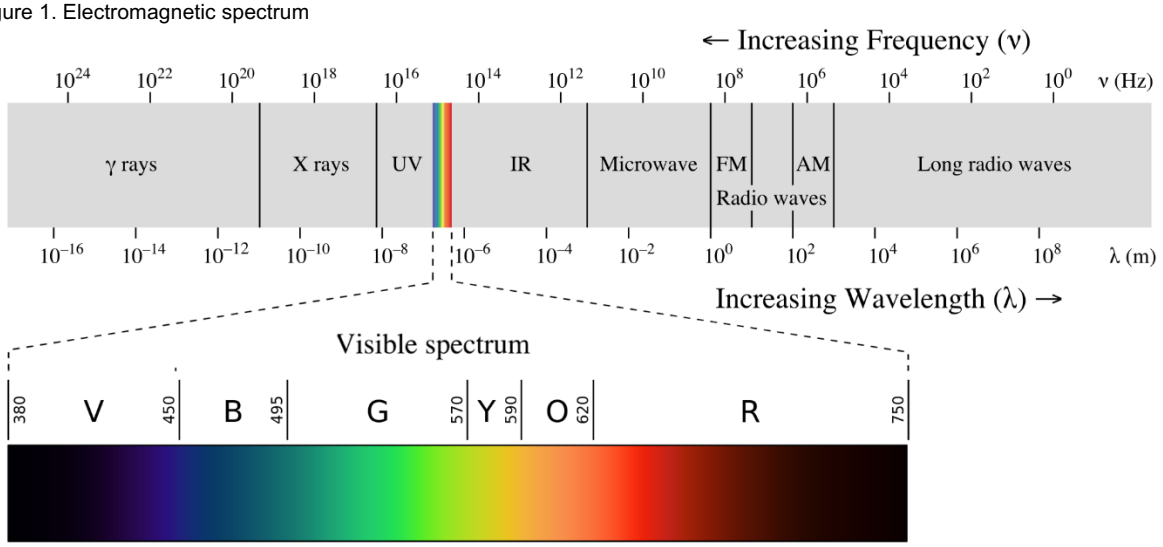
Earth Observation – current opportunities

1. Remote sensing doesn't bite.

Remote sensing is a technique of acquiring information (data) remotely using passive or active systems. In the passive system, electromagnetic waves reflected from the object are analysed by satellite sensors and converted into digital data. In the active system, such as radar, the satellite emits bursts of pulses in a particular wavelength and analyses fraction of this incident energy that is reflected directly backwards toward the sensor. The best day-to-day life example of remote sensing is a camera integrated into a smartphone device. This camera takes pictures in the passive way or the active way when flash is used, and sensors convert the visible spectrum of light into digital formats representing an imaged object. Our eyes work also in a similar manner. We can see because a visible part of the electromagnetic spectrum i.e. Blue Green Red reflects from the observed phenomena and later is processed and interpreted by our eyes and brain.

Human beings can only see a tiny fraction of the light spectrum. Nevertheless, satellites can operate not only in the visible spectrum but also in a vast range of electromagnetic wavelengths. Figure 1 shows that visible light is only a tiny fraction of the wavelengths that can be sensed. The shorter the wavelength the more energy it conveys but also the more interaction with other objects/particles it has. Therefore, observing the earth from orbit has some limitations. Firstly there is atmospheric scattering, which is an unpredictable diffusion of radiation by particles in the atmosphere. This scattering is responsible for the blue sky during the day and the red and orange colours during the sunrise and the sunset. Secondly, there is also an atmospheric absorption of the energy in some particular wavelengths. A big limitation to the earth observation also imposes cloud coverage because statistically, clouds obscure more than 60% of the earth's surface and also cast shadows at any given moment. Moreover, most of the satellites cannot operate over the night-time, unless they are active radar systems. Fortunate for the earth observation, the longer the wavelength the less interaction with the atmosphere, clouds, rain, etc. The microwaves of the radar satellites can penetrate through clouds and do not depend on sunlight, which makes them so important.

