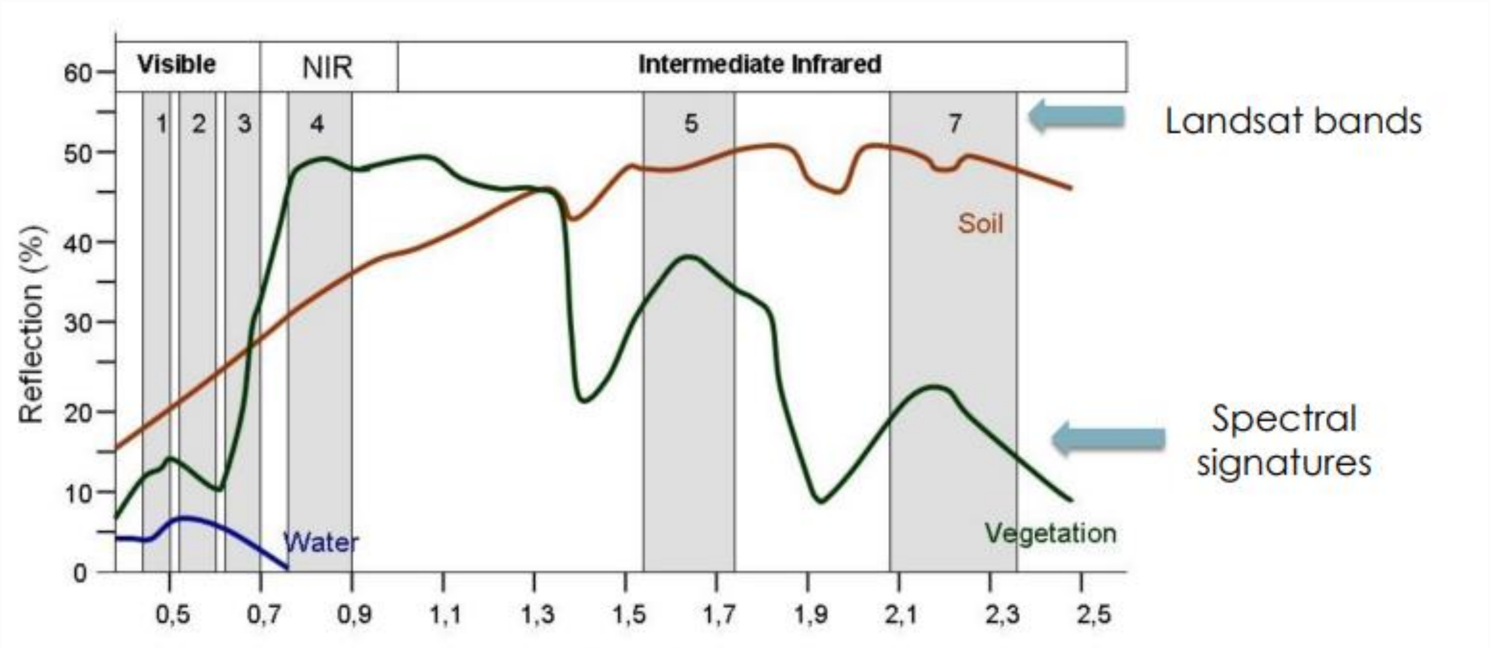
Temporal variation: of emissivity and reflectivity like that in diurnal and seasonal cycle.

Polarization variation: are introduced by the material in the radiation reflected or emitted by it.

Each of above four features of EMR may be interdependent i.e. shape may be different at different times, or in different spectral bands.

Spectral reflectance/signature

- Spectral reflectance (also called as spectral signature) is the percentage of EMR reflected by the object in each wavelength or spectral bands
- Spectral reflectance curve shows the relationship of electromagnetic spectrum with the associated percent reflectance for any given material
- reflectance = (reflected energy/incident energy)
- The reflectance properties of an object depend on its physical, chemical properties, surface roughness as well as EMR wavelength

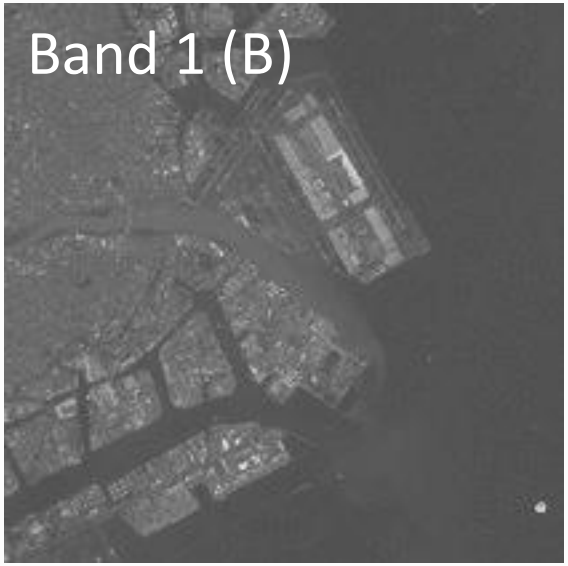


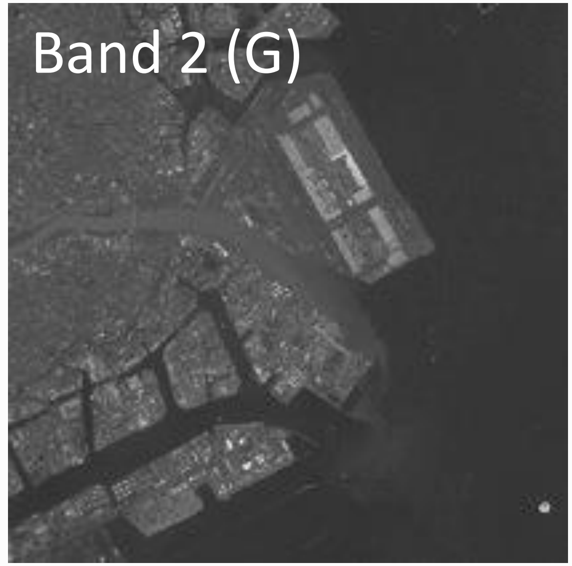
- https://seos-project.eu/remotesensing/remotesensing-c01-p06.html

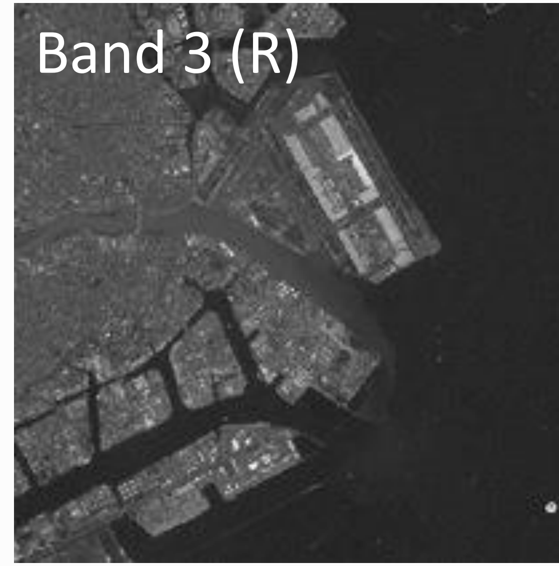
Reflectance characteristics of water

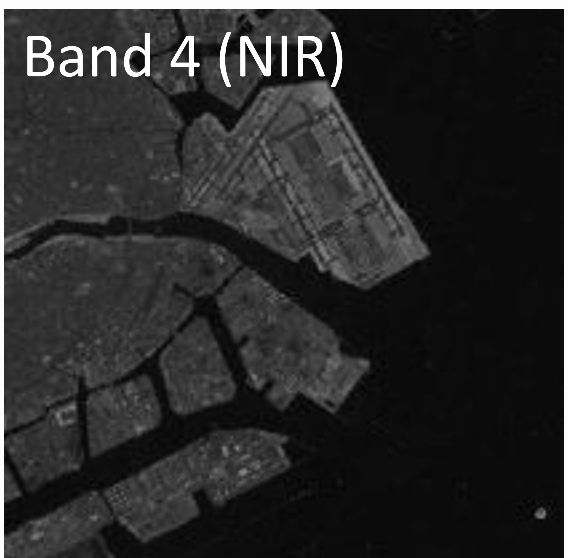
- Clear water appears blue as mainly short wavelengths are reflected (0.4-0.5 µm).
- Water absorbs completely the near IR (0.8-3 µm), so that it appears black there.
- Depending on the suspension, turbidity and other color giving features in the water it can appear differently.
- To separate water from land: Near IR 0.8-3 µm is better

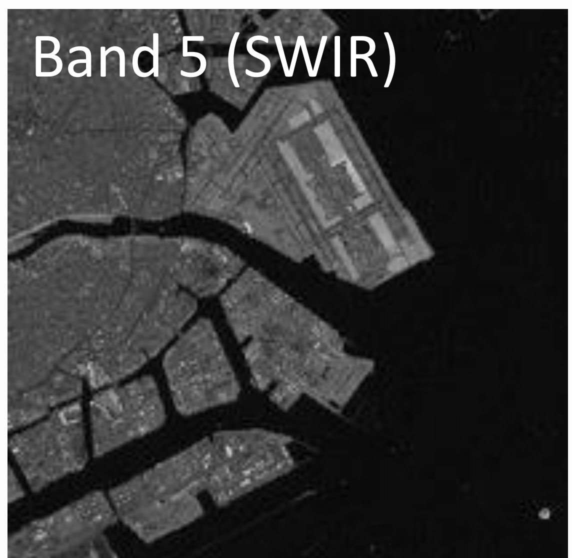
Reflectance characteristics of water





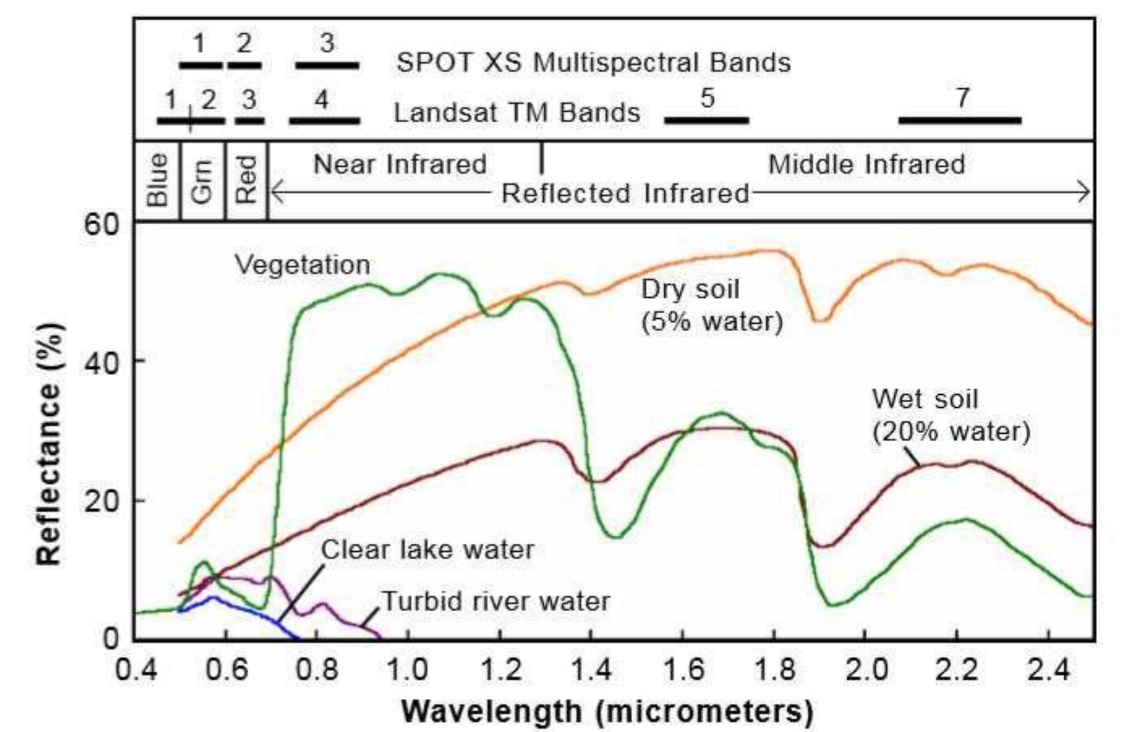






Reflectance characteristics of soil

- Soils are background in many vegetation covered areas and the only reflecting objects in vegetation free areas.
- Strong reflection in the visible spectrum, the actual reflection characteristics depend on soil moisture.
- Soil reflection increases continuously from the blue wavelength onwards over a broad range of wavelengths.
- If multispectral images are available – this characteristic (among others) can be used for the identification of soils



