EART97051 Environmental Data (EDSML) - Earth Observation & Remote Sensing

1 Physical principles, orbits, sensors & resolution

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Course structure and outline of content

Summary: Remote sensing principles, sensors, data types & essential image processing tools (mainly optical data and an introduction to SAR data and its uses)

Assessment: Friday 13.00 – 16.00

Course Outline: Lectures and related practical exercises

1. Monday am - Physical principles of remote sensing, sensor/platform technology, resolution and raster image data, basic image display and online data sources
2. Monday pm - Point operations and contrast enhancement
3. Tuesday am - Multi-band algebraic operations & spectral indices
4. Tuesday pm - Colour coordinate transformations & enhancements
5. Wednesday am – SAR imaging and a brief introduction to InSAR
6. Wednesday pm – free time
7. Thursday am & pm – Group work developing an Environmental EO App using GEE, and presentations
8. Friday am – free study time
9. Friday pm – assessment time

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Module Learning Objectives

In this course, the emphasis is on **EO data and numerical tools for processing them, to extract and understand their information**, rather than on coding. However, there will be time for you to experiment with coding (especially in the GEE sessions with Shuaib) and the assessment will offer an opportunity to write some code to process image data yourself.

Liu & Mason, Image Processing and GIS for Remote Sensing: Techniques and Applications, Second Edition, 2016, Wiley, Online ISBN:9781118724194

Plus there are tons of resources (and ready code) available for EO applications. Check out:

1. eo-learn https://pypi.org/project/eo-learn
2. GitHub.com/arcgeospatial/awesome-earthobservation-code
3. GitHub.com/sentinel-hub/eo-learn-workshop
4. GitHub.com/earthlab/earth-analytics-python-env
5. ESE Jupyter notebooks (by Raul Adraeinsen)
6. Earthdatascience.org/courses/earth-analytics-python
7. Raster data format descriptors and drivers GDAL.org

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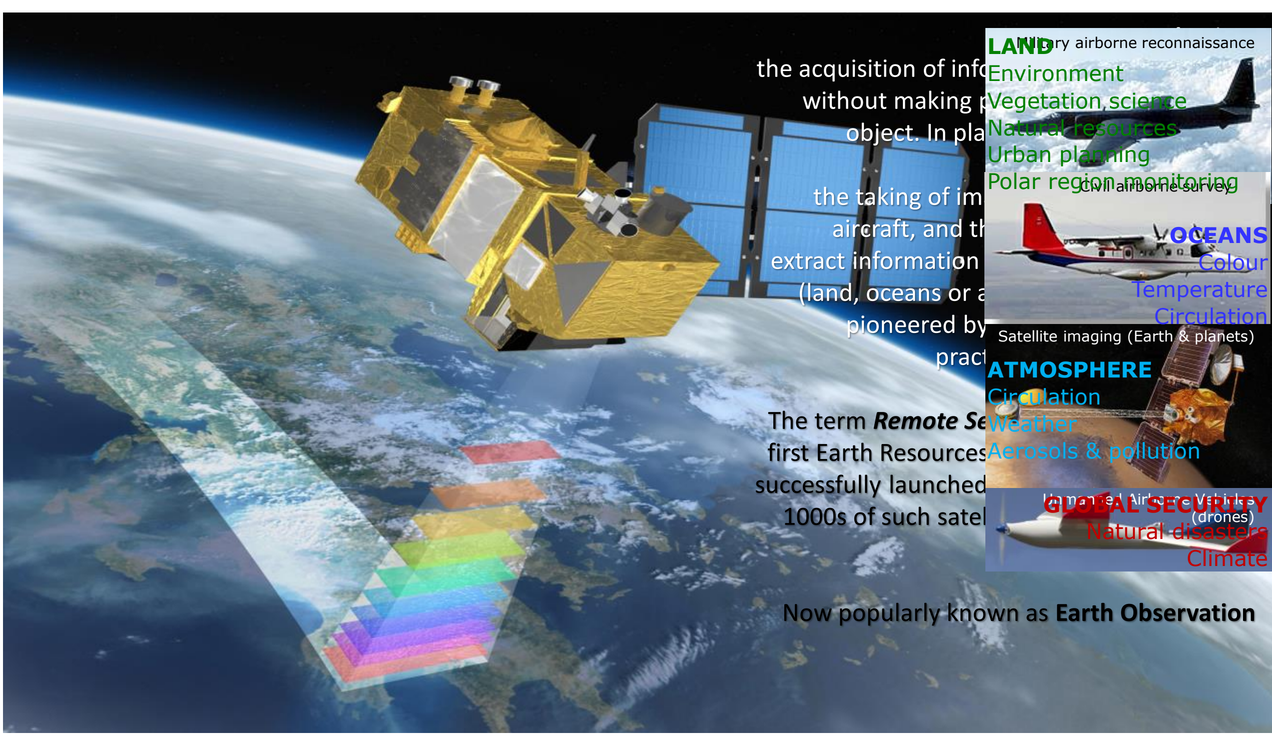

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Three major aspects of remote sensing/earth observation to consider:

1) **Physical principles:** energy, waves, photons, interactions, atmosphere
2) **Technology:** sensors & platforms (satellites, aircraft etc.)
3) **Applications**: what can we do with these data?
4) **Data processing:** how can we effectively extract information?

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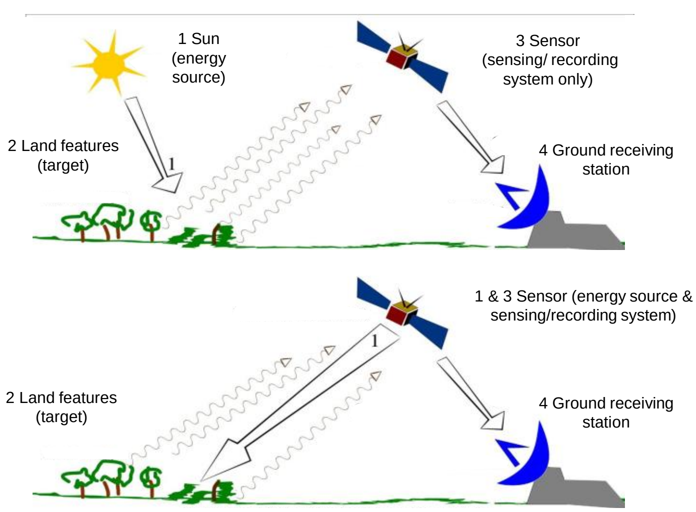
Types of remote sensing

Passive remote sensing system

Active remote sensing system



Modified after Arkarjun

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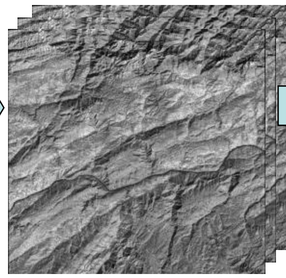
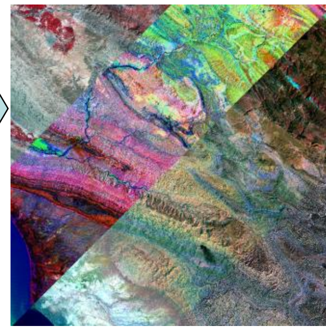
Conventional workflow <2000

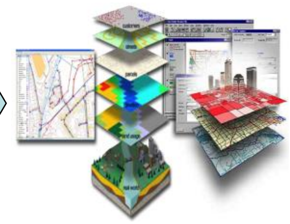
Remotely Sensed (EO) data collection (level-0 raw data)



Search & order/pay for raw data delivery (uncorrected level-0 binary .bil)



Process and produce GIS-ready images (level-2 products)



Interpret & analyse locally and distribute information via web etc

National & corporate archives (Server)

Local storage

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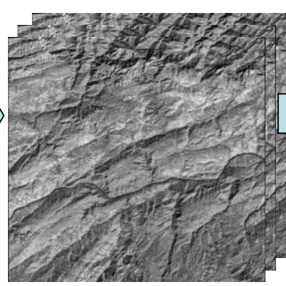
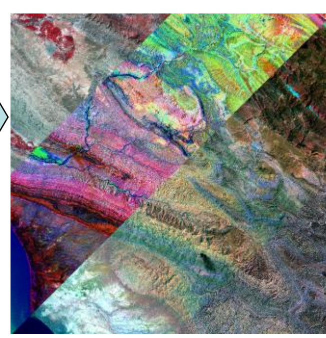
Increasingly online workflow 2000 - 2015

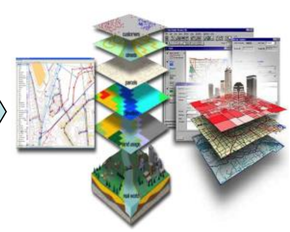
Remotely Sensed (EO) data collection (level-0 raw data)



Search, download geo-coded data (level-1 geotiffs, .hdf etc)



Process and produce GIS-ready image images (level-2 products)



Interpret & analyse locally and distribute information via web etc

National & corporate archives (Server)

Local storage

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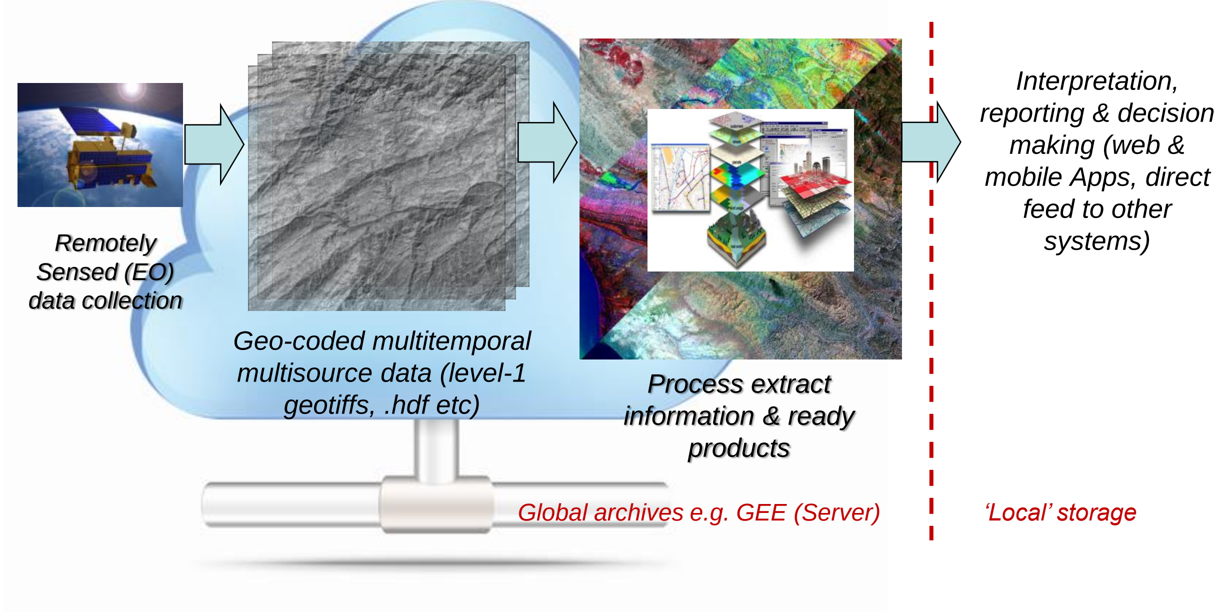
Current and future workflow



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Major land-based remote sensing applications

- **Geological mapping**: **structure and lithology** – enhancement of visualisation and image interpretation - multi-spectral imaging (lithological & mineral-group discrimination)
- Mineral exploration: **mineralogical mapping** with hyper-spectral imaging (mineral identification)
- Water & resources: **surface water bodies** (rivers, lakes, ice, snow, etc.); **drainage systems** and **coast zones**; and their dynamics
- **Mapping & monitoring** surface geological process and geohazards: **rapid erosion** and soil loss; **land instability** – landslides and mudflows; **desertification** and; interaction between man and environment (e.g. **urbanization**, **infrastructure**, **mining**, etc.)
- **Geohazards** - **Quantitative measurement** of ground deformation: radar interferometry and subpixel disparity estimation for **earthquake deformation measurements** and **subsidence**

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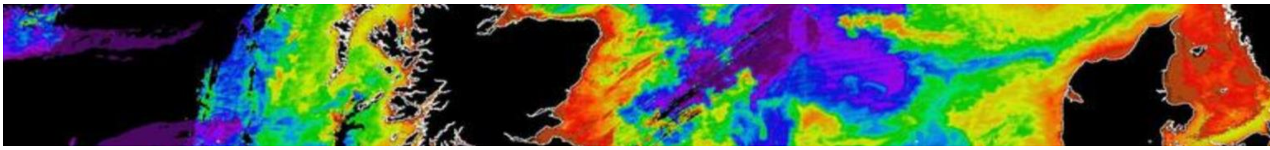

Other major remote sensing applications

- **Sea surface temperature** for climate and weather forescasting
- **Total suspended solids** for hydrodynamic modelling
- **Ocean colour & chlorophyll content** for plankton and algae concentration
- **Sea surface height, pattern & circulation** for navigation, and ocean mixture modelling

- Solar & terrestrial **radiation budget**
- **Air quality** (aerosols, trace gases, haze) time-series & forecasting
- Cloud properties & **ozone** observations for air quality
- **Hydrological cycle & meterological** observations for forecasting
- **Volcanic** eruptions
- **Pollution** monitoring

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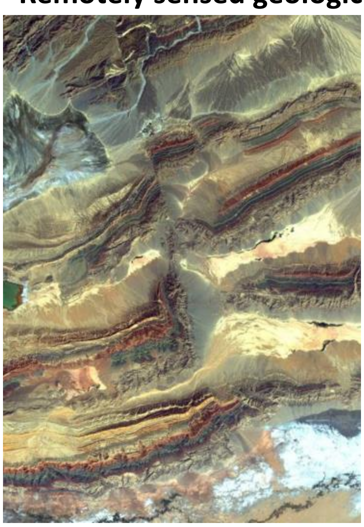
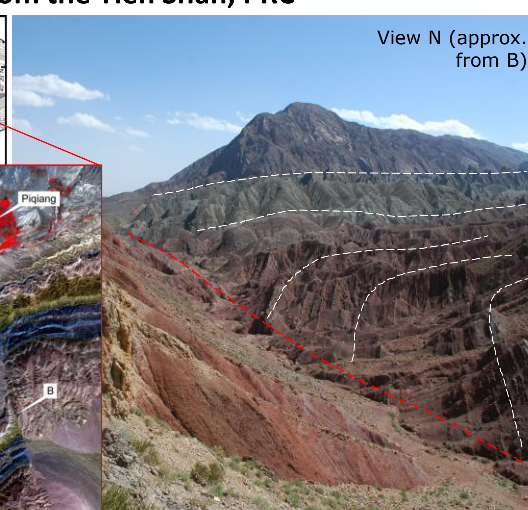
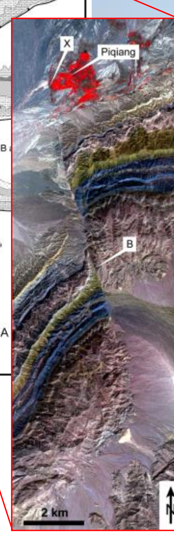
Remotely sensed geological mapping - an example from the Tien Shan, PRC







