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SPACE INNOVATION

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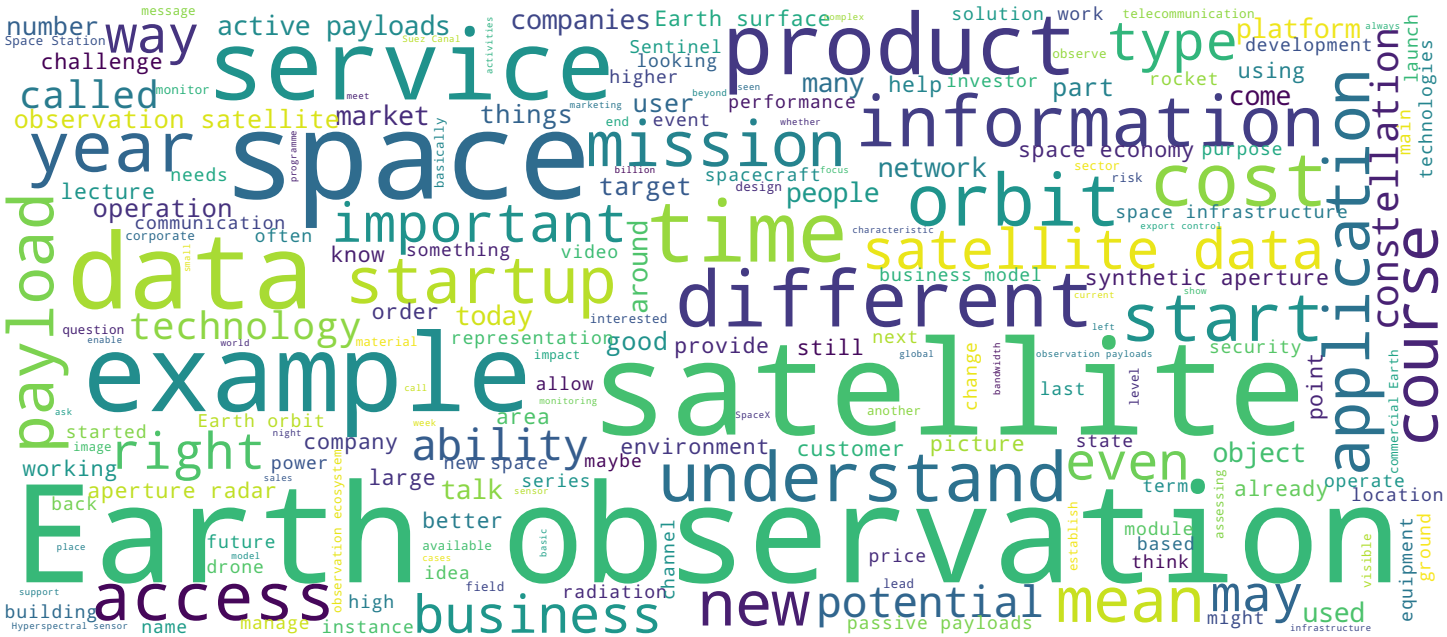
Earth observation infrastructures

New Space Economy

Andrea Alberti
PMOD/WRC

École polytechnique fédérale de Lausanne



Search MOOC

Video

EPFL

Space Assets – Earth Observation

- Introduction to Earth Observation
- The Earth Observation ecosystem
- EO infrastructure: satellites, passive and active payloads
- Earth Observation enablers and market share

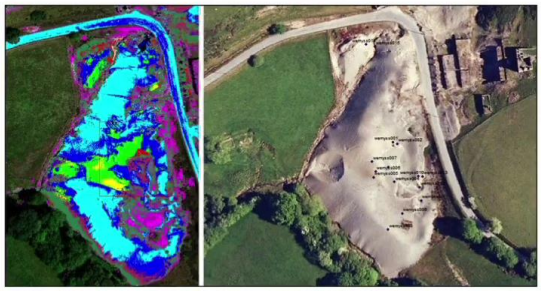
Hi, and welcome back. My name is Andrea Alberti. Together, we will understand the basics of Earth observation, what it is about, what enables it, and its potential. This module will be followed and strongly complemented by a series of lectures from specialists that will demonstrate the full potential of Earth observation as a powerful toolkit to analyze the Earth surface.