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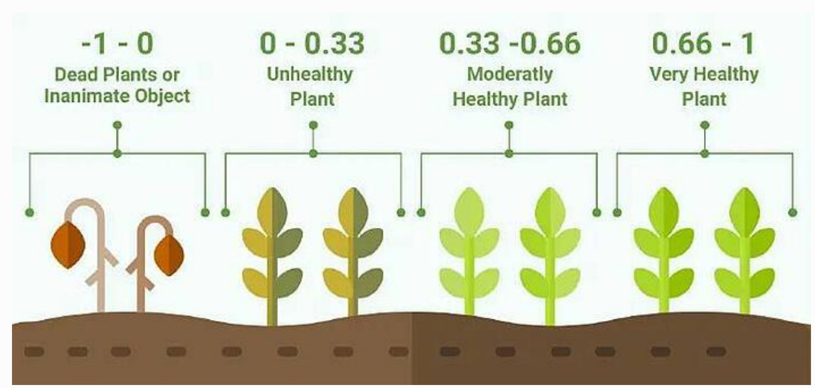
Reflectance characteristics of vegetation

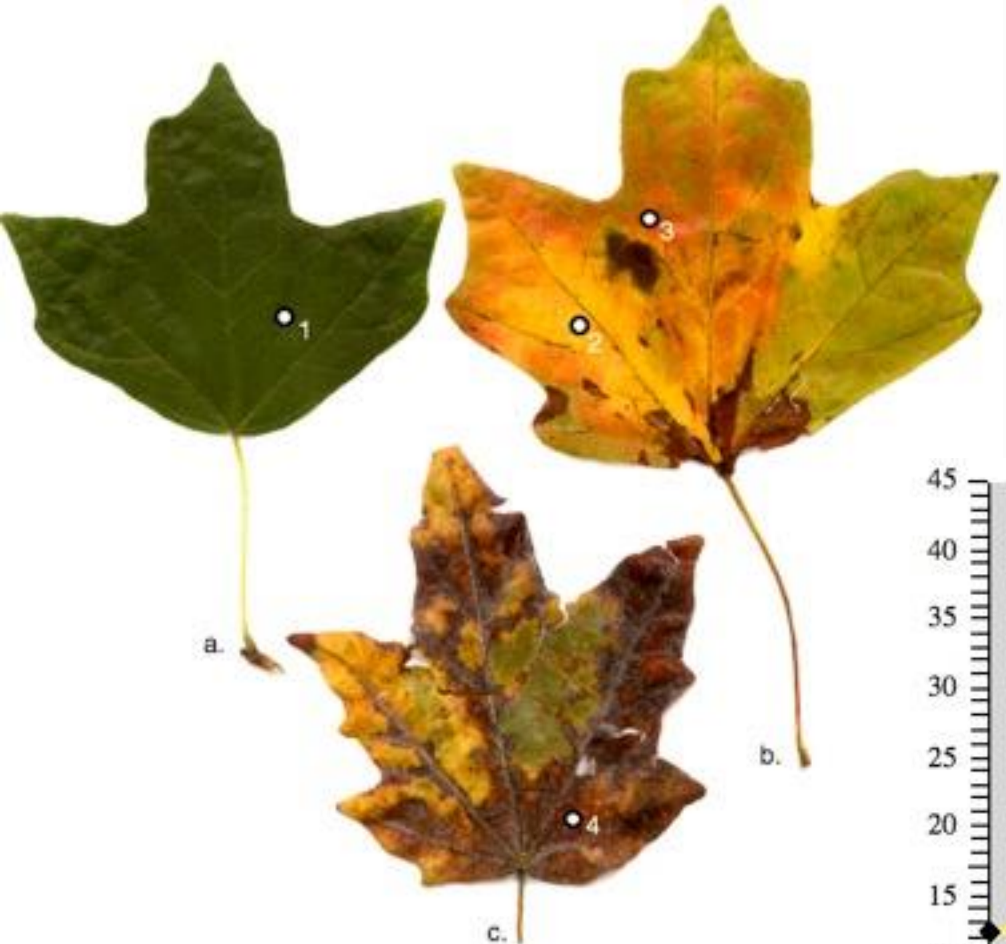
- Vegetation is green (chlorophyll), which is absorbing particularly blue and red, main reflection and transmission is at green.
- The cell structure of the leaves causes a strong reflection also in the near IR (0.8-1.1 μm).
- Vegetation absorbs (blue, red) and reflects very typically (near IR), so that vegetation can often easily be distinguished from non-vegetation.
- Often identified using normalized difference vegetation index (NDVI)

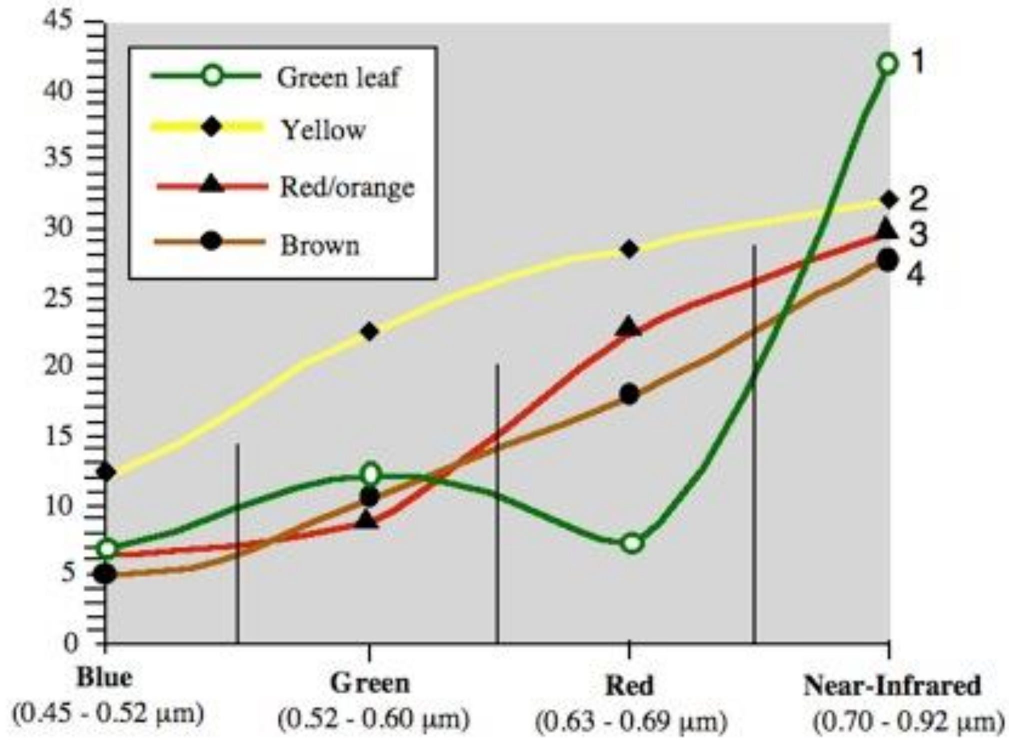
$$NDVI = \frac{NIR - RED}{NIR + RED}$$



NDVI represents plant health

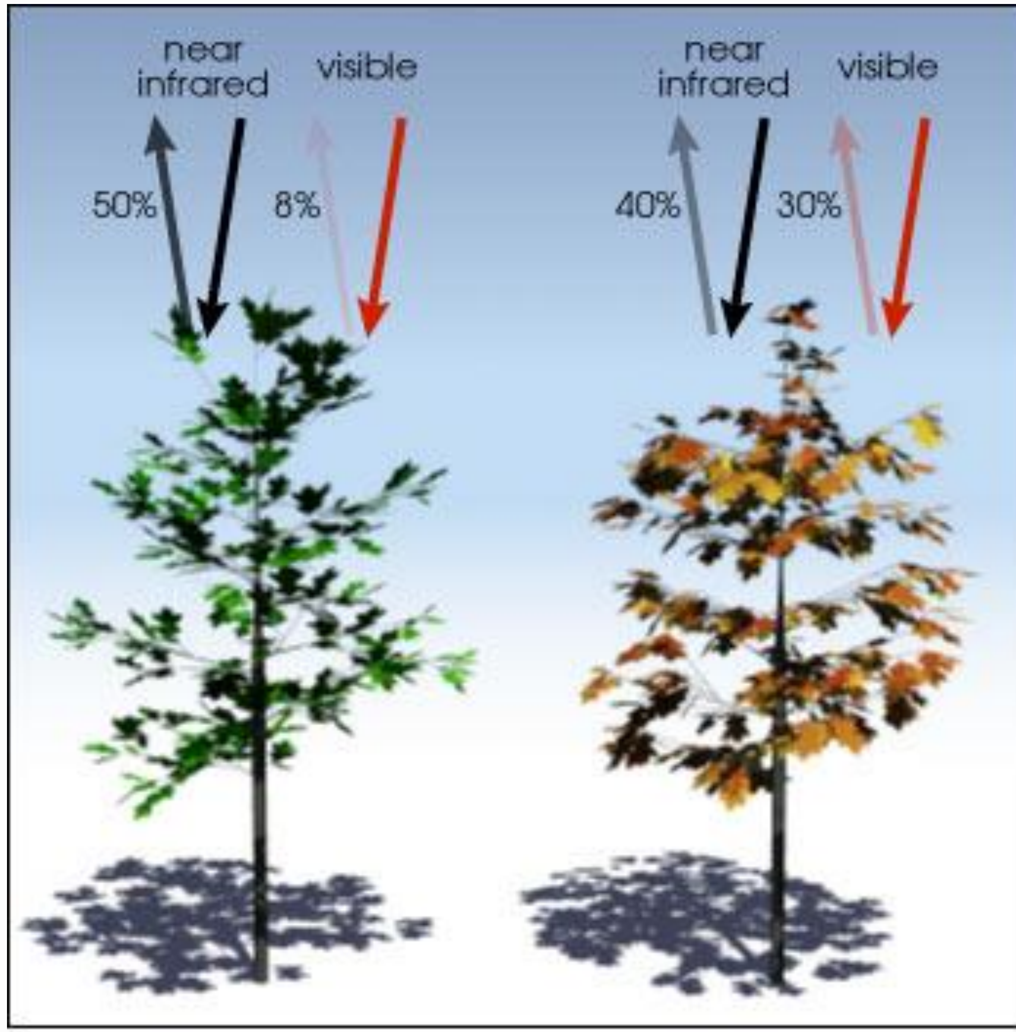
Spectral reflectance of oak leaves





NDVI: healthy/unhealthy tree

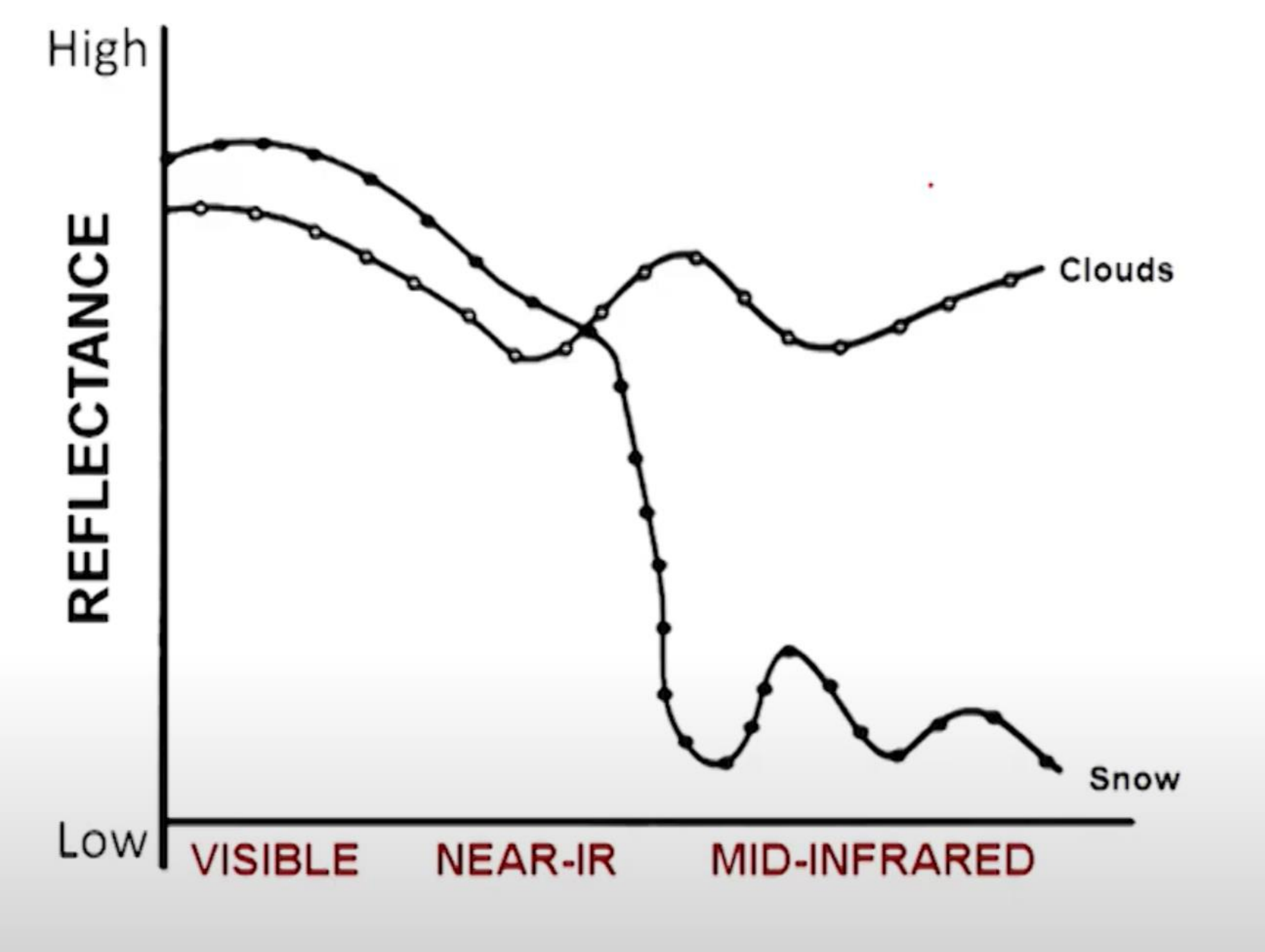
$$NDVI = \frac{NIR - RED}{NIR + RED}$$



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

The relationship between NIR and red bands for healthy (left) and unhealthy (right) vegetation. Source: NASA