Figure 1. Electromagnetic spectrum



Source: https://commons.wikimedia.org/wiki/File:EM_spectrumrevised.png

In fact microwaves over 4 cm in length freely pass through clouds and do not scatter on water droplets, dust, etc. Therefore, Sentinel 1 – radar satellite of Copernicus satellites fleet, for instance, operates on a C band which for this satellite is approximately 5,55cm long. The C band guarantees that the quality of the sensed images is not influenced by clouds even under heavy rain conditions. For more information on the radar bands please consult Figure 2.

Figure 2. Radar frequencies

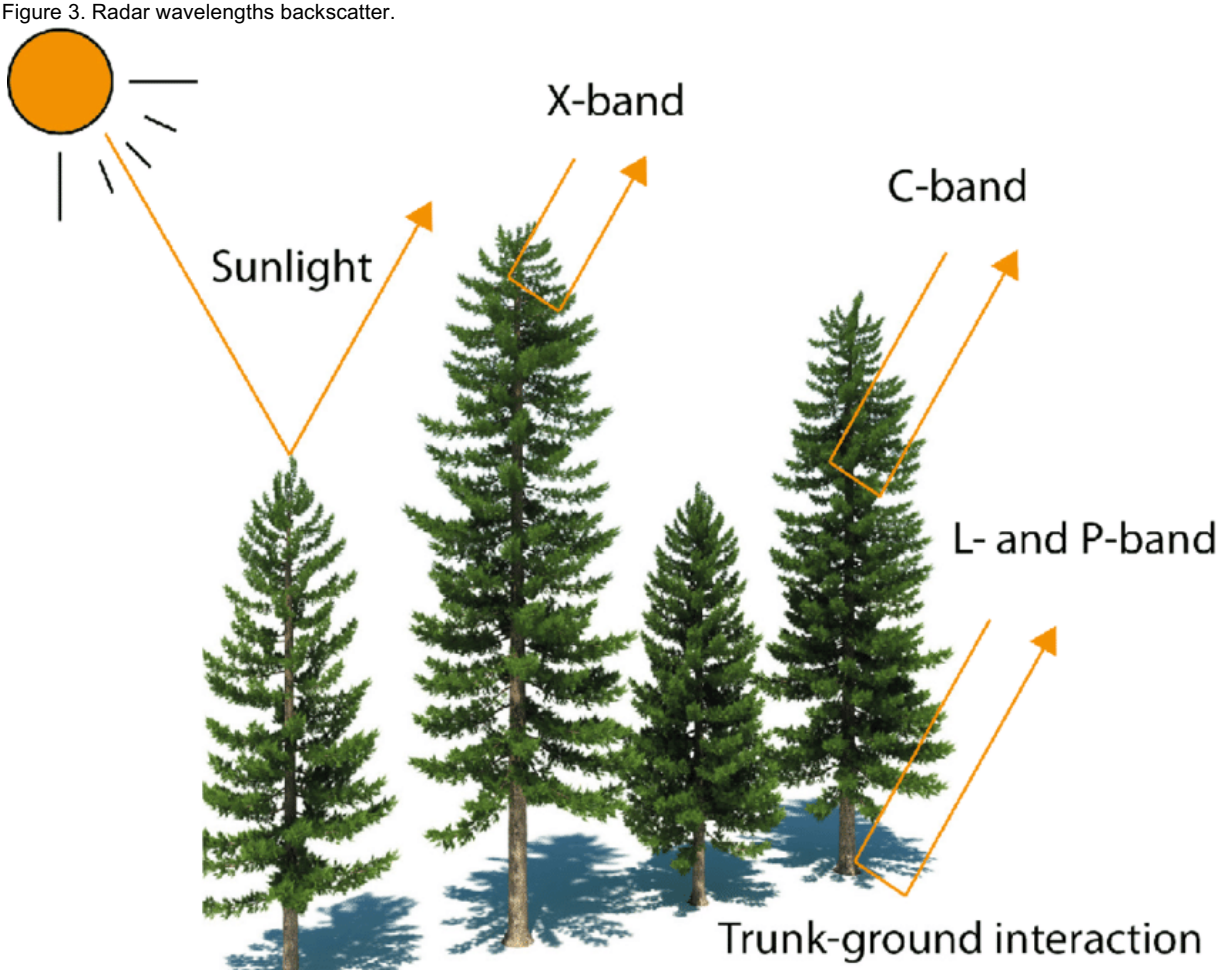
Band	Frequency	Wavelength	Typical Application
Ka	27 – 40 GHz	1.1 – 0.8 cm	Rarely used for SAR (airport surveillance)
K	18 – 27 GHz	1.7 – 1.1 cm	rarely used (H_2O absorption)
Ku	12 – 18 GHz	2.4 – 1.7 cm	rarely used for SAR (satellite altimetry)
X	8 – 12 GHz	3.8 – 2.4 cm	High resolution SAR (urban monitoring,; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4 – 8 GHz	7.5 – 3.8 cm	SAR Workhorse (global mapping; change detection; monitoring of areas with low to moderate penetration; higher coherence); ice, ocean maritime navigation
S	2 – 4 GHz	15 – 7.5 cm	Little but increasing use for SAR-based Earth observation; agriculture monitoring (NISAR will carry an S-band channel; expends C-band applications to higher vegetation density)
L	1 – 2 GHz	30 – 15 cm	Medium resolution SAR (geophysical monitoring; biomass and vegetation mapping; high penetration, InSAR)
P	0.3 – 1 GHz	100 – 30 cm	Biomass. First p-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.