Notes

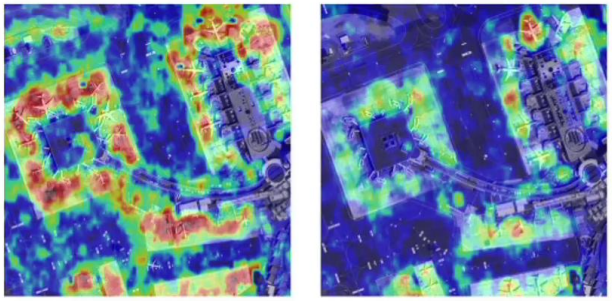
Summary

0m 05s

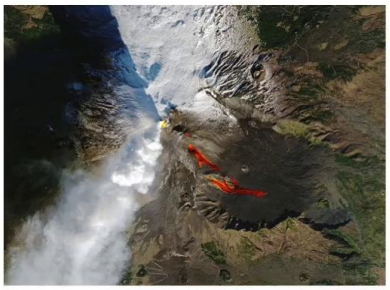
Introduction to Earth Observation



mine waste mapping at one of the mid-Wales mine sites (sdg.ac.uk)

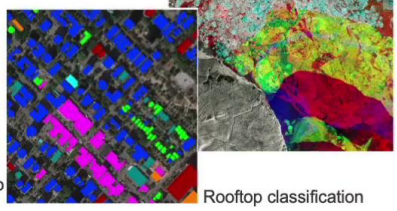


"Situational Awareness of Large Infrastructures Using Remote Sensing: The Rome–Fiumicino Airport during the COVID-19 Lockdown" Comparison 2019 VS 2020 first Covid Lockdown

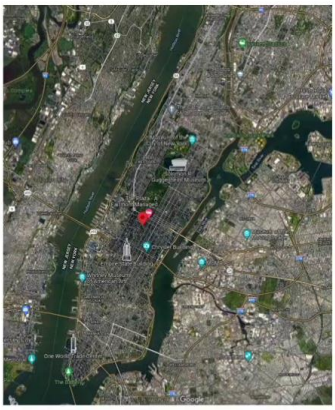


Etna Vulcan, 2018 OLI + TIRS (Landsat-8, NASA)

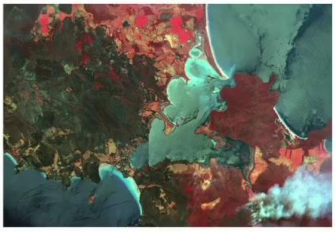
Trenches in Aksum Airport (Tigray, Ethiopia) render the runway unusable, 2020 (CapellaSpace)



Rooftop classification



Manhattan (Google Maps)



wildfires in Tasmania. Australia (Digital Globe/Getty)

Movement ice in the Lincoln Sea Canada. (Copernicus Sentinel data (2016-17) ESA

What is Earth observation? Intuitively, we are into a space economy course. We might conclude it is about images from satellites or about a collection of information about the Earth. We have all seen pictures from satellites in our lives, whether we are looking at the news and sometimes the most dramatic scenes are represented, whether we are using Google Maps, for example, to check out our next holiday destination, or we are picking a restaurant. The representation of the message we are fed with is supported very often by visual information from satellites, satellite imagery. Is this all about Earth observation?

Notes

Summary

0m 35s

Introduction to Earth Observation

- What? “Earth observation is the gathering of information about planet Earth’s physical, chemical and biological systems. It involves monitoring and assessing the status of, and changes in, the natural and man-made environment.”
- Why? “Human civilization is having an increasingly powerful influence on the Earth system. Earth observations are invaluable for assessing and mitigating the negative impacts. They can also be used for exploiting new opportunities, such as the sustainable management of natural resources.”

www.earthobservations.org

Most formally, Earth observation is defined as follows. Let's read together. Earth observation is the gathering of information about planet Earth's physical, chemical, and biological systems. It involves monitoring and assessing the status of, and changes in, the natural and man-made environment. Why Earth observation is important? Human civilization is having an increasingly powerful influence on the Earth system. Earth observations are invaluable for assessing and mitigating the negative impacts.