Spectral reflectance of cloud vs snow



Instruments for measuring spectral reflectance

- Measurement of reflectance and emittance of various materials in laboratory and at natural field conditions.
- Two categories
- a) Spectrometer – measures the spectral distribution of entire EMR
- b) Radiometer – measures the content of radiation within predetermined spectral bands

- If the spectrum is observed by eye – spectroscope
- If the spectrum is recorded on photography film – spectrograph
- If the instrument produces a spectrum that can be scanned in some way with a detector to determine the wavelength position of emission or absorption lines in the source – spectrometer
- If in addition, the instrument can measure the radiant exitance of these lines – spectroradiometer

Spectroradiometer

Spectroradiometer measures spectral signatures of objects from a distance

Readings are taken between 8am to 10:30am and between 3pm to 5pm to refrain from very high or low sun elevation

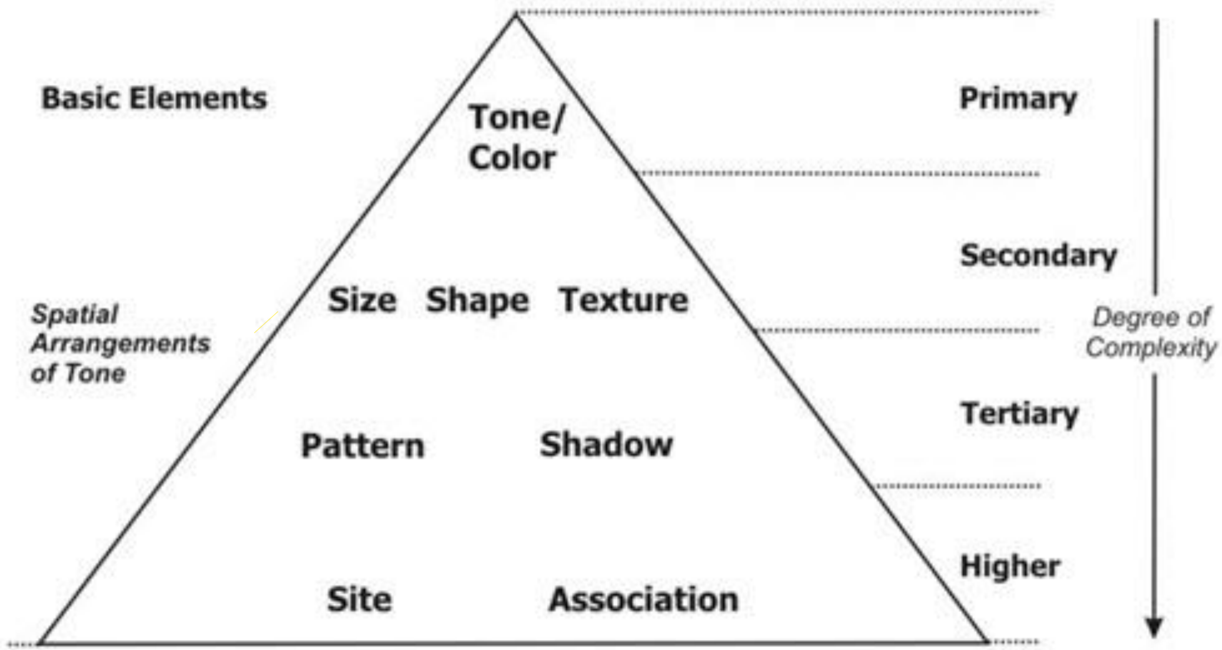
Reflected radiance can be measured by holding device vertically over the object at around 1.5m height

Analytical Spectral Devices FieldSpec-spectrometer, wavelenght 350 - 2500 nm

Application of reflectance values

- They provide useful inputs to the design and calibration of remote sensing sensors.
- The databases of reflectance values would be helpful to possibly decide the sensor parameters, such as optimal number of spectral bands, optimal ground resolution, etc.
- These can also provide input data for radiometric and atmospheric corrections of satellite images, which requires field reflectance measurements of the targets/objects with illumination and viewing geometry equivalent to that of the imaging sensor of interest.

8 Elements of visual interpretation



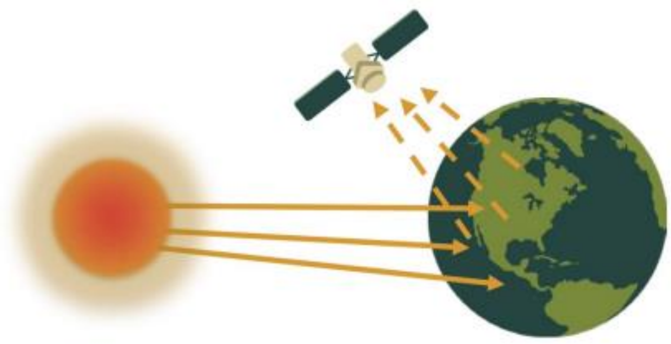
Tone is the relative brightness of grey level on black and white image or color.
Texture refers to the frequency of tonal variation in an image. Depends on resolution.
Pattern: Pattern refers to the spatial arrangement of the objects.
Size: Size of objects on images must be considered in the context of the image scale or resolution.
Shape: Shape refers to the general form, configuration or outline of an individual object.
Shadow: Shadow is a helpful element in image interpretation for height estimation.
Association: Association refers to the occurrence of certain features in relation to others objects in the imagery.
Site: Site refers to topographic or geographic location.

Definition of each element: http://ecoursesonline.iasri.res.in/mod/page/view.php?id=2062

Satellite sensor: Passive and Active

Satellite Sensors: Passive

- Passive remote sensors measure radiant energy **reflected** or **emitted** by the Earth-atmosphere system or changes in gravity from the Earth.
- Radiant energy is converted to bio-geophysical quantities such as temperature, precipitation, and soil moisture.
- Examples: Landsat OLI/TIRS, Terra MODIS, GPM GMI, GRACE, etc.



Satellite Sensors: Active

- Active sensors provide their own energy source for illumination
- Most active sensors operate in the microwave portion of the electromagnetic spectrum, which makes them able to penetrate the atmosphere under most conditions and can be used day or night.
- Have a variety of applications related to meteorology and observation of the Earth's surface and atmosphere.
- Examples: Laser Altimeter, LiDAR, RADAR, Scatterometer, Sounder
- Missions: Sentinel-1 (C-SAR), ICESat-2 (ATLAS), GPM (DPR)

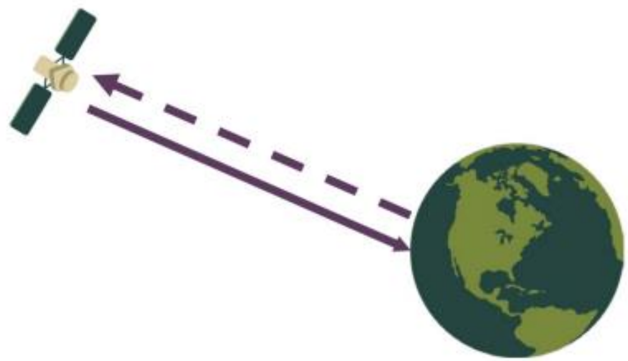


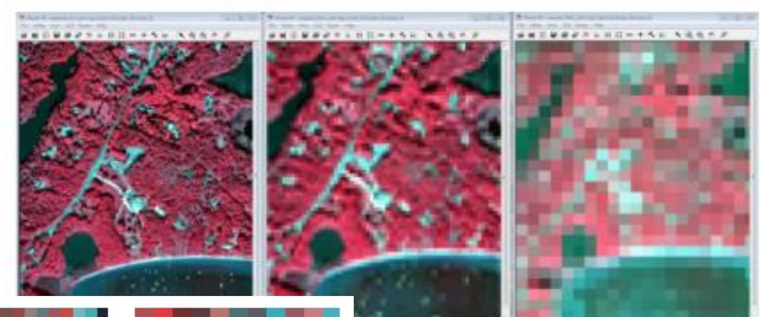
Image Credit: ARSET

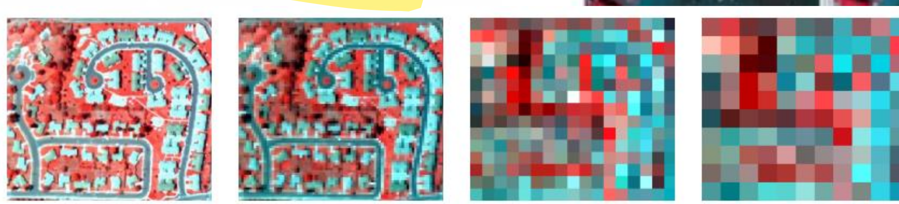
Satellite sensor: spatial resolution

Spatial resolution is a measure of the smallest object a sensor can detect, or the area on the ground that a sensor's field of view can image. In remote sensing, it refers to the size of each pixel in a digital image and the area on Earth that each pixel represents.

- Resolution depends upon satellite orbit configuration and sensor design. Different sensors have different resolutions.
- Signifies the ground surface area that forms one pixel in the image. Sub-pixel objects can sometimes be resolved.
- It is usually presented as a single value representing the length of one side of a square.
- The higher the spatial resolution, the less area is covered by a single pixel.
- The image in the bottom right shows the same image at different spatial resolutions: (from left to right) 1 m, 10 m, and 30 m.

Sensor	Spatial Resolution
DigitalGlobe (and others)	<1 m - 4 m
Landsat	30 m
MODIS	250 m - 1 km
GPM IMERG	~10 km





1 x 1 m | 4 x 4 m | 20 x 20 m (SPOT) | 30 x 30 m (Landsat TM)

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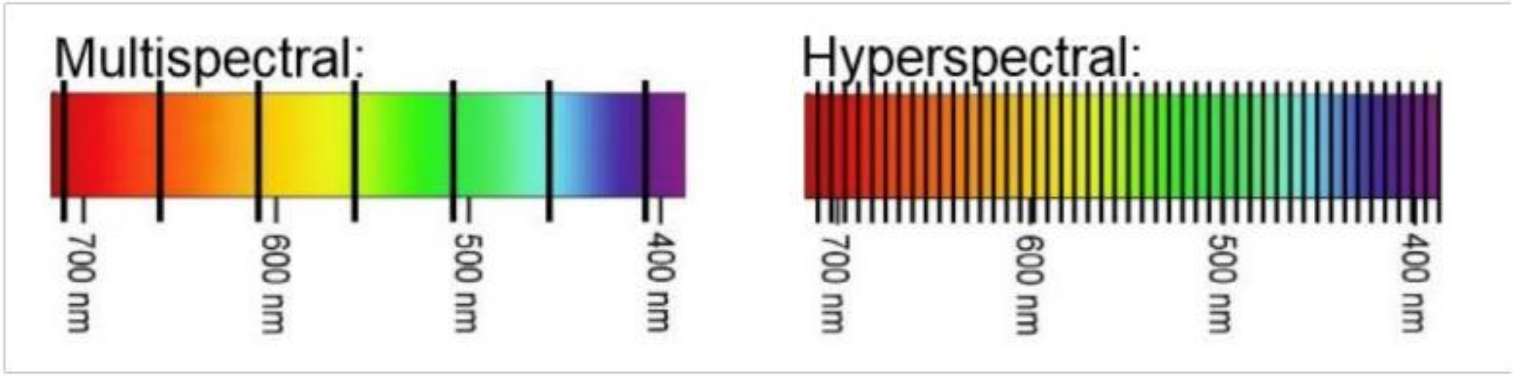
Satellite sensor: spectral resolution