Spectacular but the area is inaccessible on foot – you simply cannot cover the ground effectively but the image lets you map the fault in minutes

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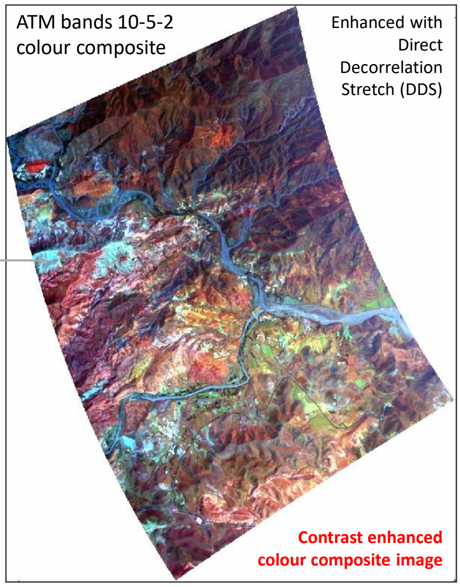
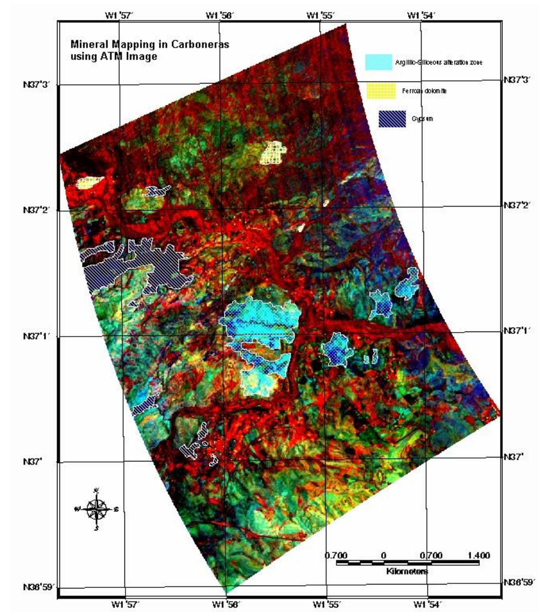
Mineral Exploration using multispectral imagery Airborne Thematic Mapper (ATM)

Gypsum (cyan)





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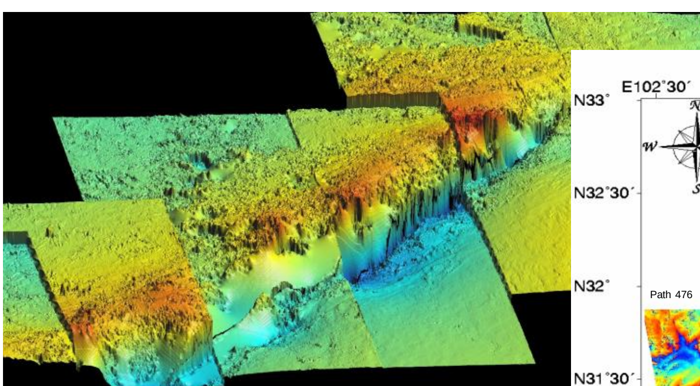
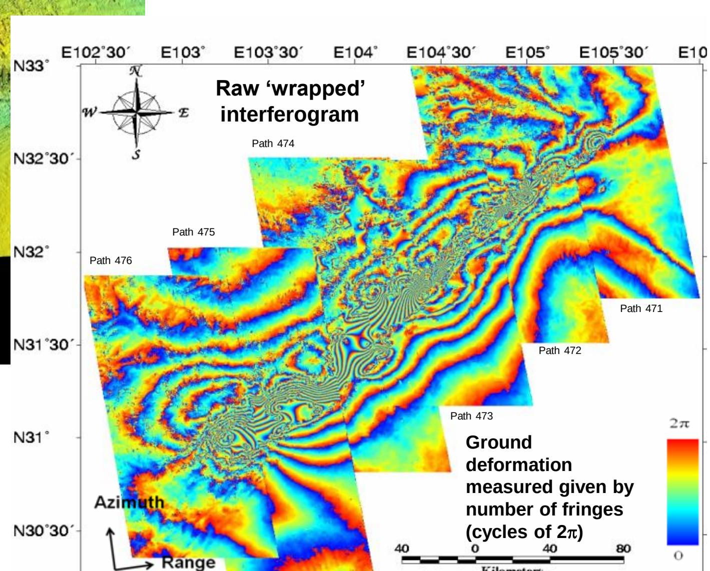
Ground deformation monitoring using Differential InSAR - Wenchuan earthquake (Longmenshan fault, China)



Deformation map (m) derived by 'unwrapping' of the raw interferogram (fight)



Wu, M-C, Liu, J. G., Cosgrove, J. C., Mason, P. J., Yan, H. & Chang, W-Y. 2014. Modelling of Yingxiu-Beichuan fault zone based on refined DInSAR data of 2008 Wenchuan earthquake, *Tectonophysics.*

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Global, high temporal resolution observations of atmosphere to reveal Earth's heat budget

Dept of Physics

Leading unique climate science missions

Contacts:
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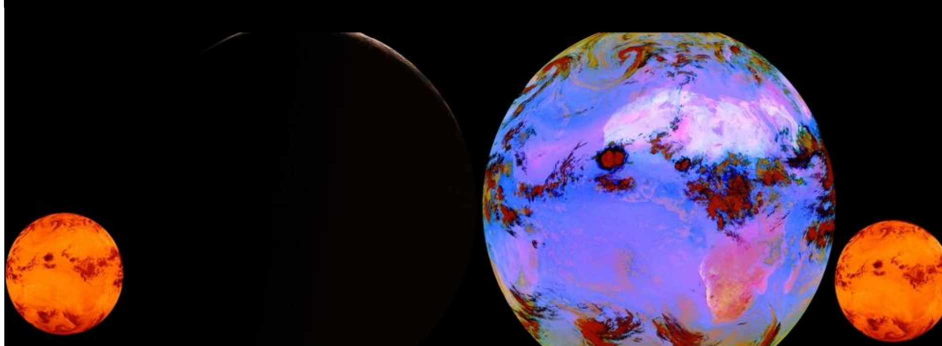
j.russell@imperial.ac.uk

Central large disks: visible and infrared rendered imagery from SEVIRI



Corresponding energy budget from GERB shown in the smaller disks. **Left:** reflected solar and emitted thermal energy; **Right:** net incoming and net outgoing energy. Combining the data allows the physical mechanisms causing variations to be identified and tracked, and their energetic effect quantified

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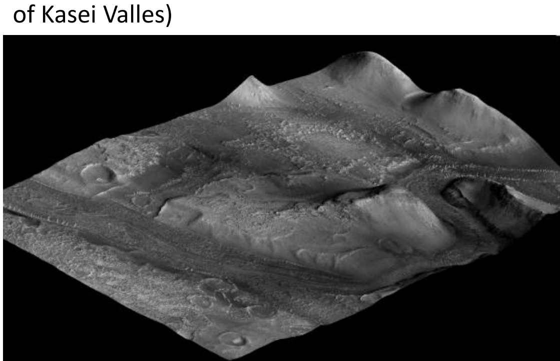
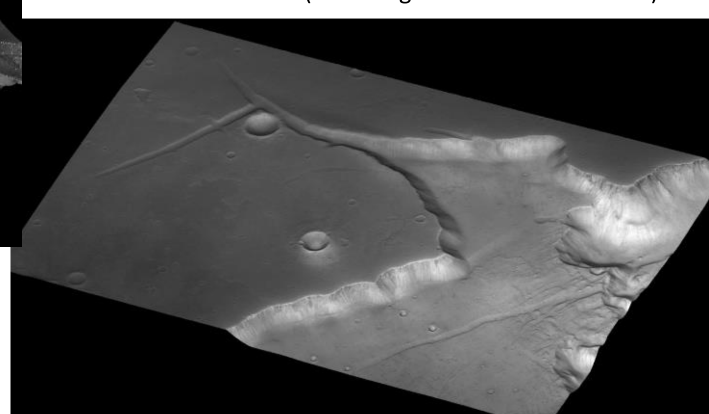
Planetary remote sensing

3D Perspective view of Martian surface – channels, craters, hills, valleys & dunes (from HiRISE images of Kasei Valles)



Digital Elevation Model (DEM) providing 3D Perspective view of Martian surface (CTX image south of Kasei Valles)



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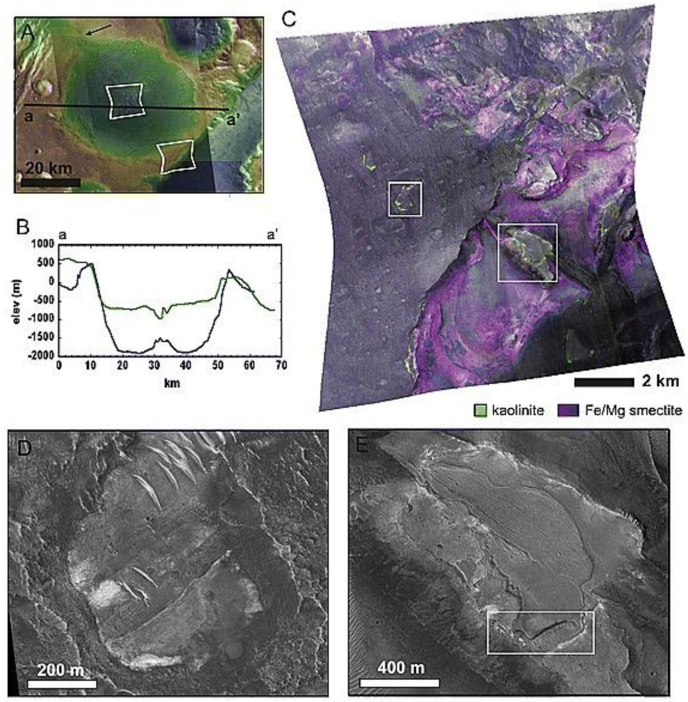
Planetary remote sensing

Nili Fossae, Mars: Hyperspectral analysis of rocks on exposed on a crater floor – showing small patches of hydrous alteration of basalts to produce clays

Images from the CRISM Hyper-spectral instrument



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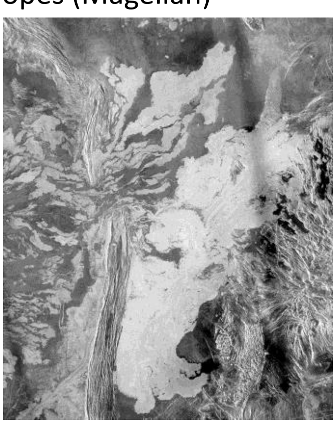
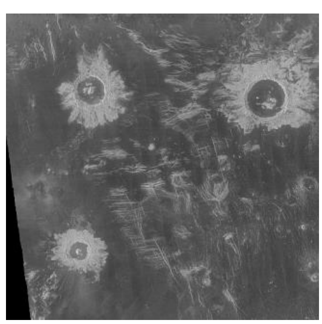
Planetary remote sensing

Venus: Synthetic Aperture Radar (SAR) images – lavas, craters, volcanic domes and rocky slopes (Magellan)

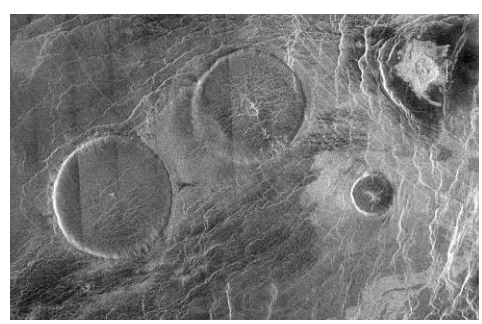


Lava flows (Ammavaru crater), flowing L to R (basaltic)

Image 500 km across

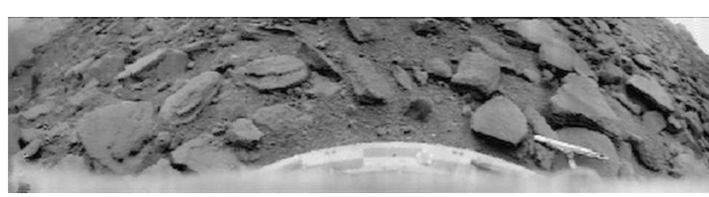


Danilova, Aglaonice & Saskja craters (20 – 30 km diameter)



Volcanoes & volcanic pancake domes (30 km diameter) in Eistla region. Formed from extrusion of high viscosity lava

Optical image from Venera 9 in 1975 (field of view a few metres)



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1 Physical principles

i.e. how does remote sensing work?
… bit of revision is needed

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1.1.1 Electro-Magnetic Radiation (EMR)

Electromagnetic radiation or EMR is an energy wave propagated through space between electric and magnetic fields

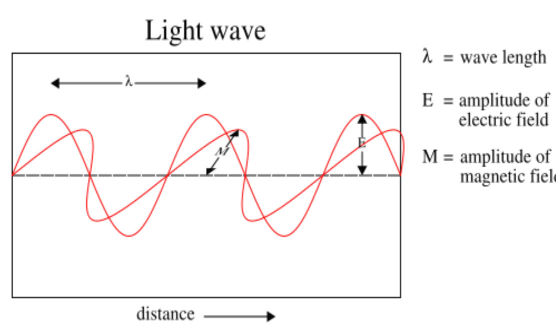
$$c = \nu\lambda \qquad (1.1)$$

where $c = 3\times10^{8}\ m/\mathrm{sec}$ is the light speed that is essentially a constant, ν frequency and λ wavelength.

High frequency EMR has short wavelength.