Notes

Summary

1m 26s

Introduction to Earth Observation

- "Earth Observation (EO) delivers information to enable fact-based decisions"
- Data is not information, information is not knowledge, knowledge is not understanding, understanding is not wisdom.

(Attributed to Clifford Stoll, paraphrasing Frank Zappa)

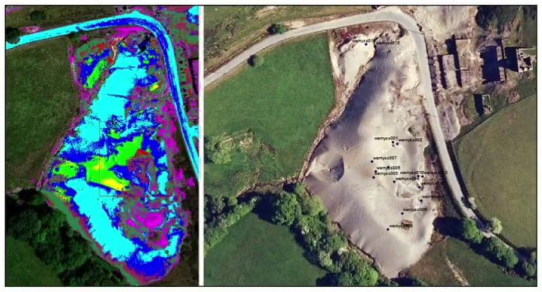
More concisely, Earth observation delivers information to enable fact-based decisions. Please note, I indicated information. We all should be aware that data is not information and information is not knowledge. Earth observation is indeed about satellite imagery and satellite data. But it is not only about that.

Notes

Summary

2m 04s

Introduction to Earth Observation



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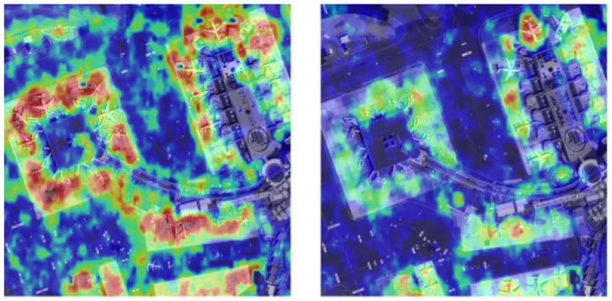

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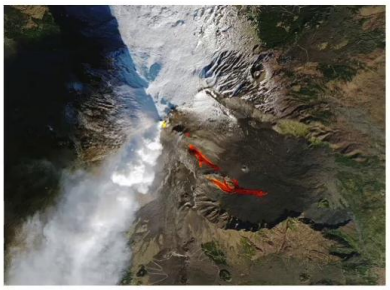
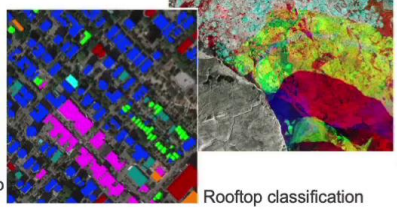
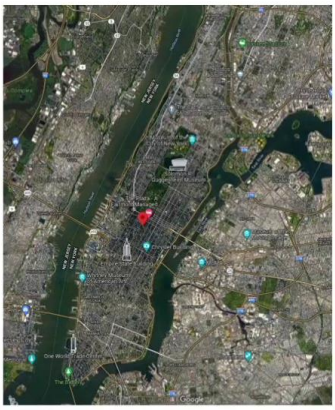


Etna Vulcan, 2018 OLI + TIRS (Landsat-8, NASA)

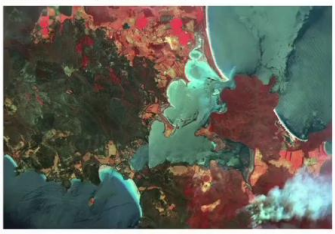
Trenches in Aksum Airport (Tigray, Ethiopia) render the runway unusable, 2020 (CapellaSpace)



Rooftop classification



Manhattan (Google Maps)



wildfires in Tasmania. Australia (Digital Globe/Getty)

Movement ice in the Lincoln Sea Canada. (Copernicus Sentinel data (2016-17) ESA

Let's step back to the examples we saw before. Most of what represented here is way beyond a simple picture a mine waste map, volcano eruption, trenches dig across an airstrip, human activities at an airport, and much more. These are all visualization of processed data combined with other data and information. To generate a representation that provide us concise information to our eyes, processing takes place to combine data from different sources and deliver us interpreted, organized information about the event we are interested to look at. Google Maps does not only provide satellite images, but merges data of different sources. Traffic data, elevation models, feed from the people to provide us an integrated platform that deliver us multiple information about the location we are observing.

