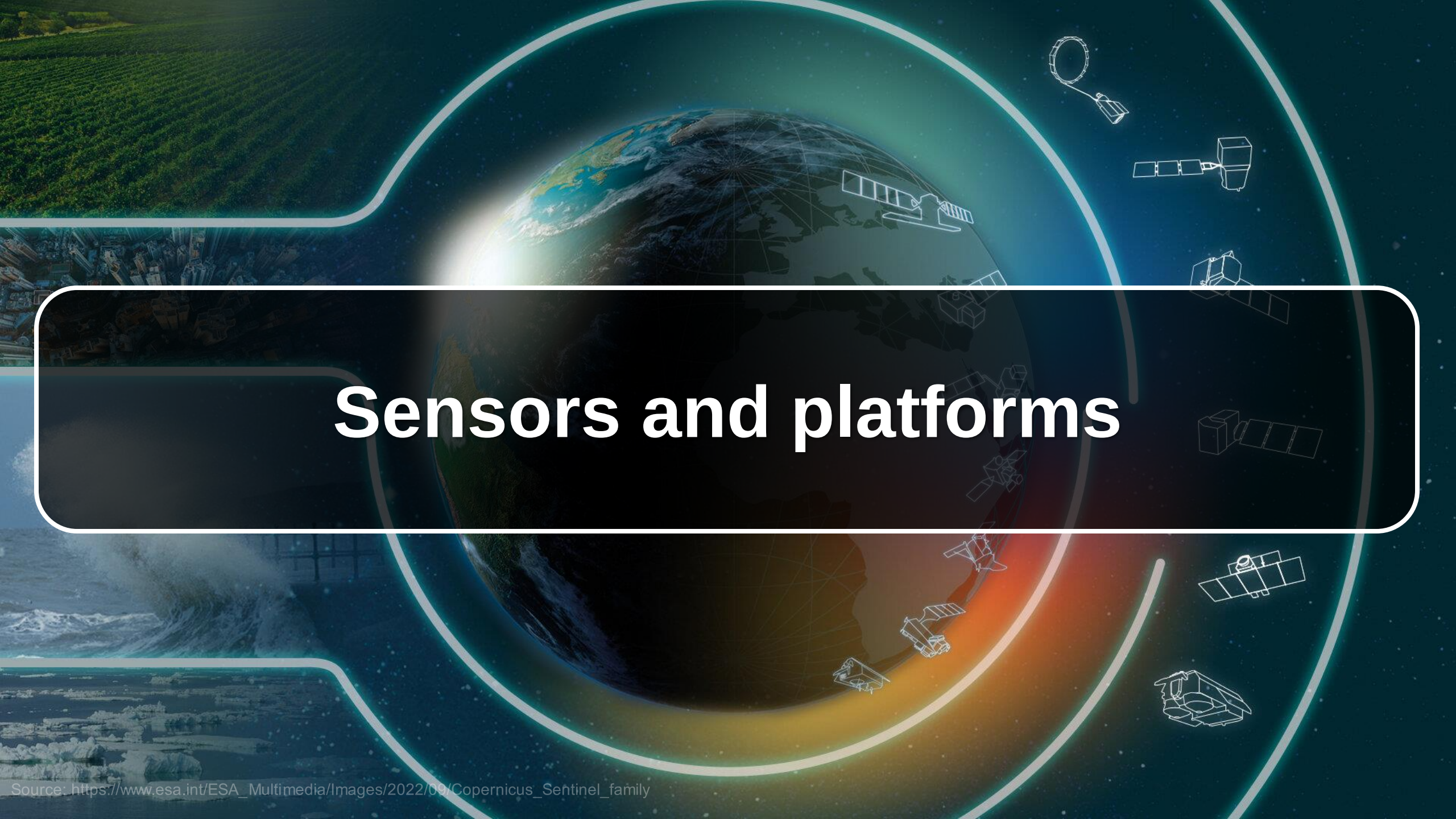
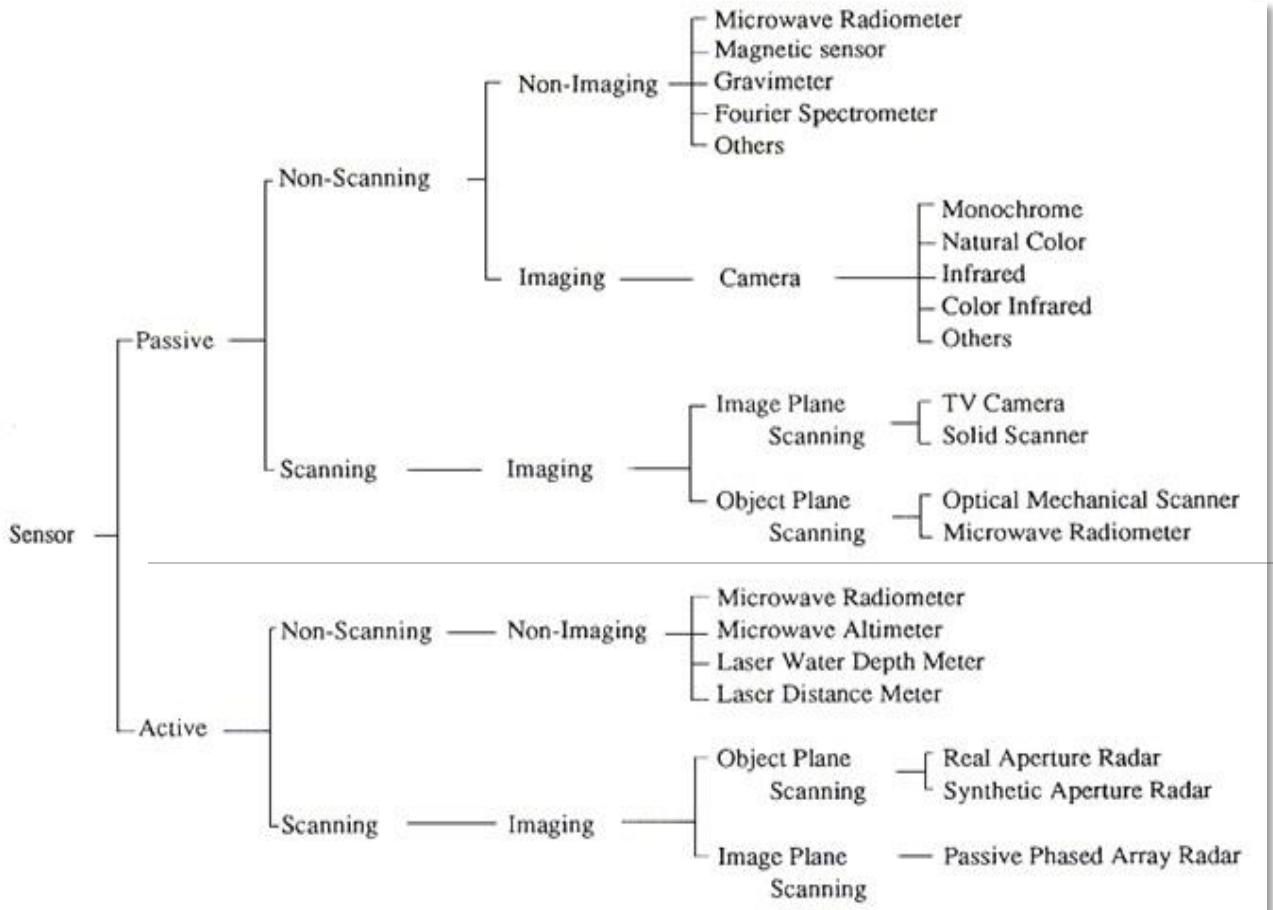
4. Optical remote sensing using ESA Copernicus´ data: sensors and platforms, image metadata, image resolution (spectral, spatial, temporal and radiometric resolution)



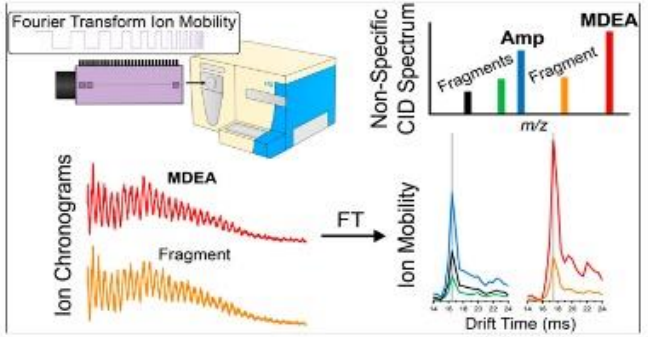
Source: https://www.esa.int/ESA_Multimedia/Images/2022/09/Copernicus_Sentinel_family

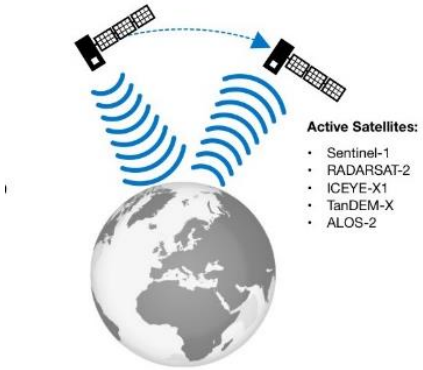
Types of sensors



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.





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.

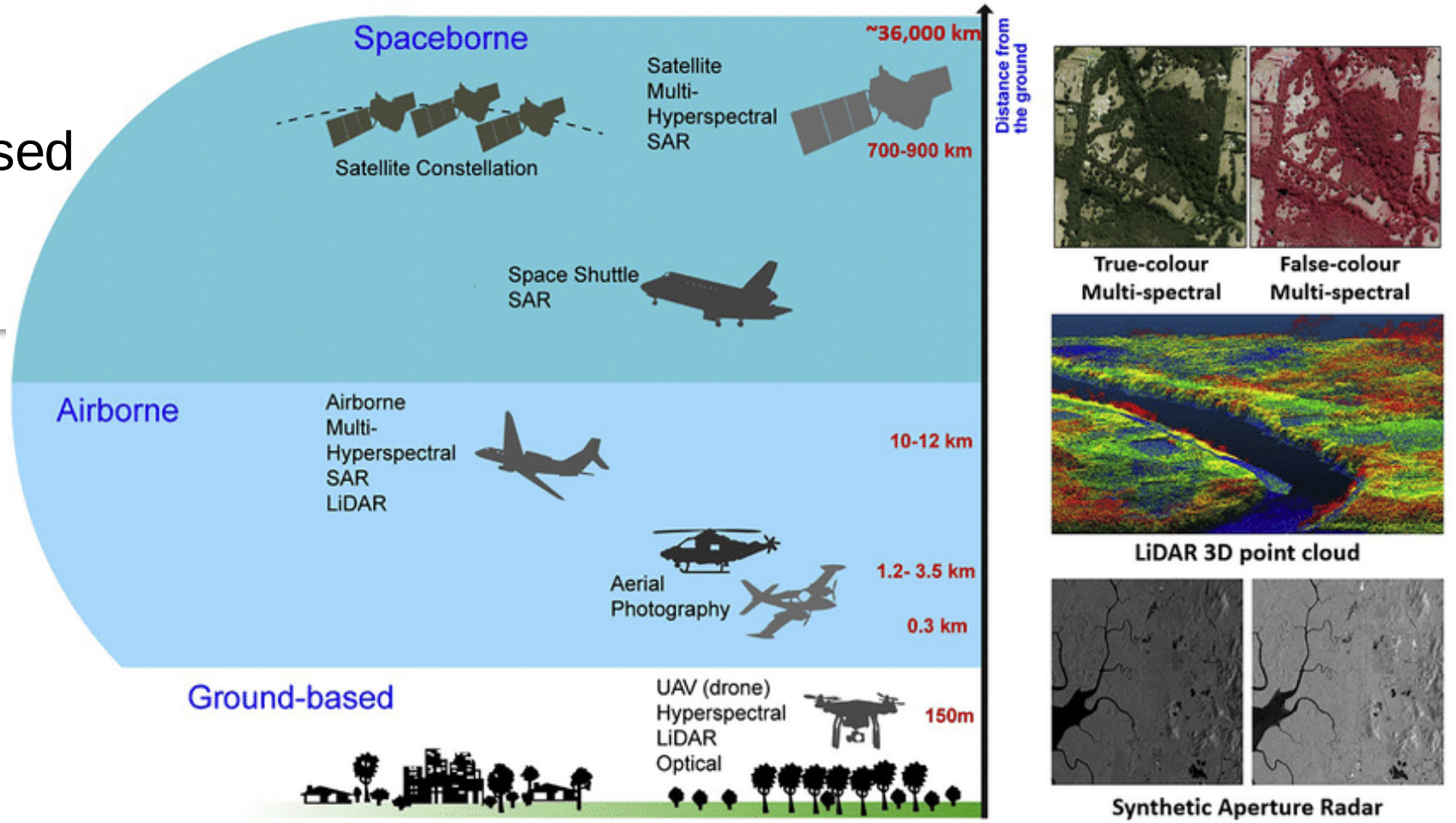
Source: https://www.esa.int/var/esa/storage/images/esa_multimedia/images/2022/09/copernicus_sentinel_family/24451531-1-engGB/Copernicus_Sentinel_family_pillars.jpg?fbclid=IwAR0Fj0JjjxucGiN6ICSRwqPmvLd1T1F5eGgv6pr7kNp53_T3XFHfv8Hojk4, https://www.geospatialworld.net/blogs/observing-the-earth-fueling-global-development-solutions/, 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



