

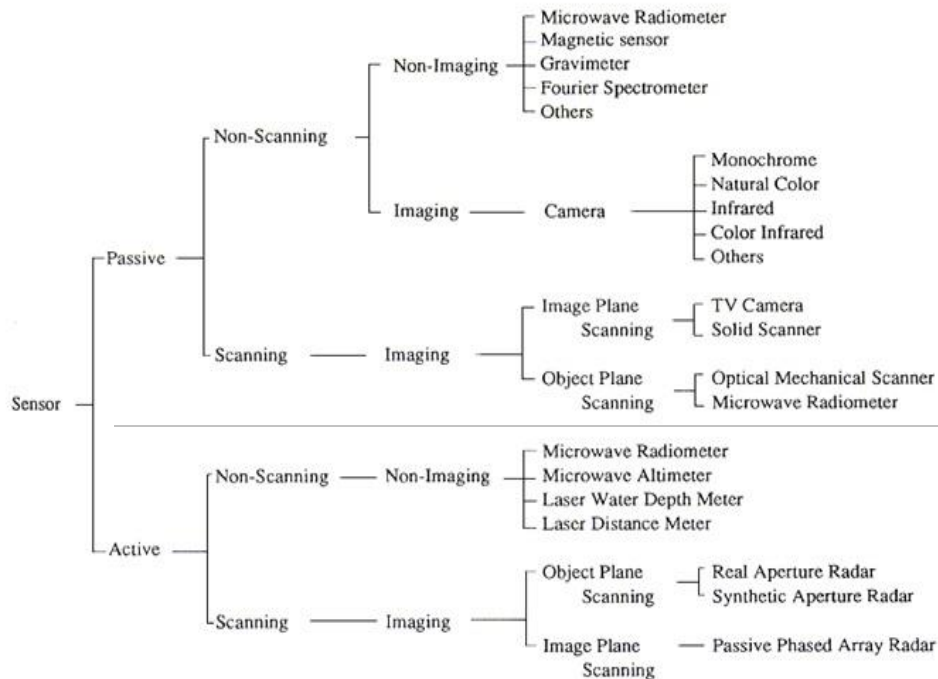


4. Optical remote sensing using ESA Copernicus' data: sensors and platforms, image metadata, image resolution (spectral, spatial, temporal and radiometric resolution)



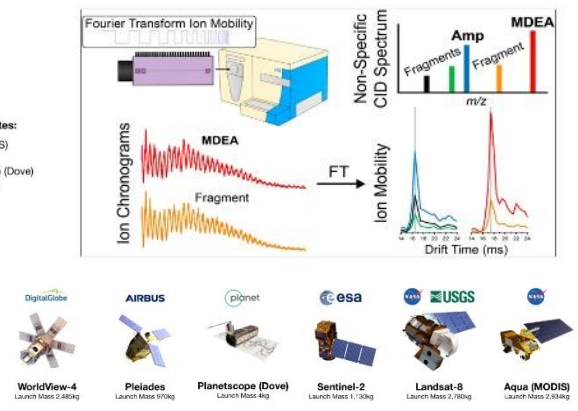
Sensors and platforms

Types of sensors



PASSIVE Earth Observation Satellites
 Passive satellites detect radiation reflected off the Earth's surface, such as visible light and infrared. In general, passive satellites are not able to work through clouds.

- Passive Satellites:**
- Aqua (MODIS)
 - Landsat-8
 - PlanetScope (Dove)
 - WorldView-4
 - Pleiades
 - Sentinel-2



ACTIVE Earth Observation Satellites
 Active satellites transmit energy towards the Earth and measure the returned signal which provides information about the Earth's surface. In general, active satellites can see through clouds.



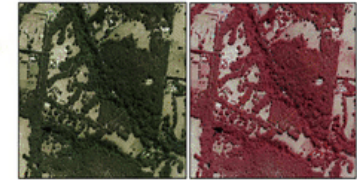
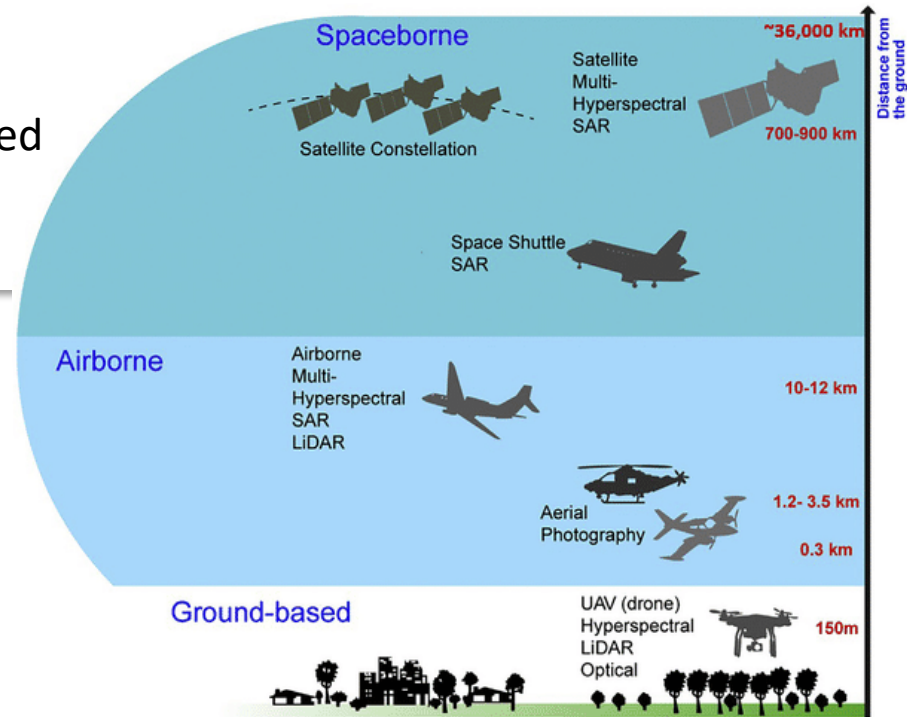
Source: https://www.esa.int/var/esa/storage/images/esa_multimedia/images/2022/09/copernicus_sentinel_family/24451531-1-engGB/Copernicus_Sentinel_family_pillars.jpg?bclid=IwAR0Fj0JjxucGiN6ICSRwqPmvLd1T1F5eGgv6pr7kNp53_T3XFHfv8H0jk4, <https://www.geospatialworld.net/blogs/observing-the-earth-fueling-global-development-solutions/>, https://www.researchgate.net/publication/224136559_The_Soil_Moisture_Active_and_Passive_SMAP_mission/figures?lo=1, <https://www.iqservices.eu/sk/novinky/faro-focus-core.html>

Types of platforms

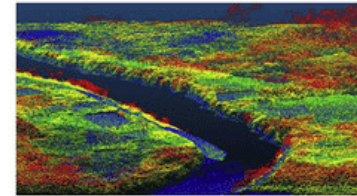
Platforms = the vehicles or carriers for remote sensing devices

3 main platforms:

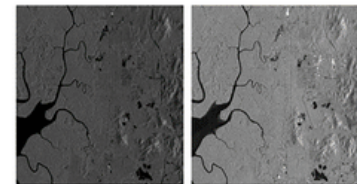
- Terrestrial/ground based
- Airborne
- Spaceborne