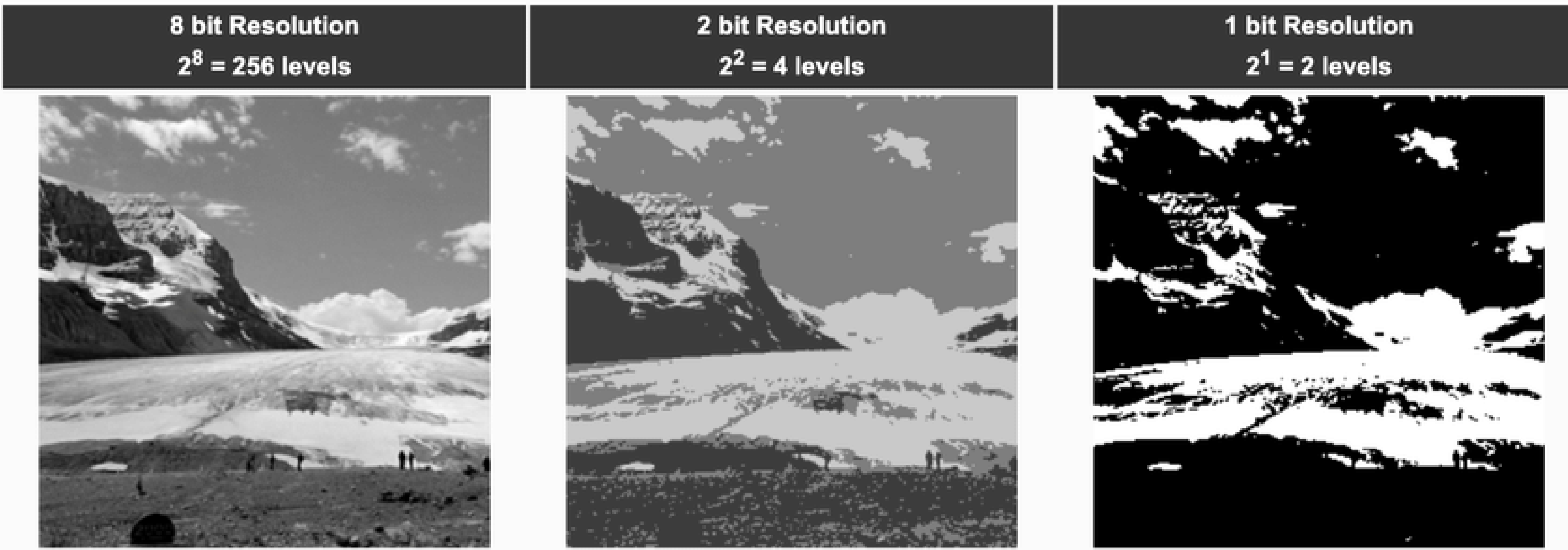
Spectral resolution, the ability of a sensor to detect small differences in wavelength

- Resolution depends upon satellite orbit configuration and sensor design. Different sensors have different resolutions.
- Signifies the number and width of spectral bands of the sensor. The higher the spectral resolution, the narrower the wavelength range for a given channel or band.
- More and finer spectral channels enable remote sensing of different parts of the Earth's surface.
- Typically, multispectral imagery refers to 3 to 10 bands, while hyperspectral imagery consists of hundreds or thousands of (narrower) bands (i.e., higher spectral resolution). Panchromatic is a single broad band that collects a wide range of wavelengths.



Satellite sensor: radiometric resolution

- Sensitivity to the magnitude of the electromagnetic energy determines the **radiometric resolution**. The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy

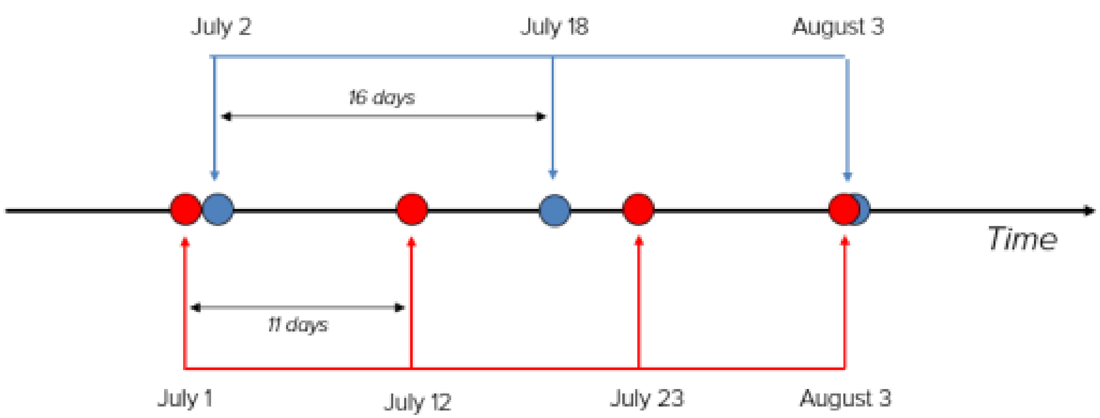


Satellite platform: temporal resolution

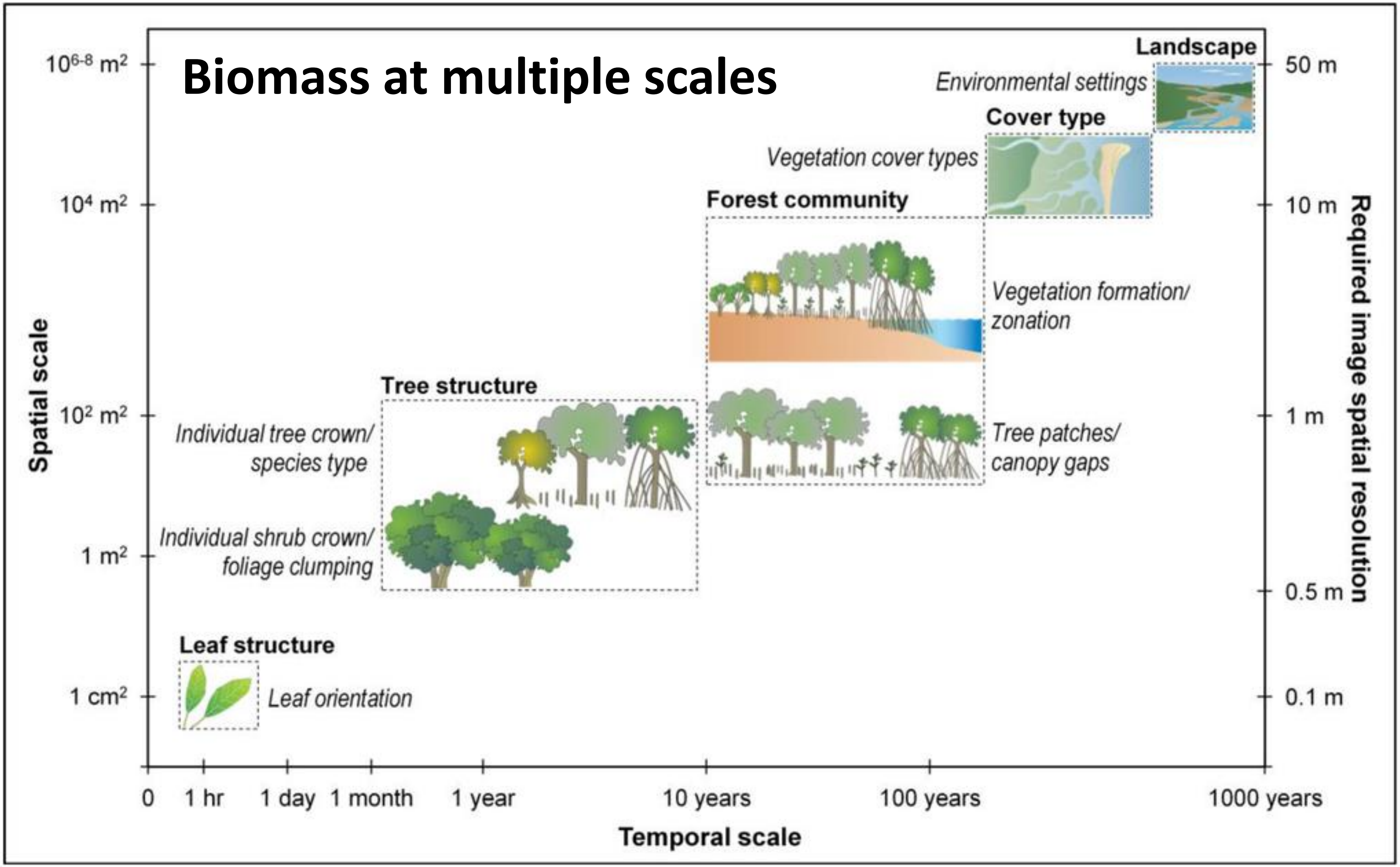
- The time it takes for a satellite to complete one orbit cycle—also called "revisit time"
- Depends on satellite/sensor capabilities, swath overlap, and latitude
- Some satellites have greater temporal resolution because:
  - They can maneuver their sensors
  - They have increasing overlap at higher latitudes

Sensor	Revisit time
Landsat	16-days
MODIS	2-days
Commercial (OrbView)	1-2 days

– **High temporal resolution:** < 24 hours - 3 days
– **Medium temporal resolution:** 4 - 16 days
– **Low temporal resolution:** > 16 days