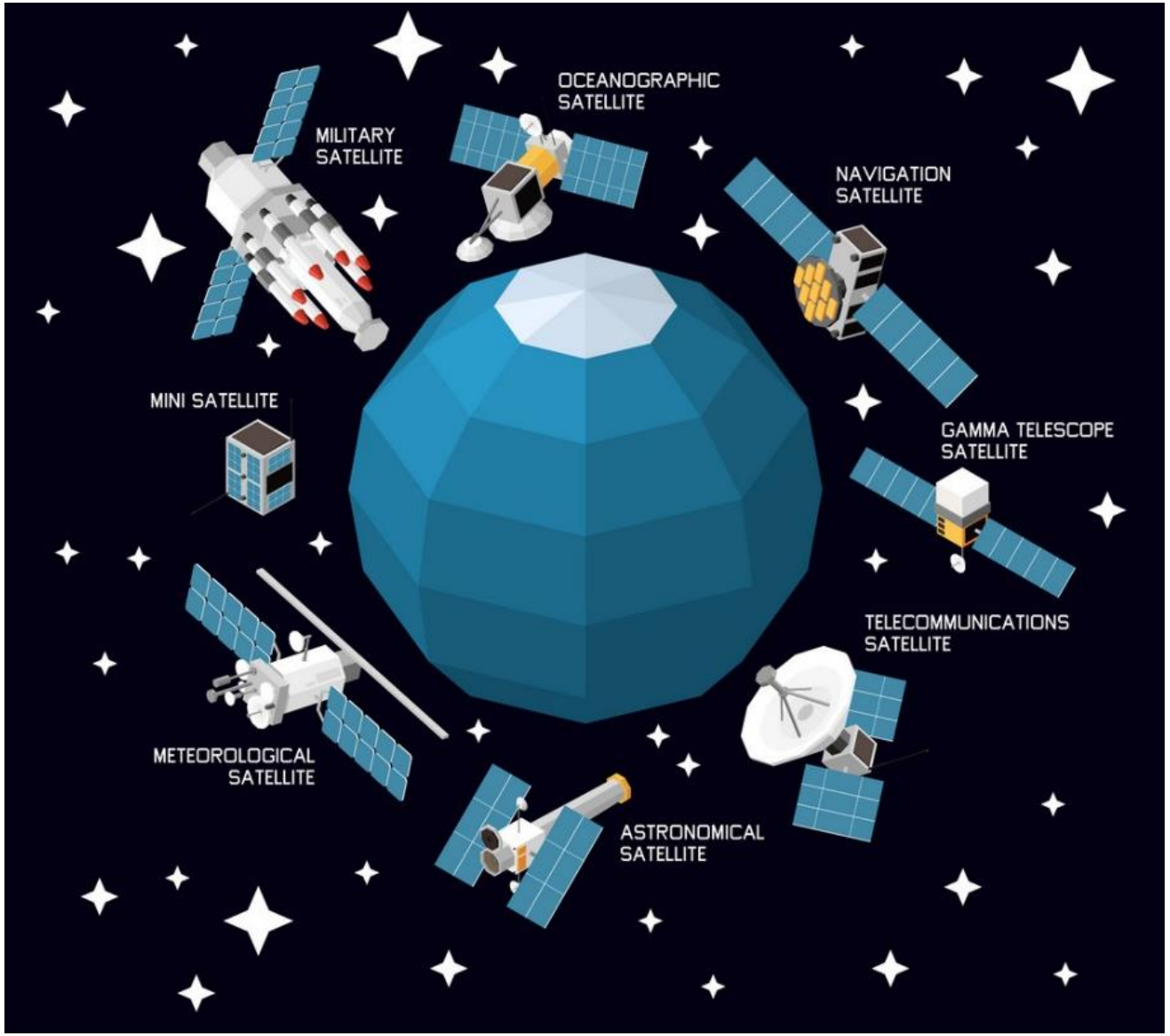
Source: https://l.facebook.com/l.php?u=https%3A%2F%2Fleclab.wixsite.com%2Fspatial%2Fpost%2Fapplications-in-remote-sensing-to-forest-ecology-and-management%3Ffbclid%3DIwAR2FmvF9puHnHJ2uK9nkkn2M17rsHxPN2oAvmXsTpJs9ALWnUSEoGwXVPw&h=AT03SEz8ODeTVHYAj5_j0w1yhRDd7_5GJQGRn5FLlgfUYVaXrZsOSK3E7IwfOd78qB94URBYG7IDfCtM0MRpRfEd7rBDDowQZTLJ4Gu8gk9ldpkxlYSKzHH1JZbM4LadoKg

Types of satellites

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

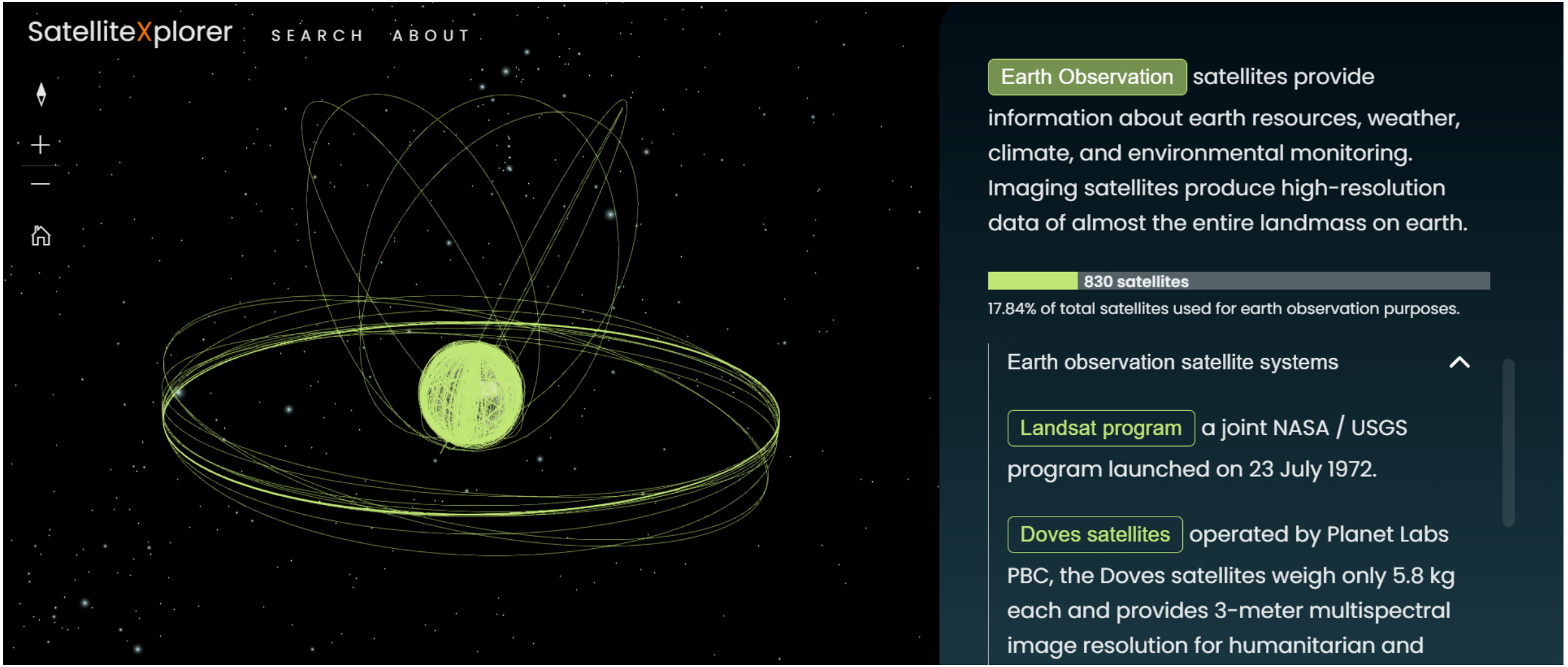
Hence such satellites are classified into six major types:

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



Source: https://www.vectorstock.com/royalty-free-vector/satellites-types-composition-vector-45762172

Types of satellites



Source: https://geoxc-apps.bd.esri.com/space/satellite-explorer/

Image metadata

Source: https://tees.tamu.edu/global/deep-tech-entrepreneurship-program.html

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

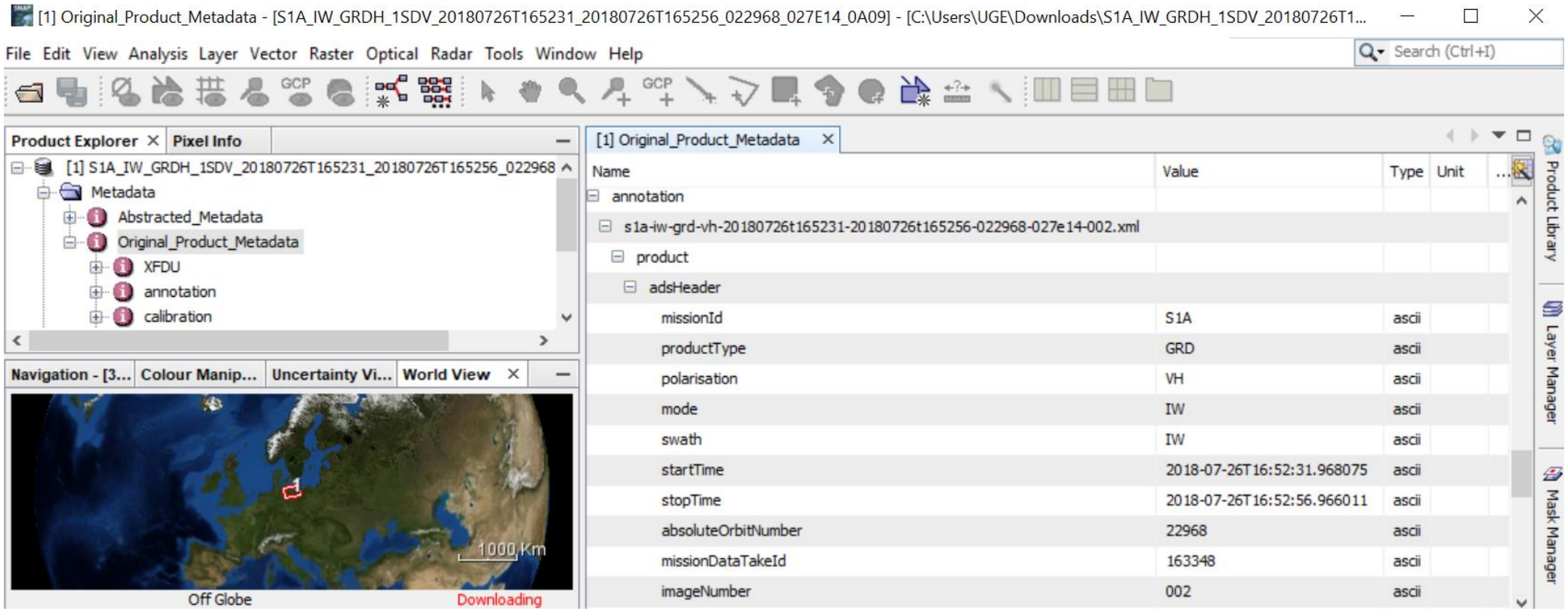
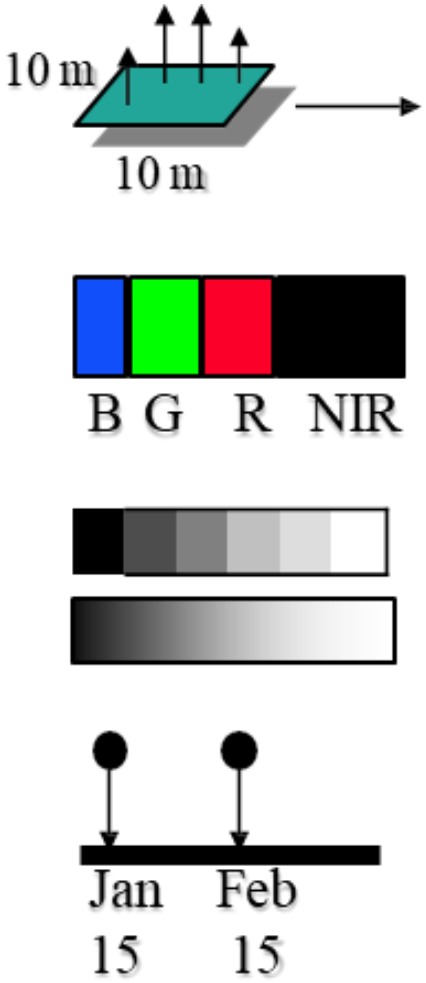