Source: https://lotusarise.com/satellite-frequency-bands-upsc/

As Figure 2 shows the longer the wavelength pulsed by the radar satellite, the more penetration properties it has (fewer interactions with ground objects). This way, satellites such as ALOS[1], which uses an L band, can penetrate through the canopy. Figure 3 shows how selected bands interact with the tree canopy.

[1] https://earth.esa.int/eogateway/missions/alos

Figure 3. Radar wavelengths backscatter.



Source: https://www.researchgate.net/figure/Illustration-of-the-scattering-penetration-in-a-forest-canopy-with-common-remote_fig4_269575726

From the layman perspective it is worth knowing that satellites' acquisitions have 3 different resolutions, which can be shortly described as follows:

1. Spectral resolution – defines which spectral bands a satellite operates in
2. Spatial resolution – defines the minimum ground square (pixel) which a satellite can depict
3. Temporal resolution – defines how often a satellite can measure the same spot on earth

There is also the radiometric resolution which defines how many bits the data are encoded.

1.2 Ordinary life experience:

Earth Observation (EO) data is present very often in our day-to-day life. For example, while planning a route in Google maps and displaying satellite background, we profit out of EO. Another example is when we are watching the weather forecast, which is partially modelled based on data from meteo satellites, we do profit from EO as well. Also worth mentioning is that radar satellites provide us with detailed information on the ground elevation. As an example, the NASA SRTM mission can be given. During this radar mission conducted from the Space Shuttle *Endeavor* in 2000, the elevation data of almost the entire globe was collected and later prepared. Now, this data is frequently used in many navigation systems and were by many countries modified for local use, such as EU-DEM a digital elevation model for the EU and associated countries[2].

These are the most intuitive examples, but do we have other ones? The answer is yes! – Our wellbeing from the perspective of the local societies to the entire global population strongly depends on data constantly being provided by many different satellites. All these domains, local urban planning, land use, environmental