Multi-remote sensing need: multiple spatio-temporal scales



Multi-remote sensing need: multiple spatio-temporal scales

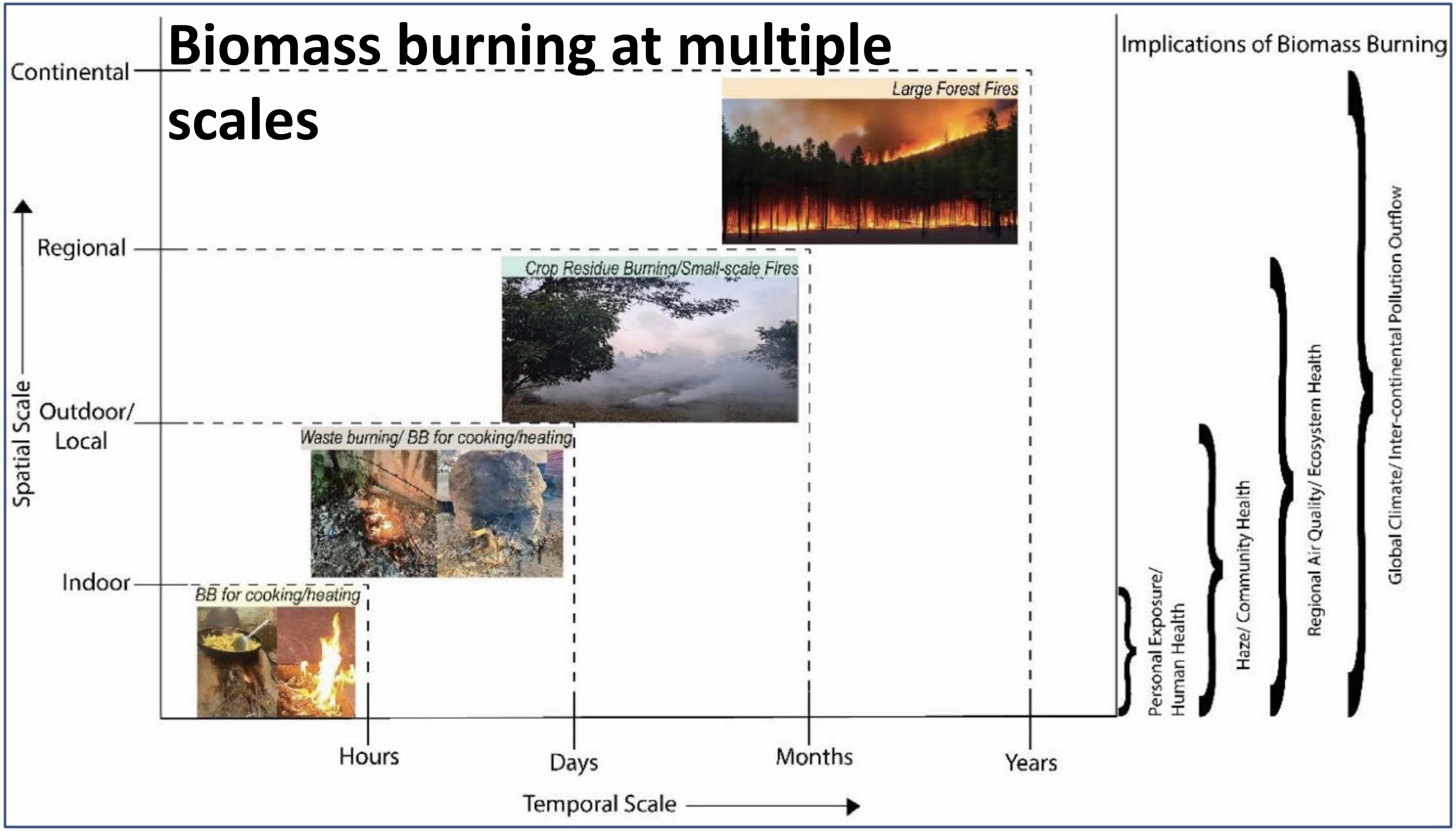


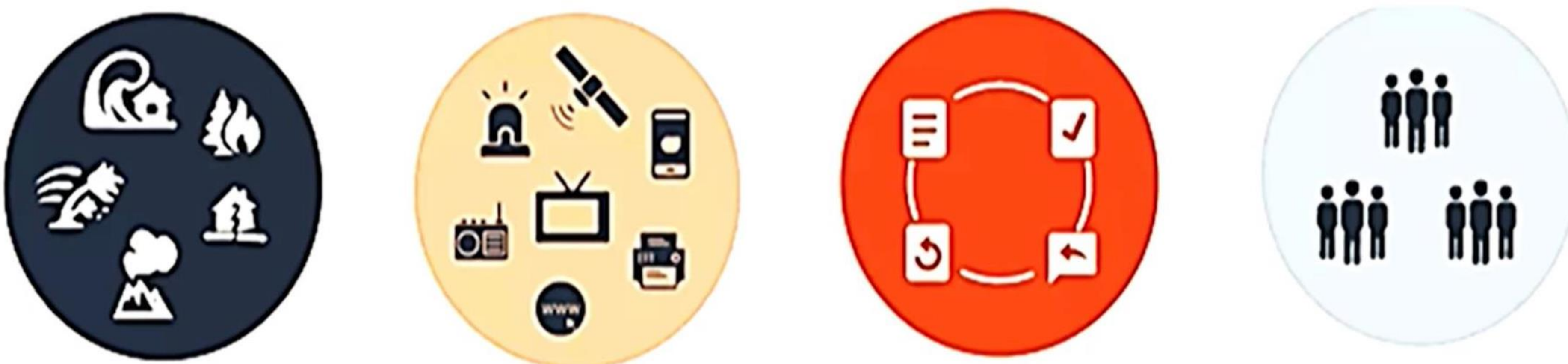
Figure 1. Spatio-temporal spread of different types of BB, namely, solid fuel burning for heating and cooking, waste burning, CRB/small-scale fires and large FFs, along with their respective implications.

Tripathi, Sachchidanand, Shweta Yadav, and Konika Sharma. "Air pollution from biomass burning in India." *Environmental Research Letters* (2024).

Multi-concept in remote sensing

The multi-concept is an important approach and one of the key concepts in remote sensing data acquisition and analysis.

It includes multi-stage (height), multi-resolution (pixel size), multi-spectral (bands), multi-detector (sensors), and multi-temporal (date), and multi-uses (applications).



Multi-hazard

Multi-technology

Multi-phase

Multi-stakeholder

The RS Multi - Concept

Multi-concept: data acquisition approach:

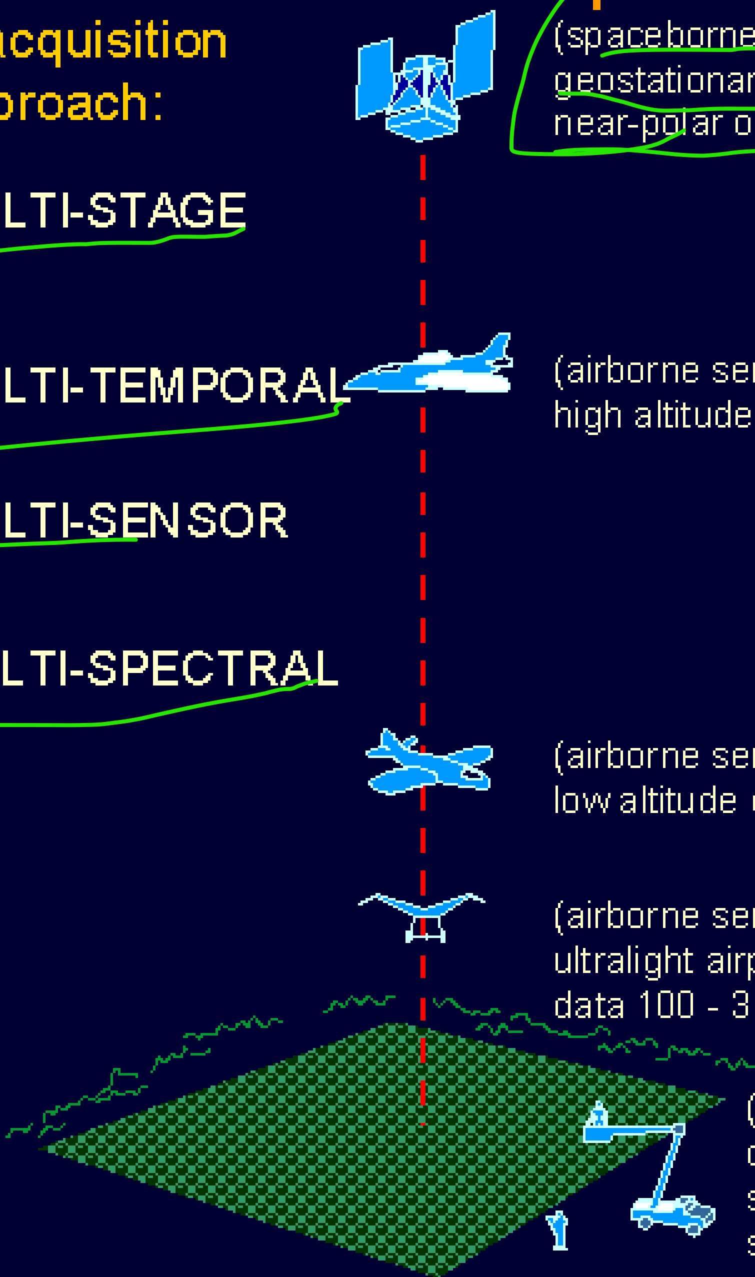
different platforms
different altitudes — MULTI-STAGE

different dates/times — MULTI-TEMPORAL

different sensors — MULTI-SENSOR

different spectral bands — MULTI-SPECTRAL

COMPLEMENTARY !!



(spaceborne sensors)
geostationary orbit 36000 km
near-polar orbit 600 - 1000 km

(airborne sensors)
high altitude data 3 - 10 km

(airborne sensors)
low altitude data 300 m - 3 km

(airborne sensors)
ultralight airplane
data 100 - 300 m

(ground observations)
close range remote
sensing 1 - 5 m
sensing in situ

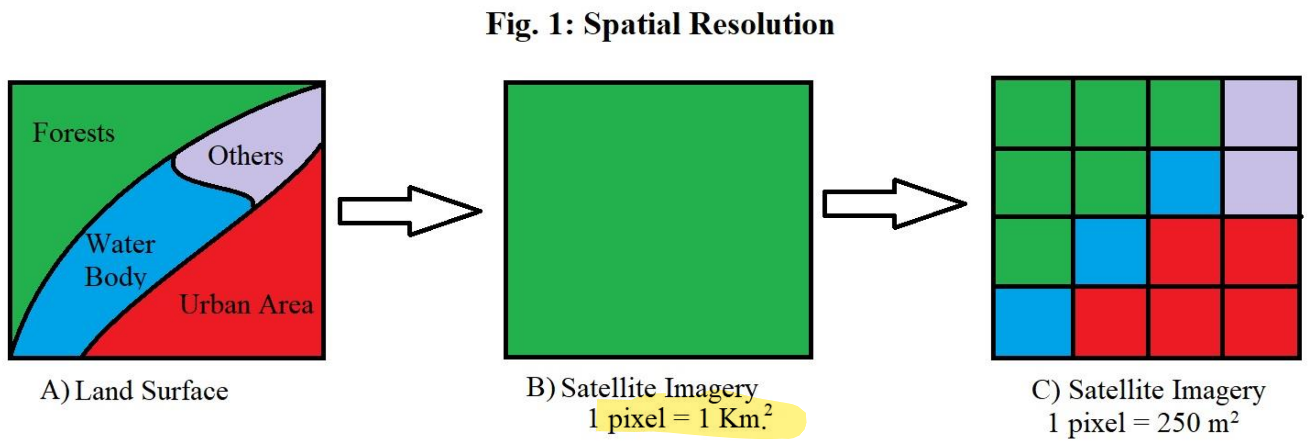
Multi-stage remote sensing

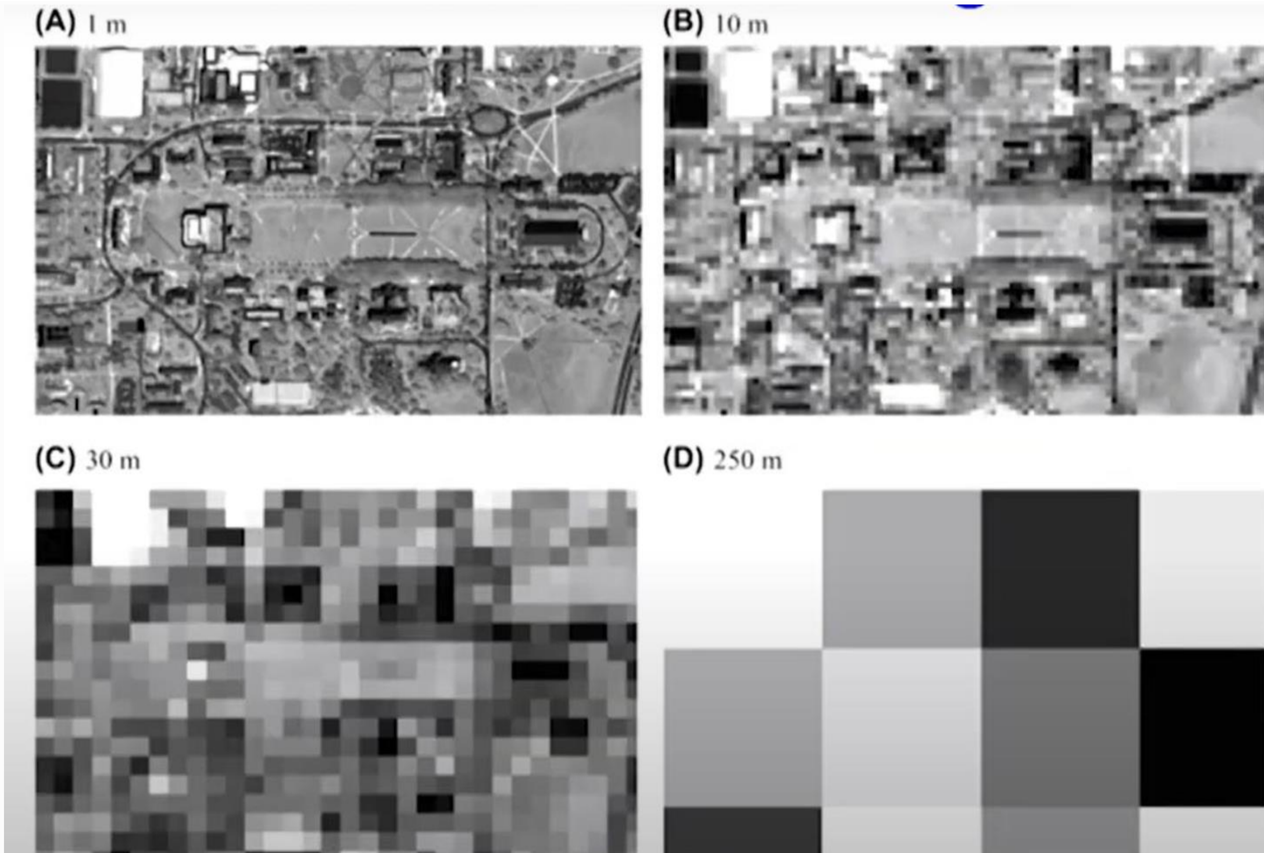
- The remote sensing data can be collected from different platforms at different altitude, such as satellite data, high altitude data, low altitude data, drone data, balloon data, and ground observations.
- Each of the platforms will provide data/images at different scales with different ground coverage.
- Lower platform will cover small area with greater details, as compared to higher platform.
- The selection of data/image will depend on the details required to be mapped and studied.
- Many times, a combination of data from various platforms helps in more reliable and accurate extraction of information, particularly where ground verification is carried out for accuracy estimation.