Image resolution

Source:
https://www.earthdata.nasa.gov/learn/backgrounders/remote-sensing

Image Resolution

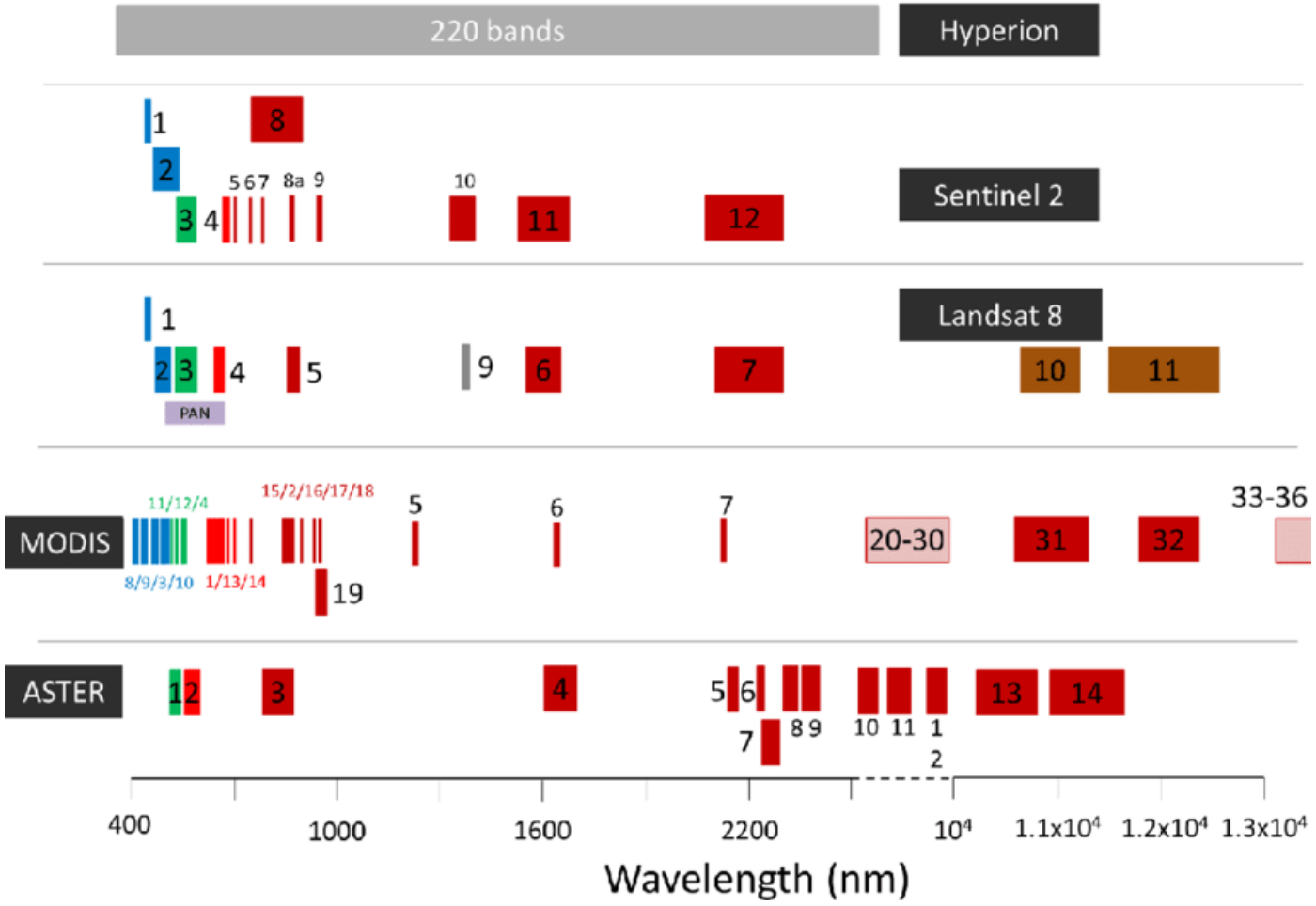


- **Spatial** - the size of the field-of-view per pixel, e.g. 10 x 10 m
- **Spectral** - the number and size of spectral regions the sensor records data in, e.g. blue, green, red, near-infrared, thermal infrared, microwave (radar).
- **Radiometric** - the sensitivity of detectors to small differences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

Jensen, 2007

Spectral resolution

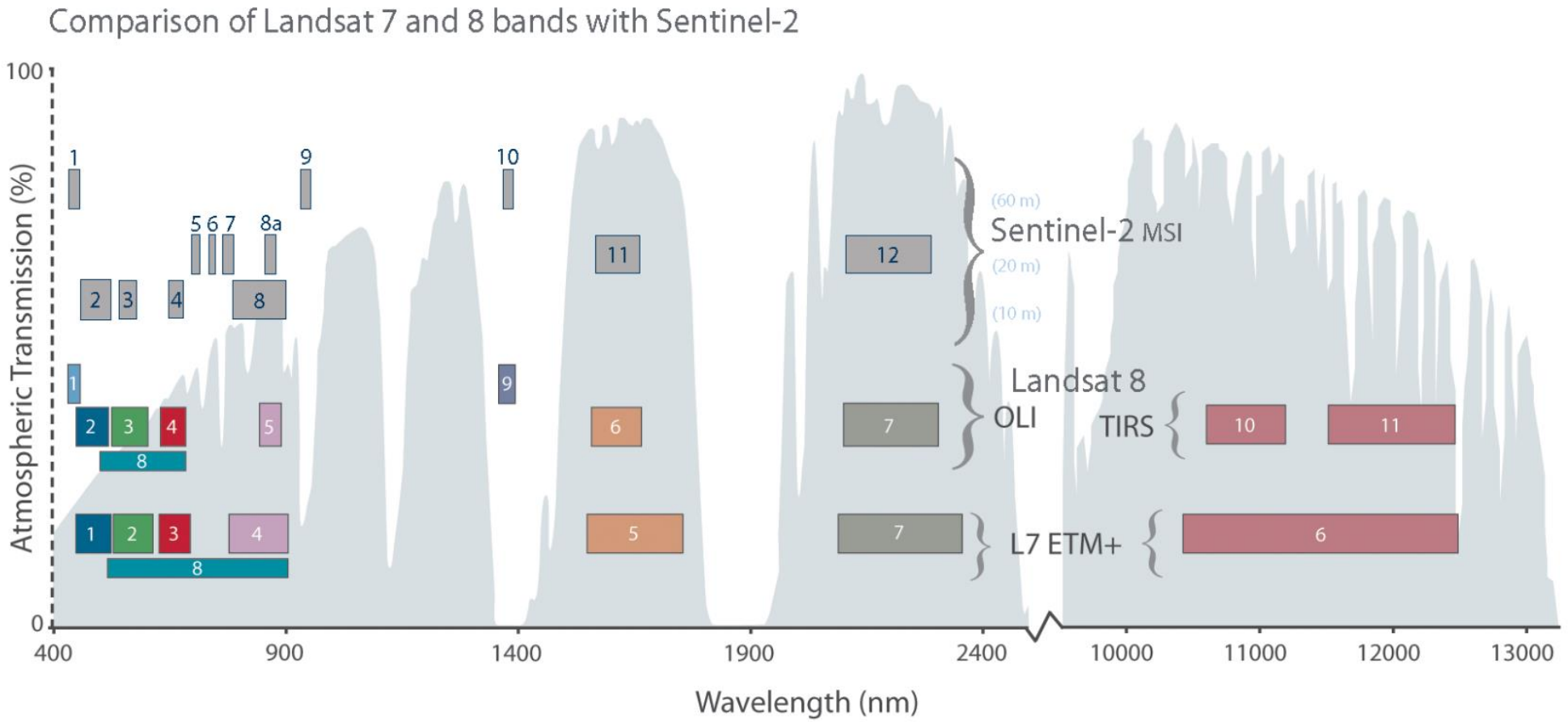
- The bandwidth (width), number, and position of specific wavelength bands that a sensor system can record



Source: https://www.researchgate.net/publication/324537528_Conservation_Technology_Series_Issue_4_SATELLITE_REMOTE_SENSING_FOR_CONSERVATION/figures?lo=1/

Spectral resolution

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



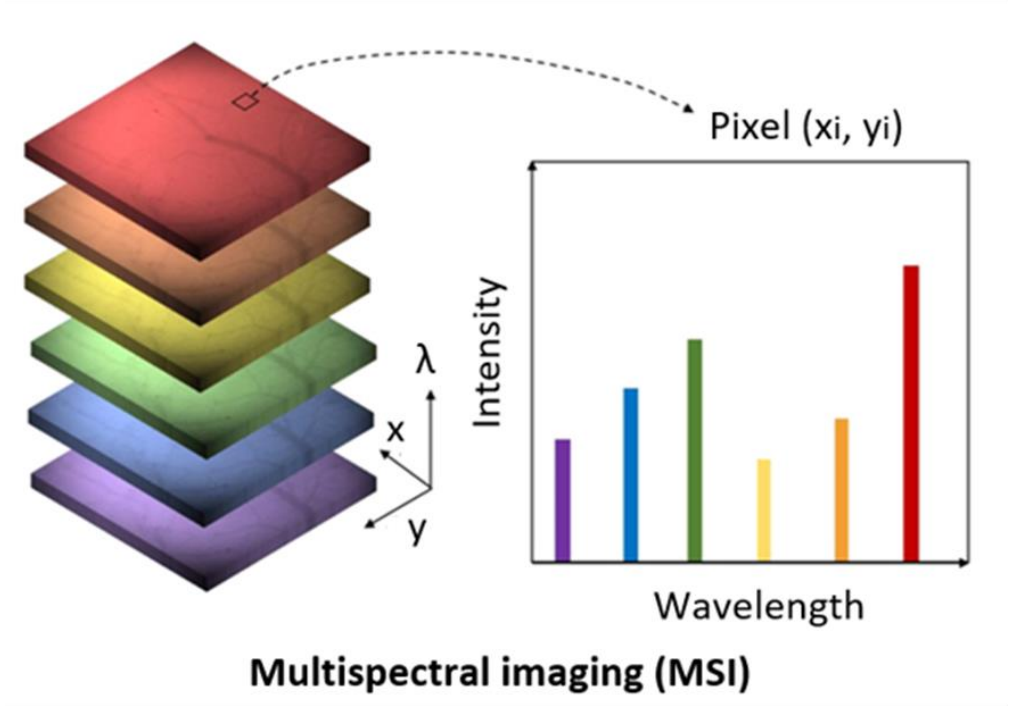
Source: https://digital-geography.com/landsat-8-how-not-to-plan-a-mission-part-2-the-sensors//