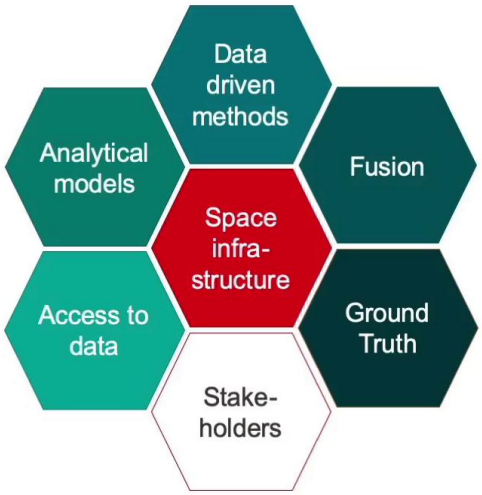
Notes

Summary

2m 31s

The EO ecosystem

- "Earth Observation (EO) delivers information to enable fact-based decisions."



We are starting to understand that Earth observation is more than just pictures. It is an ecosystem of products and services that leverages on Earth observation satellites, but not only. Earth observation satellites are the necessary space infrastructure at the core of this ecosystem, but satellites alone deliver data. The Earth observation ecosystem requires access to the data, analytical models, and data-driven methods to crunch the data, One may need complementary information to compile the products and services that we want to deliver, and we need ground truth observation to validate our products and services. Finally, we need stakeholders that allow this ecosystem to be active and prosperous.

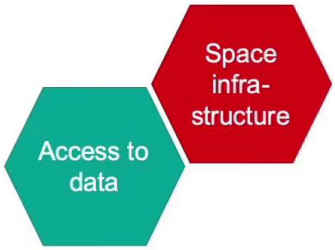
Notes

Summary

3m 37s

The Earth Observation ecosystem

- "Earth Observation (EO) delivers information to enable fact-based decisions."



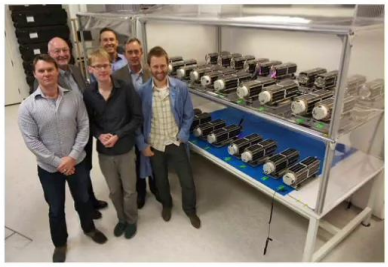
Let's start to concentrate on space infrastructure and on the access to data.

Notes

Summary

4m 32s

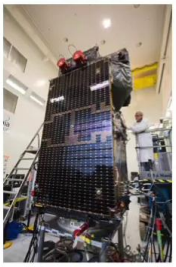
EO infrastructure: the satellites

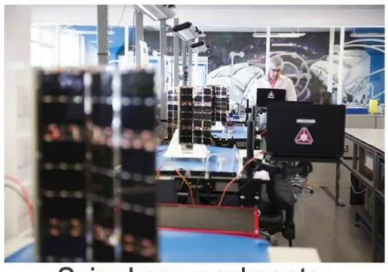

PlanetS Flock-1 cubesats


PlanetS RapidEye


Sentinel 1A


Sentinel 2B


Sentinel 3A


Spire Lemur cubesats


Satellogic NuSats


Pléiades Neo


WorldView-3


MetOp-C

ESA, Airbus, MAXAR, SPIRE, Satellogic, PlanetS, https://www.newspace.im/

Earth observation space infrastructure can be widely different. We span from CubeSats constellations as the PlanetS Flock, the Spire Lemur or [inaudible 00:04:50]. To constellations of medium-sized satellites as the Sattelogic NuSats or the PlanetS RapidEye, to the large and complex satellite systems as the WorldWiew, the MetOp or the Sentinels. There are about 30 commercial Earth observation constellations that are operational nowadays, and more than 100 that are planned or in preparation, not accounting for institutional satellites. There are many subsystems that compose a satellite. but at the core of an Earth observation satellite, we find the payloads, also called instruments or sensors.