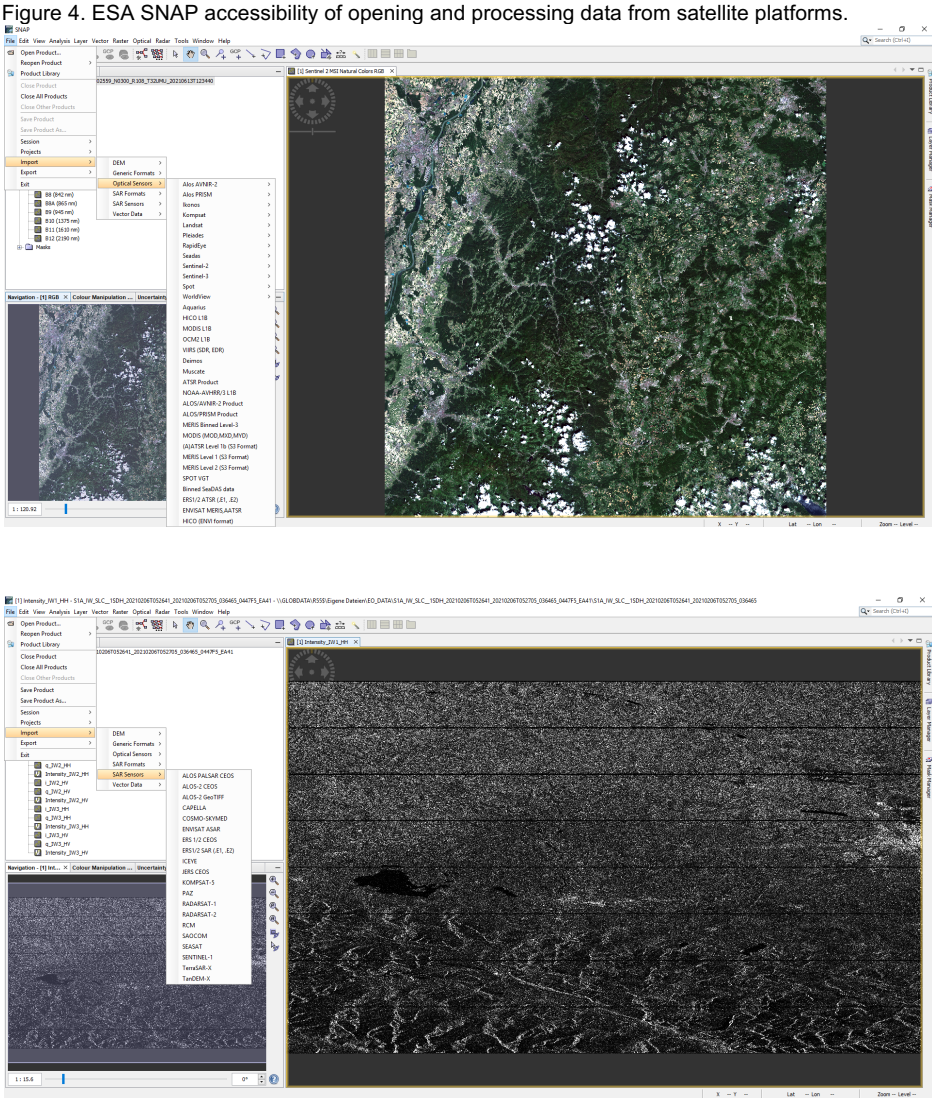
[2] https://land.copernicus.eu/imagery-in-situ/eu-dem

protection, agriculture, property insurance, or forestry profit directly or indirectly from EO data. That profitability becomes even more visible on a macro scale – regional/country/continental or global levels. Satellite data products are helpful not only in planning and protecting the environment but are also a crucial factor in supporting decision-making in case of disasters. A good example is the Disaster Charter[3], which conveys satellite analyses on main disasters in the world and provides a fast, general overview on the affected area helping in better reaction.

1.3 EO data is not an exclusive product anymore

Not even a decade ago EO data were very expensive and not available to the vast public. Nowadays, the data is easily accessible. Moreover, the data can be processed without buying an expensive license due to the freely available and tailored software ESA SNAP[4]. The software was specially developed for supporting the Sentinel satellites but also other frequently used satellite products (as shown in Figure 4).

Figure 4. ESA SNAP accessibility of opening and processing data from satellite platforms.



ESA Copernicus programme has strongly contributed to this revolution and granted free of charge permanent access to different products derived from Sentinel Missions as well as from third-party missions such as NASA Landsat. All repositories with historical and up-to-date Sentinels' acquisitions are accessible through different access points where the most important one is DIAS (Data Infrastructure and Services). Each satellite product and all archived data can be downloaded to be further processed e.g. in the SNAP software. Moreover, some satellite products can be directly visualised on the DIAS web client.

[3] https://disasterscharter.org
[4] https://step.esa.int/main/download/snap-download/

2. What does the Copernicus programme offer?

Copernicus is a successor of the GMES programme (Global Monitoring for Environment and Security). At this moment, Copernicus is the largest earth monitoring programme ever conducted by humankind. According to the Copernicus Market Report 2019[5] up to now Copernicus costs approx. 8,2 B€, however, the estimated economic benefits are between 16,2 – 21,3 B€. Moreover, the total economic benefits for the period 2017 – 2035 are assumed to be 10 times higher than the total costs of the programme[6].

