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CHAPTER 1: Sources of satellite information

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1. Introduction

Nowadays, there are numerous satellites that allow monitoring and characterizing the Earth's surface. Communication and computing technology advances have solved some previous limitations detected for Earth observation applications, such as the lack of temporal, spatial and radiometric resolution between images, the difficulty of calibration and the high cost of acquisition (Moran et al., 1997). In addition, today the European Space Agency (ESA) and National Aeronautics and Space Administration (NASA), give open and free access via the Internet to different processing-level images in near real time. Moreover, another open-source and cloud-based platform is Google Earth Engine, which combines a multi-petabyte catalogue of satellite imagery and geospatial datasets with planetary-scale analysis capabilities (Gorelick et al., 2017). Due to the high number of available commercial satellites it is important to analyse different features of the remote sensing (RS) sensors in order to select the most appropriate one in function of our objective. These features could be spatial, temporal and spectral resolutions among others.

The sensors used in RS can be classified as active or passive instruments. Passive sensors detect natural solar energy that is reflected or emitted from the observed object or scene. Active sensors measure the reflection or emission from the observed object or scene using their own energy sources. Only a part of the spectral range can be used in RS because the radiation from the objects passes through the atmosphere, which absorbs most of the spectral regions. Usually, the spectra used include visible, infrared, thermal, and microwave for Earth observations (Zhang, 2020). In general, passive sensors include different types of radiometers and spectrometers that work in visible, infrared, thermal infrared, and microwave portions of the electromagnetic spectrum. Most active sensors work in the microwave portion of the electromagnetic spectrum, allowing them to penetrate the atmosphere under cloudy conditions and operating day and night.

The ClimAlert project requires analysing the land surface and the climatic conditions in the Sudoe area (southwest Europe). For this reason, optical (visible and infrared), thermal and microwave sensors will be needed which will provide images with high-moderate spatial and temporal resolution. The analysis focuses on images acquired from polar-orbiting satellites because of their widespread use, global applicability and higher spatial resolution compared to geostationary satellites (Li et al., 2013).

2. Sentinel Missions

Within the Copernicus programme (European Union's Earth Observation Programme), ESA is developing a family of missions called Sentinels with the goal to replace the current older Earth observation missions, and Copernicus is “looking at our planet and its environment for the ultimate benefit of all European citizens” (Copernicus, 2018). Each Sentinel mission is based on a constellation of two satellites to fulfil revisit and coverage requirements. The missions carry a range of technologies, such as radar and multispectral imaging instruments for land, ocean and atmospheric monitoring (ESA, 2020). The information obtained through these satellites is free and open access to its users from Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home). In order to achieve the objectives proposed in ClimAlert, we have analysed the main characteristics of the missions Sentinel-1, Sentinel-2 and Sentinel-3.

The **Sentinel-1** mission comprises a constellation of two satellites (Sentinel-1A and Sentinel-1B), operating day and night performing Synthetic Aperture Radar (SAR) imaging, enabling them to acquire imagery regardless of the weather for land and ocean services. Sentinel-1 satellites have a sun-synchronous, near-polar and circular orbit, and their orbit height is 693 km. Sentinel-1A was launched on April 3, 2014 and Sentinel-1B on April 25, 2016 (Copernicus, 2016). The Sentinel-1 mission includes C-band imaging operating at a centre frequency of 5.405 GHz. It includes a right-looking active phased array antenna providing fast scanning in elevation and azimuth, data storage capacity of 1410 Gb and 520 Mbit/s X-band downlink capacity. It provides dual polarisation capability (vertical and horizontal), very short revisit times (12 days repeat cycle at equator with one satellite, 175 orbits/cycle, and 6 days repeat cycle at equator with two-satellite constellation) and rapid product delivery. The radiometric resolution of the C-band SAR is 16 bits. Sentinel-1 operates in four imaging modes with different resolution and coverage. The main characteristic of the four acquisition modes are:

- Stripmap (SM): SM mode will be used on request mainly for emergency management. SM has a swath width of 80 km and a spatial resolution of 5 x 5 m.
- Interferometric Wide Swath (IW): IW mode allows to map the global landmasses (land, coastal areas, seas, polar areas and ocean relevant areas). This is the main acquisition mode over land and satisfies the majority of service requirements. IW has a swath width of 250 km swath width and a spatial resolution of 5 x 20 m.
- Extra Wide Swath (EW): EW mode will be used primarily over selected European seas, Arctic and Southern Ocean areas, mainly for sea-ice monitoring services and maritime surveillance. EW has a swath width of 400 km and a spatial resolution of 20 x 40 m.
- Wave (WV): Over open ocean, WV mode will be the main operational acquisition mode acquiring vignettes at regular intervals. WV has a swath width of 20 x 20 km swath width and a spatial resolution of 5 x 5 m.

Each mode can produce products at SAR Level-0, Level-1 Single Look Complex (SLC), Level-1 Ground Range Detected (GRD), and Level-2 Ocean (OCN). The SAR Level-0 products consist of the sequence of compressed unfocused SAR raw data. Level-1 SLC products consist of focused SAR data geo-referenced using orbit and attitude data from the satellite and provided in zero-Doppler slant-range geometry. Level-1 GRD products consist of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model. Level-2 OCN products include components for Ocean Swell spectra (OSW). The OSW is a two-dimensional ocean surface swell spectrum and includes an estimate of the wind speed and direction per swell spectrum (ESA, 2013a).

The **Sentinel-2** mission comprises a constellation of two polar-orbiting satellites (Sentinel-2A and Sentinel-2B), phased at 180° to each other, and placed in the same sun-synchronous orbit at a mean altitude of 786 km. It aims at monitoring variability in land surface conditions, and its wide swath width (290 km) and high revisit time (10 days at equator with one satellite, and 5 days with 2 satellites under cloud-free conditions which results in 2-3 days at mid-latitudes) will support monitoring of Earth's surface changes. To do this, each of the satellites in the Sentinel-2 mission carries a Multi-Spectral Instrument (MSI) whose radiometric resolution is 12 bits. Sentinel-2A was launched on June 23, 2015 and Sentinel-2B followed on March 7, 2017 (ESA, 2018). In Table 1, Sentinel-2 spectral and spatial resolutions are provided for its 13 spectral bands.

Sentinel-2 produce products at Level-0, Level-1A, Level-1B, Level-1C and Level-2A, but only the Level-1C and Level-2A products are released to users. Level-0 is compressed raw data. The Level-0 product contains all the information required to generate the Level-1 (and upper) product levels. Level-1A is uncompressed raw data with spectral bands coarsely coregistered and ancillary data appended. Level-1B data is radiometrically corrected radiance data. The physical geometric model is refined using available ground control points and appended to the product, but not applied. Level-1C product provides orthorectified Top-Of-Atmosphere (TOA) reflectance, with sub-pixel multispectral registration. Cloud and land/water masks are included in the product. Level-2A product provides orthorectified Bottom-Of-Atmosphere (BOA) reflectance, with sub-pixel multispectral registration. A scene classification map (cloud, cloud shadows, vegetation, soils/deserts, water, snow, etc.) is included in the product (ESA, 2019a).

Table 1. Wavelengths and Bandwidth of the Multi-Spectral Instrument (MSI) (ESA, 2019a).

	Spectral Resolution				**Spatial Resolution (m)**
	Sentinel-2A		**Sentinel-2B**		
Band	**Central wavelengths (nm)**	**Bandwidth (nm)**	**Central wavelengths (nm)**	**Bandwidth (nm)**	
1 (blue)	442.7	21	442.3	21	60
2 (blue)	492.4	66	492.1	66	10
3 (green)	559.8	36	559	36	10
4 (red)	664.6	31	665	31	10
5 (red edge)	704.1	15	703.8	16	20
6 (red edge)	740.5	15	739.1	15	20
7 (red edge)	782.8	20	779.7	20	20
8 (near infrared)	832.8	106	833	106	10
8a (near infrared)	864.7	21	864	22	20
9 (water vapor)	945.1	20	943.2	21	60
10 (cirrus)	1373.5	31	1376.9	30	60
11 (shortwave infrared)	1613.7	91	1610.4	94	20
12 (shortwave infrared)	2202.4	175	2185.7	185	20