Spectral resolution

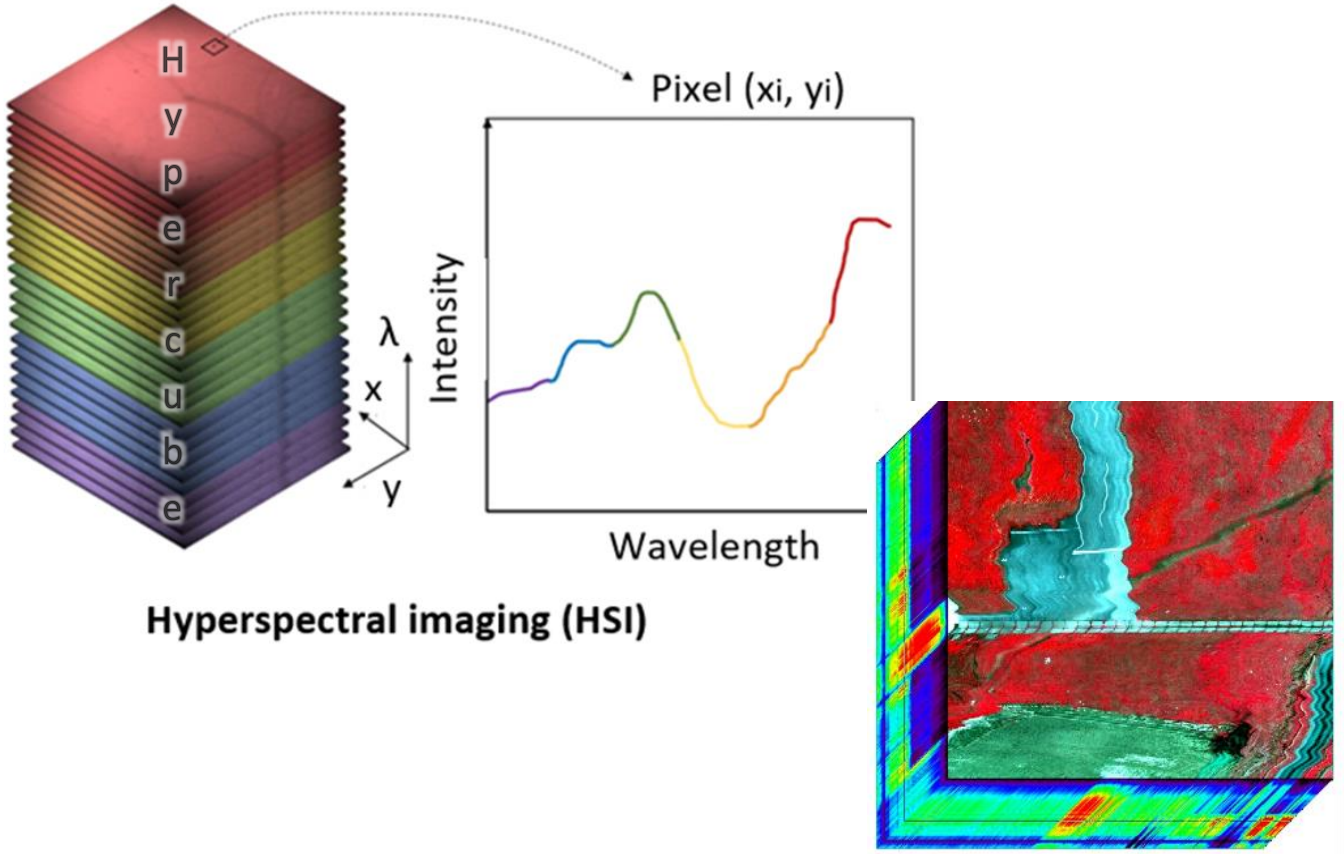
	Sentinel-2A MSI			Landsat 8 OLI		
Band	Spectral region	Wavelength range (nm)	Resolution (m)	Spectral region region	Wavelength range (nm)	Resolution (m)
B1				Blue	435–451	30
B2	Blue	458–523	10	Blue	452–512	30
B3	Green peak	543–578	10	Green	533–590	30
B4	Red	650–680	10	Red	636–673	30
B5	Red edge	698–713	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			

Source: https://bg.copernicus.org/articles/15/5455/2018/

Spectral resolution



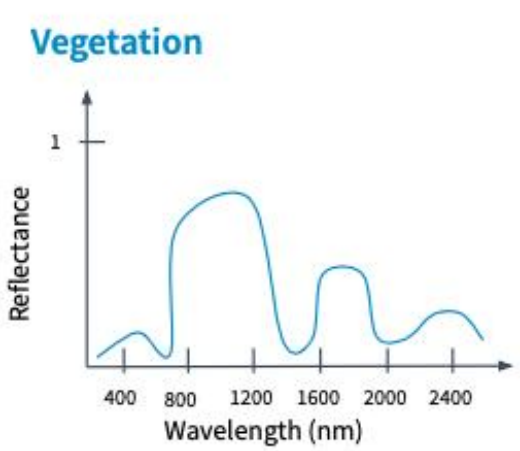
Multispectral imaging (MSI)

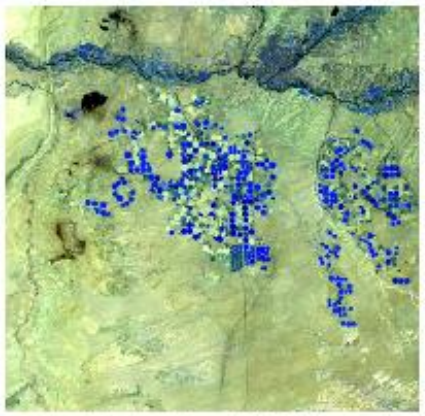


Hyperspectral imaging (HSI)

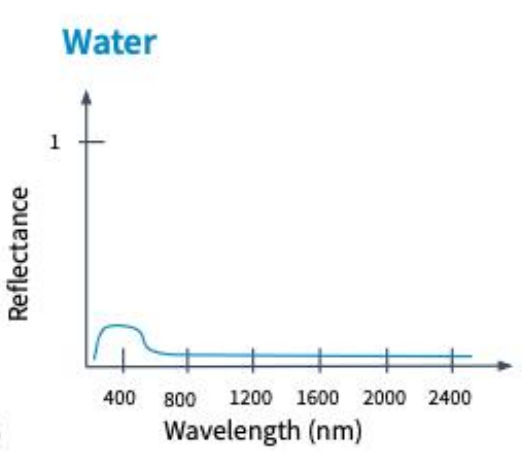
Source: https://www.pyroistech.com/hyperspectral-and-multispectral-imaging/, Institute of geography

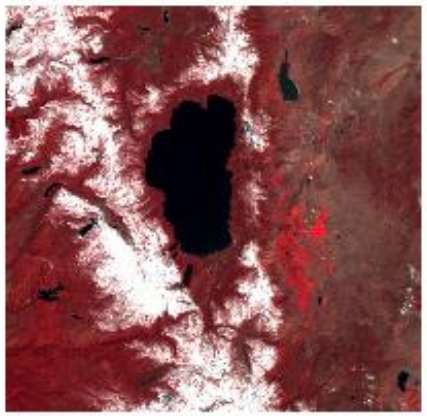
Spectral resolution vs. spectral curve



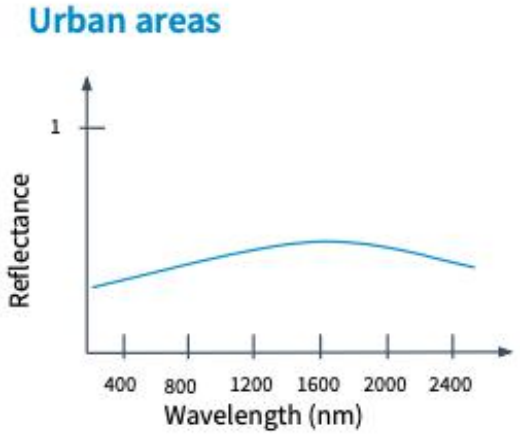


Center pivot irrigation, NASA Landsat, 2020
swir2 - swir1 - nir



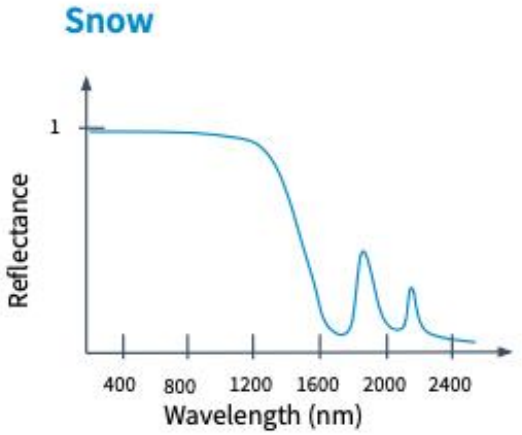


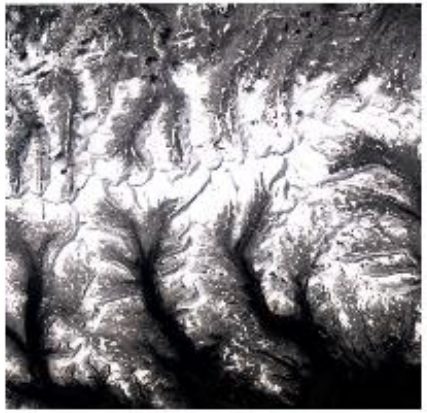
Lake Tahoe, NASA Landsat, 2020
nir - red - green



*Note: spectral signatures have been generalized

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





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

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

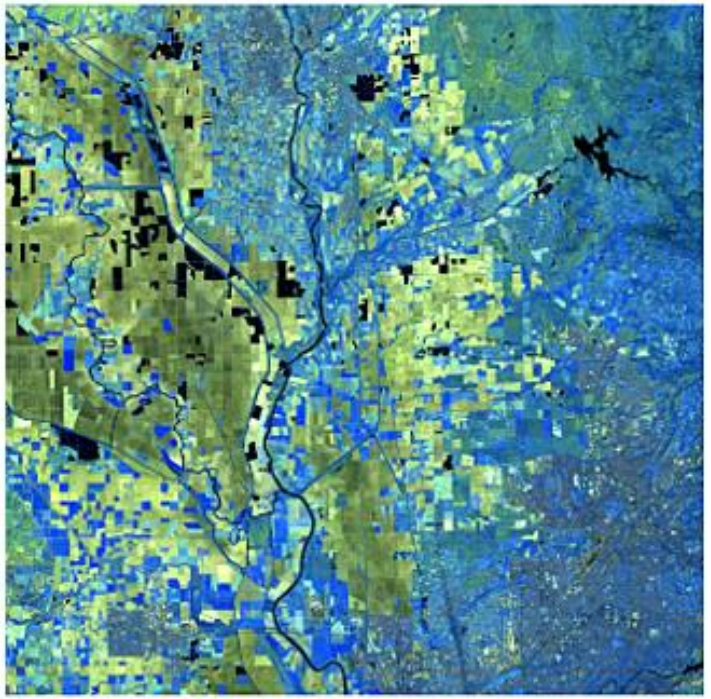
Source:
https://kb.descarteslabs.com/knowledge/introduction-to-remote-sensing

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



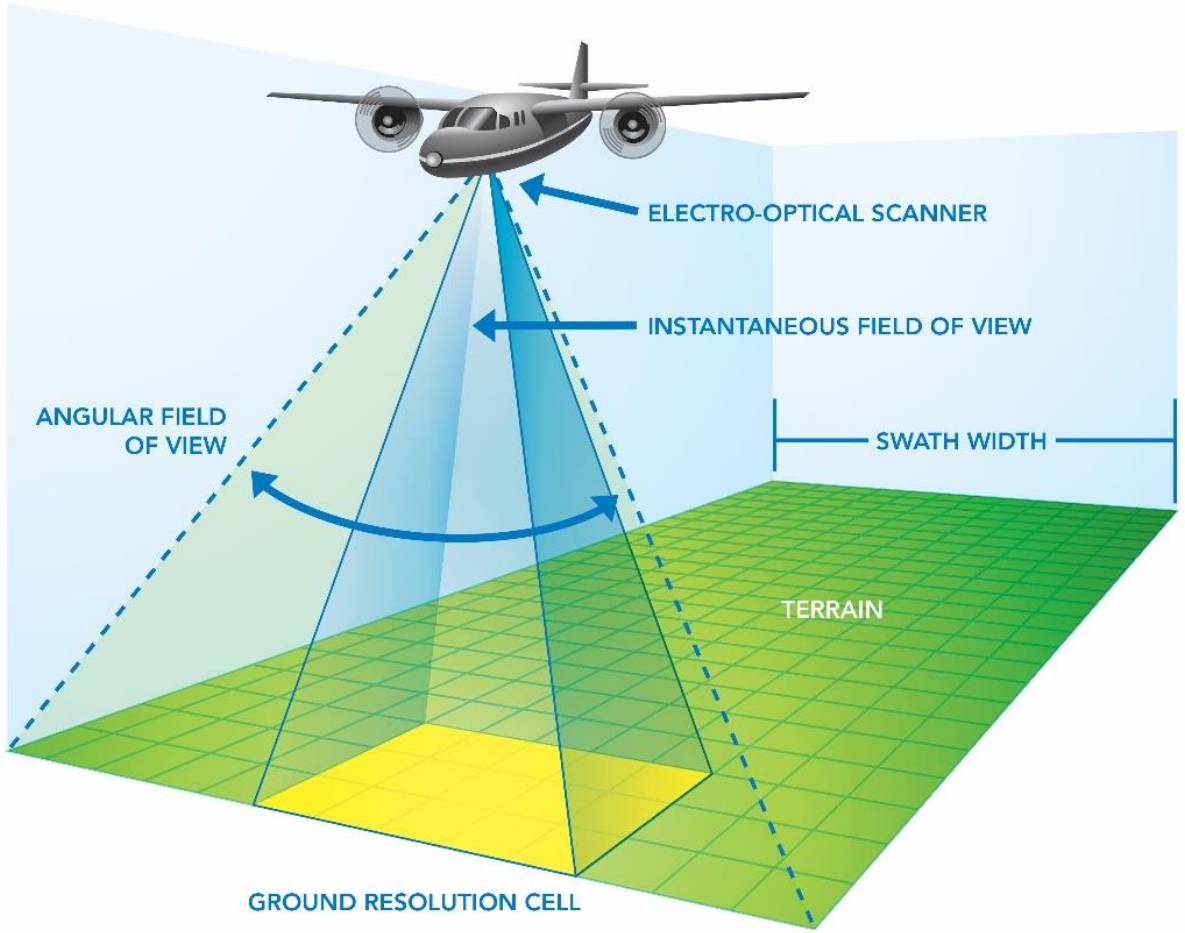
ESA Sentinel 2: swir2-swir1-nir bands

- *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.*

Source: https://blog.descarteslabs.com/a-look-into-the-fundamentals-of-remote-sensing