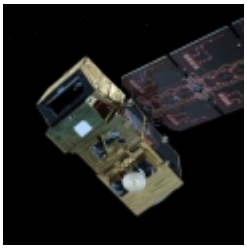
Copernicus consists of three main components:
- Free of charge satellite data products are available on a different level of processing,
- 6 main Copernicus Services, which serve information on thematic phenomena such as Land, Atmosphere, Marine, Security, Climate, and Emergency. These services are based on Sentinel and other satellites products but also based on a network of many additional *in situ* measurements, and other data streams.
- DIAS data repositories, which provide the same data streams of Sentinel data products, and Copernicus Services with some observable differences in an accessible content. In all DIAS the provided data is free of charge but cloud computing resources, as well as third-party licenses, are chargeable. Additionally, there is ESA open access hub[7] that can be used for downloading Sentinel data. Worth mentioning is also the Sentinel Hub, a playground application and EO browser[8], which in its free version, displays different bands combinations of Sentinel 2 showing vast applicability of this data. These solutions are integrated with some DIAS as well.
The alternative to DIAS is Copernicus Open Hub[9], which only allows to download data.

2.1 Sentinel constellation:

This is a fleet of satellites that is progressively growing. Up to now Sentinel 1, Sentinel 2, Sentinel 3, and Sentinel 5Precursor are fully operating. All products delivered by these satellites are available through the access hubs mentioned above. Each type of satellite is meant to serve different observations so the whole fleet complements each other in sense of global monitoring of the environmental and physical conditions of our planet. Moreover, to guarantee the most frequent revisit time, each sentinel mission consists of 2 satellites. For instance Sentinel 1 mission is represented by Sentinel 1A and Sentinel 1B. There are already contracts to enrich these tandems with new satellites such as Sentinel 3C and Sentinel 3D, but also it is planned to expand the whole fleet with new Sentinel missions which will be introduced in Copernicus 2.0.[10]

[5] https://www.copernicus.eu/sites/default/files/PwC_Copernicus_Market_Report_2019.pdf
[6] https://www.copernicus.eu/en/news/news/study-estimates-copernicus-benefits-be-10-times-its-costs
[7] https://scihub.copernicus.eu/
[8] https://apps.sentinel-hub.com/sentinel-playground/
[9] https://scihub.copernicus.eu/
[10] https://www.d-copernicus.de/infothek/news/news-details/news/copernicus-20-die-naechsten-sentinel-missionen/?tx_news_pi1%5Baction%5D=detail&tx_news_pi1%5Bcontroller%5D=News&cHash=1a36cd53a69561337be344758e6ed0f9