Sentinel-3 is a multi-instrument mission to measure sea surface topography, sea and land surface temperature, ocean colour and land colour with high accuracy and reliability. The mission will support ocean forecasting systems, as well as environmental and climate monitoring. The Sentinel-3 satellites (Sentinel-3A and Sentinel-3B) have a sun-synchronous orbit, and their orbit height is 814.5 km. Sentinel-3A was launched on February 16, 2016 and Sentinel-3B on April 25, 2018 (ESA, 2019b). Sentinel-3 satellites carry four main instruments:

- Ocean and Land Colour Instrument (OLCI): OLCI is a programmable, medium-resolution, imaging spectrometer operating in the solar reflective spectral range. The primary objective of OLCI products is to screen the ocean and land surface to harvest information related to biology. OLCI also provides information on the atmosphere and contributes to climate study. OLCI has a swath width of 1270 km and a spatial resolution of 300 m, in 21 spectral bands (see Table 2).

- Sea and Land Surface Temperature Instrument (SLSTR): SLSTR is a dual scan temperature radiometer (near-nadir and backward views), which principal objective is to provide global and regional sea and land surface temperature to a very high level of accuracy for both climatological and meteorological applications. SLSTR has a swath width of 740 km (backwards)/1420 km (nadir). Its spatial resolution is of 500 m for solar reflectance bands (S1 to S6) and 1 km for thermal infrared bands (S7 to S9 and F1 and F2) (see Table 3).
- Synthetic Aperture Radar Altimeter (SRAL): SRAL is a redundant dual-frequency (C-band + Ku-band) nadir-looking altimeter instrument, and the core instrument of the topographic payload. The main frequency used for range measurements is the Ku-band (13.575 GHz, bandwidth 350 MHz), while the C-band frequency (5.41 GHz, bandwidth 320 MHz) is used for ionospheric correction. The main application is the study of ocean topography including mean sea level, wave height, wind speed over the surface, sea-ice, ocean currents, Kelvin and Rossby waves, eddies and tides.
- Microwave Radiometer (MWR): MWR instrument supports the SRAL to achieve the overall altimeter mission performance by providing wet atmosphere correction. The MWR radiometer measures water vapour, cloud water content and thermal radiation emitted by the Earth.

Sentinel-3 has a temporal resolution of 27 days (385 orbits/cycle). The two in-orbit Sentinel-3 satellites enable a short revisit time of less than 2 days for OLCI and less than 1 day for SLSTR at equator (ESA, 2019b).

Sentinel-3 offers many data products through its different instruments: OLCI; SLSTR; Synergy (combination of the products of OLCI and SLSTR instruments); and Altimetry. As a summary of the main products distributed to users, we can see Figure 1.

Table 2. Ocean and Land Colour Instrument (OLCI) band characteristics (ESA, 2013b).

Band	Central wavelengths (nm)	Bandwidth (nm)	Function
Oa01	400	15	Aerosol correction, improved water constituent retrieval
Oa02	412.5	10	Yellow substance and detrital pigments (turbidity)
Oa03	442.5	10	Chlorophyll absorption maximum, biogeochemistry, vegetation
Oa04	490	10	High Chlorophyll
Oa05	510	10	Chlorophyll, sediment, turbidity, red tide
Oa06	560	10	Chlorophyll reference (Chlorophyll minimum)
Oa07	620	10	Sediment loading
Oa08	665	10	Chlorophyll (2nd Chlorophyll absorption maximum), sediment, yellow substance/vegetation
Oa09	673.75	7.5	For improved fluorescence retrieval and to better account for smile together with the bands 665 and 680 nm
Oa10	681.25	7.5	Chlorophyll fluorescence peak, red edge
Oa11	708.75	10	Chlorophyll fluorescence baseline, red edge transition
Oa12	753.75	7.5	O_2 absorption/clouds, vegetation

Oa13	761.25	2.5	O2 absorption band/aerosol correction
Oa14	764.375	3.75	Atmospheric correction
Oa15	767.5	2.5	O_2A used for cloud top pressure, fluorescence over land
Oa16	778.75	15	Atmospheric correction/aerosol correction
Oa17	865	20	Atmospheric correction/aerosol correction, clouds, pixel co-registration
Oa18	885	10	Water vapour absorption reference band. Common reference band with SLSTR instrument. Vegetation monitoring
Oa19	900	10	Water vapour absorption/vegetation monitoring (maximum reflectance)
Oa20	940	20	Water vapour absorption, Atmospheric correction/aerosol correction
Oa21	1020	40	Atmospheric correction/aerosol correction

Table 3. Sea and Land Surface Temperature Instrument (SLSTR) band characteristics (ESA, 2013c).