Notes

Summary

4m 38s

EO infrastructure: the payloads

- Optical
  - Panchromatic
  - (multi-,hyper-) Spectral
- Radio
  - Microwave radiometry

- Optical
  - Laser imaging, detection, and ranging (LIDAR)
- Radio
  - Radar
  - Synthetic Aperture Radar (SAR)
  - Radio Occultation

Image Source: Radiant Earth
See also https://business.esa.int/newcomers-earth-observation-guide

We can classify Earth observation payloads in different manners. Here we classify them as active or passive payloads. Let's start to look at passive payloads first. Here, the sensors rely on capturing the radiation that leads the target, either because of the sun radiation that is being reflected by the target, or because of the thermal radiation that is being emitted by the target itself. These payloads are working much alike a traditional photographic camera without the need for an active man-made stimuli.

Notes

Summary

5m 36s

Passive optical EO payloads: panchromatic

- acquiring “black and white” data

March 27, 2021, Credit: PlanetS (estimated 0.5-0.8 m GSD)

Let's start to look at some typical passive payloads. To do this, we use a famous case that happened in March 2021 when the Ever Given container transport ship got stuck into the Suez Canal. We have optical passive payloads that deliver panchromatic that is black and white data, mostly in the form of pictures, and in some cases, of videos. These payloads are generally delivering fast rate data and with higher ground resolution. That means smaller pixels on ground.

Notes

Summary

6m 16s

Passive optical EO payloads: multispectral

- acquiring data over multiple spectral channels (“colors”)
  - e.g. RGB and beyond

March 28, 2021 Credit: Maxar (WorldView3, estimated 0.3 m GSD)

Passive optical payloads can also deliver data with spectral content. These payloads are generally called multispectral sensors.

Notes

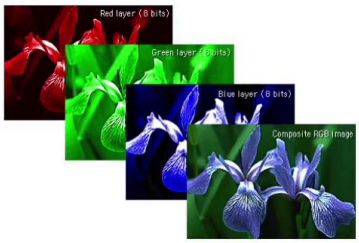
Summary

6m 53s

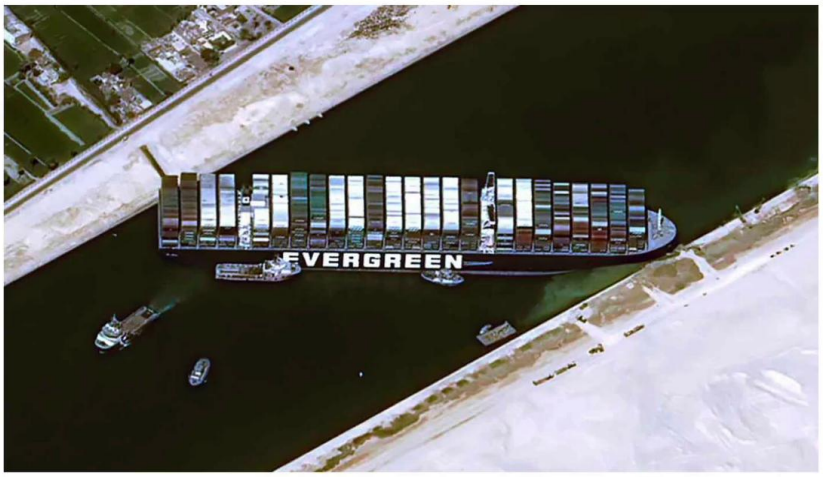
Passive optical EO payloads: multispectral

Multispectral camera assembly with 4 bandpass filters (e.g.MAPIR)

Imaging payload (e.g. ISI EROS NG)



- acquiring data over multiple spectral channels ("colors")
  - e.g. RGB and beyond



March 25, 2021 Credit: Airbus Pleiades (Pleiades)

A normal color image delivers us with three spectral bands: the red, the green, and the blue. In addition, many payloads offer additional spectral bands, let's say, additional colors in the visible and in the infrared range. The payloads that generate multispectral content are substantially highly sophisticated cameras equipped with special imagers, depending on the technology and on the design solution adopted. For example here, a series of filters are placed right in front of the imager, or here, a series of independent imagers are equipped, each with a dedicated filter. Multispectral payloads typically operate in the visible and in the infrared region and are present together with panchromatic payloads on many institutional and commercial Earth observation satellites.