2.2 What are the main characteristics of Sentinel products, and what kind of information do they provide?

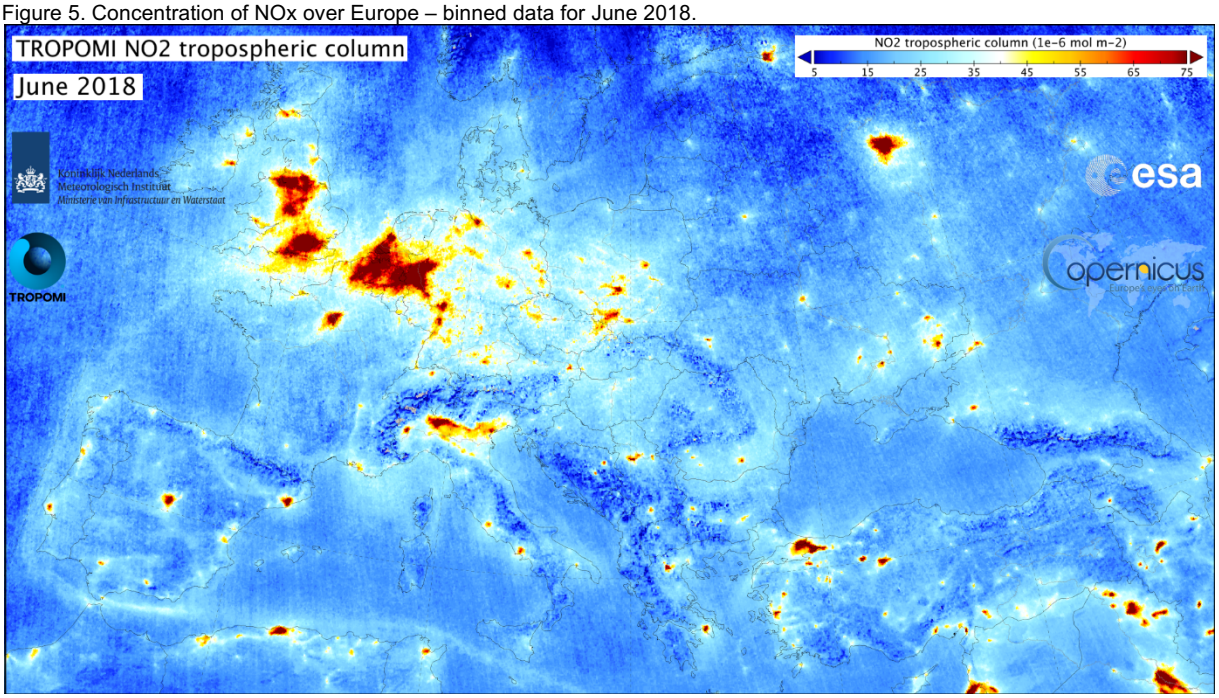
Satellite	picture	Short description
Sentinel 1[11]		Cloud and daytime independent active SAR* system operating in C band 5,55 cm length (compare with Figure 2): very useful for agriculture, deforestation, flood mapping, land use classification, soil moisture, ground displacement monitoring, oil spills on water, digital elevation model creation, and more. The Tandem of these two satellites has a revisit time of 6 days and provides spatial resolution down to 5m. Depending on the user's needs, Sentinel 1 also provides information on different wave polarisation. **SAR – synthetic aperture radar. This is a system that uses a short physical antenna but through modified data recording and processing techniques it synthesizes the effect of a very long antenna.*
Sentinel 2[12]		Cloud dependant passive system, which provides spectral information in 13 bands with ground resolution varying from 10 to 60m. The revisit time of this tandem is approximately 5 days, however, in the mid-latitudes, it varies from 2 to 3 days. Data from this mission is frequently used in agriculture, environmental monitoring such as land use land cover, forest monitoring, disaster mapping, etc. A few years ago Sentinel 2 was used for a case study of preparing new global land cover mapping with a spatial resolution of 10m. Even though in many world regions the classification had low accuracy, for European conditions it reached 89% and is now presented as free of charge downloadable product[13].
Sentinel 3[14]		Cloud dependant passive with the cloud-independent radar system. The system is mostly focused on measuring sea-surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy. The satellite carries four main instruments: OLCI: Ocean and Land Colour Instrument; SLSTR: Sea and Land Surface Temperature Instrument; SRAL: SAR Radar Altimeter; MWR: Microwave Radiometer. The satellite provides data with coarse resolution, for instance, Land Surface Temperature has a spatial resolution of 1000m pixel size. In general, Sentinel 3 products are strongly oriented on analysing whole ecosystems, environmental monitoring, and climate monitoring.

[11] https://sentinel.esa.int/web/sentinel/missions/sentinel-1
[12] https://sentinel.esa.int/web/sentinel/missions/sentinel-2
[13] http://s2glc.cbk.waw.pl/
[14] https://sentinel.esa.int/web/sentinel/missions/sentinel-3

Sentinel 4 (not operating yet)[15] Sentinel 5 (not operating yet)[16] **Sentinel 5 Precursor (S5p)[17]**		These 3 satellites are focused on air quality monitoring. Up to now, only S5p is operating and, thanks to the TROPOMI* instrument on-board, it has already revolutionized air monitoring. The satellite allows displaying data with a resolution of 3,5x 7km which is the best available resolution achieved by air monitoring satellites. Products delivered by Sp5 are NOx, SOx, CO, ozone, aerosols, methane, and formaldehyde. Considering unexceptional spatial resolution, this satellite gives insight into global air conditions and allows to analyse climate as it has never been done before. Figure 5 clearly shows how NOx was emitted over the EU in June 2018. The next Figure, Figure 6, shows how the pandemic drastically reduced NOx emissions. * TROPOMI is a spectrometer that senses ultraviolet (UV), visible (VIS), near (NIR), and short-wavelength infrared (SWIR).