True-colour Multi-spectral False-colour Multi-spectral



LiDAR 3D point cloud



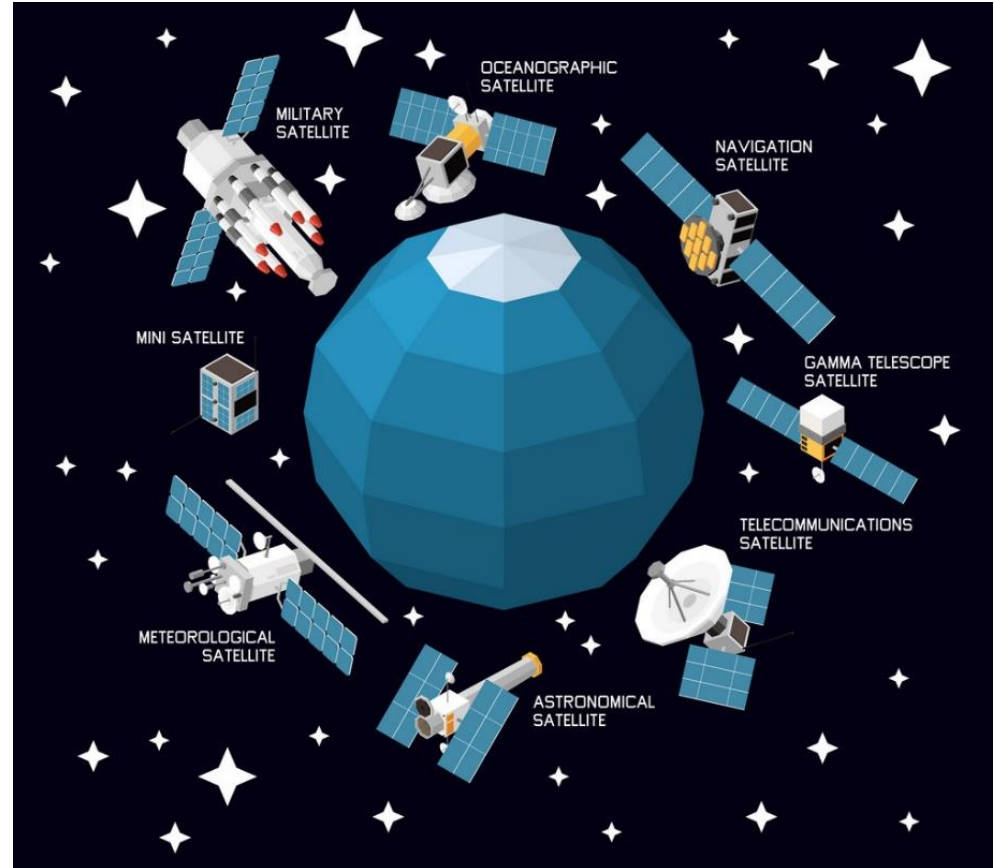
Synthetic Aperture Radar

Types of satellites

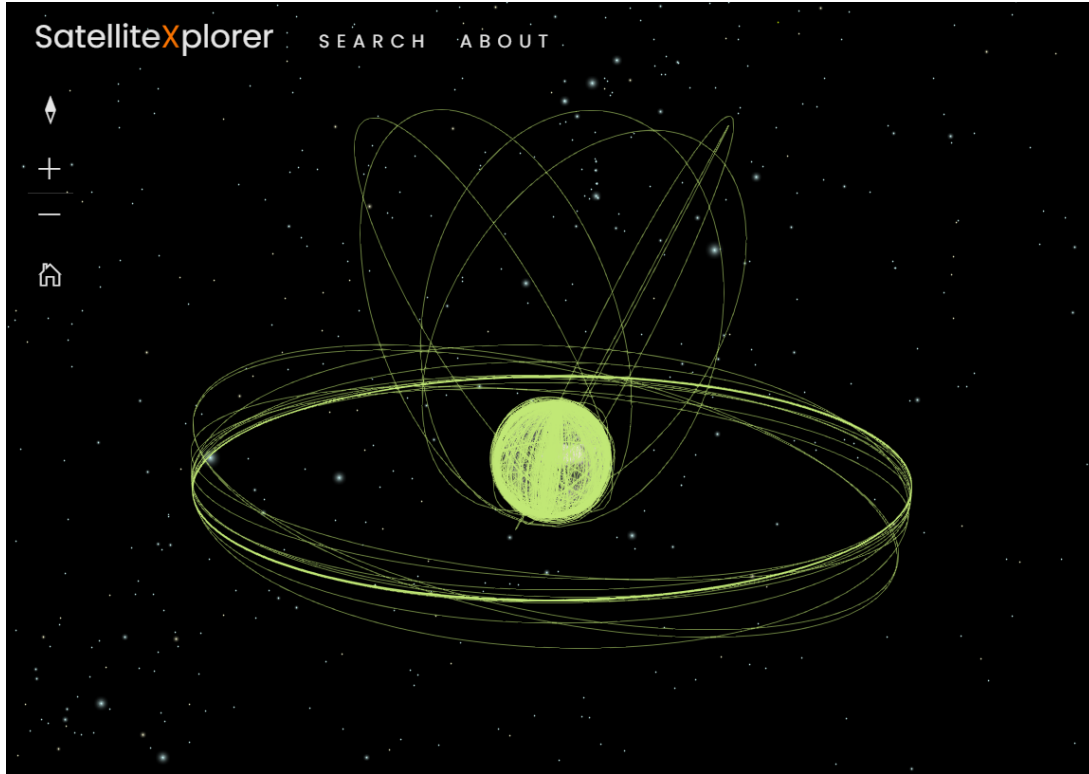
Today man-made or artificial satellites are widely used for a large number of purposes.

Hence such satellites are classified into six major types:

- Astronomical
- Communication
- Weather
- Remote sensing
- Navigation
- Reconnaissance satellites



Types of satellites



The screenshot shows the 'Satellite Explorer' interface. At the top left, the logo 'SatelliteXplorer' is displayed, followed by 'SEARCH' and 'ABOUT' links. On the left side, there is a vertical navigation menu with icons for a compass, a plus sign, a minus sign, and a home icon. The main content area features a 3D visualization of the Earth with several overlapping satellite orbits shown as glowing green lines. The background is a dark space filled with stars.

Earth Observation satellites provide information about earth resources, weather, climate, and environmental monitoring. Imaging satellites produce high-resolution data of almost the entire landmass on earth.

830 satellites
17.84% of total satellites used for earth observation purposes.

Earth observation satellite systems ^

Landsat program a joint NASA / USGS program launched on 23 July 1972.

Doves satellites operated by Planet Labs PBC, the Doves satellites weigh only 5.8 kg each and provides 3-meter multispectral image resolution for humanitarian and



Image metadata

Metadata

- In the Earth observation domain, metadata is the descriptive information about the data
- Metadata provides the user information about the content, source, quality, condition for use, lineage, and other relevant characteristics

The screenshot displays a software interface for handling Earth observation data. The main window is titled "[1] Original_Product_Metadata - [S1A_IW_GRDH_1SDV_20180726T165231_20180726T165256_022968_027E14_0A09]". The interface includes a menu bar (File, Edit, View, Analysis, Layer, Vector, Raster, Optical, Radar, Tools, Window, Help) and a search bar (Search (Ctrl+F)).

The **Product Explorer** on the left shows a tree structure:

- [1] S1A_IW_GRDH_1SDV_20180726T165231_20180726T165256_022968
 - Metadata
 - Abstracted_Metadata
 - Original_Product_Metadata
 - XFDU
 - annotation
 - calibration

The main data table displays the following metadata:

Name	Value	Type	Unit
annotation			
s1a-iw-grd-vh-20180726t165231-20180726t165256-022968-027e14-002.xml			
product			
adsHeader			
missionId	S1A	ascii	
productType	GRD	ascii	
polarisation	VH	ascii	
mode	IW	ascii	
swath	IW	ascii	
startTime	2018-07-26T16:52:31.968075	ascii	
stopTime	2018-07-26T16:52:56.966011	ascii	
absoluteOrbitNumber	22968	ascii	
missionDataTakeId	163348	ascii	
imageNumber	002	ascii	

The bottom left shows a globe view labeled "Off Globe" with a "Downloading" status. A scale bar indicates 1000 Km.



Image resolution



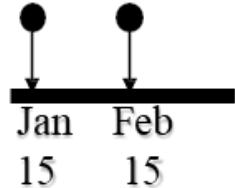
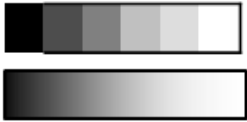
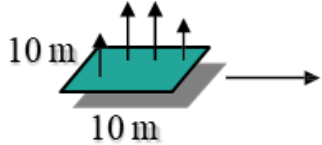
30 m/px