Spatial resolution

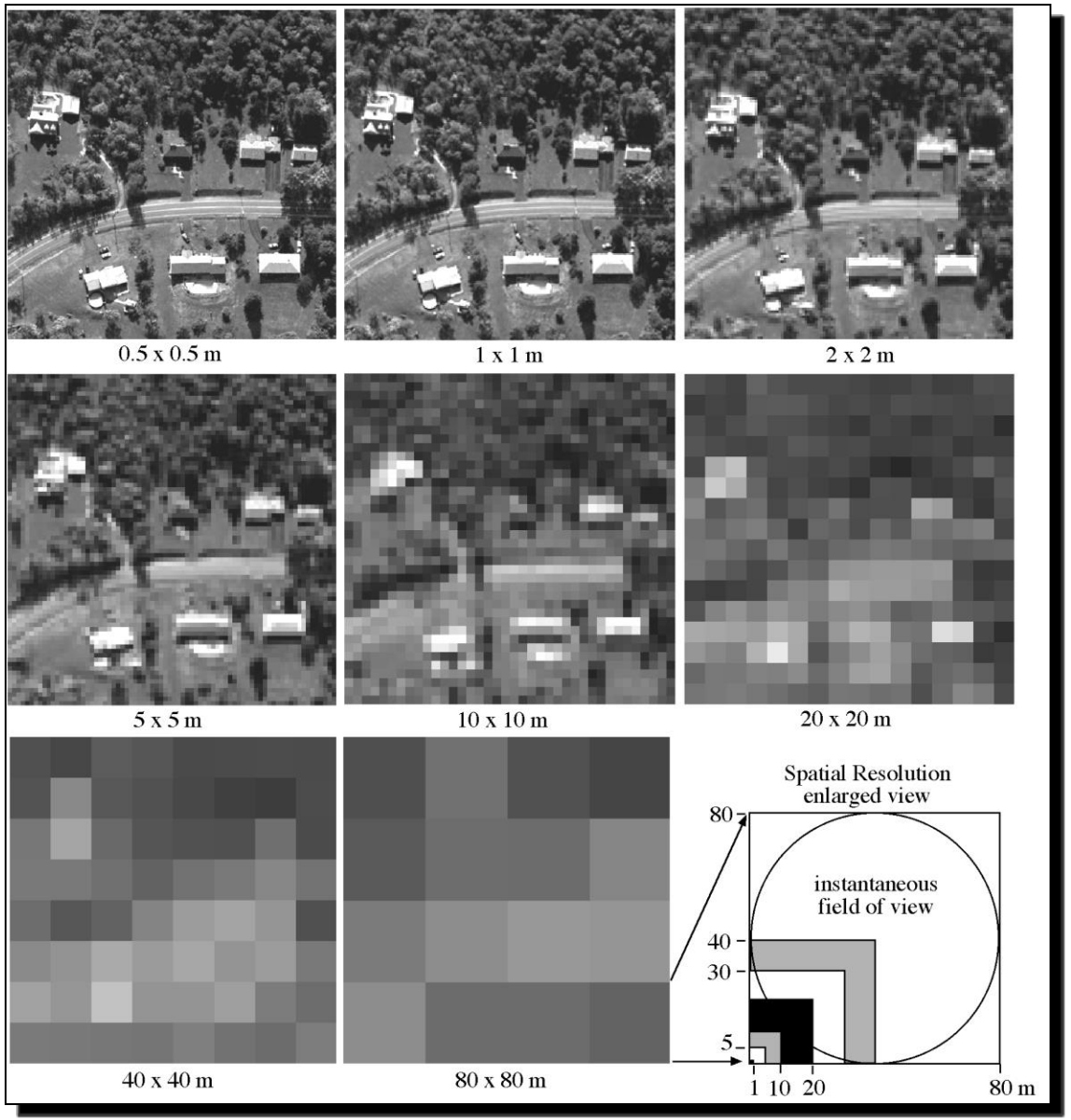
- The size of the smallest object that can be detected by a satellite – pixel size
- Pixel: smallest unit of an image
- Instantaneous field-of-view (IFOV)
- Distance on the ground that corresponds to one side of one pixel in image



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

Source: https://skywatch.com/what-resolution-do-i-need-when-using-satellite-earth-observation-data/

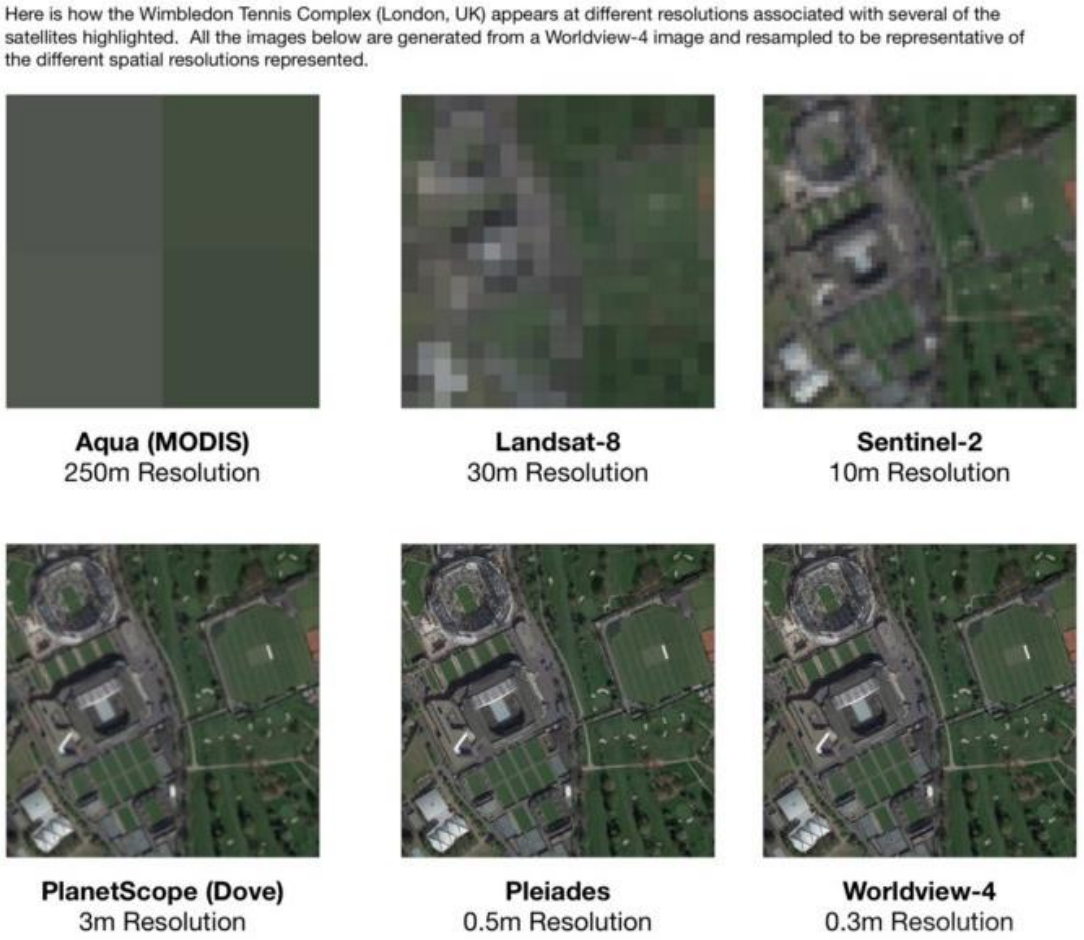
Spatial resolution

Source: https://www.earthdata.nasa.gov/learn/backgrounders/remote-sensing/

Spatial resolution

Main scales

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



Spatial Resolution: Sensor Comparison

Source: https://www.agridico.com/l/radiantearthinsight/

Spatial resolution

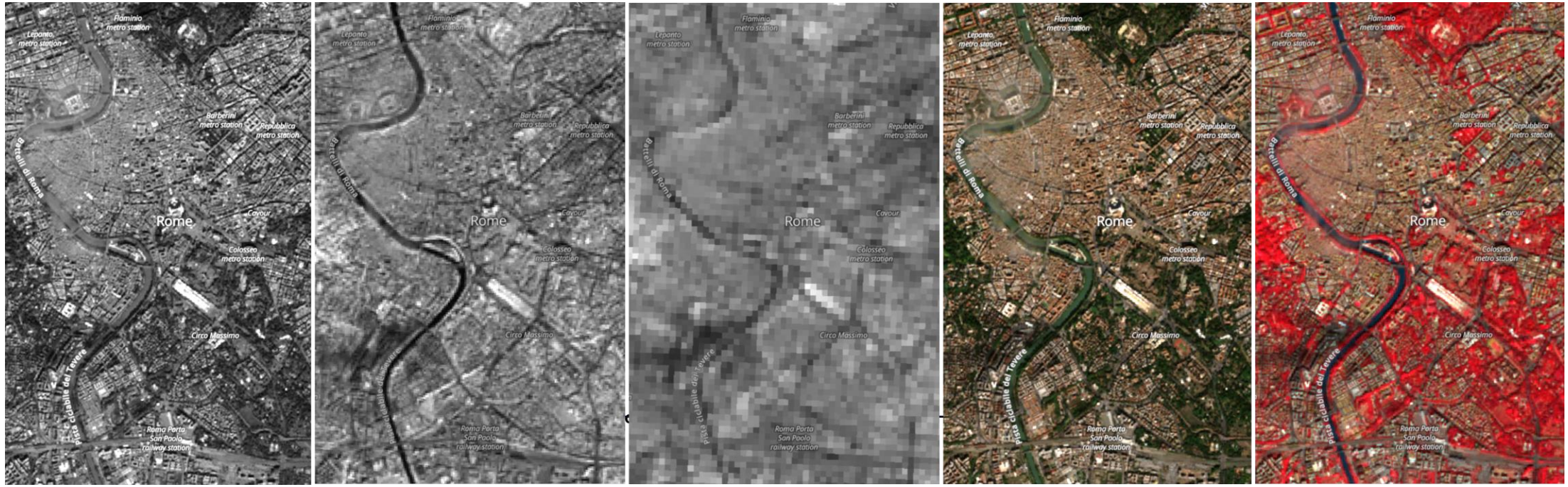


Image from the Sentinel 2A satellite, display in bands B-3 (10m), B-8a (20m), B-9 (60m) and in the true color composition B-4-3-2 (10m) and false color composition B-8A-4-3