Notes

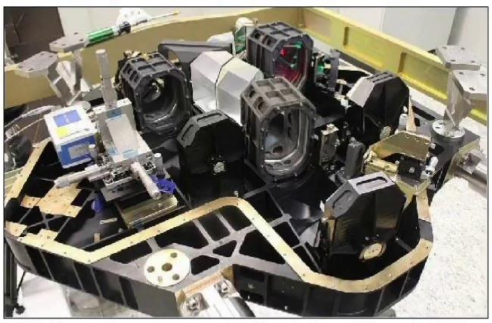
Summary

7m 03s

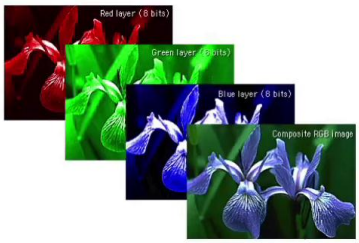
Passive optical EO payloads: hyperspectral

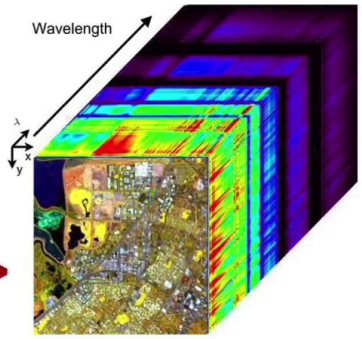
Multispectral camera assembly with 4 bandpass filters (e.g.MAPIR)

Imaging payload (e.g. ISI EROS NG)



PRISMA ("hyper-")spectrometer, 237 bands from 400 nm to 2505 nm





"Hyperspectral image compression: Adapting SPIHT and EZW to anisotropic 3-D wavelet coding"

Hyperspectral sensors are instead highly sophisticated payloads that are able to distinguish a much more detailed spectral content of the scene under observation. Multispectral sensors provide a limited amount of bands or colors to the users. Hyperspectral sensors instead provide a highly resolved spectral content, very often in a continuous fashion of a portion of the electromagnetic spectrum. The design and development of a hyperspectral sensor is generally very complex, and they are mostly built through institutional funding.

Notes

Summary

8m 04s

Passive optical EO payloads: beyond what meets the eye

Hyperspectral and multispectral sensors jointly support data products generation to monitor

- Atmosphere
- Water
- Vegetation
- Forestry
- Land use
- Mineralogy
- …and much more

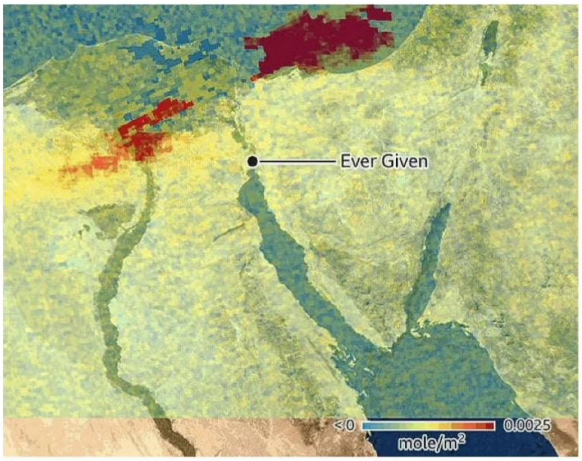
Hyperspectral imagers, together with multispectral imagers, support a generation of so-called data products that offer the ability to understand our environment well beyond what meets the eye. These payloads actively contribute to monitoring atmosphere: water, vegetation, forestry, land use, mineralogy, and much more.