100 m/px

300 m/px

Source: <https://www.earthdata.nasa.gov/learn/backgrounders/satellite-sensing>

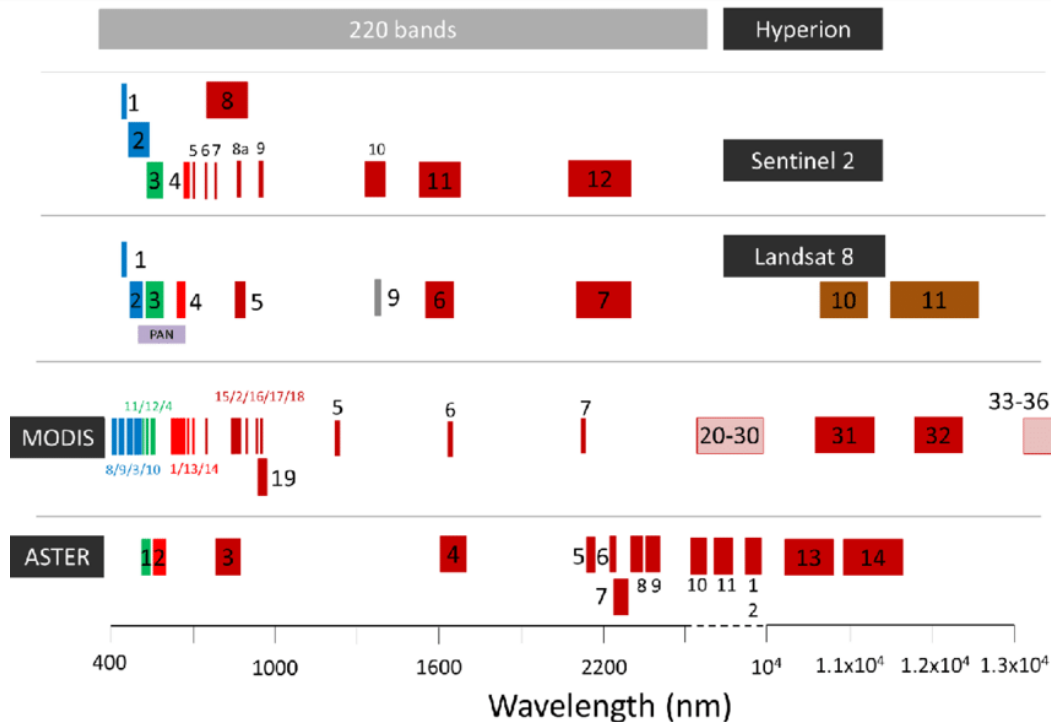
Image Resolution



- **Spatial** - the size of the field-of-view, e.g. 10 x 10 m
- **Spectral** - the number and size of spectral regions the sensor records data in, e.g. blue, green, red, near-infrared, thermal infrared, microwave (radar).
- **Radiometric** - the sensitivity of detectors to small differences in electromagnetic energy. (8bit, 16bit)
- **Temporal** - how often the sensor acquires data, e.g. every 30 days

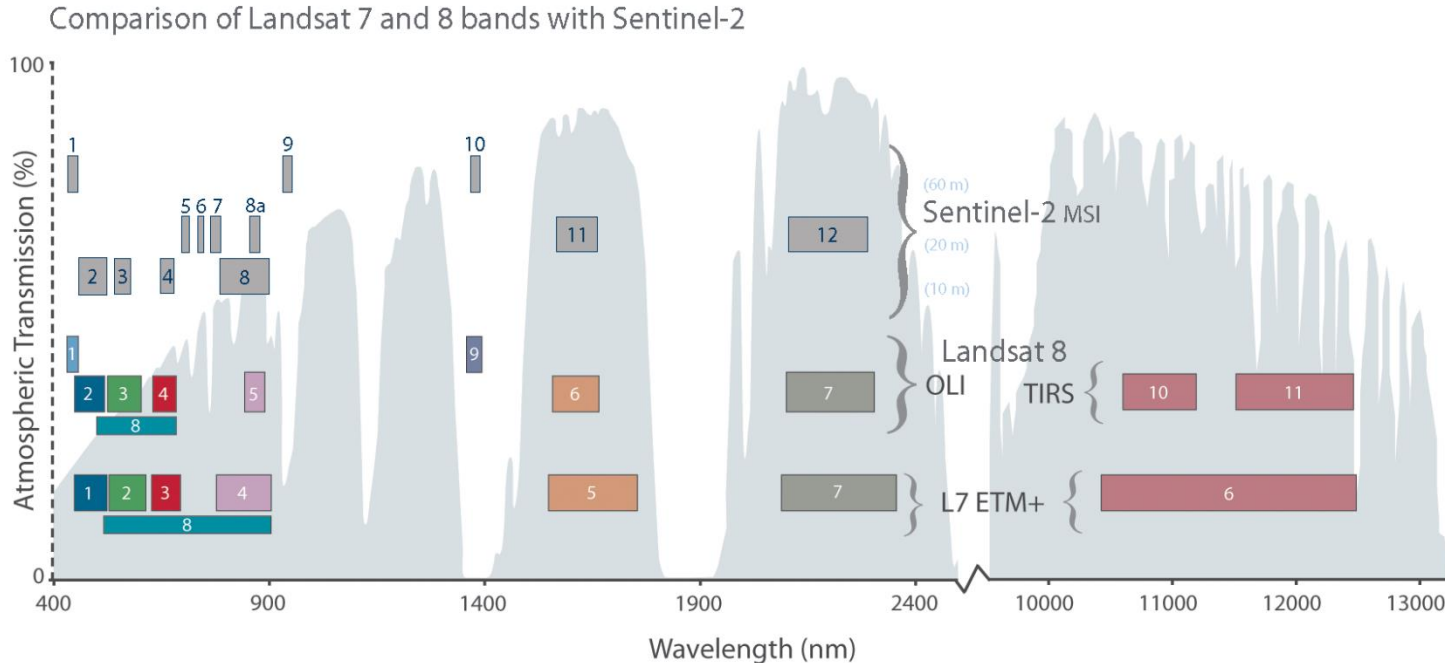
Spectral resolution

- The bandwidth (width), number, and position of specific wavelength bands that a sensor system can record



Spectral resolution

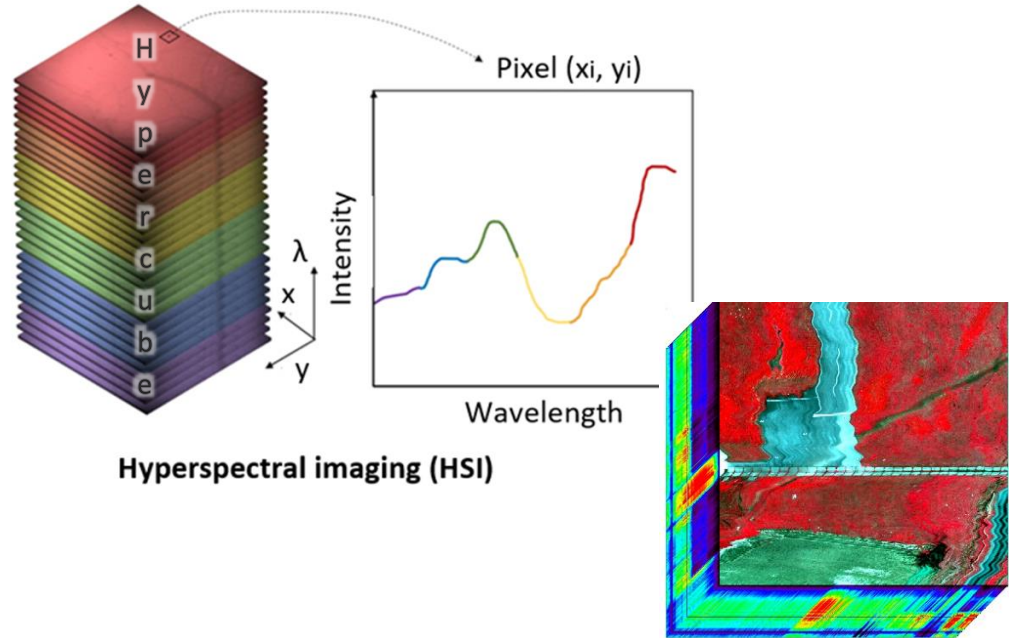
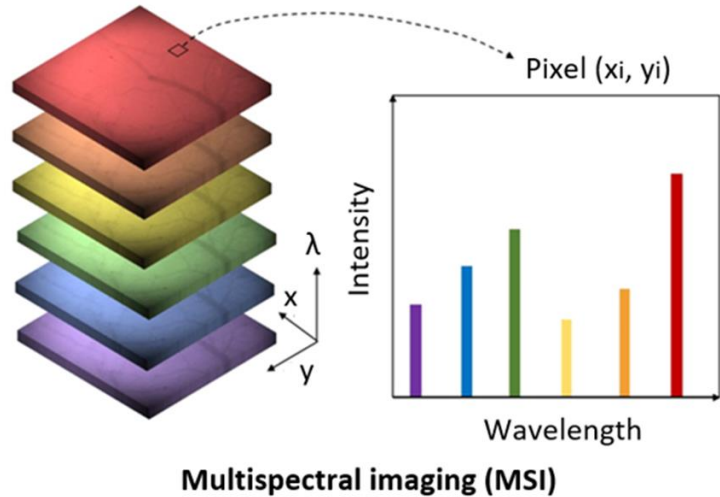
- The bandwidth (width), number, and position of specific wavelength bands that a sensor system can record