The TROPOMI instrument can even detect leakages of gases in pipelines.[18] [19]

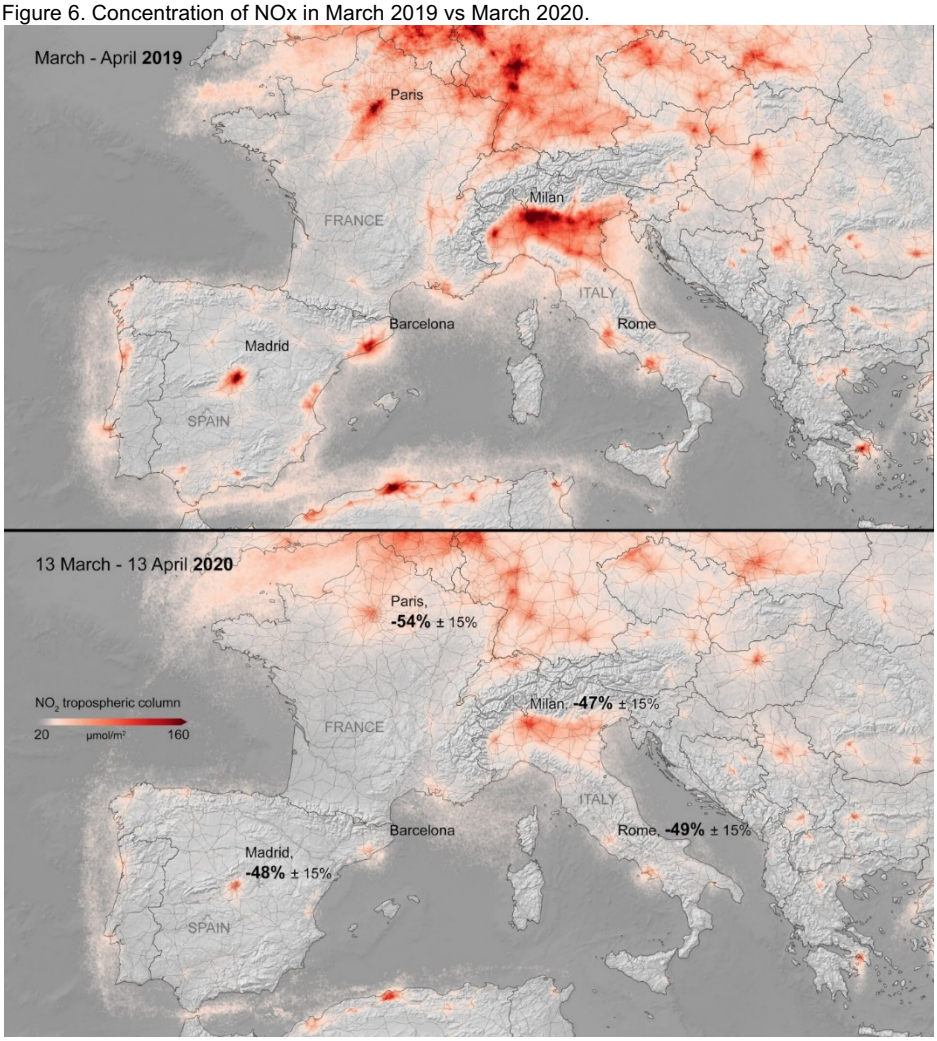
Figure 5. Concentration of NOx over Europe – binned data for June 2018.



Source: http://www.tropomi.eu/data-products/nitrogen-dioxide

[15] https://sentinel.esa.int/web/sentinel/missions/sentinel-4
[16] https://sentinel.esa.int/web/sentinel/missions/sentinel-5
[17] https://sentinel.esa.int/web/sentinel/missions/sentinel-5p
[18] https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Monitoring_methane_emissions_from_gas_pipelines
[19] http://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Connecting_the_dots_nitrogen_dioxide_over_Siberian_pipelines