Notes

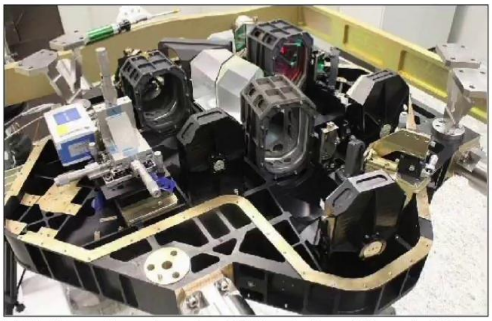
Summary

8m 46s

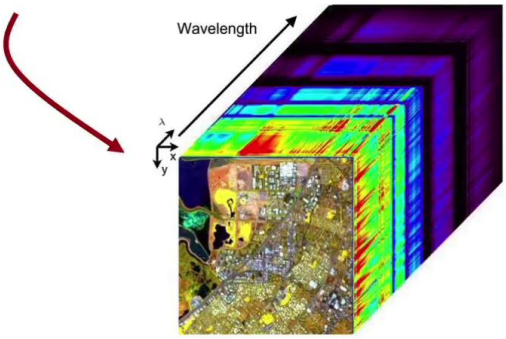
Passive optical EO payloads: beyond what meets the eye



Sulphur Dioxide levels at Suez Canal, March 23rd to March 29th 2021
(Sentinel 5P processed SO2 data product)



PRISMA ("hyper-")spectrometer, 237 bands from 400 nm to 2505 nm



"Hyperspectral image compression: Adapting SPIHT and EZW to anisotropic 3-D wavelet coding"

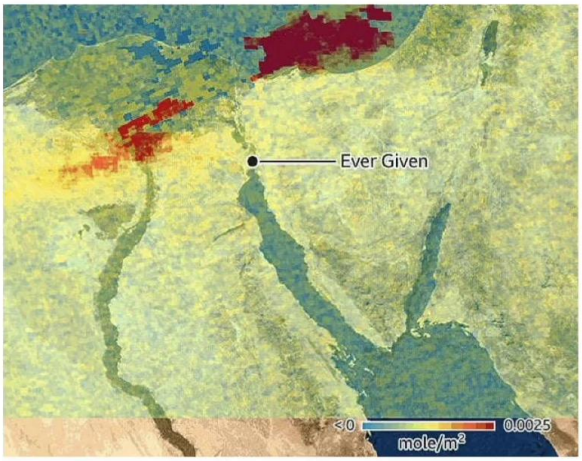
In this example on the left, it is visualized the measured increase in sulfur dioxide gas emissions as the Suez Canal was blocked by the Ever Given. Commercial ships were being hoteling at the entrance of the channel in the Mediterranean Sea.

Notes

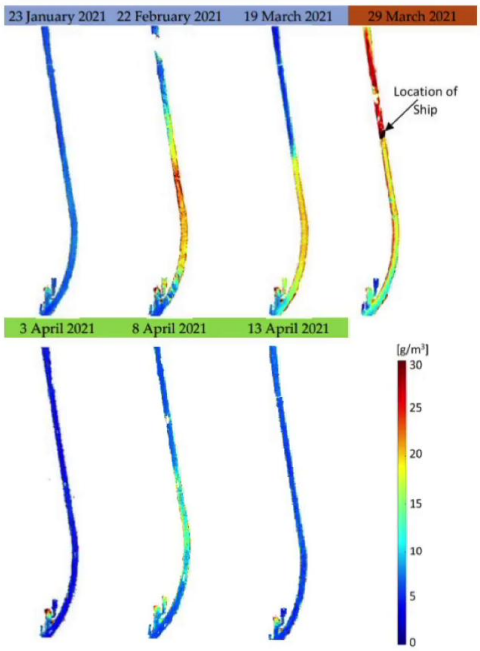
Summary

9m 10s

Passive optical EO payloads: beyond what meets the eye



Sulphur Dioxide (SO2) levels at Suez Canal, March 23rd to March 29th 2021 (ESA Sentinel 5P processed SO2 data product)



Evolution of Total Suspended Matter (TSM) in the Suez Canal during the Evergreen blockade.