Multi-stage remote sensing

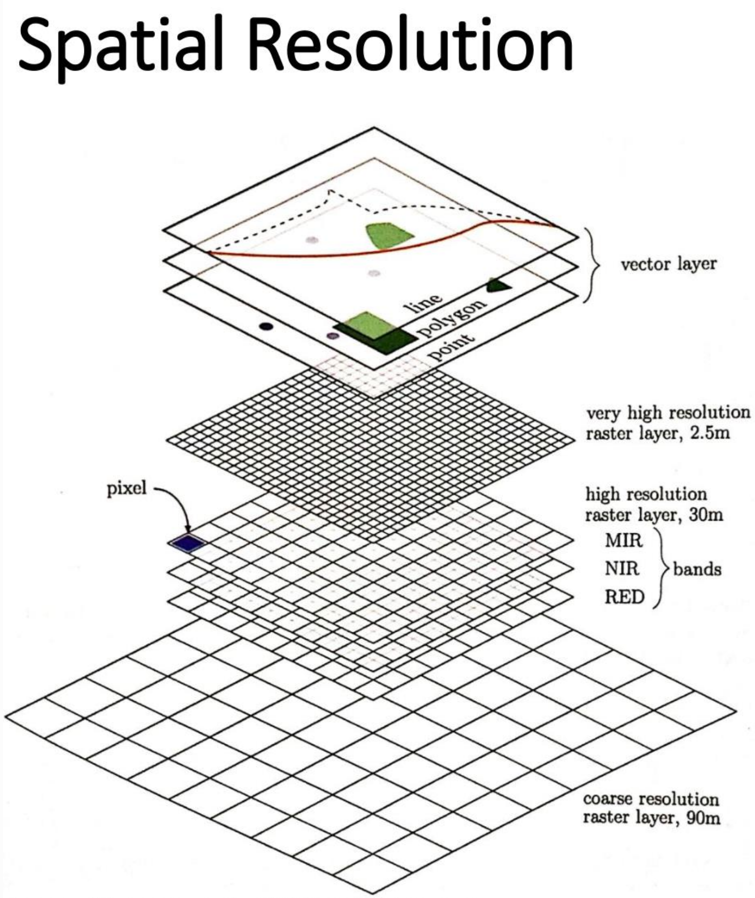
Platform	Advantages	Disadvantages
Hand or ground	• Can be used to identify the reflectance characteristics of an individual leaf, plant, or area. • Flexible availability. • Useful for real-time spraying applications.	• Collect the reflectance characteristic from a single point, not creating image.
UAV	• Flexible availability. • Relatively low cost. • Very high spatial resolution. • Changeable sensors.	• Relatively unstable platform can create blurred images. • Geographic distortion. • May require certification to operate. • May be limited in height above ground. • Processing the data into field images may be prone to error.
Aircraft	• Relatively flexible availability. • Relatively high spatial resolution. • Changeable sensors.	• High cost. • Availability depends on weather condition.
Satellite	• Some free images. • Clear and stable images. • Large area within each image. • Good historical data.	• High cost for high spatial resolution images. • Clouds may hide ground features. • Fixed schedule. • Data may not be collected at critical times. • May need to sort through many images to obtain useful information.

Multi-resolution images

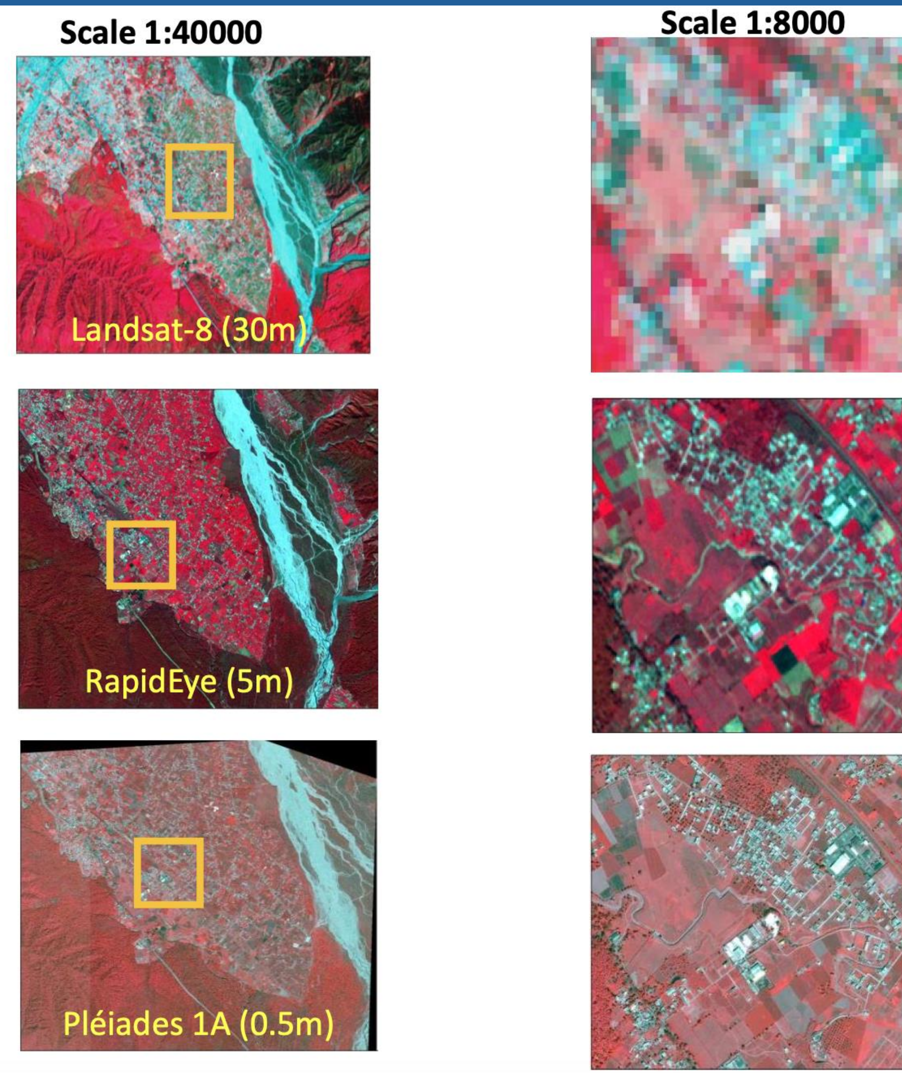




Spatial resolution



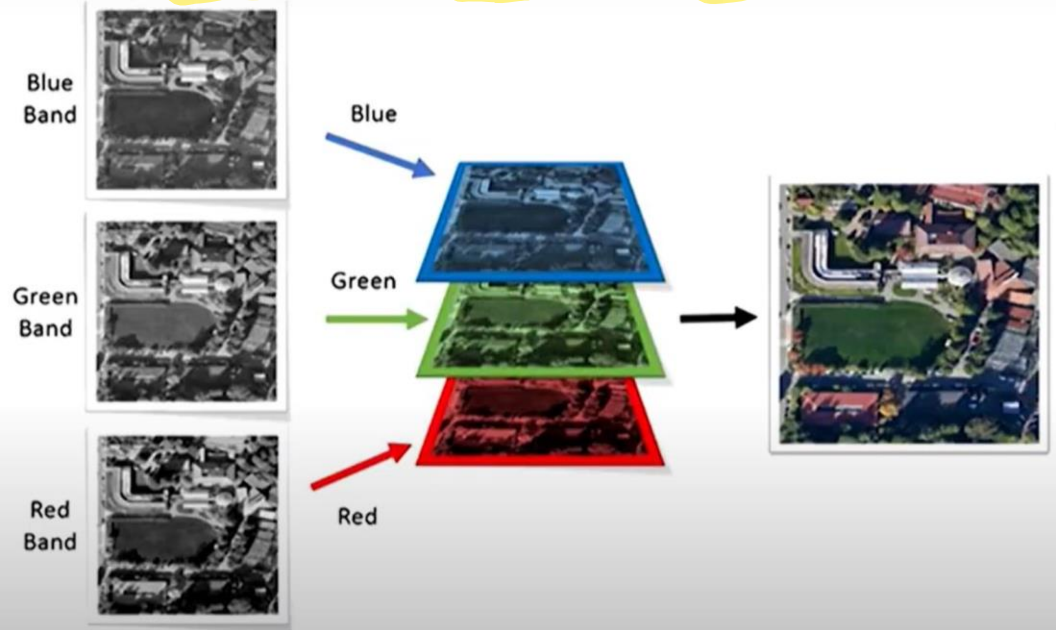
Source: Wegmann et al., (2016) and ESA project



High resolution is better when detailed study/thematic map needed.
- But costs more in acquisition, processing and analysis, and area coverage is limited.

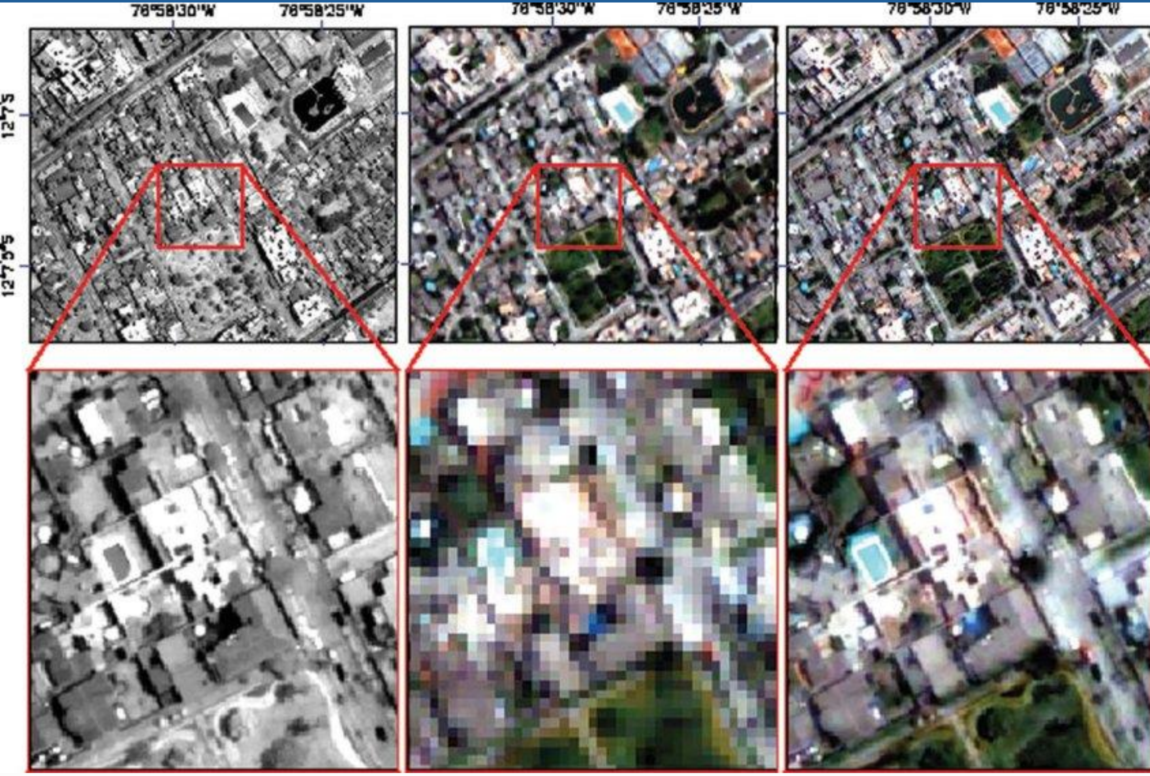
Multi-band remote sensing

- Multi-band indicates individual spectral bands within a given region of the EMS e.g., visible, infrared, thermal, microwave etc.
- Such images are needed to correctly identify various objects on the ground as they might look differently in each wavelength region, depending on the reflected and emitted energy.
- Multi-band images are also required to generate color composite for better interpretation, as human eyes are more sensitive to colors for identification of features than individual B&W image.