Source: Institute of geography, PF UPJŠ, Košice

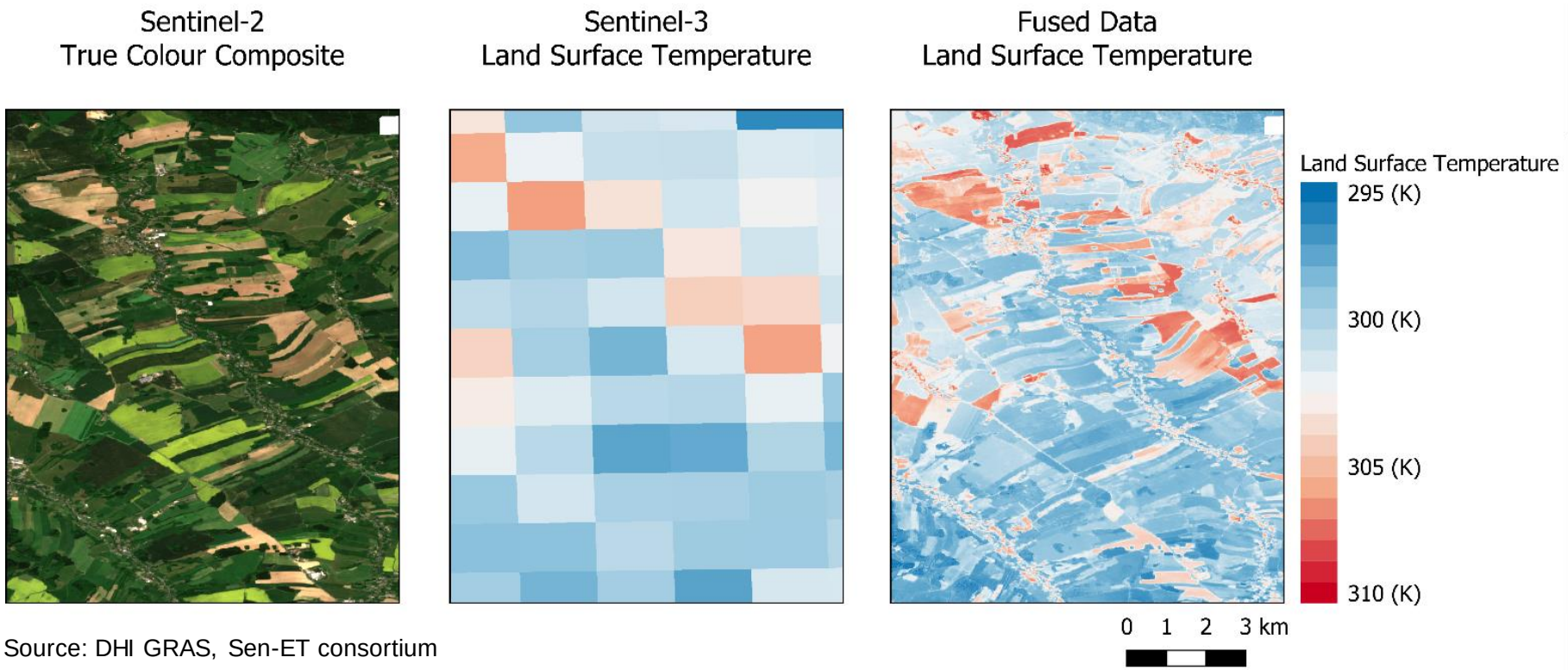
Spatial resolution

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

Sentinel-2 MSI		Landsat-8 OLI		SPOT-5 HRG		
Band [m]	Range [nm]	Band [m]	Range [nm]	Band [m]	Range [nm]	Name
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)	$10,895 \pm 295$			Thermal 1
		B11 * (100)	$12,005 \pm 505$			Thermal 2

Source: https://www.semanticscholar.org/paper/Sentinel-2's-Potential-for-Sub-Pixel-Landscape-Radoux-Chom%C3%A9/a9d3e039e7645eb3c1e1586077fae34e7bbea396/figure/1

Spatial resolution



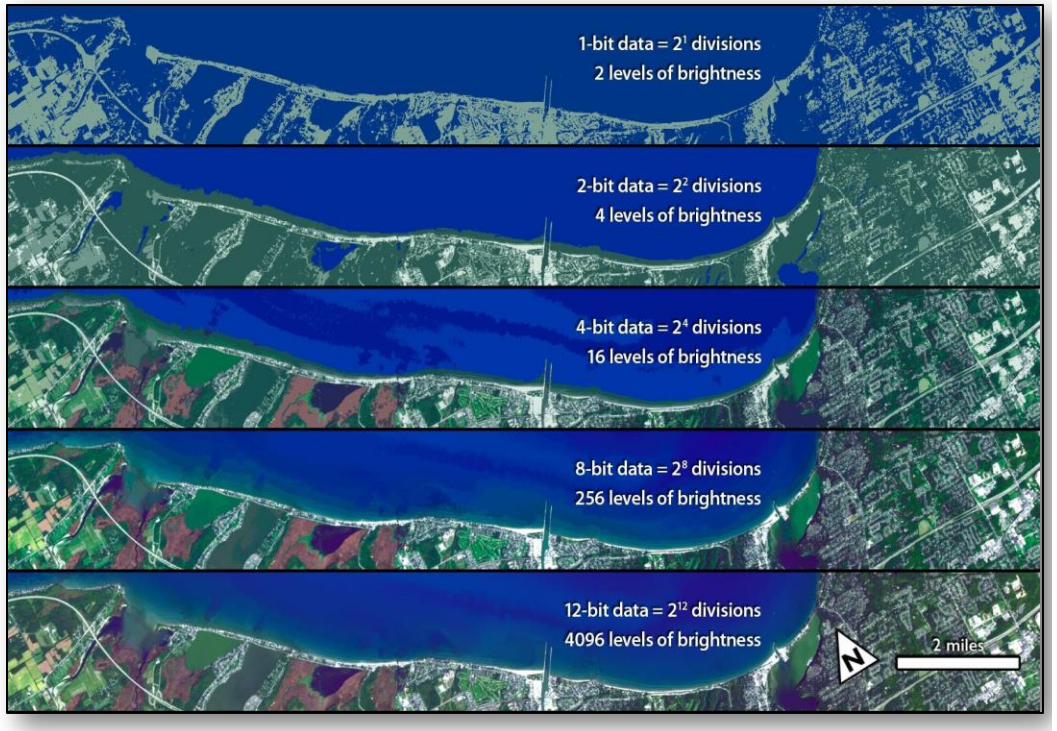
Source: DHI GRAS, Sen-ET consortium

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

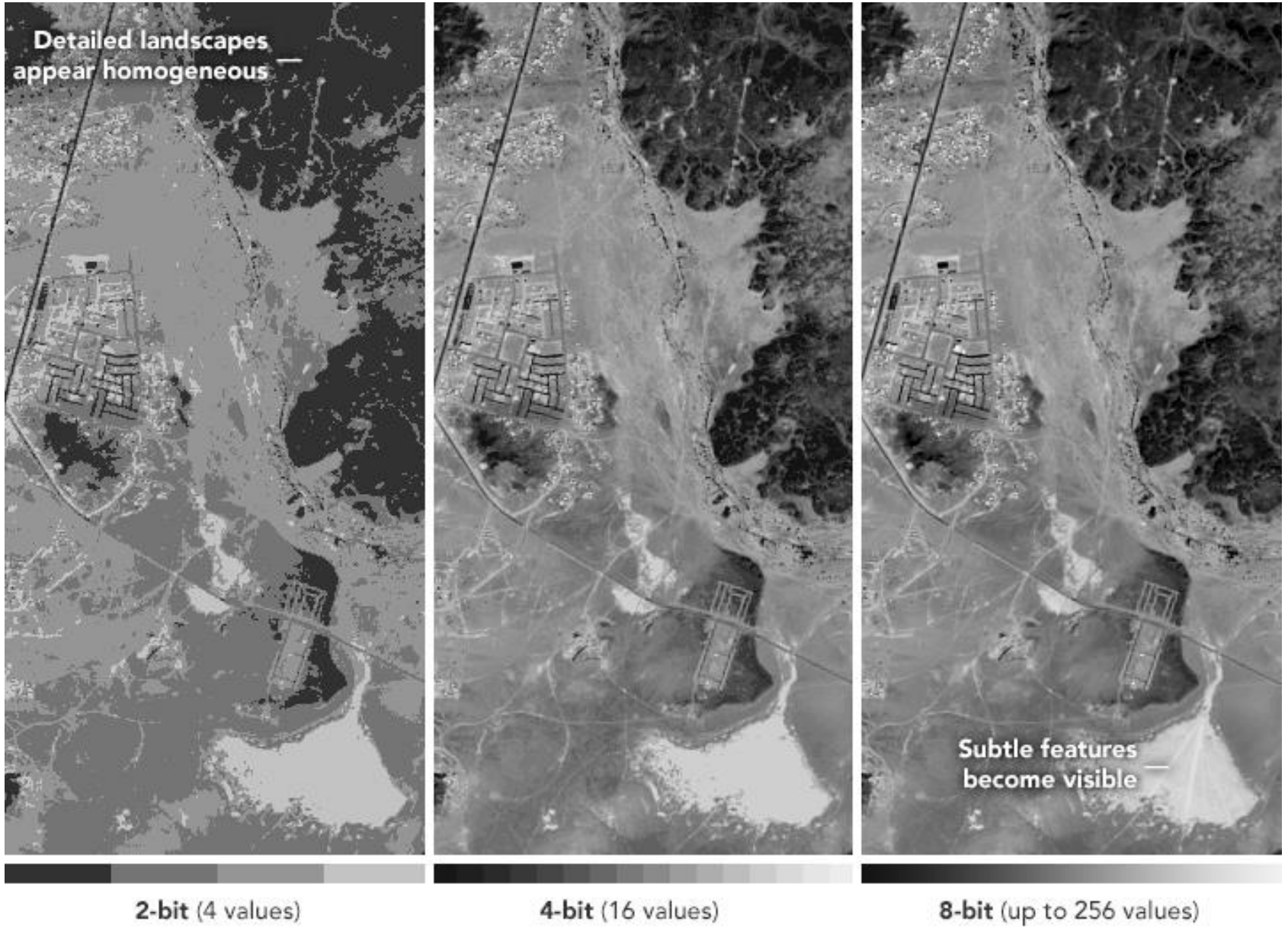
- The sensitivity of detectors to small differences in electromagnetic energy
- Measured in bits (a number to the exponential power of 2)
- The higher the number, the finer the radiometric resolution

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



Source: http://jukebox.esc13.net/untdeveloper/RM/Stats_Module_4/mobile_pages/Stats_Module_410.html, https://www.bu.edu/earth/faqs-rsgs/

Radiometric resolution



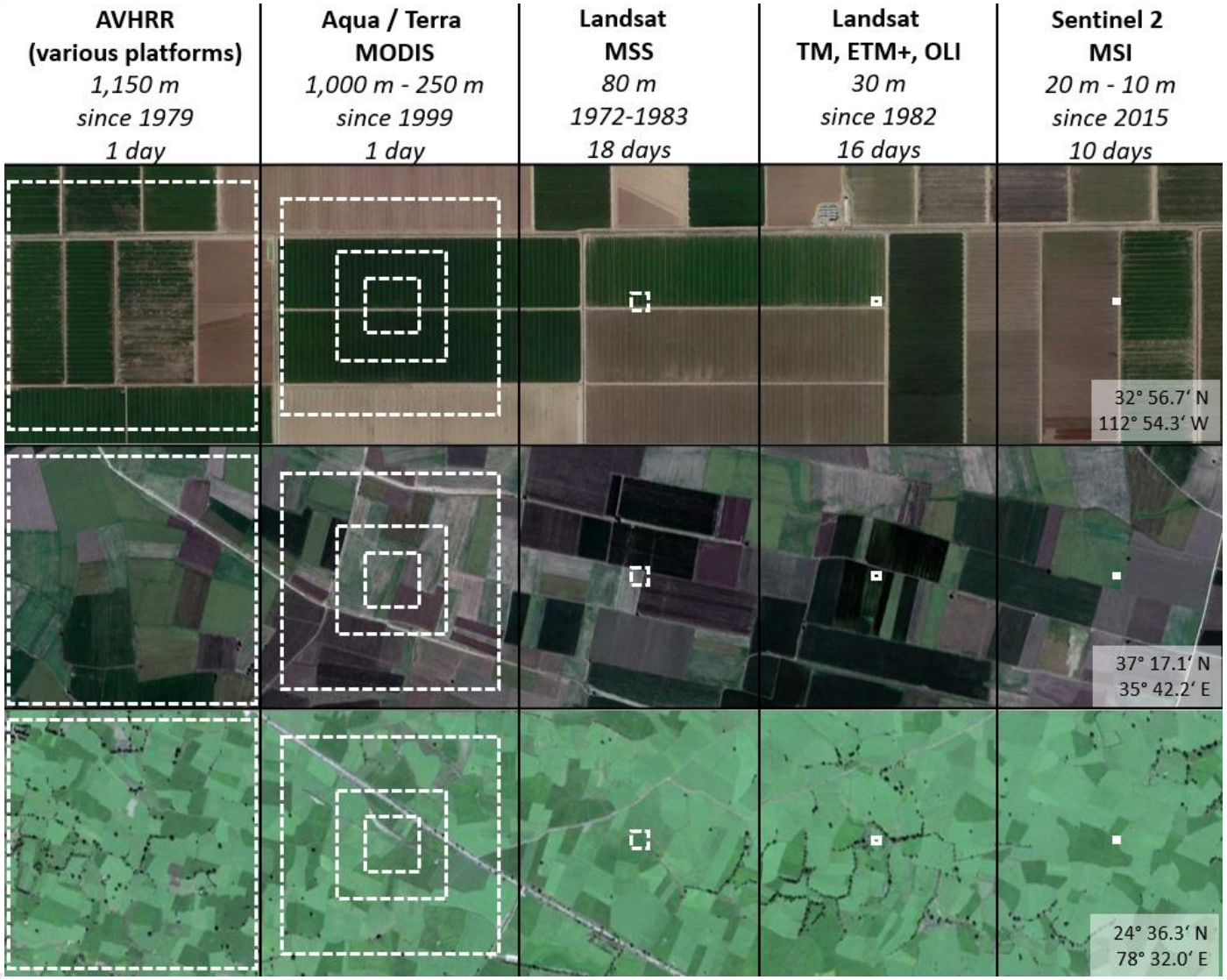
Source:
https://landsat.visibleearth.nasa.gov/view.php?id=91071