Band	**Central wavelengths (nm)**	**Bandwidth (nm)**	**Function**
S1 (visible)	554.27	19.26	Cloud screening, vegetation monitoring, aerosol
S2 (visible)	659.47	19.25	NDVI, vegetation monitoring, aerosol
S3 (near infrared)	868	20.6	NDVI, cloud flagging, Pixel co-registration
S4 (cirrus)	1374.8	20.8	Cirrus detection over land
S5 (shortwave infrared)	1613.4	60.68	loud clearing, ice, snow, vegetation monitoring
S6 (shortwave infrared)	2255.7	50.15	Vegetation state and cloud clearing
S7 (thermal infrared ambient)	3742	398	Sea surface temperature, land surface temperature, Active fire
S8 (thermal infrared ambient)	10854	776	Sea surface temperature, land surface temperature, Active fire
S9 (thermal infrared ambient)	12022.5	905	Sea surface temperature, land surface temperature
F1 (thermal infrared fire emission)	3742	398	Active fire
F2 (thermal infrared fire emission)	10854	776	Active fire

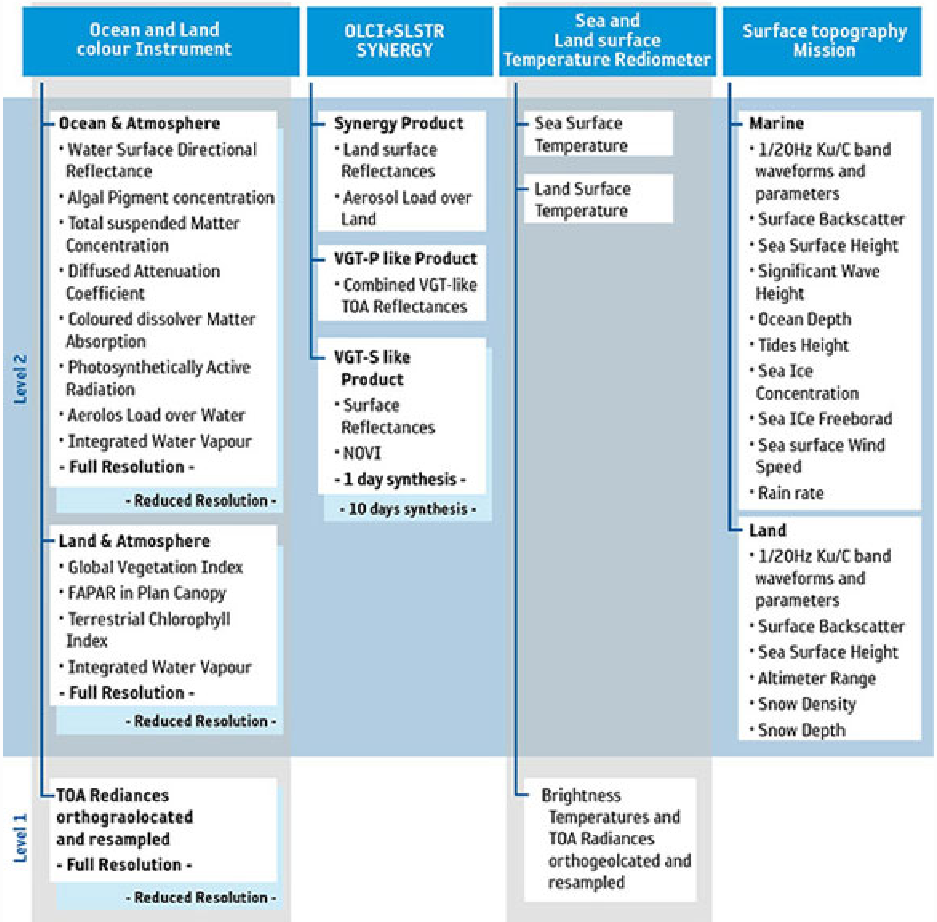

Figure 1. Sentinel-3 products structure (ESA, 2019b).