The magnetic field is related to the electric field in such a way that magnetic fields move perpendicular the electric field

We can receive EMR directly or reflected by another body



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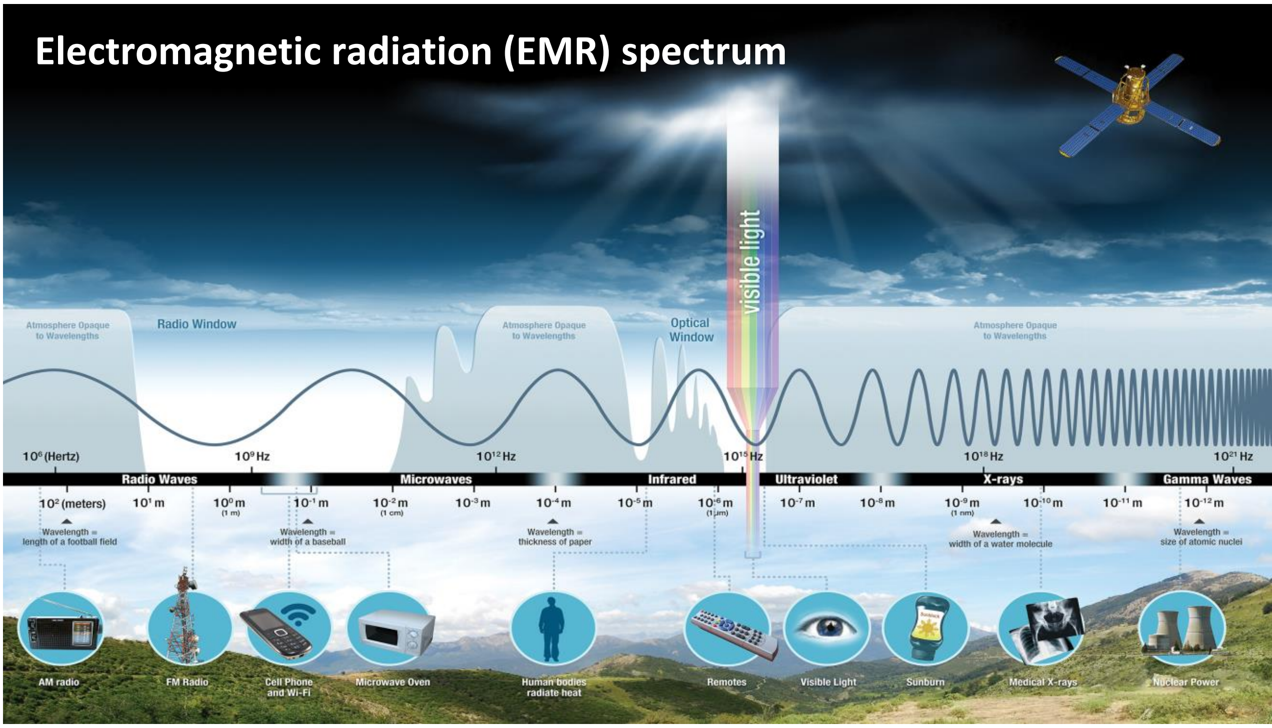

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Major spectral regions that can be used

Visible light region	0.38 - 0.75 *µm*
Blue	0.45 - 0.52 *µm*
Green	0.52 - 0.60 *µm*
Red	0.60 - 0.75 *µm*
Visible-Photographic IR film	0.4 – 0.9
Reflective Infrared (IR) region	0.75 - 3.0 *µm*
Near Infrared (NIR)	0.75 - 1.3 *µm*
Short Wave Infrared (SWIR)	1.3 - 3.0 *µm*
Thermal infrared regions	3-5 *µm* & 8-14 *µm*
Microwave:	0.1 (1mm) to 100 *cm*

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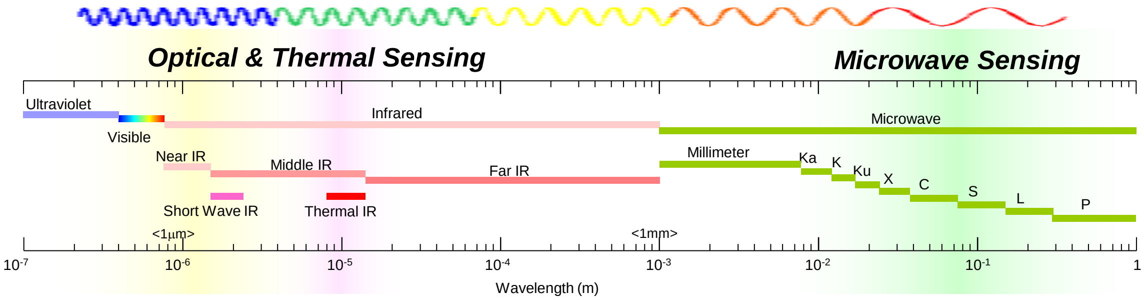
Types of Remote Sensing expanded



Based on electromagnetic spectrum, remote sensing is generally categorized as:

1. Passive	Optical (reflected light) Sensing :	Visible to Short Wave Infrared
	Thermal (emitted energy) Sensing:	Thermal Infrared
2. Active	Microwave Sensing:	imaging radar
	Light Detection And Ranging:	LiDAR (at variable $\lambda\sigma$)

(Different sensor technology needed for each)

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1.1.2 Photons and EMR energy

EMR can be described by wave theory but actually EMR is composed of many discrete units of matter called photons (or quanta) according to the particle theory of quantum physics.

$$Q = h\nu$$

Q = energy of a photon, joules (J)
h = Planck's constant, $6.626\times10^{-34}\,Js$
ν = frequency (1.2)

Relate the wave and photon definitions of EMR by solving (1.1) for ν in (1.2), we then have:

$$Q = \frac{hc}{\lambda} \quad (1.3)$$

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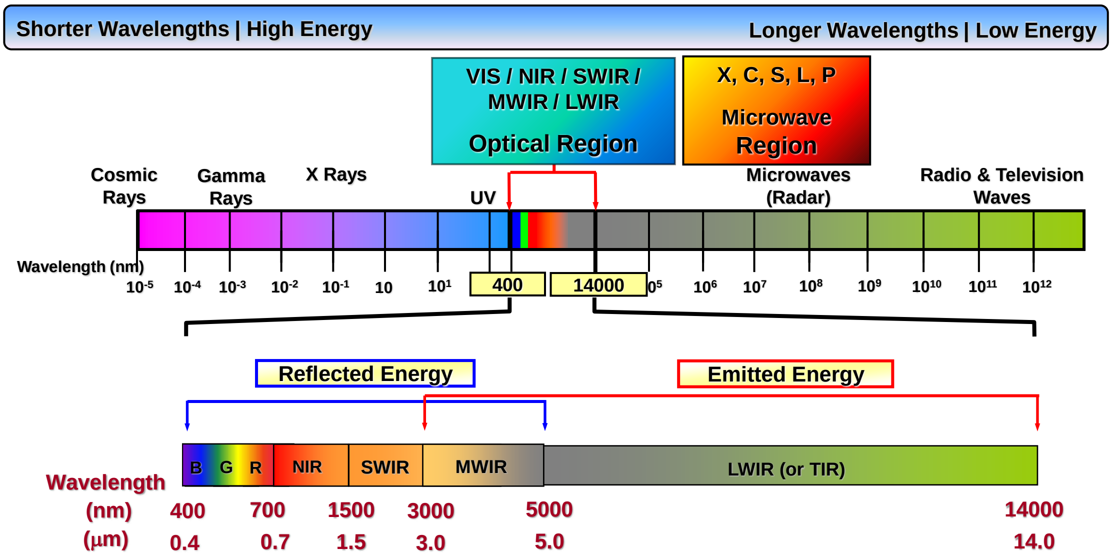
Electromagnetic Spectrum and its Energy



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1.1.3 Stefan-Boltzmann law

Or black-body radiant emittance

All matter at temperature greater than absolute zero (0° K, or -273º C) emits EMR.

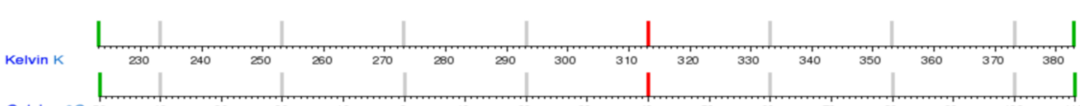
How much energy an object radiates is a function of the surface temperature of the object as expressed by *Stefan-Boltzmann law:*

$$M = \sigma T^4 \quad (1.4)$$

M = total energy flux density radiated from the surface of a material, Wm^{-2}

σ = *Stefan-Boltzmann constant* $5.6697 \times 10^{-8} Wm^{-2} K^{-4}$

T = absolute temperature (K) of the emitting material



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1.1.4 Wien's displacement law

Now we try to link the temperature of an object radiating energy to the EMR wavelength at its radiation peak (the wavelength at which blackbody radiation reaches the maximum).

This is *Wien's displacement law:*

$$\lambda_m = \frac{A}{T} \tag{1.5}$$

λ_m = wavelength of maximum spectral radiation, μm

A = 2898 μmK (Wein's constant of proportionality)

T = temperature, K

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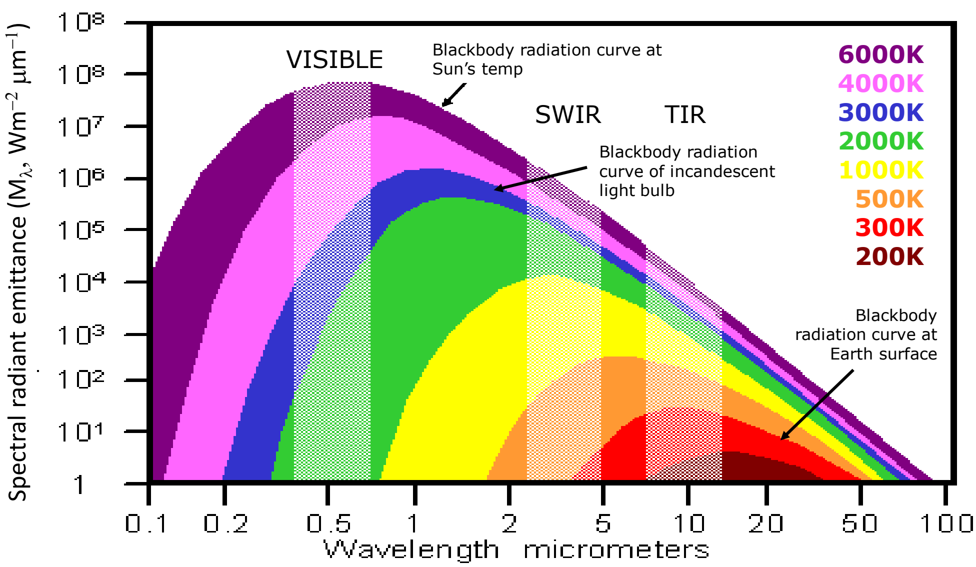
Spectral distribution of radiation and the radiation peaks of blackbodies at various temperatures



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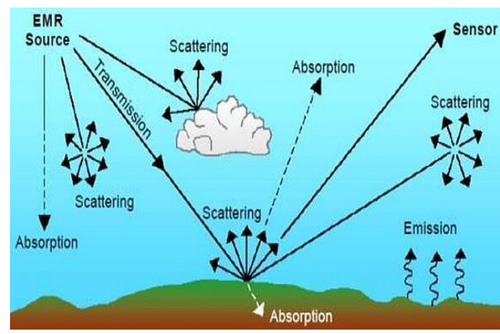
1.1.5 Interaction between EMR and atmosphere

a) Scattering: Atmospheric scattering is the unpredictable diffusion of radiation by particles in the atmosphere. There are 3 types:

- ***Rayleigh*** *scattering* is common when radiation interacts with atmospheric gas molecules and other tiny particles which are **much smaller in diameter than the wavelength** of the interacting radiation. The effect of Rayleigh scattering in the atmosphere is inversely **proportional to the 4th power of wavelength**. Hence, the effects mainly occur at short wavelengths.
- ***Mie*** *scattering* exists when atmospheric **particle diameter essentially equals the wavelength** of EMR been sensed. Water vapour and dust are the major causes of this type of scattering, and they tends to influence longer wavelengths of light.
- ***Non-selective*** *scattering* is caused by particles **much larger than the wavelength** of EMR. The effect simply blocks all the EMR with wavelengths much shorter than the dimension of the particle non-selectively. Aerosols and water droplets can cause this type of scattering.



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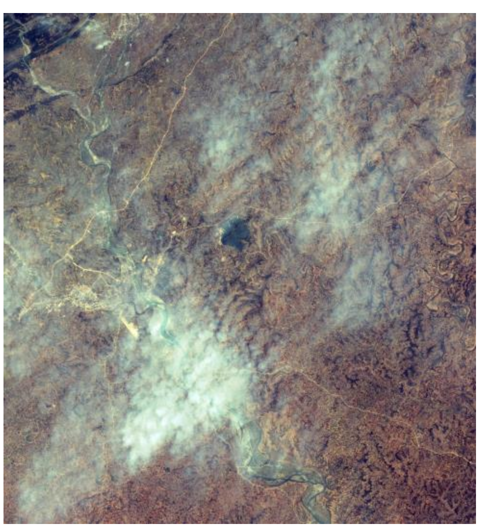
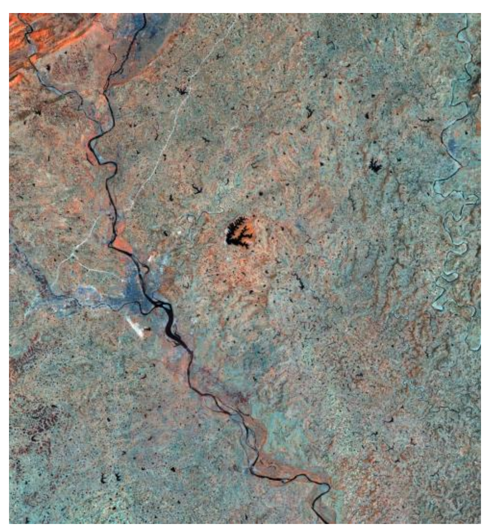
SWIR bands can penetrate thin clouds and smoke





Landsat-5 TM images over Chengdu region, China.
Left: true colour composite image of blue, green and red bands (TM321RGB).
Right: false colour composite of NIR band in R, SWIR-1 in G and SWIR-2 in B (TM457RGB).

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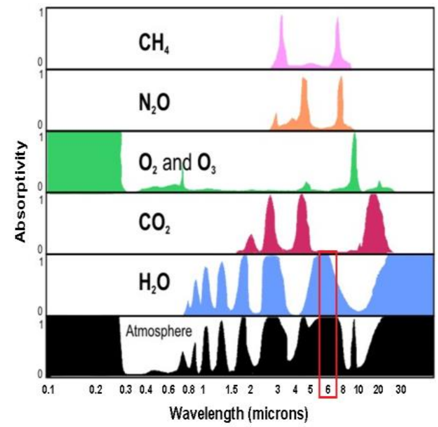
1.1.5 Interaction between EMR and atmosphere

b) Absorption: Atmospheric absorption results in the effective loss of EMR energy to atmospheric constituents. This absorption normally occurs at particular wavelengths.

- The most efficient absorbers of solar radiation in this regard are water vapour, carbon dioxide and ozone.
- One result of this is that the atmosphere is opaque within the spectral ranges where solar radiation is largely absorbed, and these spectral ranges therefore **cannot be used for remote sensing**.
- The atmosphere is largely transparent to sensors in spectral ranges where little absorption occurs. These spectral ranges are suitable for remote sensing and called ***atmospheric windows***.