Temporal resolution

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

Depends on:

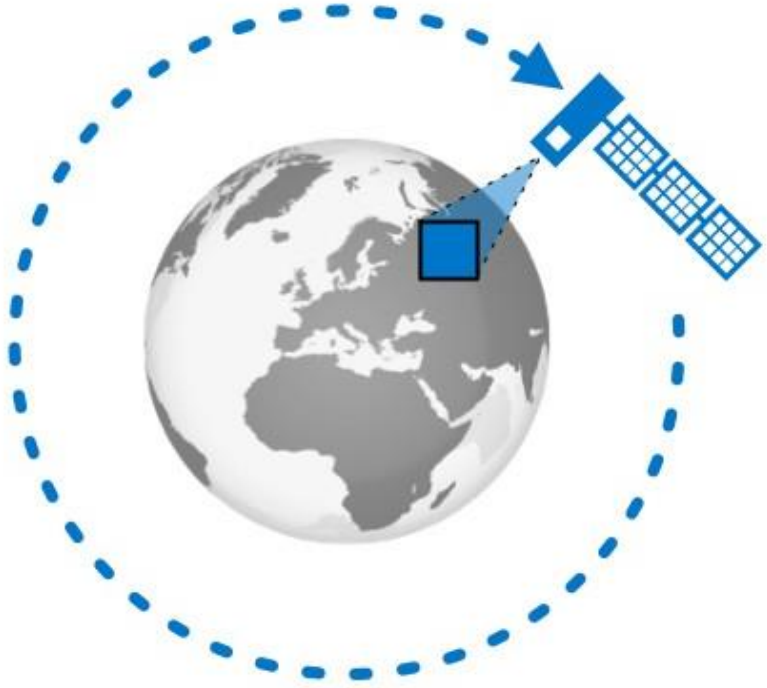
- Orbital characteristics
- Image swath width / footprint
- Off-nadir viewing capabilities (i.e., pointable optics)
- Number of satellites in the family

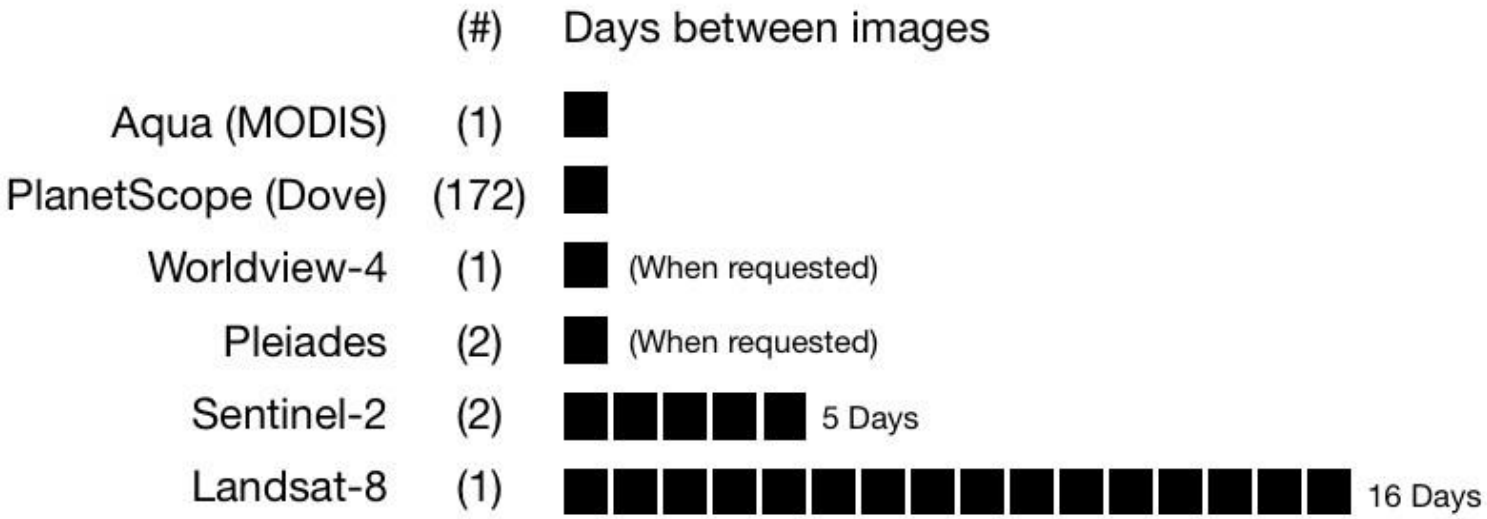


Source: https://pages.cms.hu-berlin.de/EOL/geo_rs/S11_Time_series.html

Temporal resolution

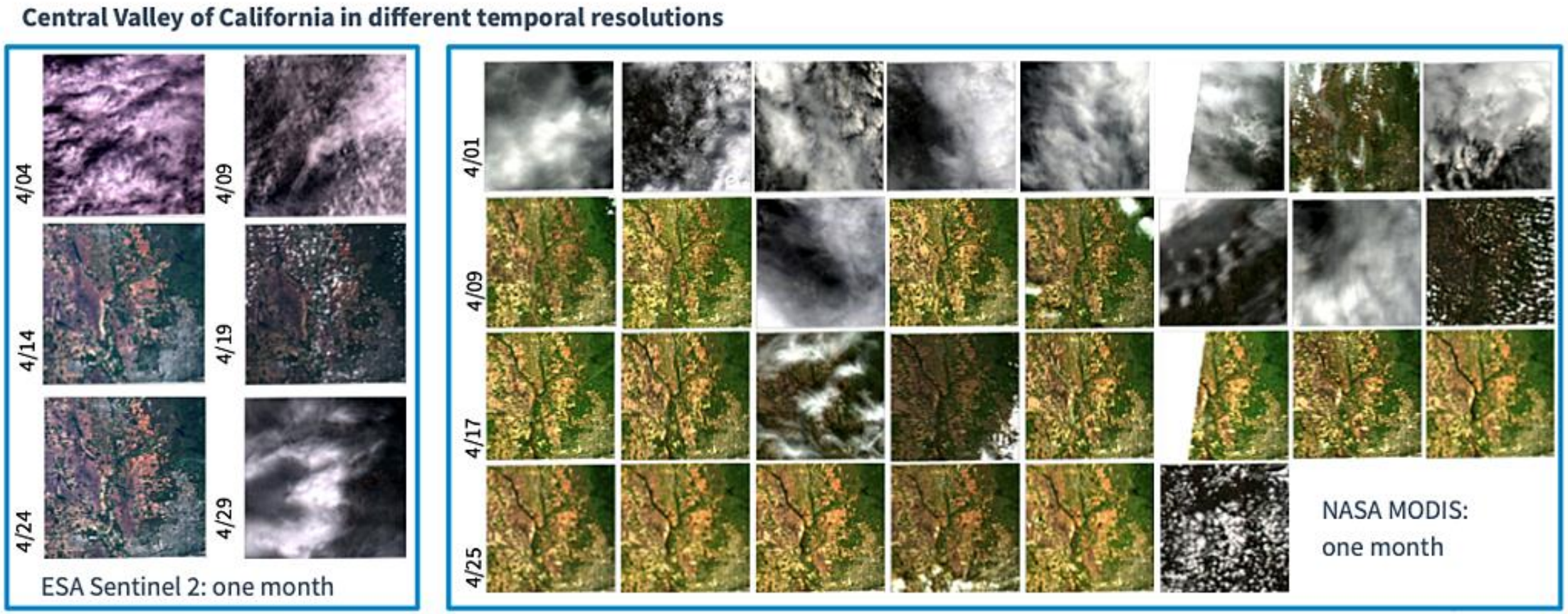
Temporal resolution varies by satellite and describes the time it takes for an individual satellite to orbit and revisit a specific area. Some satellites operate as a constellation with multiple satellites working together to increase their global coverage daily.