3. Landsat Missions

In ClimAlert, **Landsat 8** is another of the most interesting satellites to use. Landsat 8 was launched on February 11, 2013 and is the last satellite launched within the Landsat Missions carry out between NASA and the USGS (United States Geological Survey) to provide moderate resolutions measurements of the Earth's terrestrial and polar regions in the visible, near-infrared, short wave infrared, and thermal infrared (NASA, 2020a). The Landsat 8 satellite orbits the Earth in a sun-synchronous, near-polar orbit, at an altitude of 705 km, and has a 16-day repeat cycle with an equatorial crossing time: 10:00 a.m. +/- 15 minutes. The Landsat 8 scene size is 185-km-cross-track-by-180-km-along-track. Landsat 8 has two instruments, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), through which it can measure in 11 bands of the electromagnetic spectrum (see Table 4). The data are registered with a radiometric precision over a 12-bit dynamic range. Data products are free and open access from EartExplorer (https://earthexplorer.usgs.gov/), Glovis (https://glovis.usgs.gov/) and the LandsatLook Viewer (https://landsatlook.usgs.gov/). Data products are available for two levels. At Level-1, the data are radiometrically calibrated and orthorectified, and the on-demand interface corrects satellite images for atmospheric effects to create Level-2 data products (USGS, 2020a).

Table 4. Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) band characteristics (NASA, 2020a).

Instrument	Band	Wavelengths (μm)	Spatial Resolution (m)
OLI	1 (coastal aerosol)	0.43-0.45	30
	2 (blue)	0.45-0.51	30
	3 (green)	0.53-0.59	30
	4 (red)	0.64-0.67	30
	5 (near infrared)	0.85-0.88	30
	6 (shortwave infrared)	1.57-1.65	30
	7 (shortwave infrared)	2.11-2.29	30
	8 (panchromatic)	0.50-0.68	15
	9 (cirrus)	1.36-1.38	30
TIRS	10 (thermal infrared)	10.6-11.19	100
	11 (thermal infrared)	11.5-12.51	100

Currently, there is another operative satellite within the Landsat mission. This is **Landsat 7**, which was launched on April 15, 1999, with the aim of continuing Earth observation by satellites previously launched as Landsat 4 and 5. Landsat 7 has a sun-synchronous and a near-polar orbit, at an altitude of 705 km, and has a 16-day repeating cycle with an equatorial crossing time: 10:00 a.m. +/- 15 minutes. Landsat 7 presents the Enhanced Thematic Mapper Plus (ETM+) sensor, which measures in 8 spectral bands of the electromagnetic spectrum, including a panchromatic and a thermal band (see Table 5). On May 31, 2003, the Scan Line Corrector (SLC) system failed, resulting in bands with no data within the images captured by the sensor. The SLC system is a component of the ETM+ sensor, which compensates the forward movement of the satellite during image acquisition. The SLC failure has caused that the ETM+ sensor traces a zigzag pattern along the satellite ground track. This situation produces bands without data within the images. Despite this, and in the undamaged areas of the image (approximately 75 percent of the total data), Landsat 7 offers excellent data quality due to the meticulous calibration standards it presents. Like Landsat 8, data products are free and open access from EartExplorer (https://earthexplorer.usgs.gov/), Glovis (https://glovis.usgs.gov/) and the LandsatLook Viewer (https://landsatlook.usgs.gov/). Data products are available for two levels. At Level-1, the data are radiometrically calibrated and orthorectified, and the on-demand interface corrects satellite images for atmospheric effects to create Level-2 data products (NASA, 2020b; USGS, 2020b).

Table 5. Enhanced Thematic Mapper Plus (ETM+) sensor band characteristics (USGS, 2020b).