Spectral resolution

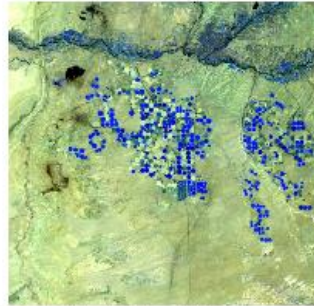
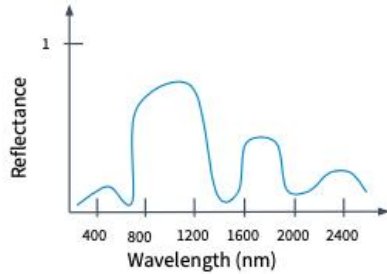
Band	Sentinel-2A MSI			Landsat 8 OLI		
	Spectral region	Wavelength range (nm)	Resolution (m)	Spectral region	Wavelength range (nm)	Resolution (m)
B1				Blue	435–451	30
B2	Blue	458–523	10	Blue	452–512	30
B3	Green peak	543–578	10	Green	533–590	30
B4	Red	650–680	10	Red	636–673	30
B5	Red edge	698–713	20	NIR	851–879	30
B6	Red edge	733–748	20	SWIR1	1566–1651	30
B7	Red edge	773–793	20	SWIR2	2107–2294	30
B8	NIR	785–899	10			
B8A	NIR narrow	855–875	20			
B11	SWIR	1565–1655	20			
B12	SWIR	2100–2280	20			

Spectral resolution



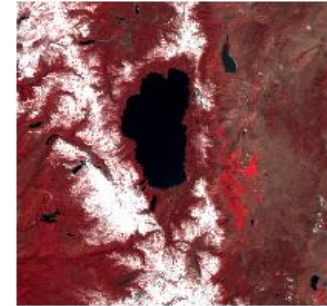
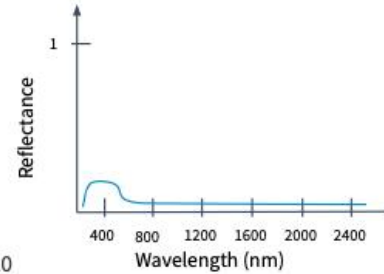
Spectral resolution vs. spectral curve

Vegetation



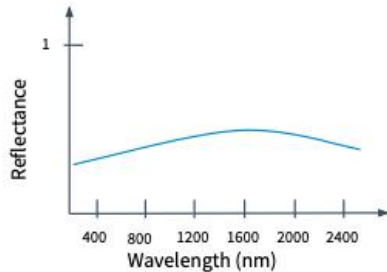
Center pivot irrigation, NASA Landsat, 2020
swir2 - swir1 - nir

Water



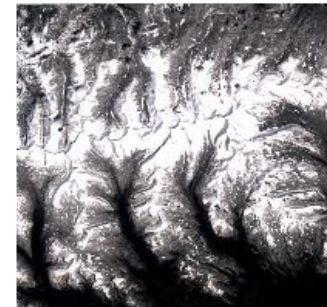
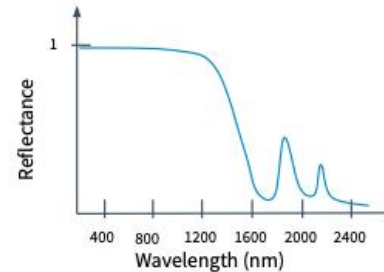
Lake Tahoe, NASA Landsat, 2020
nir - red - green

Urban areas



Los Angeles, NASA Landsat, 2020
red - green - blue

Snow



The Uintas, NASA Landsat, 2020
red - green - blue

*Note: spectral signatures have been generalized

Satellites can observe objects using different frequency bands all at once. You can choose different combinations of bands – color compositions to emphasize specific features.

Source:
<https://kb.descarteslabs.com/knowledge/introduction-to-remote-sensing>

Spectral resolution vs. spectral curve

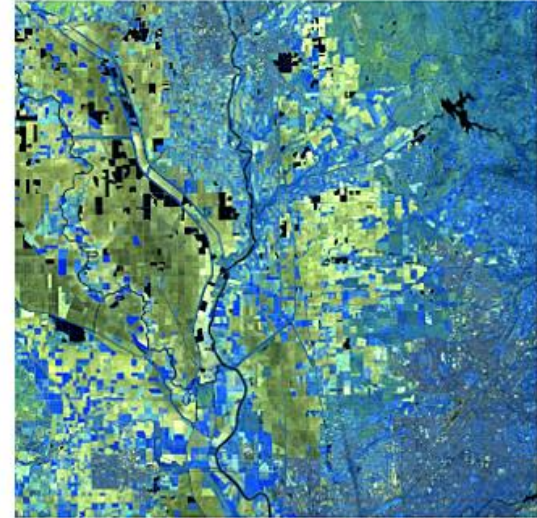
Central Valley of California in different spectral resolutions



ESA Sentinel 2: red-green-blue bands



ESA Sentinel 2: nir-red-green bands

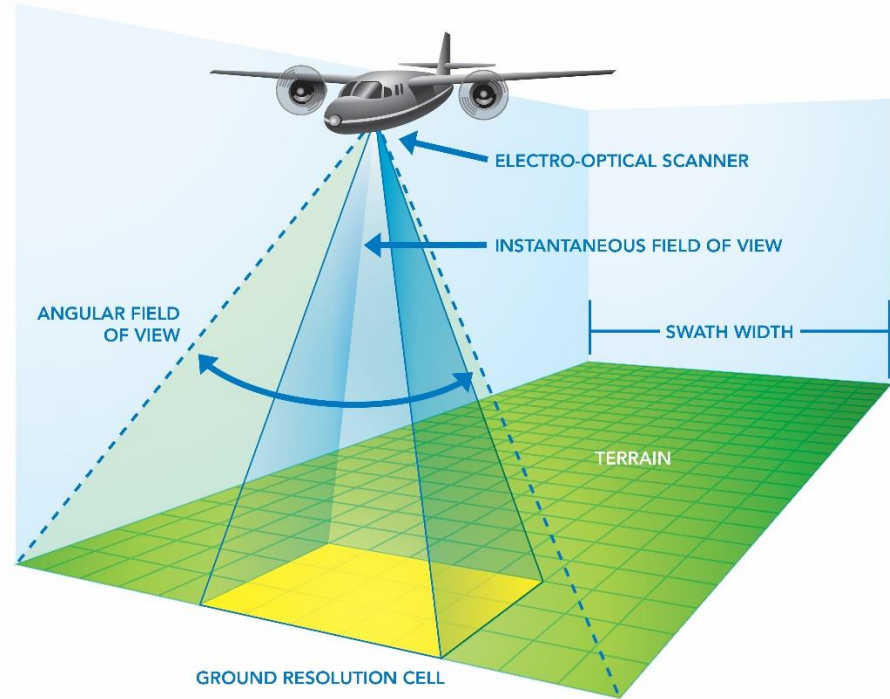


ESA Sentinel 2: swir2-swir1-nir bands

- *The first image shows red, green, and blue bands; this is the visible range and appears the same as what it would look like out the window of an airplane.*
- *The middle image is looking at near infrared, red, and green bands, where we see all the vegetation popping out strongly as a red color, since near infrared radiation is being reflected very strongly.*
- *The final image displays the two short wave infrared bands and near infrared. Agricultural fields emitting very strongly in the infrared bands, and are seeing more detail in the soil properties in yellow and brown.*

Spatial resolution

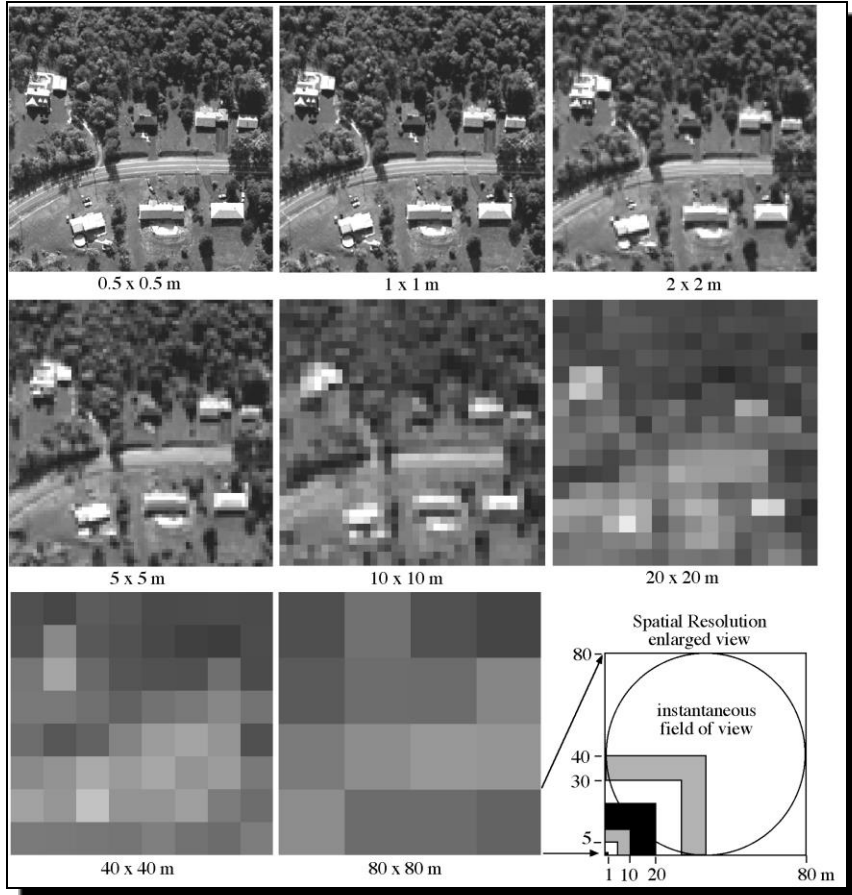
- The size of the smallest object that can be detected by a satellite – pixel size
- Pixel: smallest unit of an image
- Instantaneous field-of-view (IFOV)
- Distance on the ground that corresponds to one side of one pixel in image