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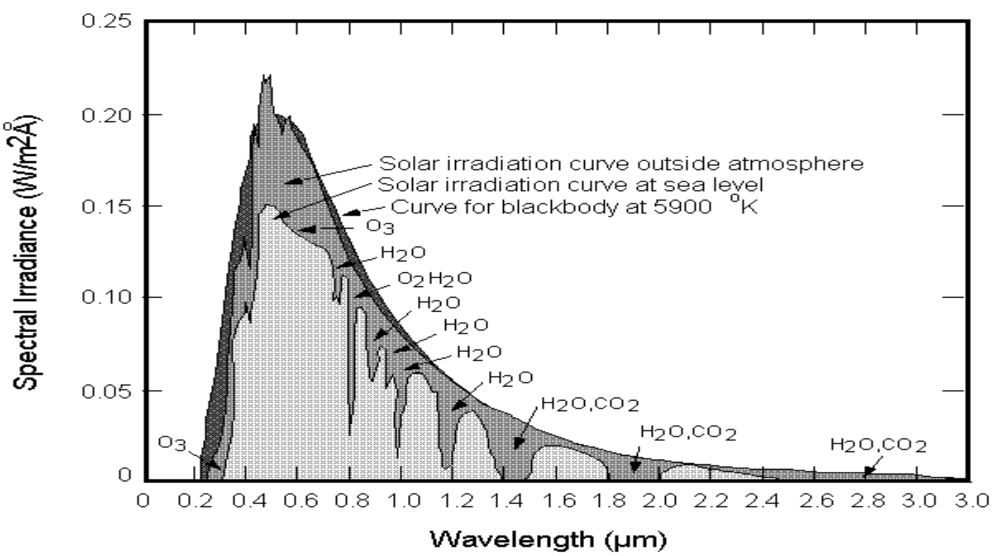
Solar radiation and atmospheric absorption zones



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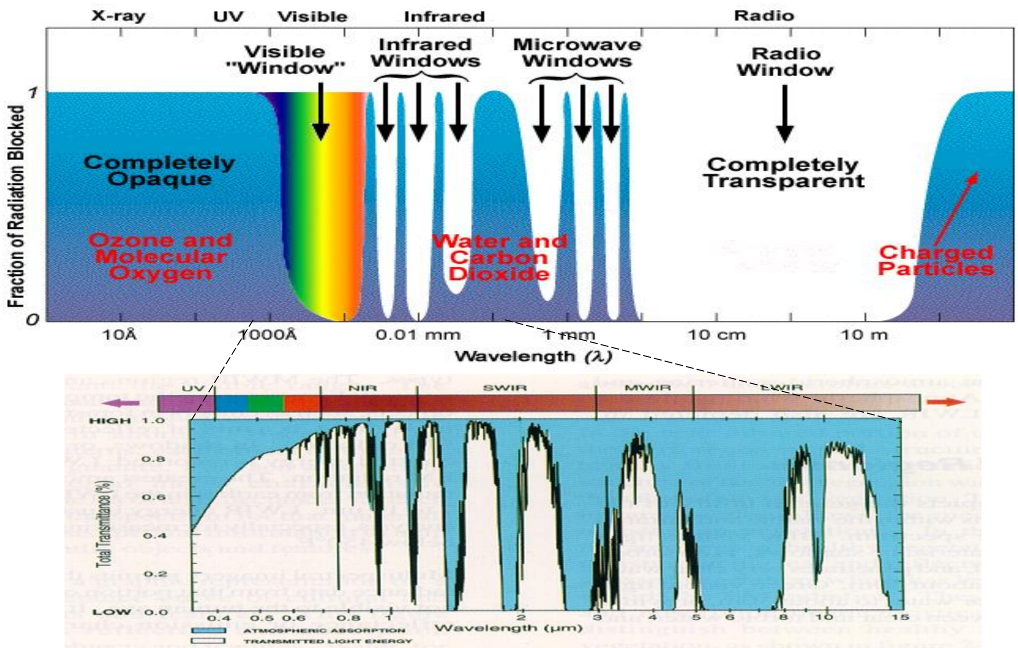
Atmospheric windows and absorption zones



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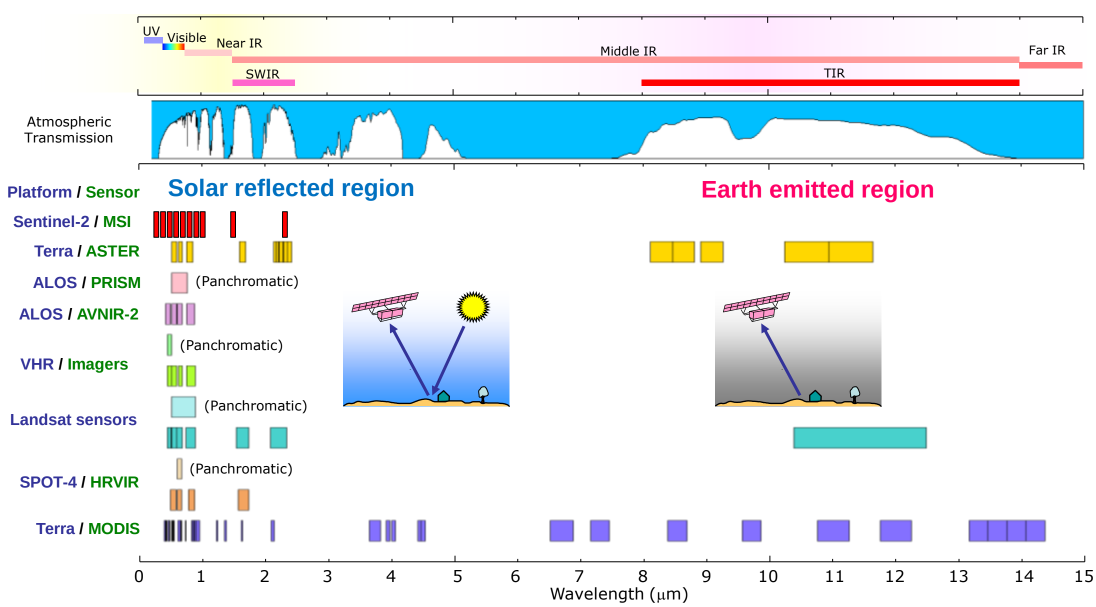
Spectral coverage of optical & thermal sensors



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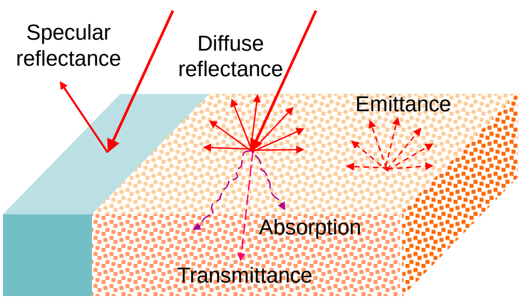
1.1.6 EMR interaction with earth surface

When solar EMR impinges on the Earth's surface, it will be partially **reflected, absorbed** and **transmitted** depending on the spectral properties of the surface materials:

$$E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda) \tag{1.6}$$

Where, E denotes energy, subscripts I, R, A, T indicate Incident, Reflected, Absorbed and Transmitted, λ is the wavelength of EMR.



The absorbed and transmitted solar EMR energy will increase the earth temperature and eventually (later) be emitted from the earth's surface according to ***Stefan-Boltzmann law***.

Reflectance behavior depends on several things, including surface roughness …

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Surface roughness

- There are two general types of reflecting surfaces that interact with EMR:
  - ***specular*** (smooth)
  - ***diffuse*** (rough)
- These terms are defined geometrically and relatively, not physically. A surface may appear smooth in a physical sense, i.e. it appears and feels smooth, but at a scale on the order of wavelengths of light, many irregularities may occur throughout that surface.
- Radiation impinging on a diffuse (rough) surface tends to be reflected in many directions (Lambertian or diffuse scattering).
- The ***Rayleigh*** criterion can be used to determine surface roughness with respect to radiation. A surface is smooth if the following condition is true, otherwise it is rough:

$$h < \frac{\lambda}{8\sin\theta}$$

where h is the surface irregularity height, or surface roughness, λ the wavelength and θ the angle between incident EMR and the surface.

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Key parameters of spectral properties

- ***Spectral reflectance*** is the reflectivity of a material to EMR at a particular wavelength.

$$\rho(\lambda) = \frac{E_R(\lambda)}{E_I(\lambda)} \qquad (1.7)$$

- ***Albedo,*** or the total radiant reflectance, is the integral of reflected spectral radiation, weighted by irradiance, over all spectral range. Useful general measure of an object's reflective properties

$$\rho = \frac{\int_0^\infty \rho(\lambda) E(\lambda) d\lambda}{E} \qquad (1.8)$$

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1.2 Introduction to Satellite Remote Sensing and Sensor Technology

i.e. how remotely sensed image data are acquired ….

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1.2.1 Platform

- **Ground:** portable spectrometer for field ground truth data collection
- **Airborne:** target orientated investigation
- **Spaceborne:** regional information and regular monitoring



Each has advantages and disadvantages

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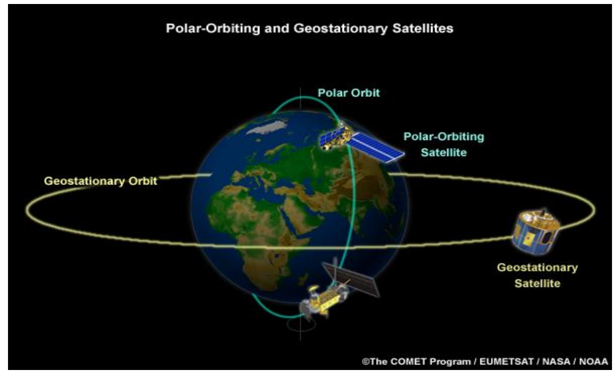
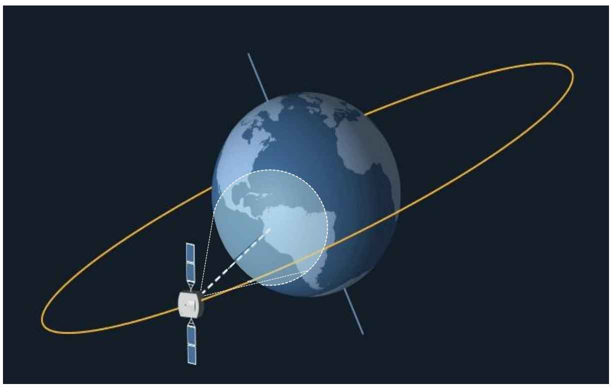
1.2.2 Orbits

Geostationary orbit:

At altitude of ~36000 km, synchronous with the rotation of the Earth.

Used by most meteorological satellites, e.g. GOES, and communication satellites.





Produces images of low spatial resolution (~1 km) but allows continuous monitoring of up to a third of the earth surface, with very frequent repeat (~30 or 60 mins).

Recent sensor development has achieved 50 m resolution on this orbit!!

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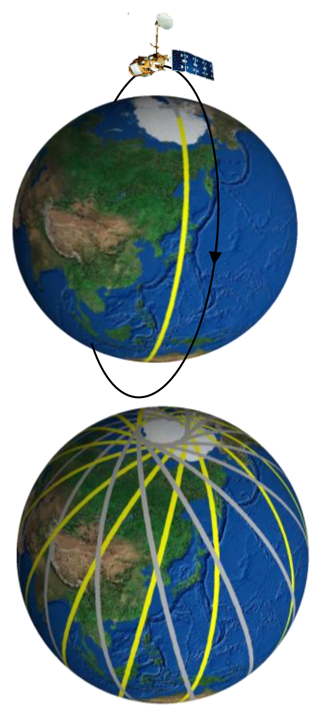
1.2.2 Orbits

Circular, near-polar, sun-synchronous:

Altitude 400-900 km, and so covering most of the earth (except the near polar areas), at nearly the same local time imaging (hence sun-synchronous), at the same scale of intermediate to high spatial resolution, revisit the same scene in a fixed period (e.g. 18 days for Landsat 4 & 5).



Most Earth Observation satellites:

e.g. Landsat, all Sentinels, SPOT, ERS, ENVISAT, Terra, JERS, ALOS, Radarsat, NOAA, IKONOS, QuickBird, OrbitView, etc.

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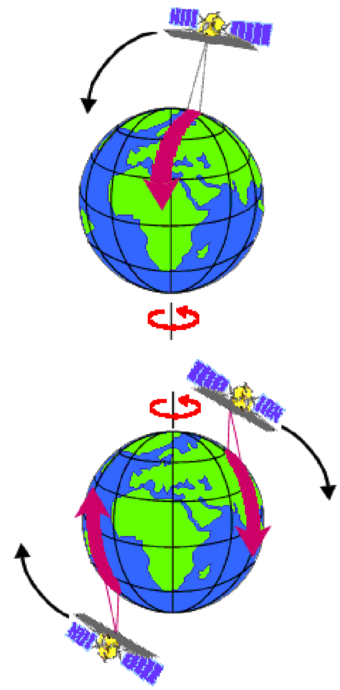
1.2.2 Orbits

Ascending and descending passes:

This type of obits must have inclination angle of ~98º rather than going exactly through the north and south poles.

The satellite travels towards North pole of the Earth and then toward the South pole on the second half of its orbit. These are called **ascending and descending passes**.

The inclination angle is configured such that the **descending pass is always on the sunlit side (day)**. Sensors recording only reflected solar energy image the Earth only on the descending pass, when solar illumination is available (**thermal and active sensors may operate on the night side**)



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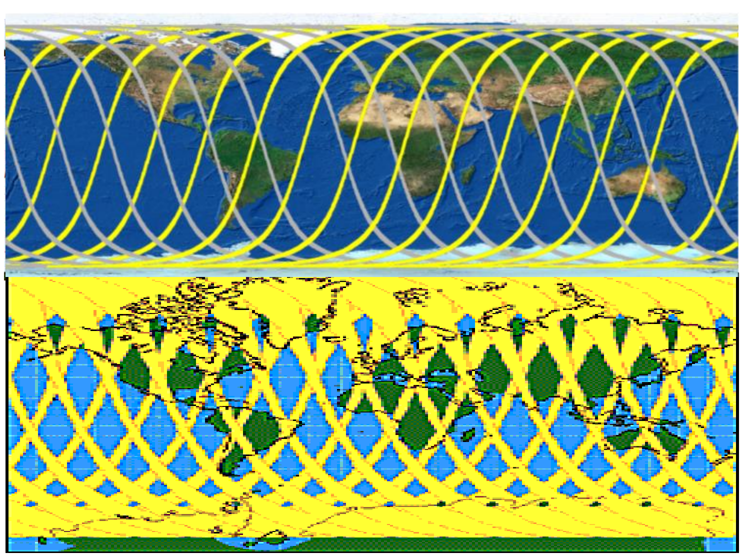
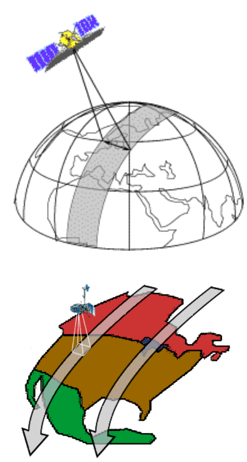
Orbital paths Swath, revisit period and overlap





Revisit period >= Reimaging period!