Multi-sensor remote sensing

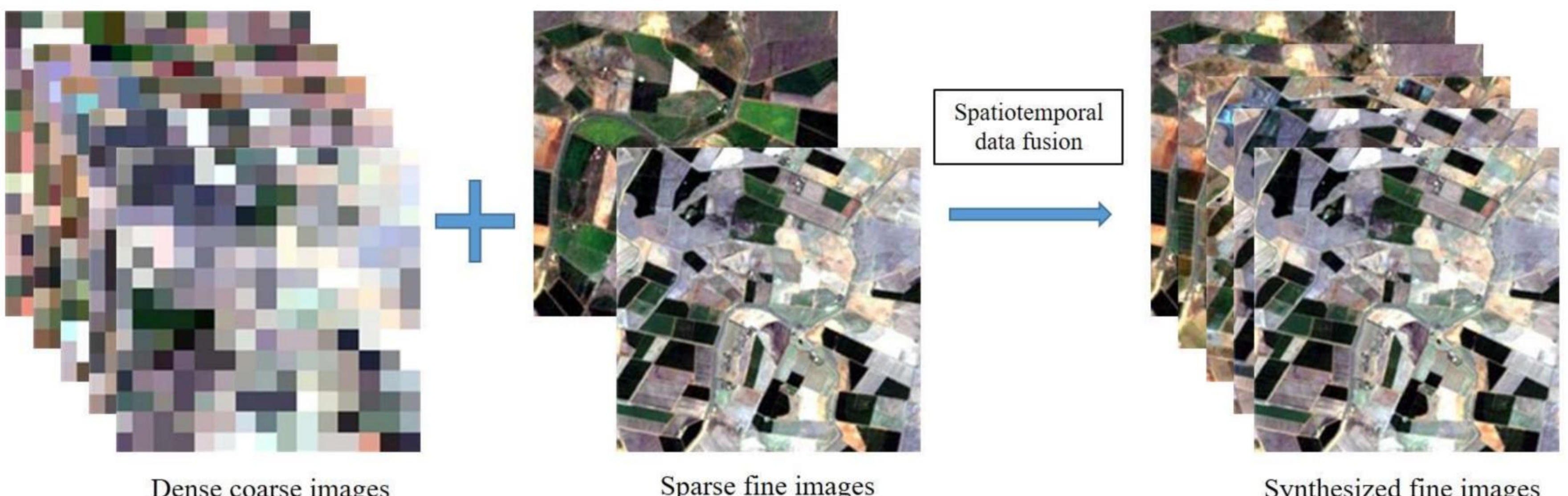
- The satellite images taken from various sensors are helpful in accurate identification and mapping of features.
- These sensors provide data at different resolutions and different wavelength region of the same area, thus helpful in recognition of objects.
- Moreover, data fusion techniques are very popular to merge data from two sensors and get the resultant image which has the best information out both the input images.



Fusion of panchromatic and multispectral imagery

Spatiotemporal fusion of Multisource Remote Sensing Data

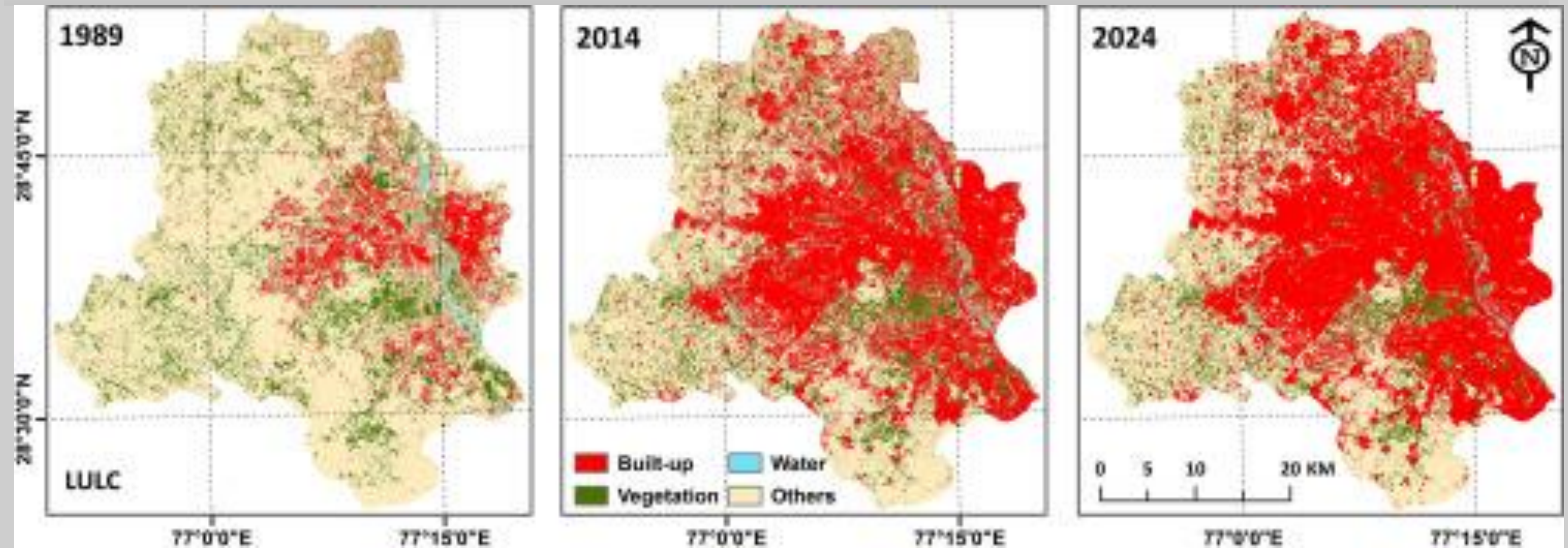
https://www.tandfonline.com/doi/full/10.1080/01431161.2010.512928 and panchromatic imagery



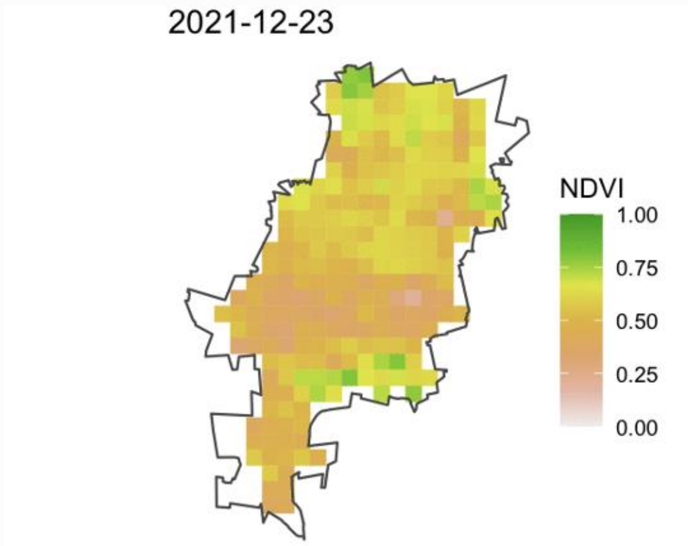
https://www.mdpi.com/2072-4292/10/4/527

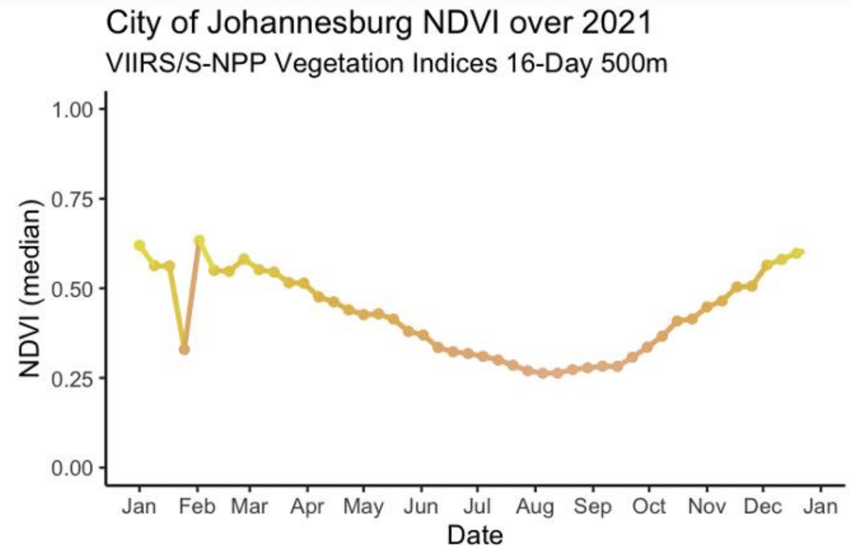
Multi-temporal remote sensing

- Images taken from same satellite of the same area can be acquired repetitively at regular interval, and used to study the change scenario.
- Images taken from different satellites can also be used to study the change scenario by having reduced time interval.
- These images are useful particularly for mapping and monitoring the dynamic events and features, such as flood, crop growth, forest fire etc.