Spatial Resolution: Comparison

Source: Jensen 2000

Spatial resolution



Example of different spatial resolutions

Source: Jensen 2000

Spatial resolution



Triple Sat Constellation
80 cm spatial resolution



Landsat-8 image
15 m spatial resolution

Spatial resolution

What Spatial Resolution Do I Need?

Spatial resolution is the area represented by a pixel. For example, in a 10-meter resolution dataset each pixel represents a 10 m by 10 m square on the ground.

National Aeronautics and
Space Administration



Spatial resolution

Main scales

- < 1 meter = Very high resolution: fine details in urban context, roofs, cars, small boats ... Ikonos, Pleiades, QuickView
- $1 \text{ m} < \dots < 5 \text{ m}$ = High resolution: urban structures, houses, streets, individual trees, railway & road networks, ... SPOT 5
- $5 \text{ m} < \dots < 30 \text{ m}$ = Middle resolution: fine landcover, coarse urban structure: dense urban, residential or commercial areas, ... Landsat, Spot 1-3
- $> 30 \text{ m}$ = low resolution: global landcover

Here is how the Wimbledon Tennis Complex (London, UK) appears at different resolutions associated with several of the satellites highlighted. All the images below are generated from a Worldview-4 image and resampled to be representative of the different spatial resolutions represented.



Aqua (MODIS)
250m Resolution



Landsat-8
30m Resolution



Sentinel-2
10m Resolution



PlanetScope (Dove)
3m Resolution



Pleiades
0.5m Resolution



Worldview-4
0.3m Resolution

Spatial Resolution: Sensor Comparison
Source: <https://www.agridico.com//radiantearthinsight/>

Spatial resolution

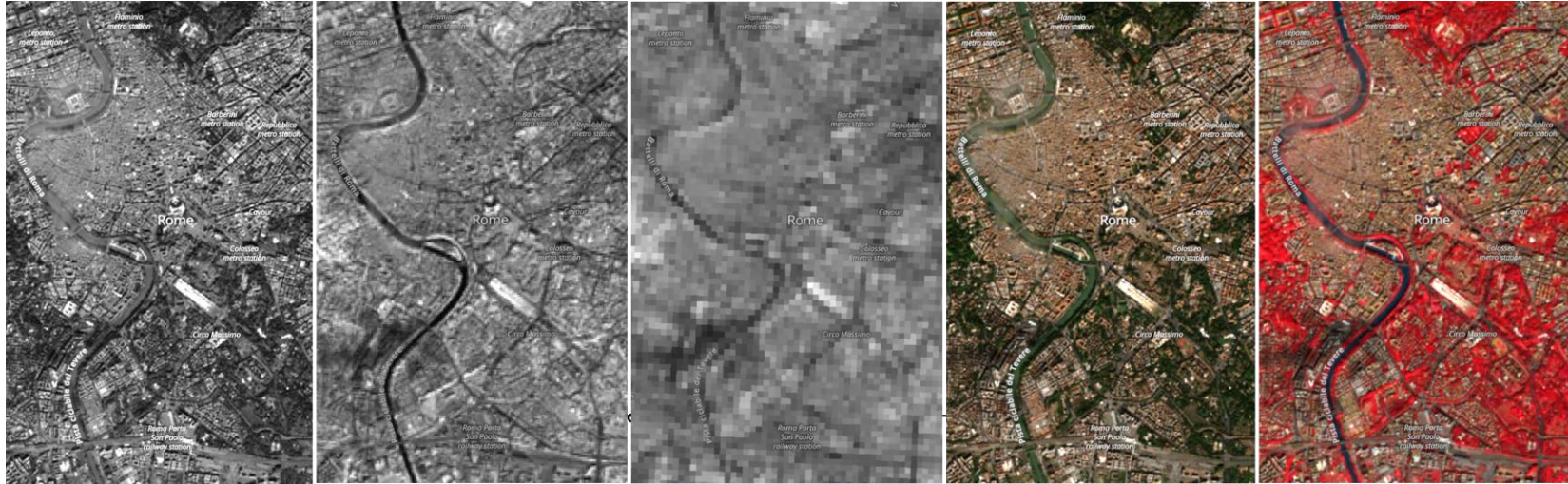


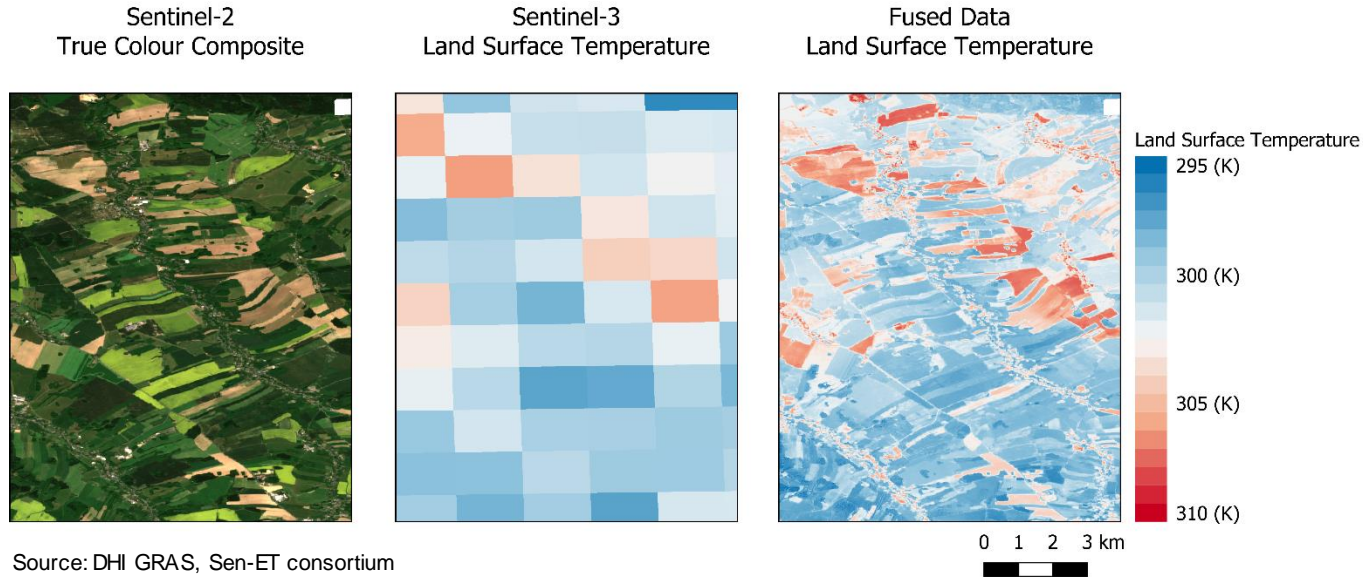
Image from the Sentinel 2A satellite, display in bands B-3 (10m), B-8a (20m), B-9 (60m) and in the true color composition B-4-3-2 (10m) and false color composition B-8A-4-3