Because of inclination angle, the obit cannot cover the polar area.

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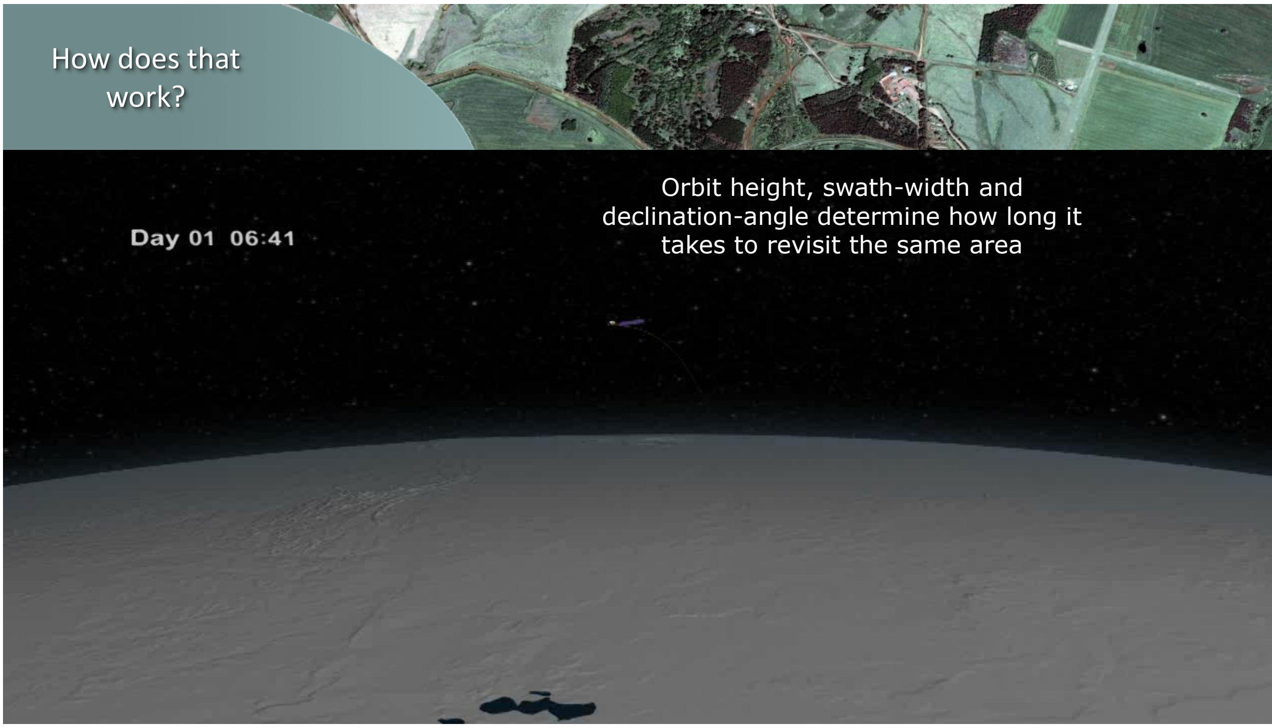

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1.2.3 Passive Sensors

Broad band multi-spectral and panchromatic optical sensor systems

- Large format and metric cameras, Multi-Spectral Scanner (MSS), Return Beam Vidicon (RBV)
- Scanners: Thematic Mapper (TM), ETM+, High Resolution Visible (HRV), AVHRR, ASTER, ASTR

Main imaging mechanisms:

- Photography (frame), one-way scanning, two-way scanning, push-broom scanning.

Imaging geometry:

- **Nadir, across track off-nadir (multi-temporal stereo and short revisit time), along track off-nadir (simultaneous stereo).**

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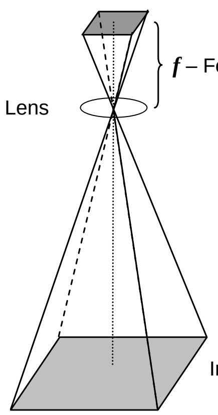
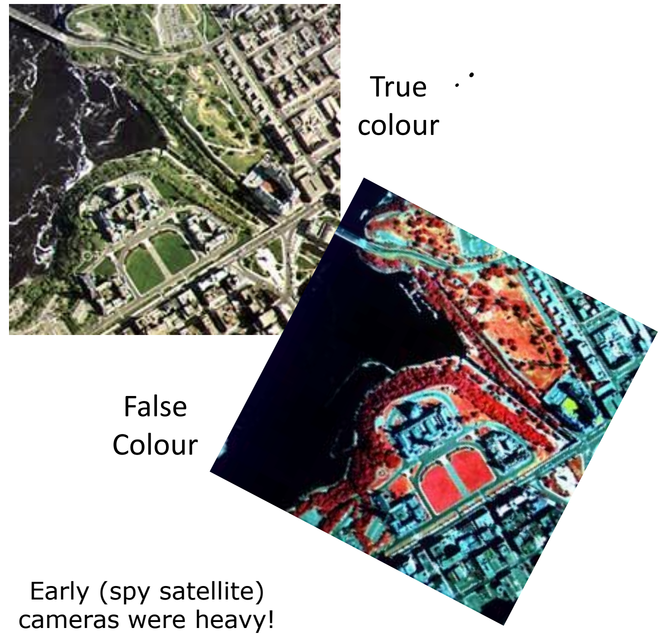
1.2.3 Sensors

Cameras and Aerial Photography



Optical concept of a frame camera system.



Early (spy satellite) cameras were heavy!

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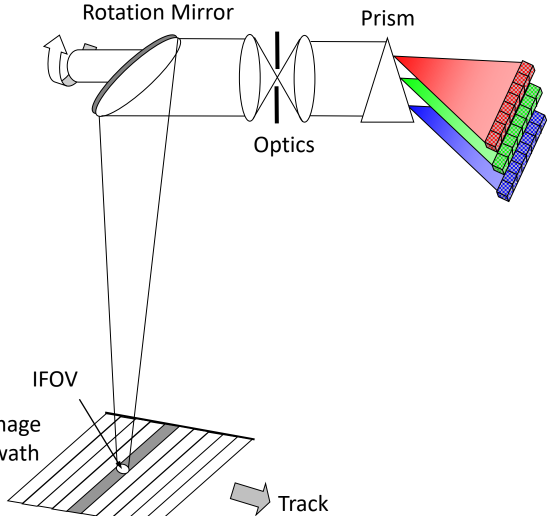
1.2.3 Sensors

Multi-Spectral Scanner



Across-track mechanical scanner

Landsat MSS one-way scan;
TM and ETM+ two-way scan

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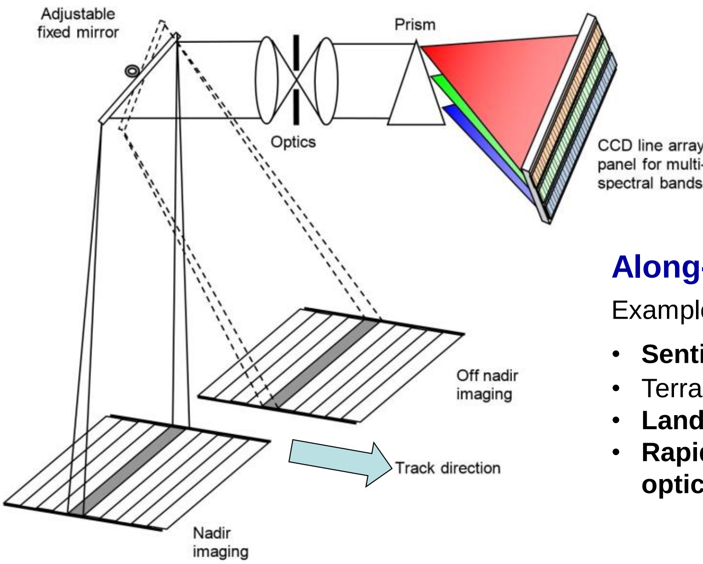
1.2.3 Sensors

Multi-spectral line scanner



Along-track 'push broom' scanner

Examples include:

- **Sentinel-2 Multispectral Instrument (MSI)**
- Terra-1 ASTER
- **Landsat 8 & 9 OLI & TIRS**
- **RapidEye, Earth I, WorldView (most VHR optical sensors, including cubesats)**

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'Whisk broom' (across track, one way scan) configuration.

A mirror scans across the satellite's path, reflecting light into a single detector which collects data one pixel at a time.

The moving parts make this type of sensor expensive and more prone to wearing out and image-internal distortions.

e.g L 1-5 MSS (two-way scan L5 & L7 TM & ETM+)

'Push broom' (along track) configuration.

Consists of a line of sensors arranged perpendicular to the flight direction of the spacecraft. Different areas of the surface are imaged as the spacecraft flies forward.

Generally lighter and less expensive than whisk broom, and can gather more light because they look at a particular area for a longer time, like a long exposure on a camera.

e.g. L8, STL-2, most VHR sensors

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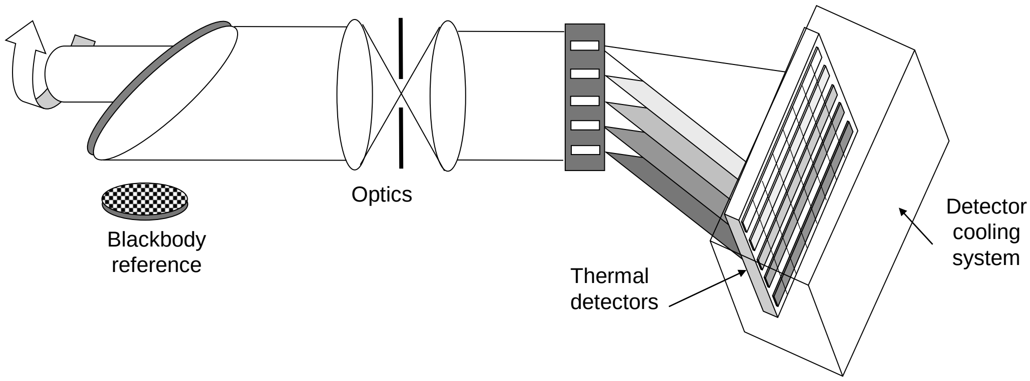
1.2.3 Sensors

Multi-spectral thermal scanner



Examples:
Airborne: TMS
Spaceborne: ASTER, TM, ETM+, TIRS

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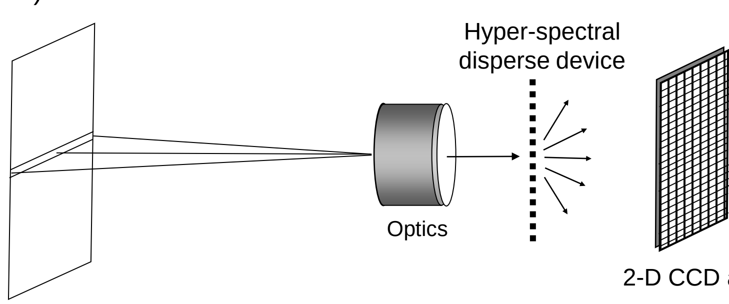
1.2.3 Sensors

Hyperspectral sensor system

These have 10s to 100s of spectral bands. Mainly airborne so far. Examples:

- Airborne Visible-Infrared Imaging Spectrometer (AVIRIS 224 bands),
- Compact Airborne Spectrographic Imager (CASI 288 bands),
- Geophysical and Environmental Research Imaging Airborne Spectrometer (GERAIS 63 bands).
- EO-1 Hyperion – 1st satellite borne sensor, NASA & USGS (220 bands VIS-SWIR, 30 m resolution)



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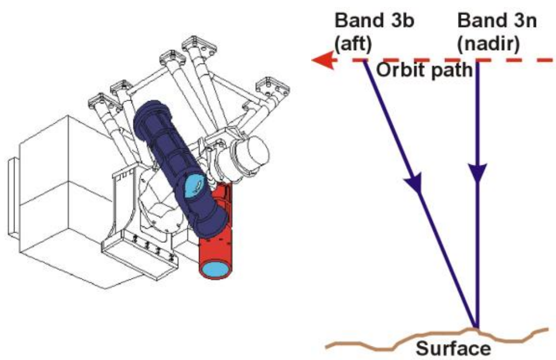
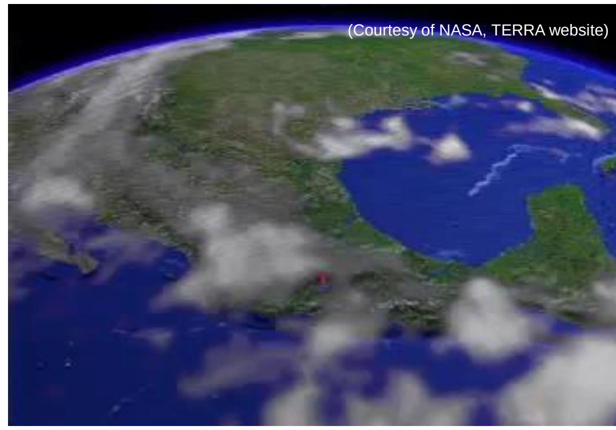
1.2.3 Sensors

Stereo Imaging



ASTER stereo imagery (nadir and back looking along track stereo) is used to generate Digital Elevation Models (DEMs) i.e. topography

Examples with on-board stereo capability: SPOT & Aster



Enabling generation of Digital Elevation Models (DEMs) for terrain analysis and 3D visualisation

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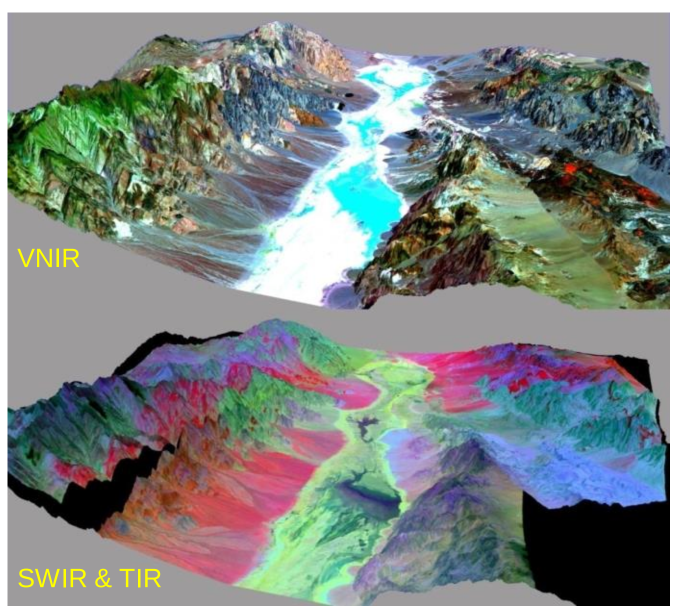
ASTER – colour composites & DEM



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1.2.4 Image Resolution

Spatial resolution

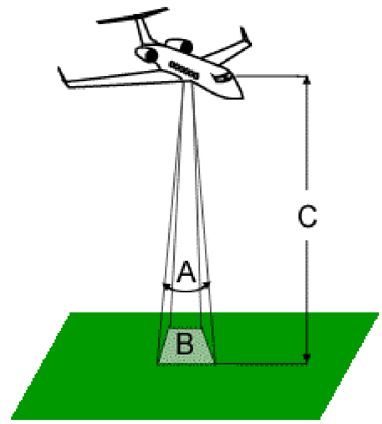
The detail discernible in an image depends on the **spatial resolution** of the sensor, which is the size of the smallest separation between two objects that can be resolved by a sensor

The spatial resolution of a passive sensor depends primarily on its *Instantaneous Field of View* (**IFOV**) which is decided by spatial sample density of an optical sensor system. The IFOV determines the size of the area seen from a given altitude (B).