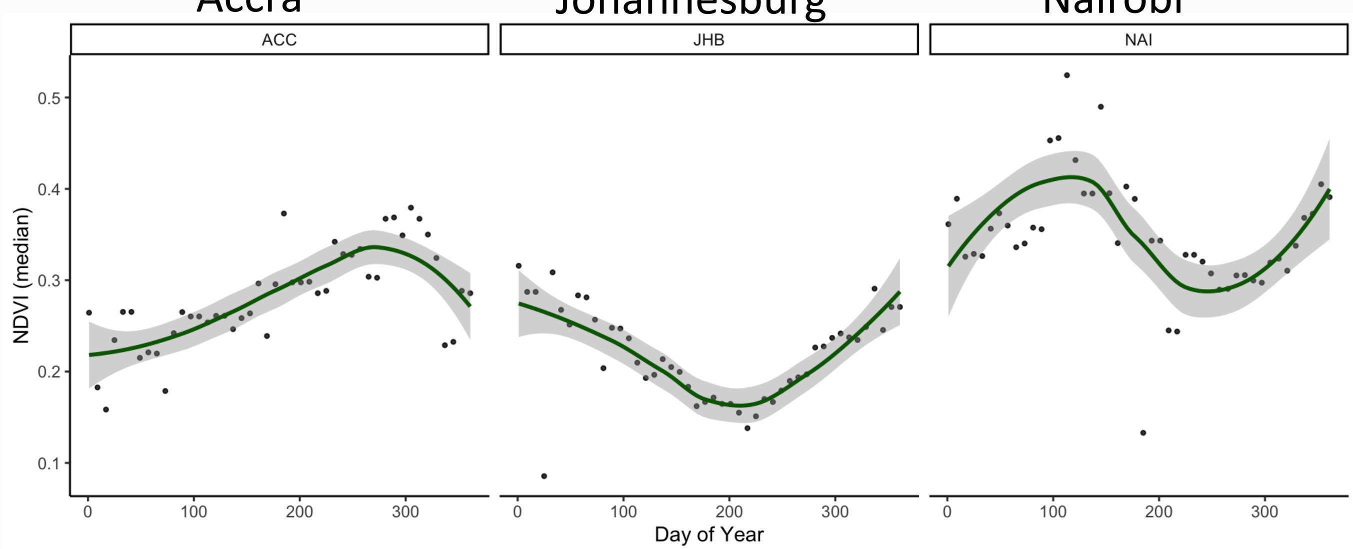


Multi-temporal NDVI to study phenology



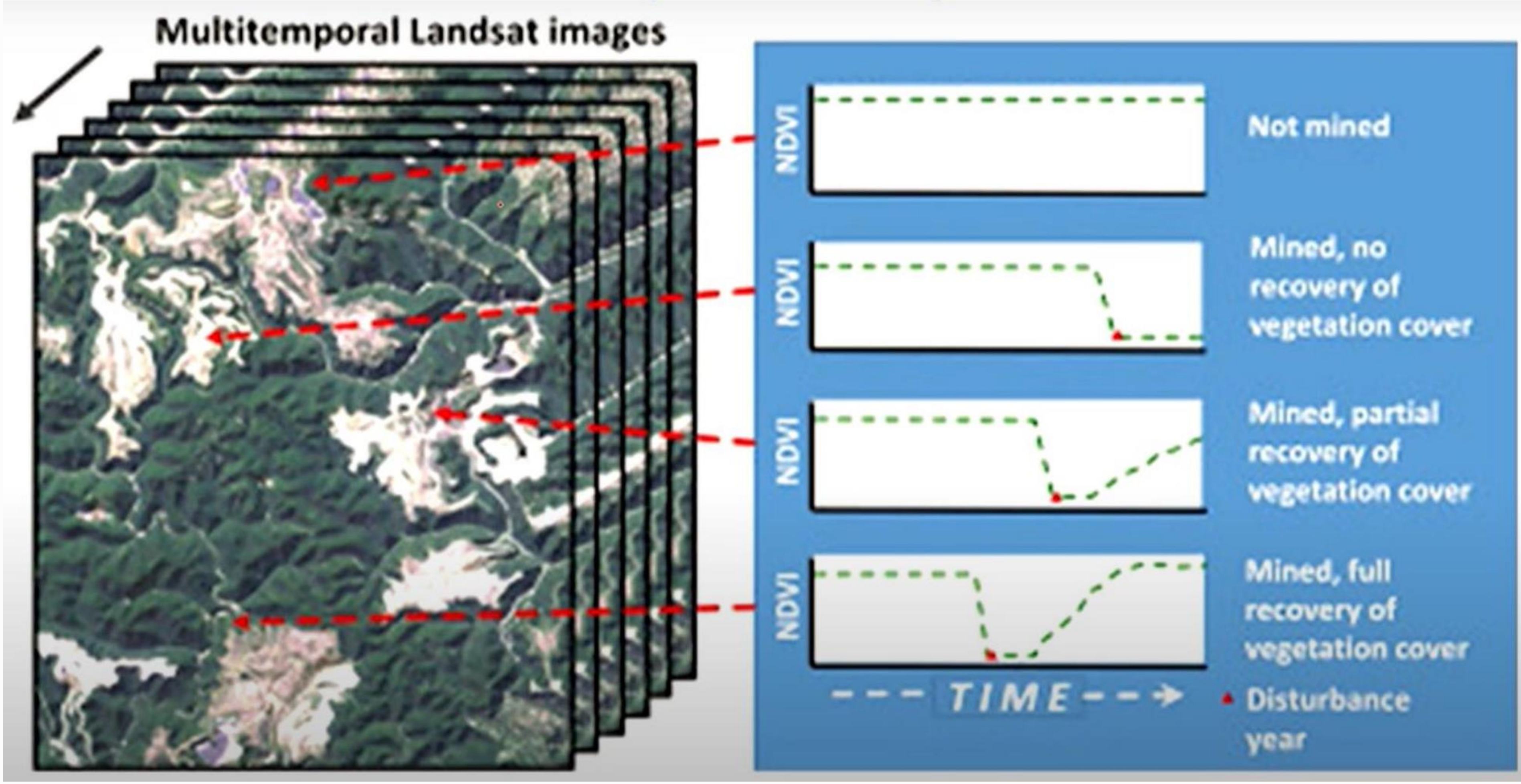


Accra Johannesburg Nairobi



https://jdmwhite.github.io/Intro_to_Spatial/NDVI_time_series.html

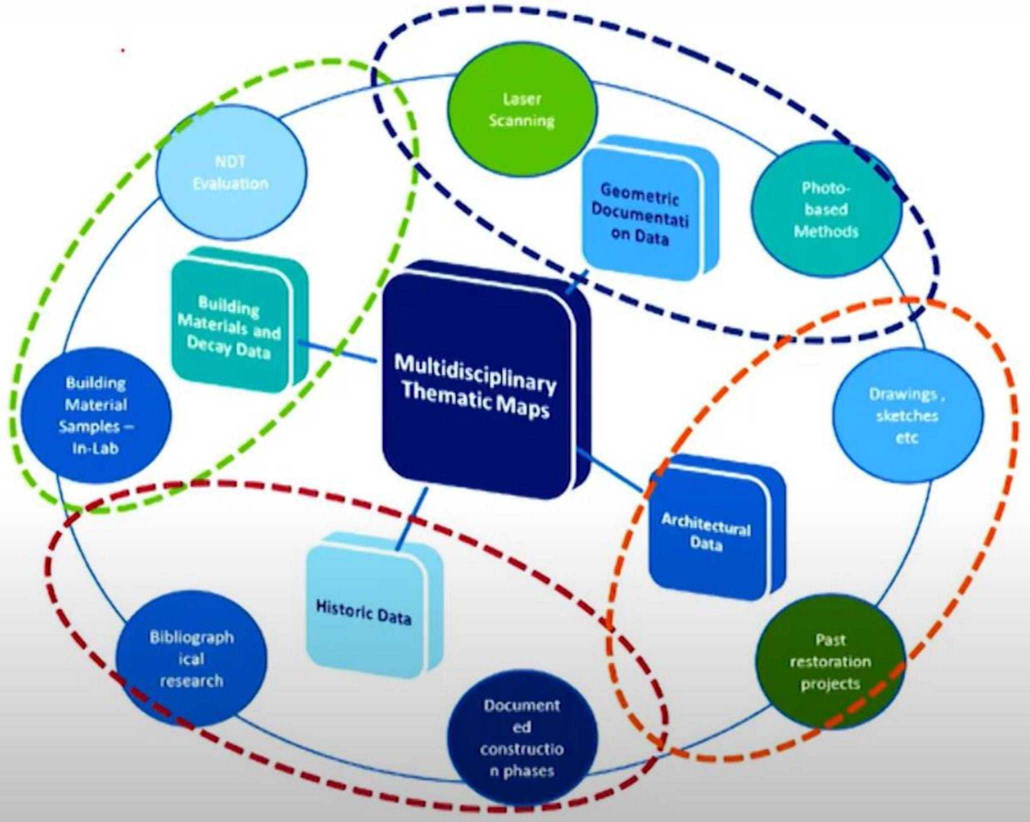
Multi-temporal remote sensing



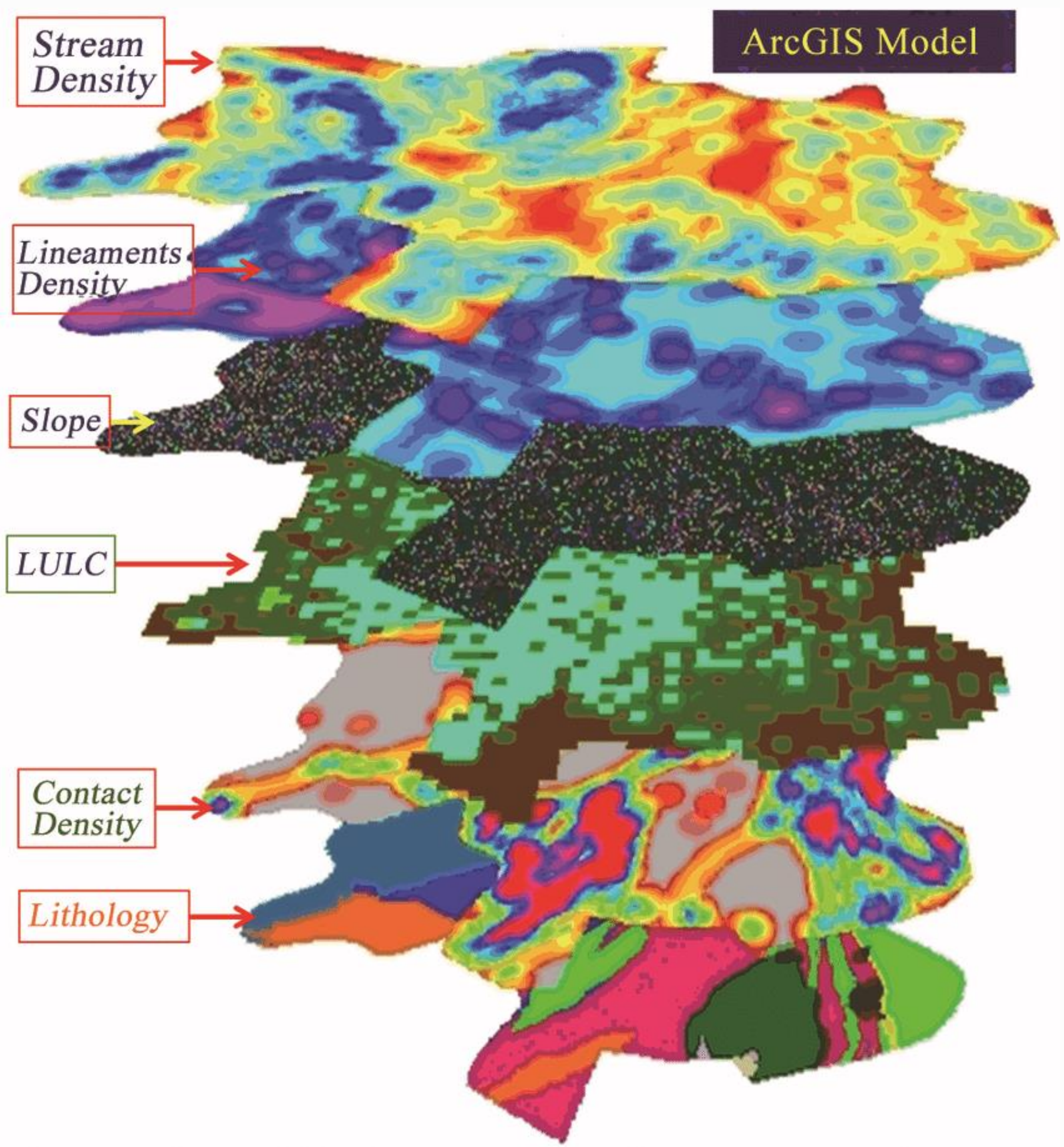
What would NDVI for paddy look like?

Multi-thematic maps

- Digital remote sensing images are like one-time write, and many times read.
- Many different themes (e.g., water, vegetation, land use, Agricultures, road network, urban, etc.) can be extracted from same set of satellite images by various users.



E.g.: Integration of the thematic maps which gives the groundwater recharge potential zones



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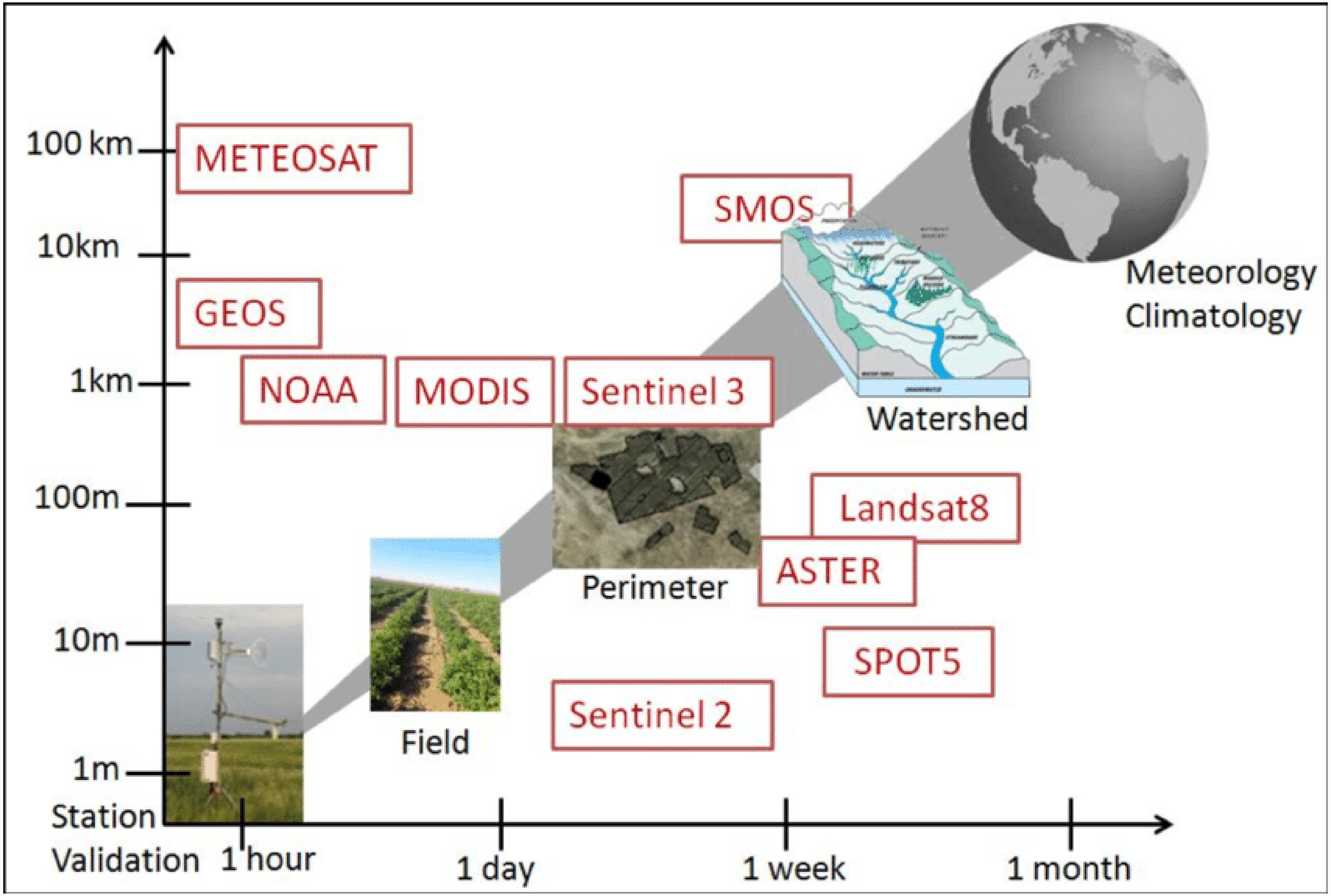
Multi-use in remote sensing

- The same set of images can be used to extract the information related to various applications, such as global change study, watershed analysis and vegetation monitoring.
- For example, a highway engineer may be interested to use images for extracting road network and assessing the road condition, whereas an irrigation engineer may require information on spatial distribution of rivers, canals, ponds, reservoir etc., in an area from the same satellite scene.

Multi-sensor / multi-resolution remote sensing data for crop monitoring and agro-hydrological applications



Thanks