Spatial resolution

Comparison of spatial resolution: Sentinel-2, Landsat-8 and SPOT-5

Sentinel-2 MSI		Landsat-8 OLI		SPOT-5 HRG		Name
Band [m]	Range [nm]	Band [m]	Range [nm]	Band [m]	Range [nm]	
B1 * (60)	443 ± 10	B1 (30)	440 ± 10			Aerosol
B2 (10)	490 ± 32.5	B2 (30)	480 ± 30			Blue
B3 (10)	560 ± 17.5	B3 (30)	560 ± 30	B1 (10)	545 ± 45	Green
B4 (10)	665 ± 15	B4 (30)	650 ± 20	B2 (10)	645 ± 35	Red
		B8 * (15)	590 ± 45	PAN (5)	595 ± 115	PAN
B5 (20)	705 ± 7.5					Red-edge 1
B6 (20)	740 ± 7.5					Red-edge 2
B7 (20)	783 ± 10					Red-edge 3
B8 (10)	842 ± 57.5			B3 (10)	835 ± 55	NIR _{wide}
B8A (20)	865 ± 10	B5 (30)	865 ± 15			NIR _{narrow}
B9 * (60)	945 ± 10					Cirrus
B10 * (60)	1375 ± 15	B9 (30)	1370 ± 10			Water Vapor
B11 (20)	1610 ± 45	B6 (30)	1610 ± 40	B4 (20)	1665 ± 85	SWIR 1
B12 (20)	2190 ± 90	B7 (30)	2200 ± 90			SWIR 2
		B10 * (100)	10,895 ± 295			Thermal 1
		B11 * (100)	12,005 ± 505			Thermal 2

Spatial resolution



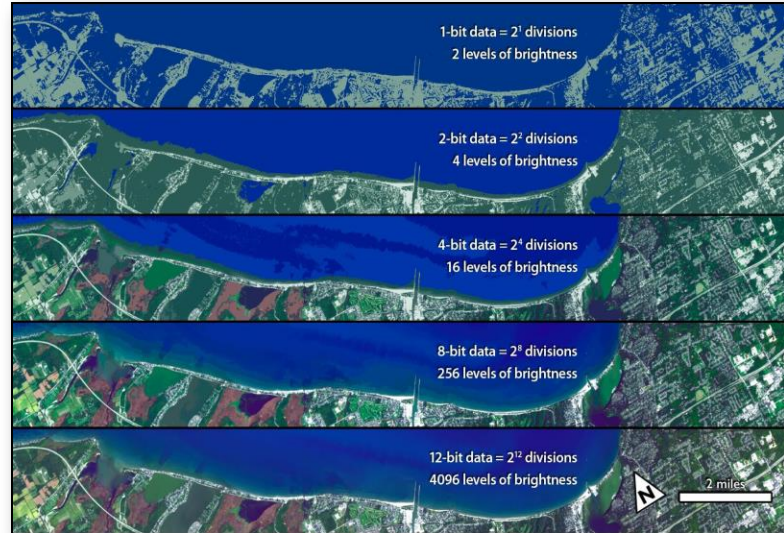
Source: DHI GRAS, Sen-ET consortium

The images show an agricultural area in southern Germany in late May 2017. The Copernicus Sentinel-2 image (left) was acquired at 20 m spatial resolution. This allows agricultural parcels and other landscape features such as roads to be distinguished. The Copernicus Sentinel-3 image (centre) captures the land-surface temperature, which is essential for estimating evapotranspiration, but here with a pixel size of around 1 km. By using advanced machine-learning algorithms, data from the two sensors can be fused, thus obtaining a 20 m representation of land-surface temperature (right) which can then be used to produce 20 m evapotranspiration maps.

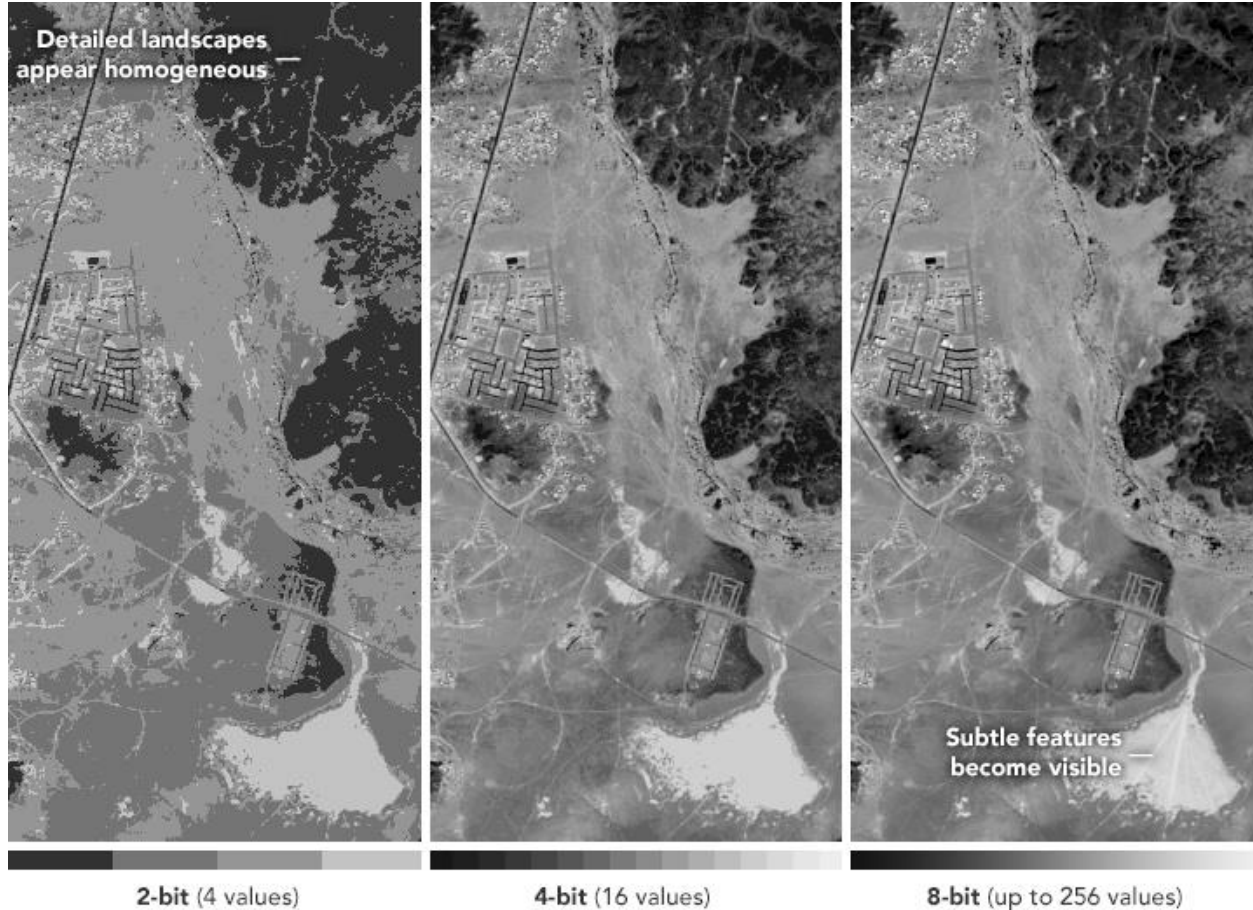
Radiometric resolution

- The sensitivity of detectors to small differences in electromagnetic energy
- Measured in bits (a number to the exponential power of 2)
- The higher the number, the finer the radiometric resolution

Number of bits	Range of quantisation levels
1	0-1
2	0-3
3	0-7
4	0-15
5	0-31
6	0-63
7	0-127
8	0-255
9	0-511
10	0-1023



Radiometric resolution



Source:
<https://landsat.visibleearth.nasa.gov/view.php?id=91071>

Temporal resolution

- Refers to the frequency at sensor collects imagery over a specific area

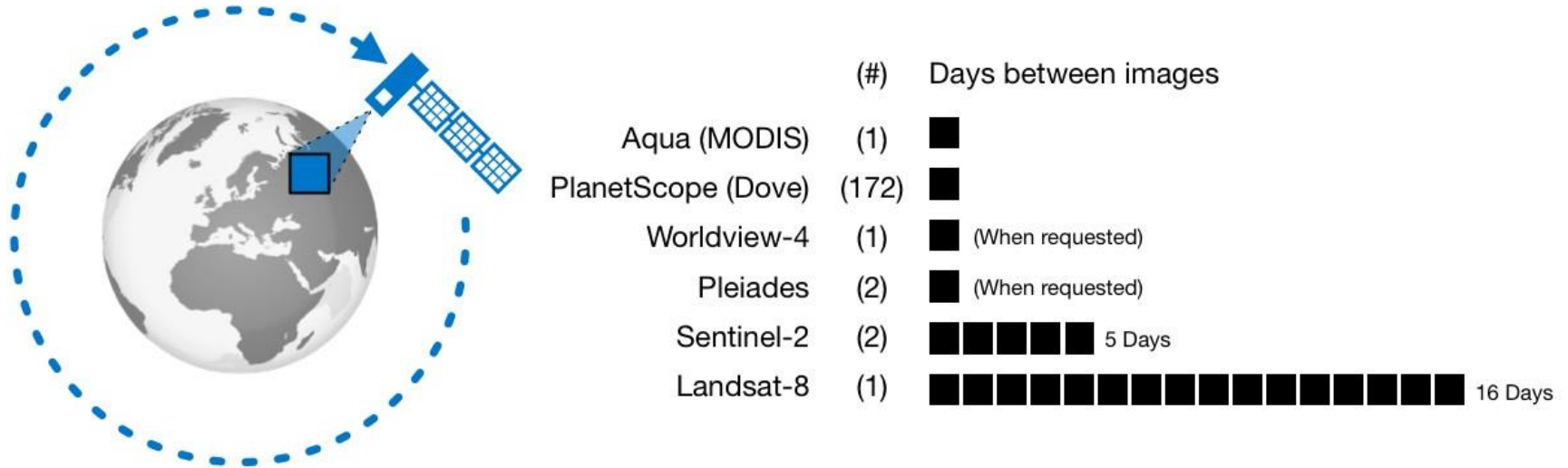
Depends on:

- Orbital characteristics
- Image swath width / footprint
- Off-nadir viewing capabilities (i.e., pointable optics)
- Number of satellites in the family



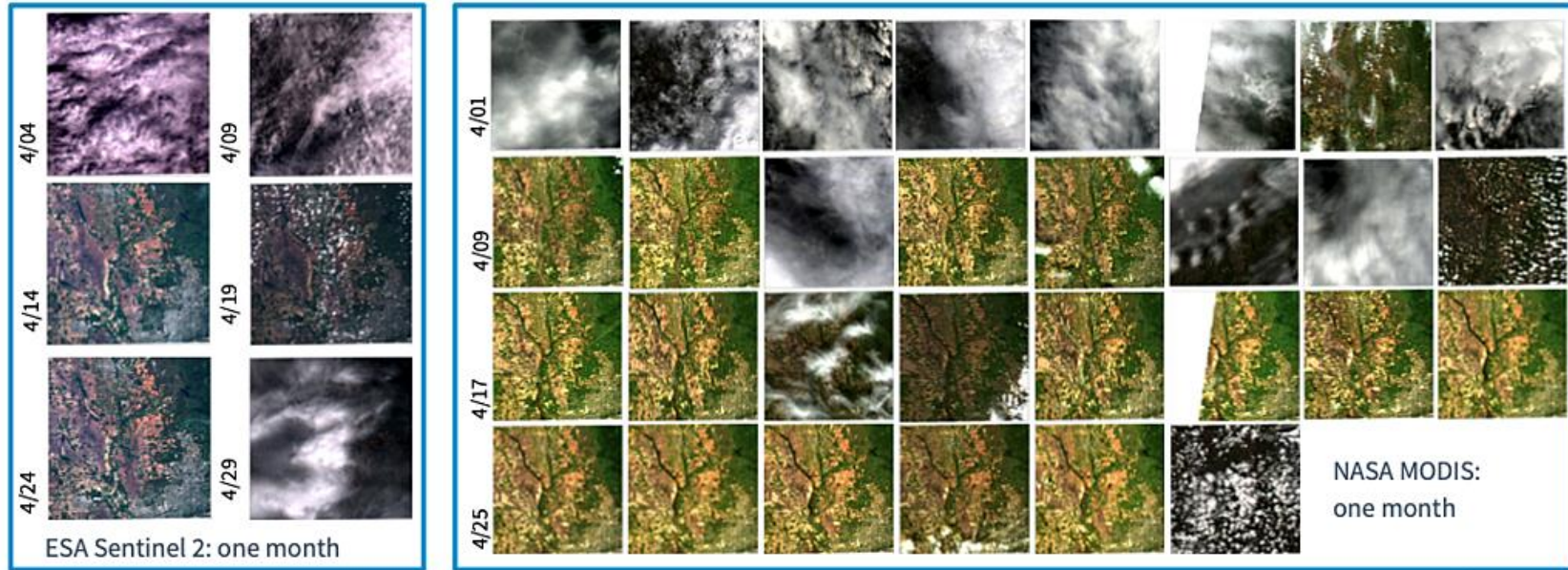
Temporal resolution

Temporal resolution varies by satellite and describes the time it takes for an individual satellite to orbit and revisit a specific area. Some satellites operate as a constellation with multiple satellites working together to increase their global coverage daily.



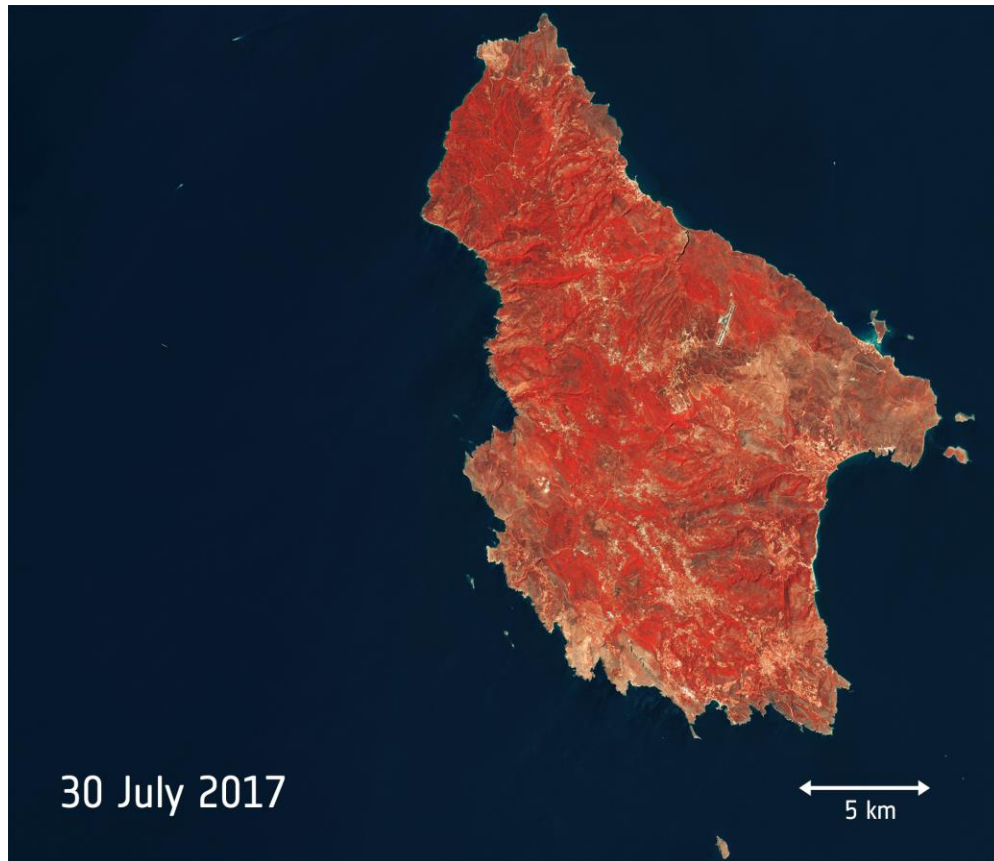
Temporal resolution

Central Valley of California in different temporal resolutions



- *Temporal resolution refers to how often images are collected for any given location on earth. For Sentinel-2 imagery, we're getting about six images per month, whereas for MODIS we're getting an image every day. However, there is tradeoff: the coarser the spatial resolution, the higher the temporal resolution, and vice versa. If we're getting very fine spatial resolution data, we're not getting it as often.*

Temporal resolution



- *The Copernicus Sentinel-2 satellite pair captured the start of a fire on the Greek island of Kythira on 4 August 2017. Five days later, a huge burn scar is visible across the western part of the island.*
- *Carrying a high-resolution multispectral optical imager, Sentinel-2 is used to monitor changes in vegetation (in this 'false-colour' image, vegetation is in red). The mission offers key information to optimise crop yield, thereby helping to improve food security. It can be used to measure leaf area, leaf chlorophyll and leaf water content to monitor plant growth, which is particularly important during the growing season.*