As shown in the Figure, IFOV is the angular cone (A) of visibility to a detector (i.e. CCD), which records the EMR reflected from area (B), over a distance or altitude (C), at a particular moment in time, as a digital number (DN) in one image pixel.

So the area viewed (B) **= IFOV × C**

The area (B) on the ground is called the **ground resolution cell** and primarily determines the image spatial resolution.



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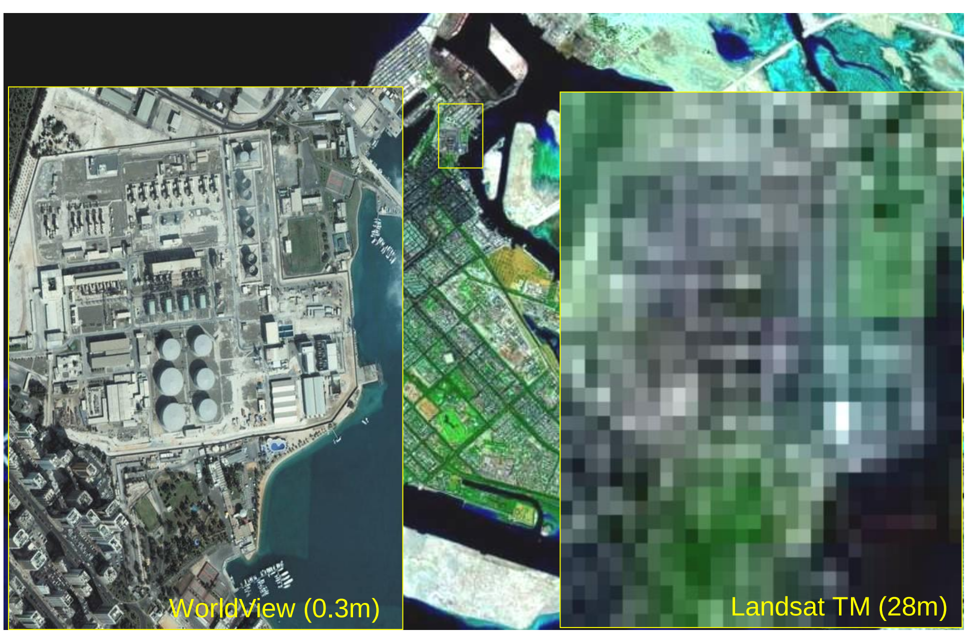
EO Satellites – Comparison of Spatial resolution



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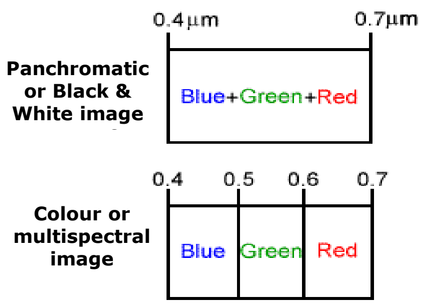
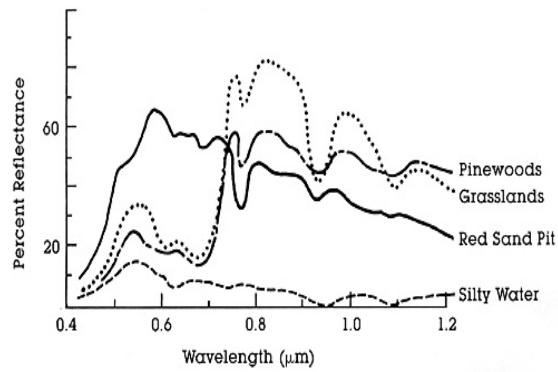
1.2.4 Image Resolution

Spectral resolution

Spectral resolution describes the ability of a sensor to define fine intervals of wavelength.

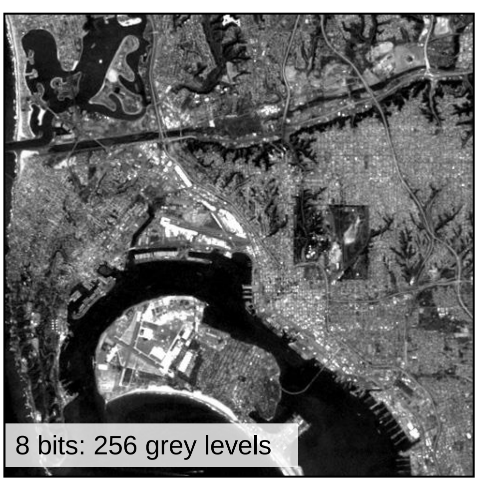




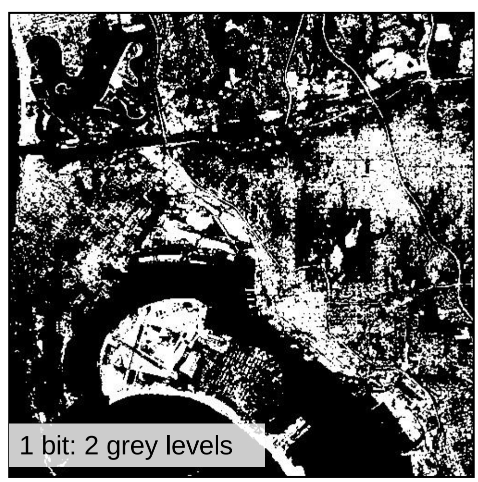
Higher spectral resolution means more spectral bands with narrower spectral intervals covering a spectral range.
A hyper-spectral sensor has 100s of narrow bands across the VIS-NIR-SWIR range (0.4 – 2.5 microns)

1.2.4 Image Resolution

Radiometric resolution



8 bits: 256 grey levels



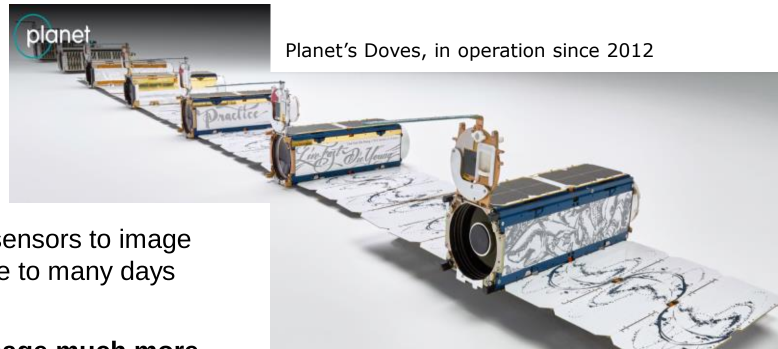
1 bit: 2 grey levels

- The sensitivity of a sensor to the magnitude of the electromagnetic energy determines its **radiometric resolution**.
- The radiometric resolution therefore describes its ability to discriminate very slight differences in sensor received energy levels (brightness), and is quantitatively characterised as a number of bits (per pixel).

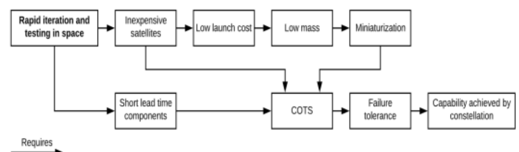
1.2.4 Image Resolution

Temporal resolution

- Temporal resolution describes the re-imaging period or repeat time.
- Absolute temporal resolution (to image the same area at same view angle, a second time) is the **revisit/repeat period**.
- Some systems **angle/point** their sensors to image between passes, separated by one to many days within the revisiting period
- Sensors in **constellations can image much more frequently** = 'Agile Aerospace'
  - ➢ **Daily VHR acquisitions** from: Planet's Doves, Earth-i, Vivid-i, SuperView, DMC, Kompsat, TripleSat
- So re-imaging period <= revisit period for any sensor
- Actual temporal resolution depends on several factors, including the satellite/sensor capabilities, the swath overlap, and latitude.



Planet's Doves, in operation since 2012



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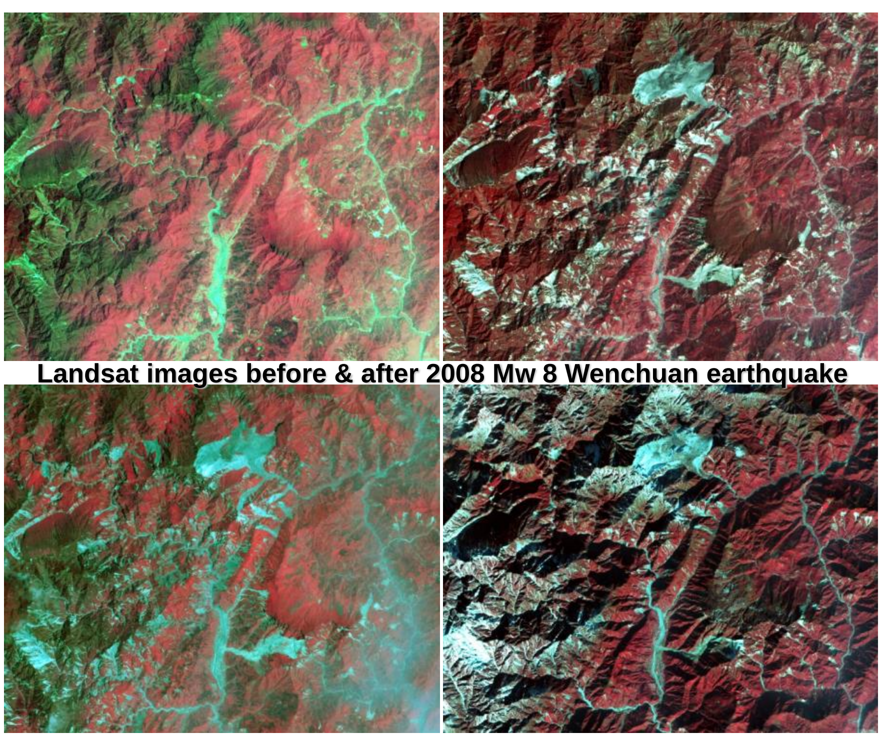
2007

2009



Landsat images before & after 2008 Mw 8 Wenchuan earthquake

2011

2013

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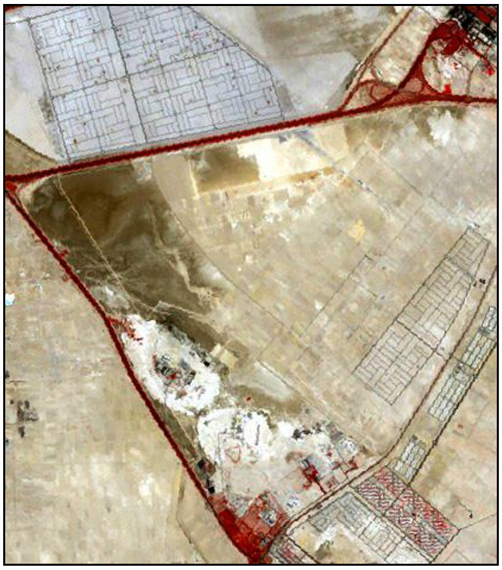
Change detection in Abu Dhabi City (UAE)



Landsat ETM+ - Aug 2000

Terra/ASTER – May 2006

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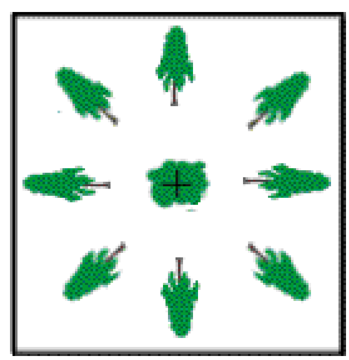
1.2.5 Geometric distortion

All remote sensing images are subject to some form of geometric distortions, caused by one or more of the following:

- Perspective of the sensor optics,
- Motion of the scanning system,
- 3D stability of the platform,
- Platform altitude, attitude, and velocity,
- Terrain relief, and
- Curvature and rotation of the Earth.



Relief displacement of camera is shown in the figure. This is the primary geometric distortion in vertical aerial photography and VHR satellite imagery.

The distortion geometry of along-track push-broom scanner imagery is similar to that of an aerial photograph but for each individual scan line.

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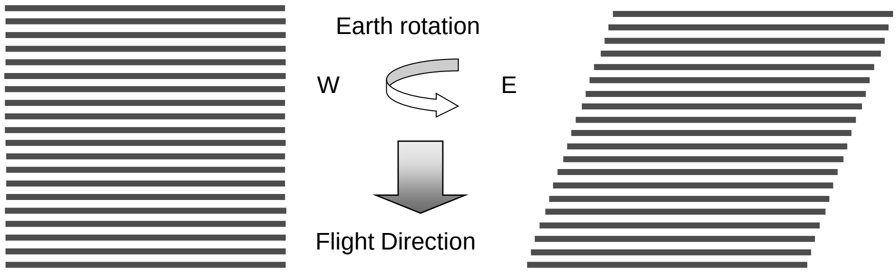
Skew distortion of satellite scanner images



- An EO satellite on a circular, near-polar, sun synchronous orbit travels nearly perpendicular to Earth rotation direction, to image nearly every part of Earth's surface at about the same local time.
- For an imaging scanner on-board the satellite, the image is build line-by-line in a time sequence, with the satellite flying above a rotating Earth.
- The Earth's rotation produces a skew effect in the image: the image is recorded as on the left, but actually covers an area of Earth's surface as on the right of the above diagram.
- This effect is typical for a push-broom scanner. For an across-track two way scanner (*e.g.* Thematic Mapper), the distortion pattern is even more complex as every pixel along a swath is imaged at a slightly different time and the actual scanning speed on the earth surface changes not only from nadir to the edge of a swath but also between swathes for and against earth rotation.