Instrument	Band	Wavelengths (μm)	Spatial Resolution (m)
ETM+	1 (visible)	0.45-0.52	30
	2 (visible)	0.52-0.60	30
	3 (visible)	0.63-0.69	30
	4 (near infrared)	0.77-0.90	30
	5 (near infrared)	1.55-1.75	30
	6 (thermal)	10.40-12.50	60
	7 (mid infrared)	2.08-2.35	30
	8 (panchromatic)	0.52-0.90	15

4. MODIS

MODIS sensor is another important sensor to analyse de Earth surface, but in this case with a lower spatial resolution. MODIS (Moderate Resolution Imaging Spectroradiometer) is an instrument aboard the Terra and Aqua satellites belonging to NASA. Both satellites orbit around the Earth, but Terra passes from north to south across the equator during the morning, while Aqua passes south to north over the equator in the afternoon (NASA, 2006). Terra and Aqua were launched on December 18, 1999 and May 4, 2002, respectively. MODIS provides high radiometric sensitivity (12-bits) in 36 spectral bands that measure visible and infrared radiation to obtain products ranging from vegetation, land surface cover, and ocean chlorophyll fluorescence to cloud and aerosol properties, fire occurrence, snow cover on the land, and sea ice cover on the oceans (NASA, 2019). MODIS has a sun-synchronous, near-polar and circular orbit, at an altitude of 705 km. Its swath dimensions are 2330 km (cross track) by 10 km (along track at nadir), and it has a temporal resolution of 1-2 days. The spectral bands of MODIS have different wavelength and spatial resolutions (see Table 6). Through the MODIS website it is possible to acquire many standard MODIS data products from several sources (https://modis.gsfc.nasa.gov/data/), and it is also possible obtain specific information for each product. In addition, the MODIS website lists a variety of tools and resources that can be used with MODIS data (https://modis.gsfc.nasa.gov/tools/).

Table 6. MODIS characteristics (NASA, 2006).

Band	Wavelengths[1]	Primary Use	Spatial Resolution (m)
1	620 - 670	Land/Cloud/Aerosols Boundaries	250
2	841 - 876		
3	459 - 479	Land/Cloud/Aerosols Properties	500
4	545 - 565		
5	1230 - 1250		
6	1628 - 1652		
7	2105 - 2155		
8	405 - 420	Ocean Color/ Phytoplankton/ Biogeochemistry	1000
9	438 - 448		
10	483 - 493		
11	526 - 536		
12	546 - 556		
13	662 - 672		
14	673 - 683		
15	743 - 753		
16	862 - 877		
17	890 - 920	Atmospheric Water Vapor	
18	931 - 941		
19	915 - 965		
20	3.660 - 3.840	Surface/Cloud Temperature	
21	3.929 - 3.989		
22	3.929 - 3.989		
23	4.020 - 4.080		
24	4.433 - 4.498	Atmospheric	

25	4.482 - 4.549	Temperature	
26	1.360 - 1.390	Cirrus Clouds Water Vapor	
27	6.535 - 6.895		
28	7.175 - 7.475		
29	8.400 - 8.700	Cloud Properties	
30	9.580 - 9.880	Ozone	
31	10.780 - 11.280	Surface/Cloud Temperature	
32	11.770 - 12.270		
33	13.185 - 13.485	Cloud Top Altitude	
34	13.485 - 13.785		
35	13.785 - 14.085		
36	14.085 - 14.385		

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

5. Other Satellites

Currently, there are also numerous commercial satellites with high or very high spatial resolution and with increasing spectral and temporal capabilities. Some of these satellites are WorldView 3, Disaster Monitoring Constellation (DMC), Spot or Pleiades among other.