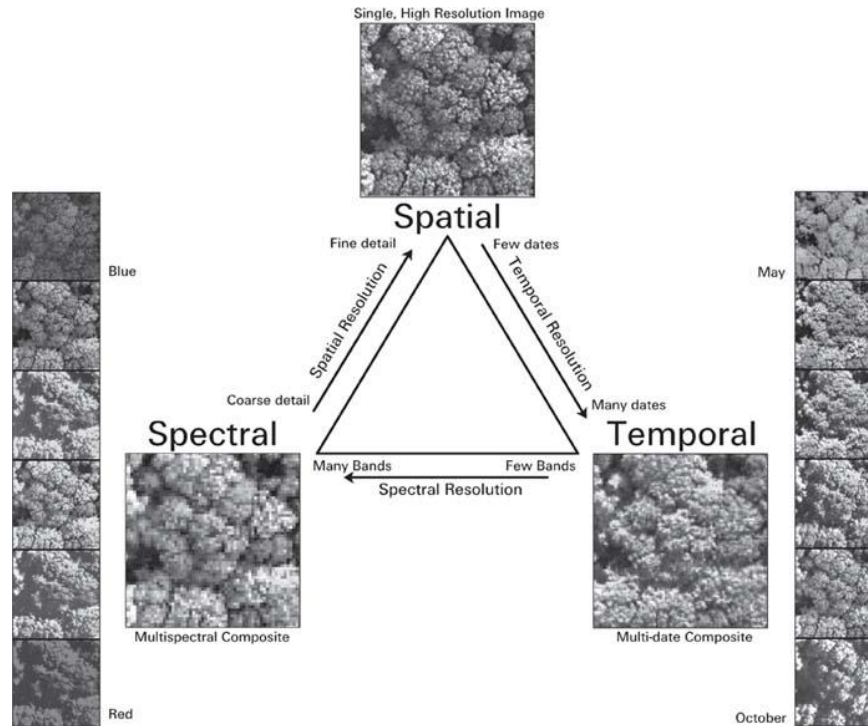
Source: ESA

Sensor Characteristics

Sensor	Number of Bands	Spatial Resolution	Temporal Resolution	Radiometric Resolution	Swath width/Footprint
MODIS	36	250 m, 500 m, 1000 m	*1 day	4096	2330 km swath width
Sentinel-2	13/1	10 m, 20 m, 60 m	*5 days	4096	290 km swath width
Landsat 5 & 7/Pan	7/1	30 m/15 m	*8 days	256	34,225 km ² footprint
Landsat 8/Pan	10/1	30 m/15 m	16 days	4096	34,225 km ² footprint
SPOT 5/Pan	3/1	20 m/10 m	*2-3 days	256/256	3600 km ² footprint
IKONOS/Pan	4/1	4 m/1 m	~3 days	2048/2048	11.3 km swath width
QuickBird/Pan	4/1	2.4 m/0.6 m	2-11 days	2048/2048	16.4 km swath width

Resolution Tradeoffs

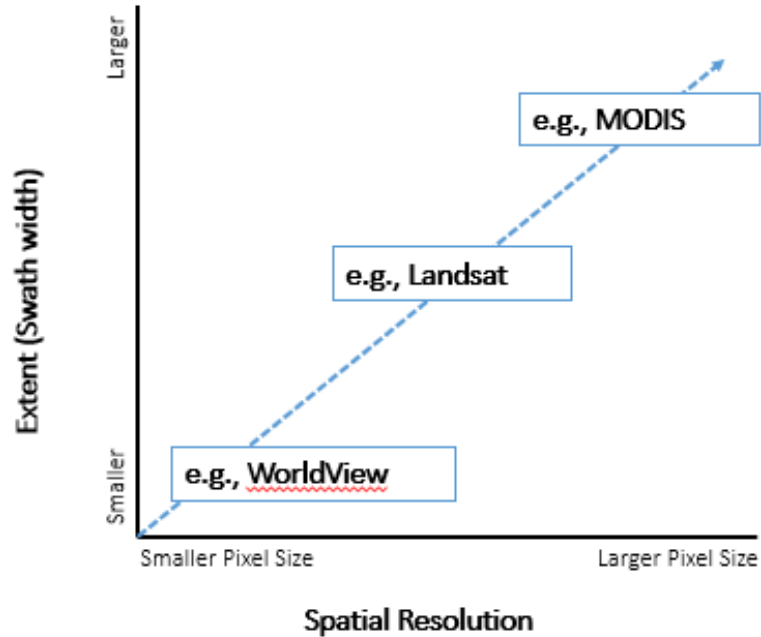
Though a finer temporal resolution is more desirable, there is often a tradeoff between a fine temporal resolution and a fine spatial resolution.



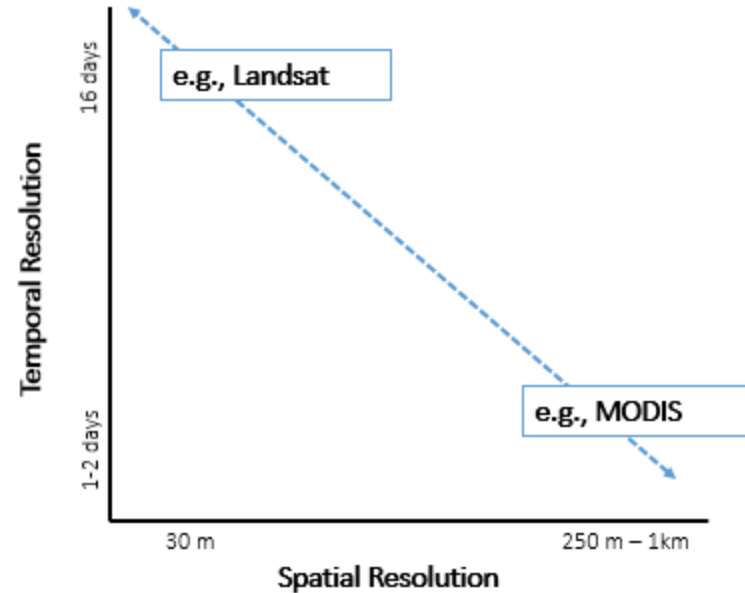
Source:
<https://kb.descarteslabs.com/knowledge/introduction-to-remote-sensing>

Resolution Tradeoffs

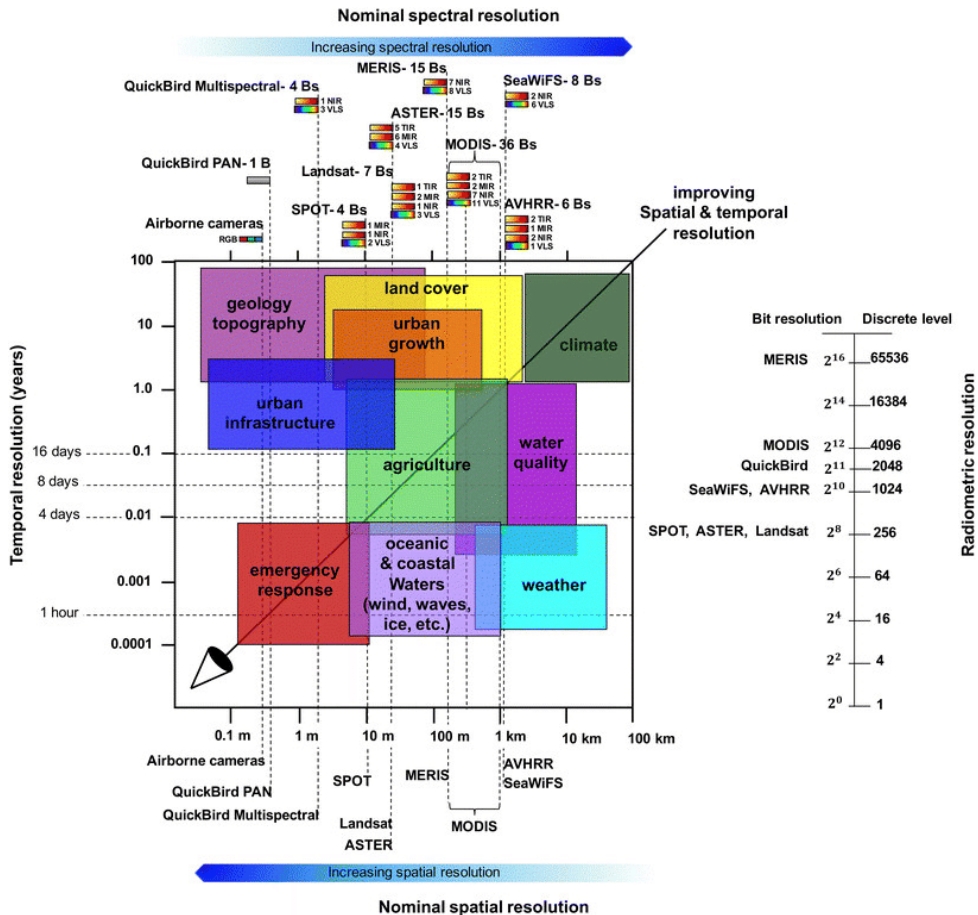
Spatial Resolution & Extent (Area) Tradeoff



Temporal & Spatial Resolution Tradeoff



Resolution Tradeoffs



Comparison of temporal, spectral and spatial resolution of satellites

Source:
https://www.researchgate.net/publication/308514016_Advances_in_remote_sensing_applications_for_urban_sustainability/figures?lo=1&utm_source=google&utm_medium=organic



Thank you for the attention