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Summary remarks (revision)

- This part falls under this LO: *Understand common data format and database structures specific to representative fields of environmental science*
- Major spectral regions are Visible (VIS, 0.3 - 0.75 mm) Near Infra-Red (NIR, 0.75 - 1.3 mm), Short-wave InfraRed (SWIR, 1.3 - 3.0 mm), Mid or Thermal Infra-Red (MIR or TIR, 3 - 5 & 8 - 14 mm) and microwave (0.1 - 100 cm) – all of which are important for remote sensing
- EMR is composed of photons - relate Planck's constant to wave theory: $Q=hv/\lambda$
- An object radiates energy as a function of temperature $M=\sigma T^4$
- Wavelength at which a blackbody radiation peaks $\lambda_{max}=A/T$
- Incident energy is affected by 3 types of scattering in the atmosphere (**Mie, Rayleigh & non-selective**, according to the size of particle w.r.t. wavelength)
- Solar radiation is absorbed by **water vapour, carbon dioxide** and **ozone**. Regions of spectrum where absorption does not occur called **atmospheric transmission windows** (they are VIS, NIR, SWIR, TIR & microwave)
- EMR impinges on the Earth's surface, and is partially **reflected, absorbed** and **transmitted** depending on the spectral properties of the surface materials
- Cont'd……..

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Summary Remarks (revision cont'd)

- There are 2 types of reflecting surfaces that interact with EMR: ***specular*** (smooth) and ***diffuse*** (rough). Rayleigh criterion is used to calculate the surface variations to predict rough or smooth
- ***Spectral reflectance*** is the reflectivity of a material to EMR at a particular wavelength. ***Albedo*** or the total radiant reflectance is the integral of reflected spectral radiation, weighted by irradiance, over all spectral range
- Most optical sensors now operate as **along-track push broom scanner**
- Ultimately, the image resolution is decided by the sensor resolution.
- For a given sensor system, within its optical resolution limit, the spatial resolution is dictated by the minimal energy level of EMR that can make a signal distinguishable from the electronic background noise, i.e. the dark current, of the instrument.
- This minimal energy of EMR is proportional to the product of **radiation intensity** over a spectral range, **IFOV** (Instant Field Of View) and **dwell time**.
- So in general, for most sensors:
  - Lower spatial resolution >> higher spectral/radiometric resolution.
  - Lower spectral resolution >> higher spatial/radiometric resolution.
  - Longer dwell time >> higher spatial/spectral/radiometric resolution.
  - Higher sensitivity of sensor >> higher radiometric resolution.

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A little bit about EO sensor development and important sensors for you ..

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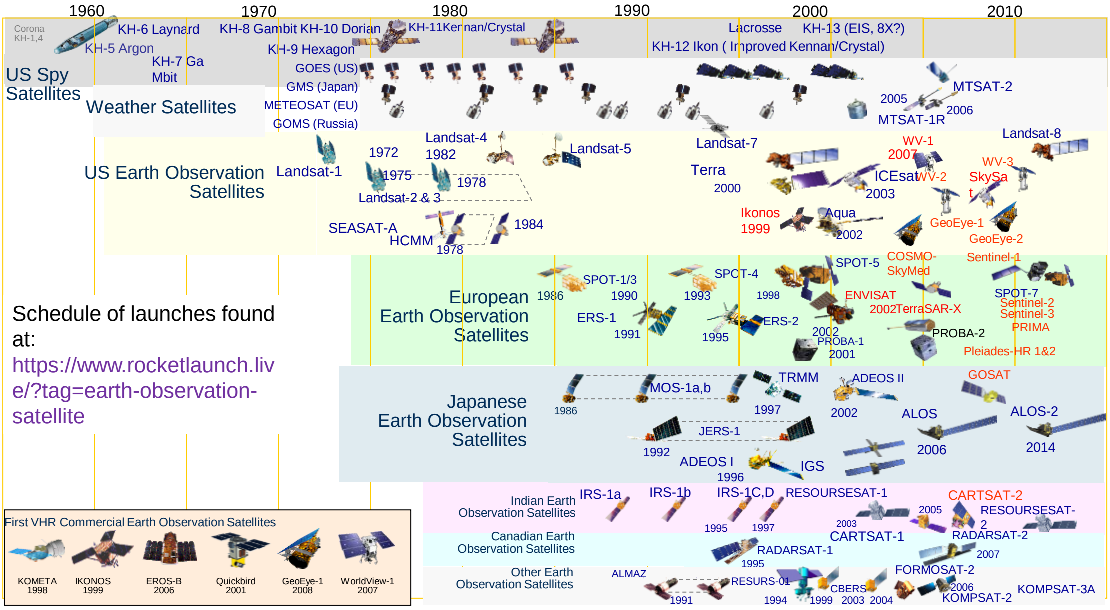
Post-Cold War development of EO history



Schedule of launches found at:
https://www.rocketlaunch.live/?tag=earth-observation-satellite

Now too many to list!!!!

Sensors

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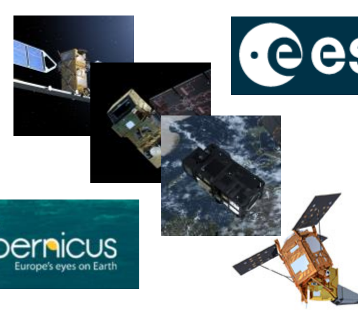
Important EO satellites

(medium resolution, routinely acquiring, available free to user)

- Landsat program (multispectral & panchromatic)
  - L5 TM & L7 ETM
  - L8 OLI & TIRS
  - L9 launched Monday, Sept. 27, 2021
- Copernicus Sentinel programme
  - S1 SAR
  - S2 MultiSpectral Imager (MSI)
  - S3 OLCI, SLSTR, SRAL & DORIS
  - S4 (trace gases & aerosols)
  - S5 (air quality & climate)
  - S5P TROPOMI



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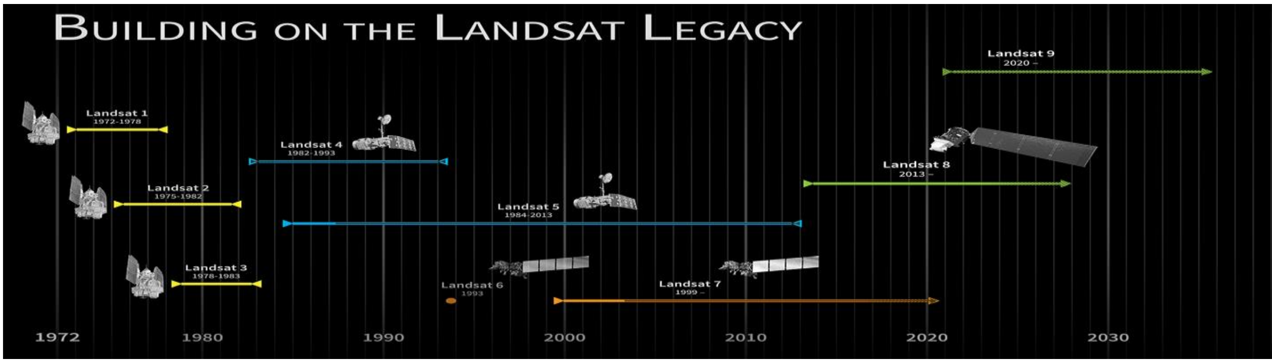
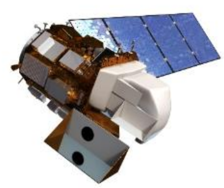


Landsat 4-7 Orbit

Altitude:	705km
Inclination:	98.2deg
Orbit:	Near-polar, sun-sync
Equator cross time:	10:30am (7) 9:30am (4-5)
Revolution:	99 minutes
Repeat cover:	16 days
Swath:	185 km



Satellite	Year	Sensor(s)	Status
Landsat 1	1972	RBV, MSS	Exp 1-6-78
Landsat 2	1975	RBV, MSS	Exp 2-5-82
Landsat 3	1978	RBV, MSS	Exp 3-31-83
Landsat 4	1982	MSS, TM	Exp 1993
Landsat 5	1985	MSS, TM	Decommissioned 2014
Landsat 6	1993	MSS, ETM	Lost
Landsat 7	1999	ETM+	2003+ Partial-operational
Landsat 8	**2013**	**OLI & TIRS**	**Operational**
Landsat 9	2021	**OLI & TIRS**	In testing

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a) Medium Resolution Sensors

Landsat 7 Enhanced Thematic Mapper (ETM+) and L8 & L9 Operational Land Imager/Thermal Infra-Red Sensor (OLI/TIRS) compared

L7 ETM+ (1999-2003)

Band	Range	Resolution
1 BLUE	0.45 - 0.52	30 m
2 GREEN	0.53 - 0.61	30 m
3 RED	0.63 - 0.69	30 m
4 NIR	0.75 - 0.90	30 m
5 SWIR	1.55 - 1.75	30 m
7 SWIR	2.09 - 2.35	30 m
6 TIR	10.4 - 12.5	60 m
8 Pan	0.52 - 0.90	15 m

L8 & L9 OLI/TIRS (2013+)

Band	Spectral Range	Resolution	
1 Coast	0.433 - 0.453	30 m	New
2 BLUE	0.45 - 0.53	30 m	
3 GREEN	0.52 - 0.60	30 m	
4 RED	0.63 - 0.69	30 m	
5 NIR	0.76 - 0.90	30 m	
6 SWIR1	1.56 - 1.66	30 m	
7 SWIR2	2.10 - 2.30	30 m	
9 Cirrus	1.36 - 1.39	30 m	New
10 TIR1	10.6 - 11.2	100 m	New
11 TIR2	11.5 - 12.5	100 m	
8 Pan	0.50 - 0.68	15 m	

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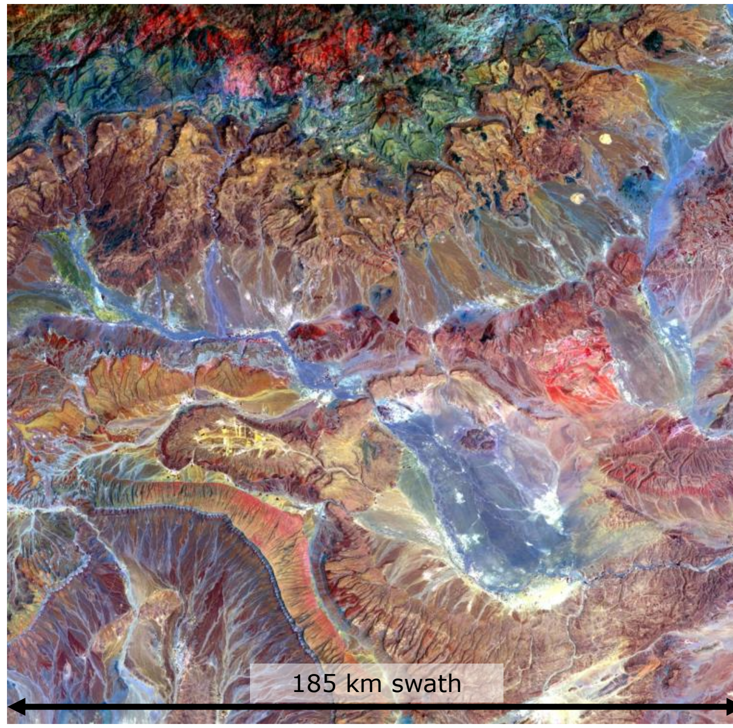
Landsat-8 OLI

bands 642 (RGB)

Morocco

This spectacular colour composite is designed to reveal spectral variations in rocks and soils.

Such images are most effective in semi-arid areas where there is little vegetative cover, and there is little atmospheric haze (or cloud)



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Landsat program naming convention & path/row system

e.g. LC80390222013076EDC00

Path number

Ground Station Identifier

LXS PPPRRR YYYYDDD GSIVV

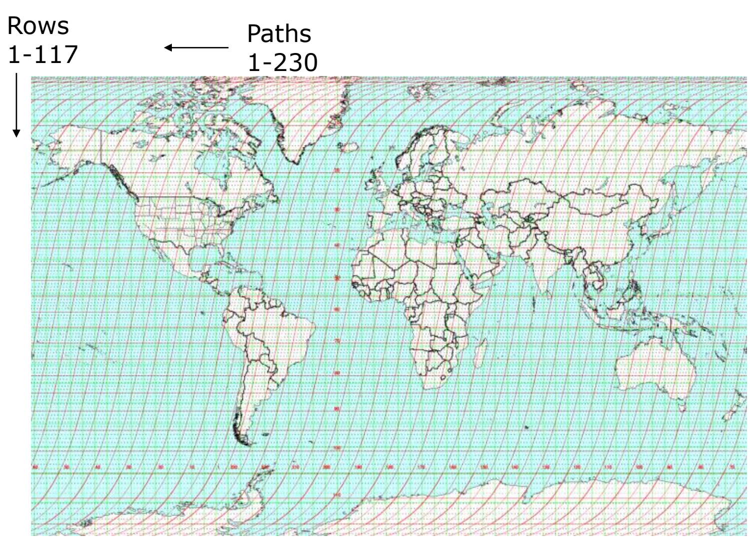
Landsat

Sensor

Satellite

Year & Julian Date

Archive Version



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Five new ESA missions – ‘Sentinels’:

- Sentinel-1A & 1B - all-weather, day-and-night Synthetic Aperture Radar (SAR) imaging for land and ocean. Launched 2014 (1A) & 2016 (1B)
- Sentinel-2 - multispectral VHR imaging for land monitoring (and for emergency services). Launched 2015 (2A) and 2017 (2B)
- Sentinel-3 - multi-instrument mission to measure sea-surface topography, sea- and land-surface temperature, ocean colour and land colour. Launched 206 (3A) and 2018 (3B).
- Sentinel-4 onboard a Meteosat 3rd Generation-Sounder (MTG-S) satellite in geostationary orbit. Dedicated to atmospheric monitoring. Launched 2019 (and 2027).
- Sentinel-5 onboard a MetOp Second Generation (Post-EPS), dedicated to atmospheric monitoring. Launched 2020.
- Sentinel-5. Dedicated to atmospheric monitoring, and -5P – TROPOMI – launched 2017

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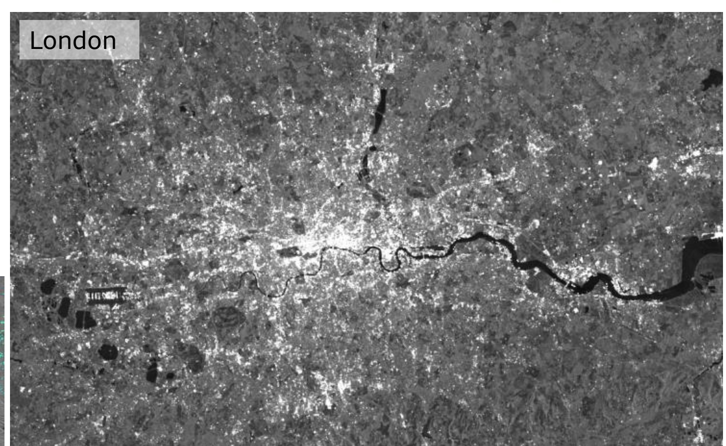
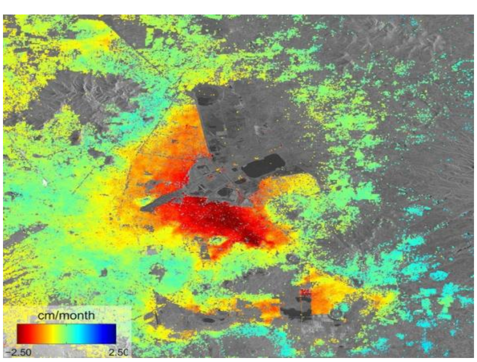
Sentinel-1 Synthetic Aperture Radar (SAR)

Sentinel-1A Launched 2014 & -1B launched 2016
C band Synthetic Aperture Radar (SAR (5.6 cm)
1-A and 1-B – each revisits every 12 days but six days apart





Subsidence in Mexico city – time-series of Sentinel-1A SAR scenes (3 Oct and 2 Dec 2014) – used to measure small-scale ground deformation - caused by ground water extraction.
Some areas subsiding at up to 2.5 cm/month (red).