WorldView 3 satellite combines very high spatial resolution with observation bands in the shortwave infrared (SWIR) in addition to the visible and near infrared (VNIR) multispectral and panchromatic bands, resulting in multiple applications, such as mineral exploration, agricultural mapping, and urban monitoring. The satellite was launched on August 13, 2014. WorldView 3 orbits the Earth in a sun-synchronous orbit, at an altitude of 617 km. Moreover, the satellite has a swath width of 13.1 km, and a revisit time of less than 1 day. WorldView 3 presents a super-spectral sensor with very high spatial resolution observations in the SWIR (8 bands at 3.7 m pixel size), multispectral VNIR (8 bands at 1.2 m pixel size), panchromatic VNIR (1 band at 0.31 m pixel size), and combined VNIR/SWIR (12 bands at 30 m pixel size). Furthermore, the satellite presents an atmospheric monitoring sensor named CAVIS (Clouds, Aerosols, water Vapor, Ice and Snow), which is composed of 12 additional bands of 30 m spatial resolution in the VNIR and SWIR, with two parallax bands designed to extract cloud height. Besides, the different bands have different spectral resolution: 1 Panchromatic band (450-800 nm), 8 Multispectral bands (400-1040 nm), 8 SWIR bands (1195-2365 nm) and 21 CAVIS bands (405-2245 nm) (Longbotham et al., 2015, 2014).

Disaster Monitoring Constellation (DMC) or TripleSat Constellation consists of 3 similar optical Earth observation satellites, which allow monitoring anywhere on Earth once a day. The three spacecraft DMC-3 were launched on July 10, 2015. These satellites have a sun-synchronous orbit, with an altitude of 651 km, and the three satellites are in same orbital plane exactly 120° apart. They have a swath width of 23.4 km and a daily revisit time. The sensor instrument provides one panchromatic band and four multispectral bands (blue, green, red and near infrared red). At nadir, spatial resolution is 0.8 m for the panchromatic band and 3.2 m for the multispectral bands. 25° off-nadir, spatial resolution is 1 m for panchromatic band and 4 m for multispectral bands. The spectral band wavelength range is: 450-650 nm (panchromatic); 440-510 nm (blue); 510-

590 nm (green); 600-670 nm (red); 760-910 nm (near infrared red) (Satellite Imaging Corporation, 2015).

Pleiades-HR (High-Resolution Optical Imaging Constellation) is a two-spacecraft constellation of Space Agency of France (CNES) equipped with optical high resolution cameras to observe the Earth's surface. Called Pleiades-1A and Pleiades-1B, the first was launched on December 17, 2011, and the second was launched on December 2, 2012. Both are phased 180° apart in the same near-polar sun-synchronous orbit at an altitude of approximately 694 km. With both satellites, there is a daily revisit time. The swath width is of 20 km at nadir. Called HiRI (High-Resolution Imager), the sensor instrument provides one panchromatic band and four multispectral bands (blue, green, red and near infrared red). Spatial resolution is of 0.5 m for panchromatic band and 2 m for multispectral bands. Spectral band wavelength range is: 480-820 nm (panchromatic); 450-530 nm (blue); 510-590 nm (green); 620-700 nm (red); 775-915 nm (near infrared red) (ESA, 2017).

SPOT-6 and SPOT-7 Commercial Imaging Constellation consists of two similar satellites designed to continue the SPOT mission by providing wide-swath high-resolution images. SPOT-6 was launched on September 9, 2012. SPOT-7 was launched on June 30, 2014. SPOT-6 and SPOT-7 operate in the phased orbit with PLEIADES-1A and PLEIADES-1B forming 4-satellites constellation. SPOT satellites have a sun-synchronous circular orbit, with an altitude of 694 km, and the two satellites are into the same orbital plane phased at 180°. The revisit time is one day with both satellites operating simultaneously, and between one and three days with only one satellite in operation. Called NAOMI (New AstroSat Optical Modular Instrument), the sensor instrument provides images with a swatch width of 60 km and up to 120 km in a one-pass mosaic between the two satellites. NAOMI measures in 5 bands of the electromagnetic spectrum, which have different spectral resolution: panchromatic (450-745 nm); blue (450-520 nm); green (530-590 nm); red (625-695 nm); near infrared (760-890 nm). Spatial resolution is from 1.5 m to 2.5 m at nadir for panchromatic band and 6 m to 10 m at nadir for multispectral bands (Astrium, 2012; ESA, 2012).