Source: https://twitter.com/MyanmarWitness/status/1492082733794959386/photo/1

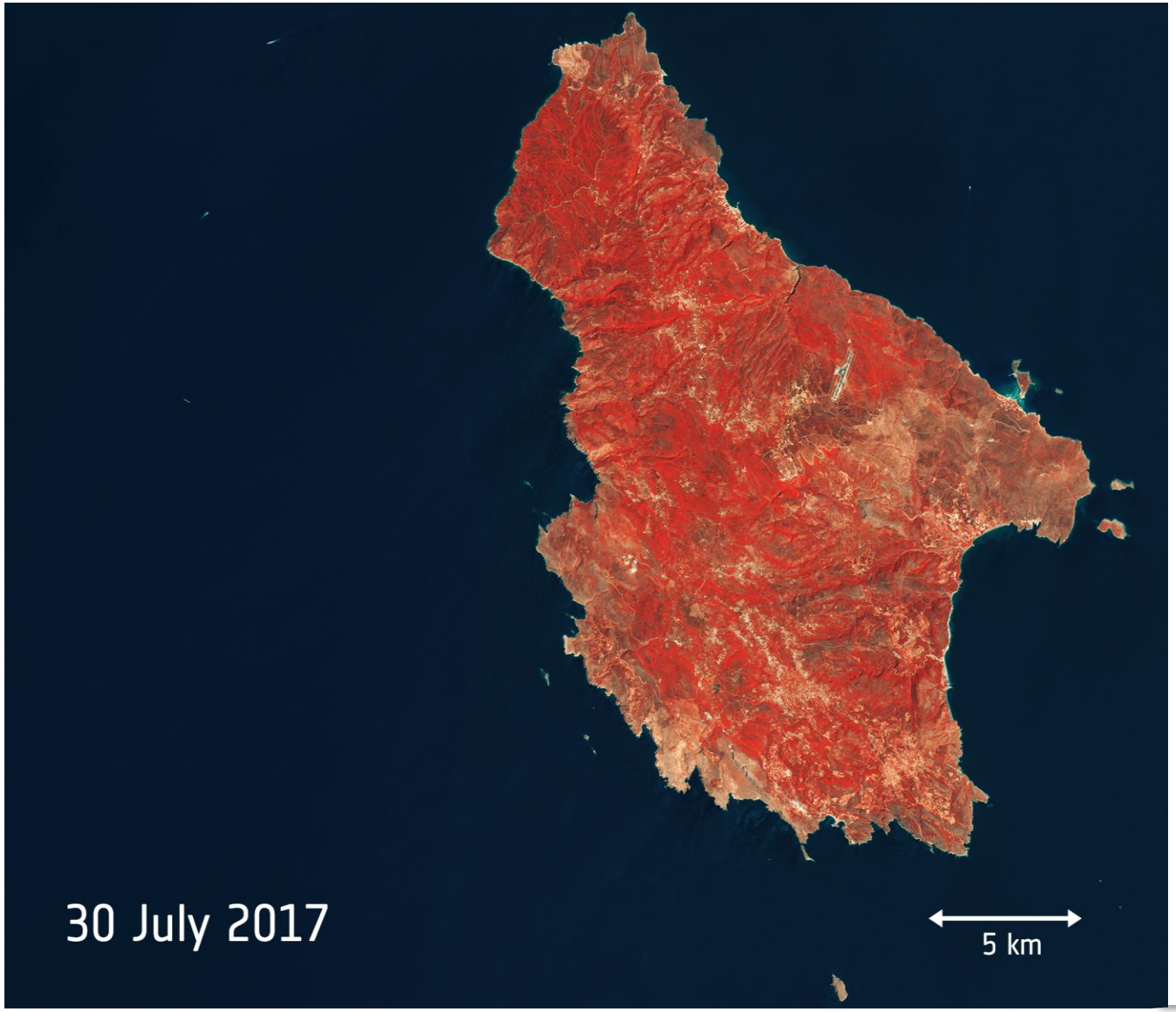
Temporal resolution



- *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.*

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

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.*

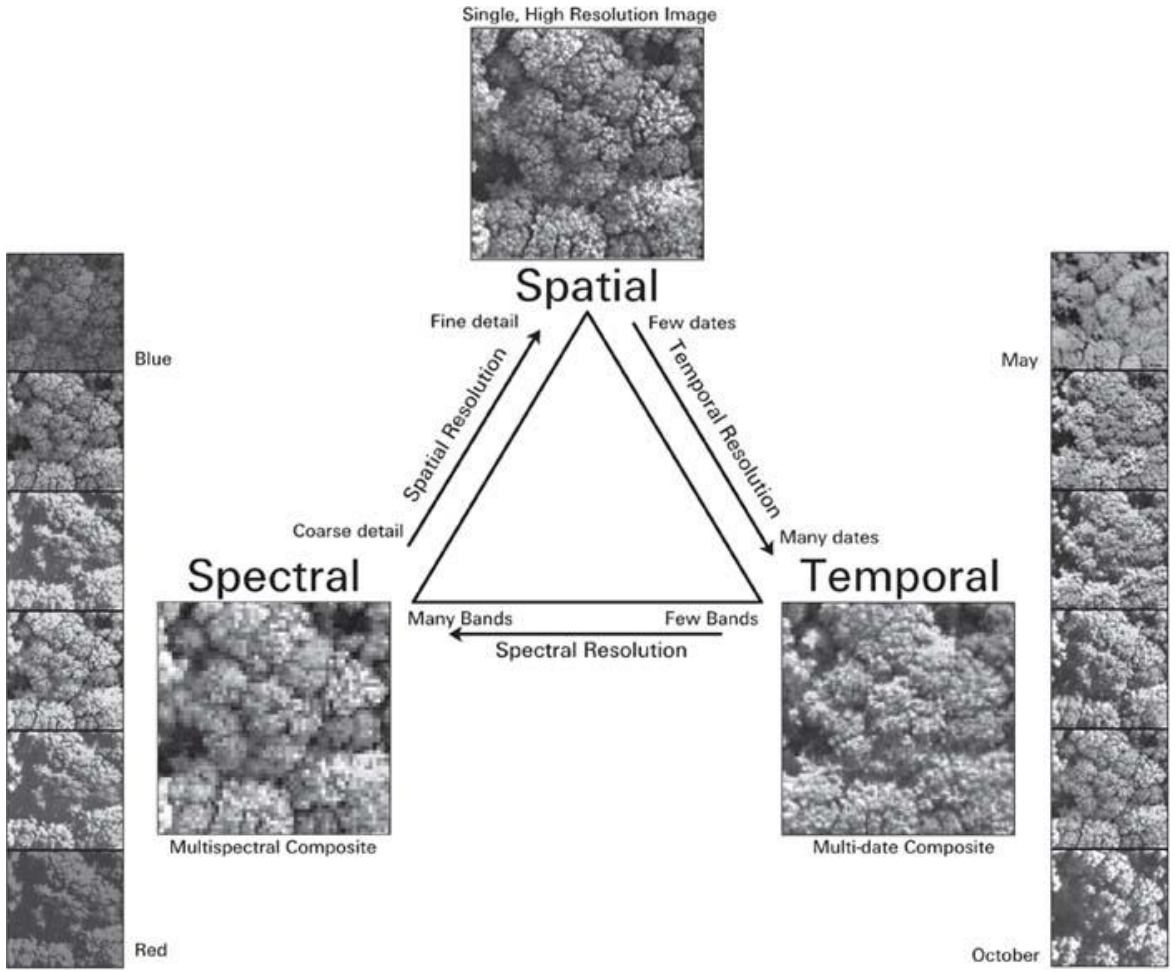
Source: ESA

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

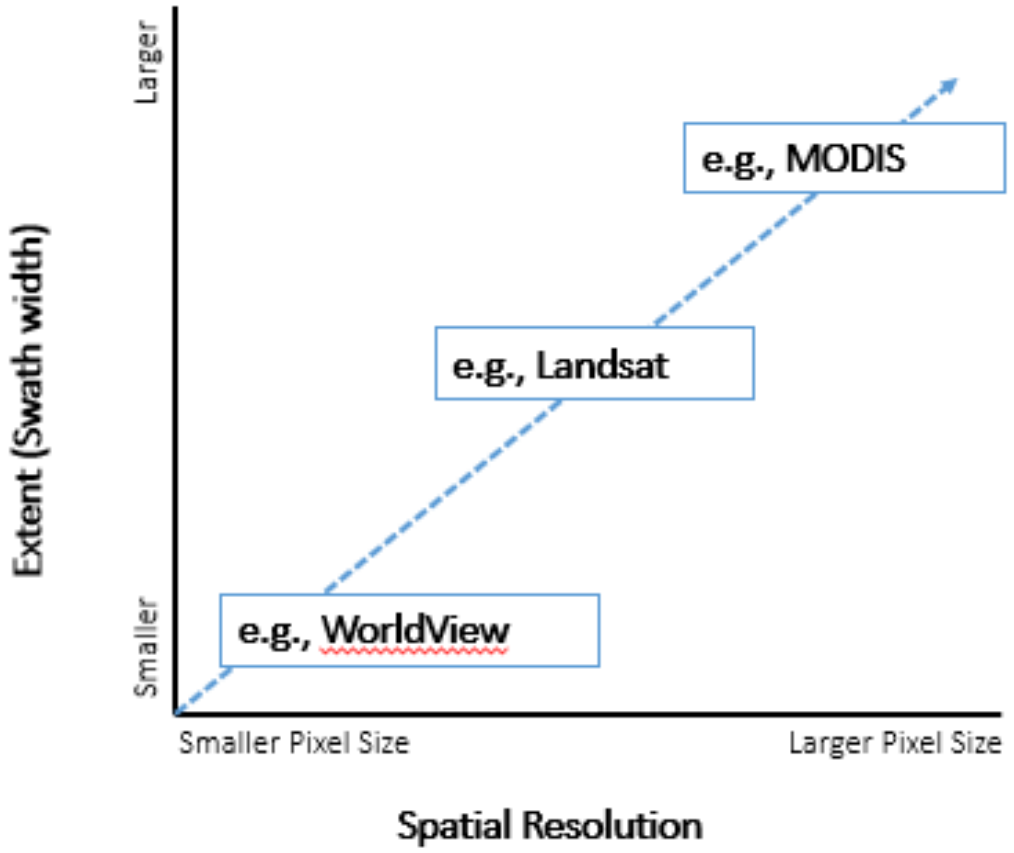
Though a finer temporal resolution is more desirable, there is often a tradeoff between a fine temporal resolution and a fine spatial resolution.



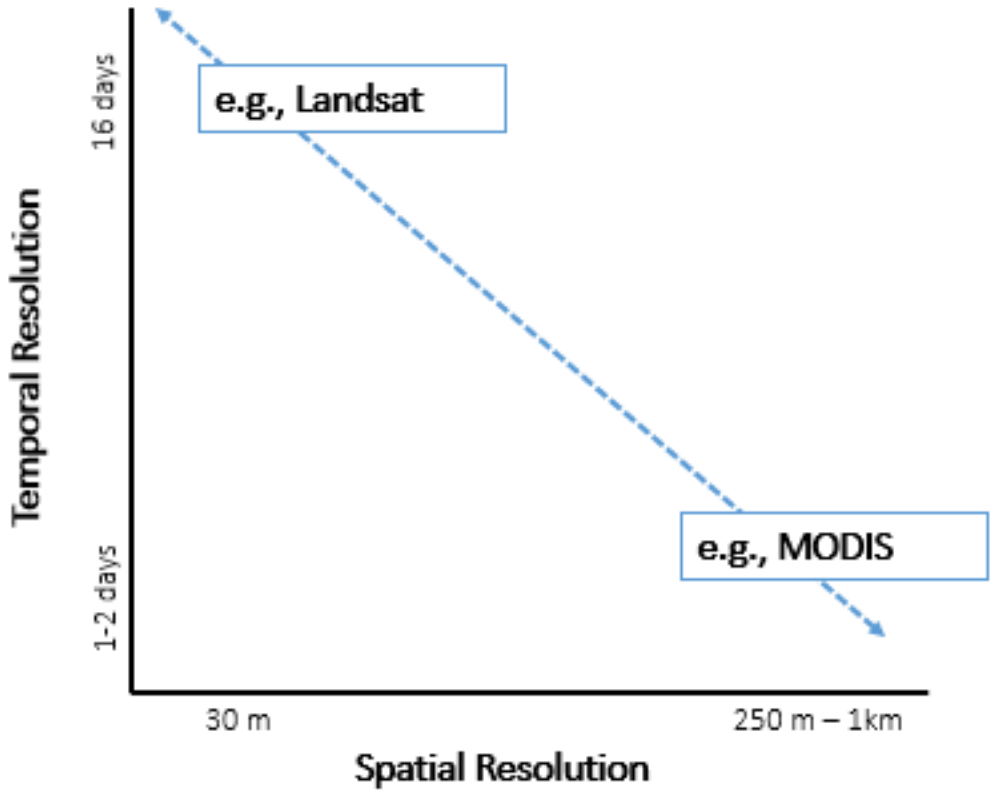
Source: https://kb.descarteslabs.com/knowledge/introduction-to-remote-sensing

Resolution Tradeoffs

Spatial Resolution & Extent (Area) Tradeoff

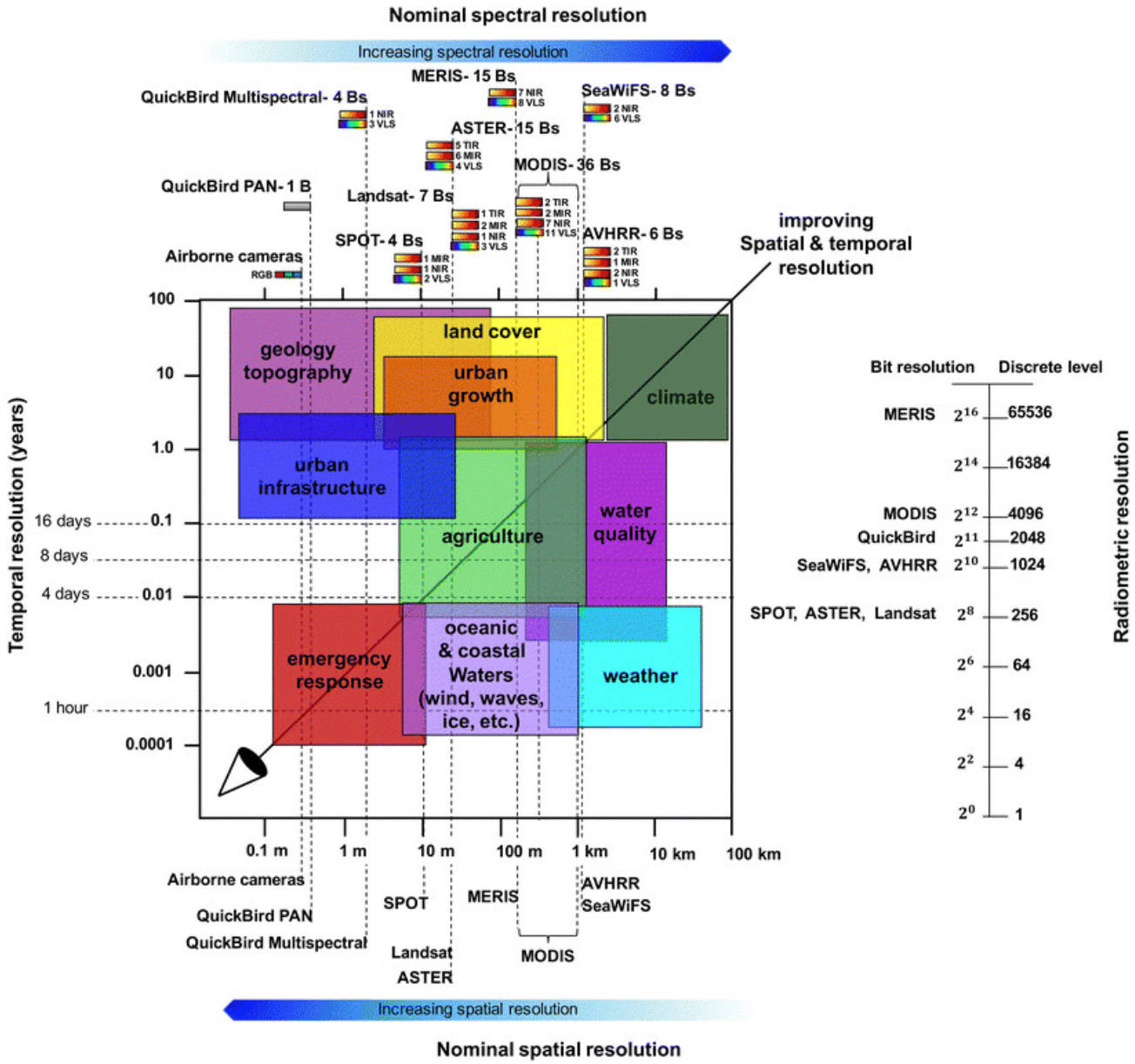


Temporal & Spatial Resolution Tradeoff



Source: https://reformingretail.com/index.php/2020/01/07/payfac-vs-iso-when-does-one-make-sense-over-the-other/

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

For more information, see the tutorial: 4. Optical remote sensing using ESA Copernicus´ data: image metadata, image resolution (spect ral, spatial, temporal and radiomet ric resolution), color compositions and spect ral indices, using SNAP software

Thank you for the attention