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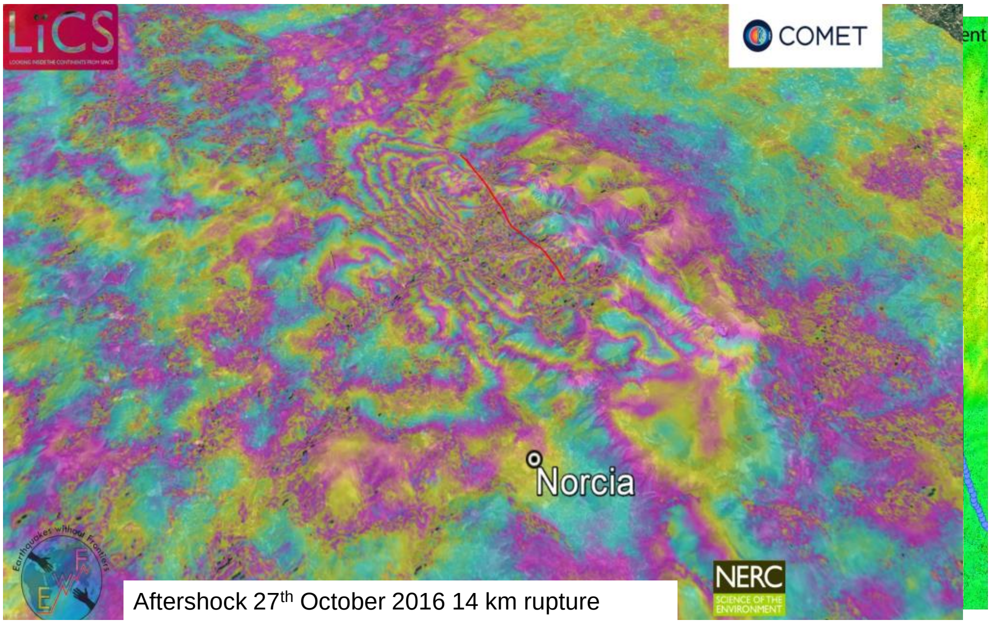
Sentinel-1 workhorse for global earthquake & volcano monitoring



Aftershock 27th October 2016 14 km rupture

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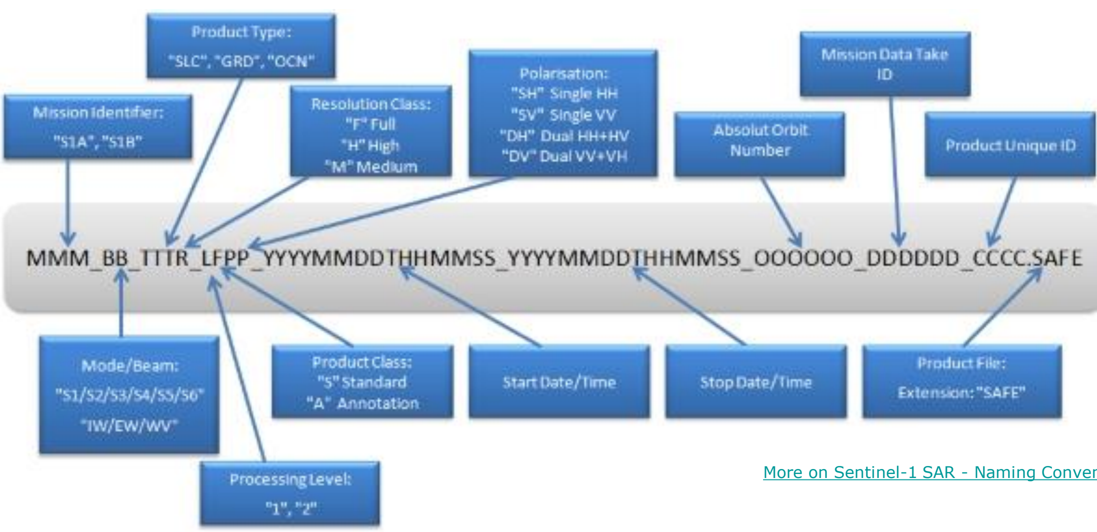
EO data products & naming conventions: Sentinel-1



More on Sentinel-1 SAR - Naming Conventions

S1 User guide: User Guide - Sentinel-1 SAR data

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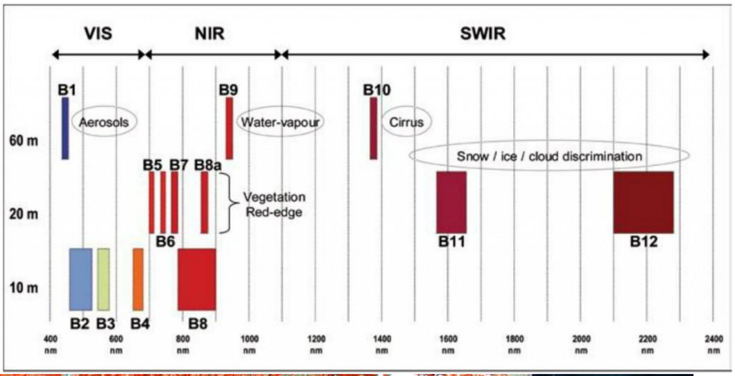
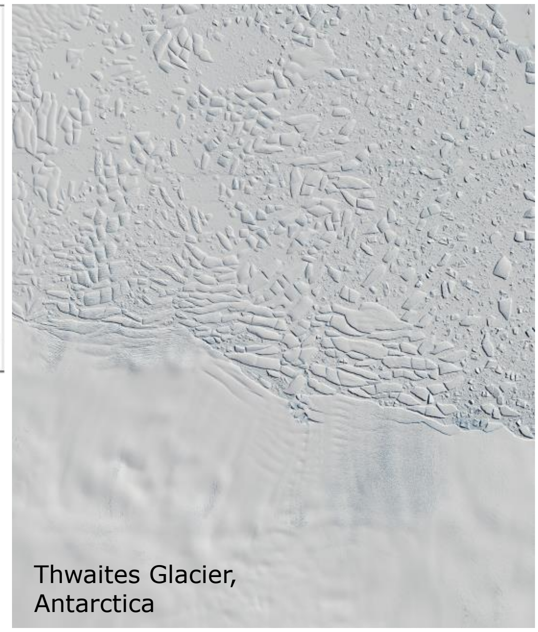
Sentinel-2 MultiSpectral Imager (MSI)

Launched 2015/2017



False colour composite
French Riviera



Thwaites Glacier,
Antarctica

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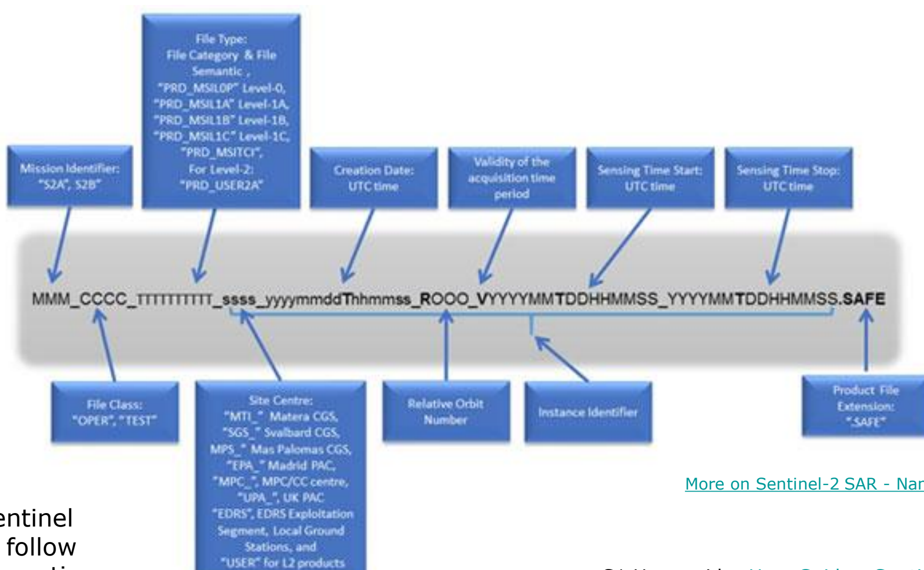
EO data products & naming conventions: Sentinel-2



More on Sentinel-2 SAR - Naming Conventions

Other Sentinel
datasets follow
similar convention

S1 User guide: User Guide - Sentinel-2 SAR data

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Important EO satellites

(Very High Resolution, routinely acquiring, Commercial thus data are not free!)

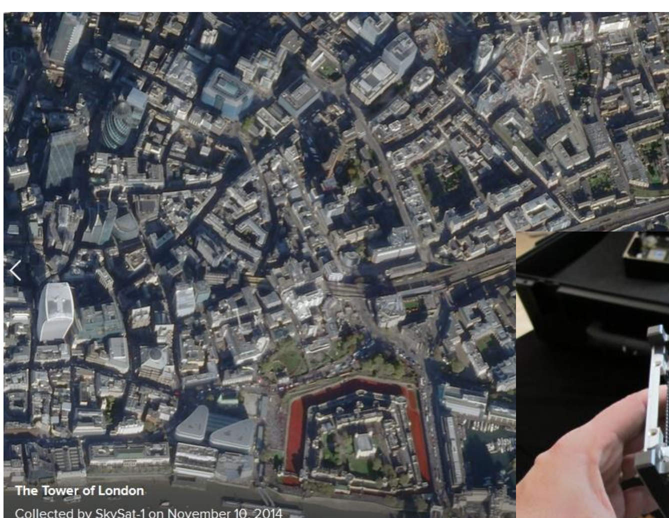
- Planet Scope (3 m and daily repeat)
  - Constellation of 180 identical ‘Doves’ - VNIR only €€
  - SkySAT (HD video & stills)
- Earth i constellation
  - Earth i, Rapid-Eye & others - VNIR only €€
- Maxar’s WorldView (0.31 cm to 4 m, and repeat every 3-4 days)
  - WV-3 multispectral & panchromatic - VIS-NIR-SWIR €€€
  - WV-1 & 2 multispectral & panchromatic – VNIR only €

- X-band high-resolution SAR (~3 m and repeat ~3 days) €€
  - TerraSAR-X
  - Tandem-X
  - IceEye
  - Capella X-SAR constellation

HD video from space - SkySat-1 & -2

- Small, high-performance, low cost satellites
- Cubesats
- Image spatial resolution : 1 m (Pan) & 2 m (MS)

Blue	0.450 - 0.515
Green	0.515 - 0.595
Red	0.605 - 0.695
NIR	0.740 - 0.900



https://www.youtube.com/watch?v=BsW6IGc4tt0

VHR sensors compared: GeoEye, Worldview, Earth i & Planet

	GeoEye-1 (2008)	WV-2 (2009)	WV-3 (2014)	Earth i (x3) (2015)	Planet Doves (2021)
Spatial Resolution:	0.41 m (Pan) 1.65 x 1.65 m (MS)	0.5 m (Pan) 2.0 or 2.4 m (MS)	0.31 (Pan) 1.24 m(VNIR)& 3.7 m(SWIR)	<1.00 m (Pan) <4.0 m (MS)	3 m (MS)
Spectral Range:	450–800 nm (Pan) 450–510 nm (B) 510–580 nm (G) 655–690 nm (R) 780–920 nm (NIR)	450–900 nm (Pan) 400-450 nm (coastal B) 450–510 nm (B) 510–580 nm (G) 585-625 nm (Y) 630–690 nm (R) 705-745 nm (R edge) 770–895 nm (NIR 1) 860-1040 nm (NIR 2)	450–800 nm (Pan) 400-450 nm (coastal B) 450–510 nm (B) 510–580 nm (G) 585-625 nm (Y) 630–690 nm (R) 705-745 nm (R edge) 770–895 nm (NIR 1) 860-1040 nm (NIR 2) 1195-1225 (SWIR1) 1550-1590 (SWIR2) 1640-1680 (SWIR3) 1710-1750 (SWIR4) 2145-2185 (SWIR5) 2185-2225 (SWIR6) 2235-2285 (SWIR7) 2295-2365 (SWIR8)	450–800 nm (Pan) 450–510 nm (B) 510–580 nm (G) 655–690 nm (R) 780–920 nm (NIR)	431-452 nm (B) 547-585 nm (G) 650-682 nm (R) 846-888 nm (NIR)
Swath Width	15.2 km	16.4 to 17.7 km		23 km	24 x 16 km
Off-Nadir Imaging	+/- 60 deg	+/- 60 deg		+/- 45 deg	+/- 60 deg
Dynamic Range	11 bits per pixel	8 or 16 bits per pixel		10 bits	8 bit
Mission Life	> 10 years	> 10 years		>10 years	Indefinitely – 180 in operation at a time
Revisit Time	< 3 days	< 3 days	< 1 day	<1 day	Daily
Orbital Altitude	681 km	770 km	620 km	651 km	

Important EO data sources

ESA Sentinel Hub https://scihub.copernicus.eu/ ALL FREE!

USGS EarthExplorer https://earthexplorer.usgs.gov ALL FREE!

Planet https://www.planet.com/products/planet-imagery NOT free BUT ESE now has an agreement for 15TB (~ 30 million sq km) of free data!!!

Maxar https://discover.digitalglobe.com/ NOT free but can negotiate free data for research

GEE – entire Landsat & Sentinel archives FREE!

Amazon cloud – entire Landsat & Sentinel archives Not FREE!

Copernicus Data and Information Access Service (DIAS) cloud: https://sentinel.esa.int/web/sentinel/sentinel-data-access Some services free, some not!