Among the many Chinese Earth observation satellites that exist today, the Gaogen series satellites stand out among others. **Gaofen (GF)** high-resolution imagery satellites is a series of Chinese civilian satellites belonging to CNSA (China National Space Administration), whose main objective is realised Earth observations. These satellites have been developed within the program China High-definition Earth Observation System (CHEOS). The Gaofen series aims to perform near-real-time observations for agricultural planning, disaster prevention and relief, climate change monitoring, geographical mapping, environment and resource surveying, maritime surveillance, and national security (China Space Report, 2016). Since the first Gaofen satellite (GF-1) was launched on April 26, 2013, more than 15 satellites belonging to the Gaofen series have been launched (Harvey, 2019). The Gaofen series presents satellites with optical, thermal and microwave sensors, which offer different characteristics for analysing Earth's surfaces. In November 2019, China announced that it would make 16-meter resolution imagery from GF-1 and GF-6 satellites openly available to users around the world (China Research Center, 2020). GF-6 was launched on June 2, 2018, and presents similar characteristics to GF-1. Both satellites have a sun-synchronous orbit and 4 days of revisit period, and their main characteristics can be seen in Table 7.

Table 7. Gaofen 1 and 6 characteristics (Harvey, 2019; Li et al., 2017; Liu et al., 2016).

Satellite	Sensor	Spatial Resolution	Band	Bandwidth (μm)	Swath Width
Gaofen-1	Panchromatic/ multispectral cameras	2 m	1 (Panchromatic)	0.45-0.90	≥ 60 km
		8 m	2 (Blue)	0.45-0.52	
			3 (Green)	0.52-0.59	
			4 (Red)	0.63-0.69	
			5 (Near infrared)	0.77-0.89	
	Wide Field of View cameras	16 m	1 (Blue)	0.45-0.52	≥ 800 km
			2 (Green)	0.52-0.59	
			3 (Red)	0.63-0.69	
			4 (Near infrared)	0.77-0.89	
Gaofen-6	Panchromatic/ multispectral cameras	2 m	1 (Panchromatic)	0.45-0.90	≥ 90 km
		8 m	2 (Blue)	0.45-0.52	
			3 (Green)	0.52-0.59	
			4 (Red)	0.63-0.69	
			5 (Near infrared)	0.77-0.89	
	Wide Field of View cameras	16 m	1 (Blue)	0.45-0.52	≥ 800 km
			2 (Green)	0.52-0.59	
			3 (Red)	0.63-0.69	
			4 (Near infrared)	0.77-0.89	
			5 (Costal)	0.40-0.45	
			6 (Yellow)	0.59-0.63	
			7 (RedEdge1)	0.69-0.73	
			8 (RedEdge2)	0.73-0.77	

Other important Earth observation-based soil moisture missions are the **Soil Moisture and Ocean Salinity (SMOS) mission** (Kerr et al., 2012), the **Hydrospheric States (NASA-Hydros) satellite mission** (Entekhabi et al., 2004) and the **Soil Moisture Active Passive (SMAP) mission** (Entekhabi et al., 2010). These missions carry passive and/or active low-frequency (L-band) microwave instruments to obtain global soil moisture information with coarse spatial resolution. SMOS is one of ESA's Earth Explorer missions, which carries an interferometric radiometer that operates in the L-band microwave range to capture brightness temperature images. SMOS provides global maps of soil moisture every 3 days with an accuracy of 4% at a spatial resolution of about 50 km. SMOS also provides salinity maps over oceans. NASA-Hydros is a NASA's mission, whose objective is to exploratory global measurements of the earth's soil moisture at 10 km resolution with 2 to 3 days revisit and land-surface freeze/thaw conditions at 3 km resolution with 1 to 2 days revisit. The Hydros instrument is a combined radar and radiometer system operating at 1.26 GHz and 1.41 GHz, respectively. The radiometer measurements allow retrieval of soil moisture in diverse (no forested) landscapes with a resolution of 40 km. The radar measurements allow the retrieval of soil moisture at relatively high resolution (3 km). Radar/radiometer data products can also be used in synergy to improve the soil moisture resolution (10 km). SMAP is a NASA mission, designed to measure soil moisture, every 2-3 days. SMAP carries L-band radar and radiometer instruments. Soil moisture content can be mapped via the radiometer data at a spatial resolution of 36 km every 2-3 days. A combination of radar and radiometer measurements would lead to a soil moisture product at a spatial resolution of 9 km.

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