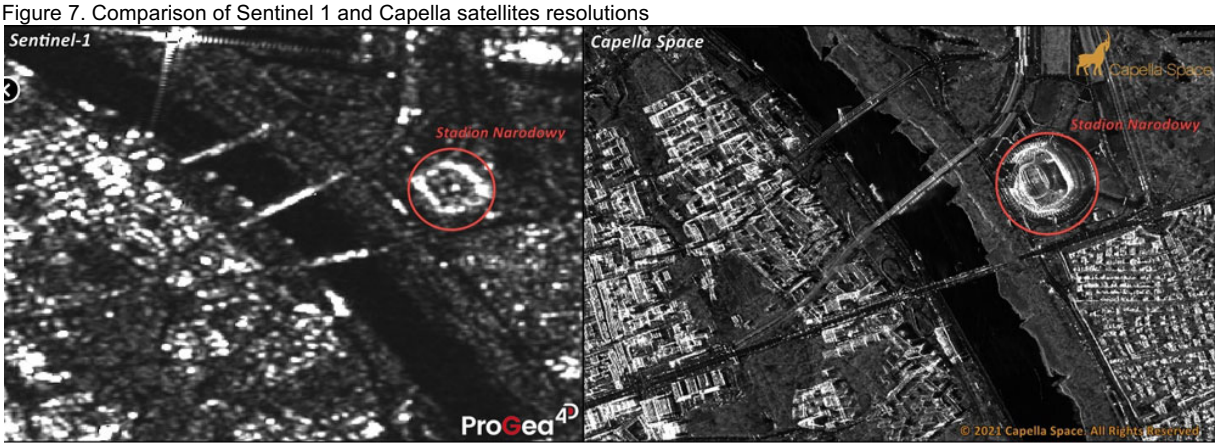
Figure 6. Concentration of NOx in March 2019 vs March 2020.



Source: https://race.esa.int/?poi=World-N1

It is also worth keeping in mind that freely available Sentinel data generally have worse resolution comparing to the commercially offered products. The following example in Figure 7, shows the Warsaw city centre imaged by two radar satellites: Sentinel 1 (on the left) and Capella Space (on the right). The national stadium is red-circled.

Figure 7. Comparison of Sentinel 1 and Capella satellites resolutions



Source: https://geoforum.pl/news/30920/capella-space-udostepnia-pierwsze-zobrazowania-polski

2.1.1 Copernicus Services – six thematic streams

There are 6 Copernicus Services that are meant to provide the vast public with information on actual environmental, security, and climate change situations. Only Copernicus Land Monitoring Services represent static datasets for European Union and associated countries for Pan-European and Local scales. As an example of available datasets, one can mention: CORINE Land Cover, digital elevation model, detailed land cover for continuous urban areas greater than 100k inhabitants, coastal zones, forest, etc. Contrary Global-scale services consist of many dynamic datasets, which are updated in some time intervals based on the information provided by Sentinel constellations and more.

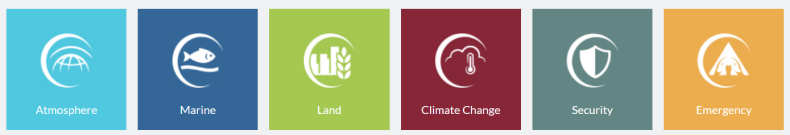
Atmosphere services are dynamic representations of actual air quality in the EU also with some forecasts for upcoming days. This information comes from Sentinel products and others, and also from local in situ measurements conducted by each member state. Incoming Sentinel 4 and 5 will strongly enrich these services with new data streams.

Marine Services use Sentinel 3 products combined with other datasets. They provide dynamic information on global and local scales. This information conveys the physical properties and quality of oceans and seas with a few day's forecast (water temperature, salinity, waves, etc.).

Climate Change Services are mostly focused on long-term forecasts of global climate.

Security Services are to show the main goals and actions of EU safety agencies such as FRONTEX.

Emergency Services show actual emergencies such as floods, fires, droughts, etc. at European and global scales.



These data is also partially accessible through some access points established by other European Institutions such as European Environment Agency (EEA).

2.1.2 DIAS – repository, data processing platform, and an access point to all Sentinel products and more…

Source: https://eo4society.esa.int/data-infrastructure/

As already mentioned all DIAS grant access to the available Sentinel satellites products since the first acquisition up to now. Each DIAS is meant to be an intuitive and user-friendly platform. Each DIAS offers satellite data searching and downloading by technical specification such as date of acquisition, product, processing level, instrument, orbit parameters, etc.

3 EO data help to create innovative ideas

EO data is accessible and free of charge as never before. The data is a goldmine of information and therefore a trigger for innovative ideas. Earth observation products can be combined with almost any aspect of our life – starting from precise farming, forest management, tourism, property insurance, food chain production, or health, ending up on global analyses of climate change.

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