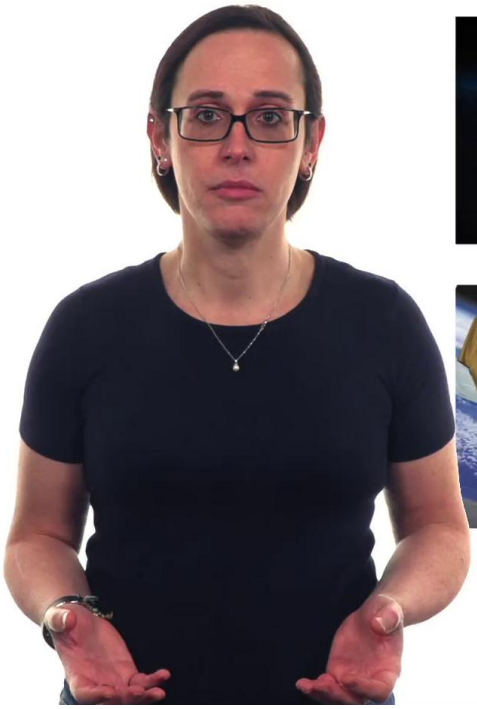
While here on the right, we see the evolution of total suspended matter in the water of the channel during the Ever Given blockade. Total suspended matter directly relates to the water habitat quality.

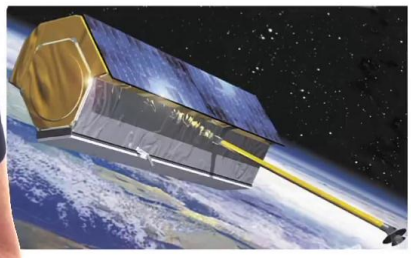
Notes

Summary

9m 29s

EO infrastructure: the payloads





- Optical
  - Laser imaging, detection, and ranging (LIDAR)
- Radio
  - Radar
  - Synthetic Aperture Radar (SAR)
  - Radio Occultation

Image Source: Radiant Earth
See also https://business.esa.int/newcomers-earth-observation-guide

Active payloads rely instead on the ability to capture the radiation that has been first generated by a man-made active piece of equipment. This radiation is directed to a target and is then reflected back to a sensor. There are active payloads that operate in the optical domain, as sliders. There are active payloads that operate in the radio domain as radars, synthetic aperture radars, and radio occultation payloads. In general, active payloads that operate in the radio domain look very different from a camera or a telescope, but still they embed technologies that allow us to monitor and observe the Earth's surface.

Notes

Summary

9m 45s

Active EO Payloads: Synthetic Aperture Radar

- See Earth surface through clouds and at night

Ever Given Friday, March 26, 2021 50 cm imagery Credit: Capella Space

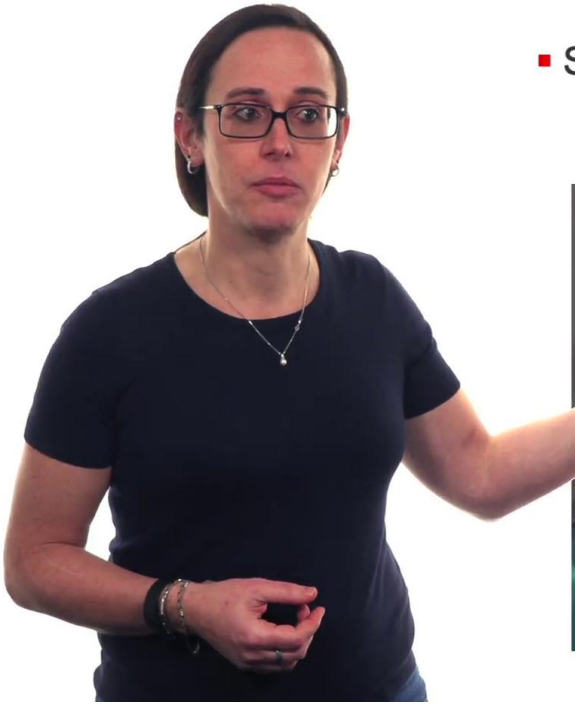
Let's look at some of the products of synthetic aperture radars. Because of the different nature of the payload and because of the different wavelengths at which they operate, synthetic aperture radar can observe the Earth's surface at night or irrespectively of cloud coverage.

Notes

Summary

10m 32s

Active EO Payloads: Synthetic Aperture Radar



- See Earth Surface through clouds and at night

March 28, 2021 Credit: Maxar (WorldView3, estimated 0.3 m GSD)

This offering is a strong complement to the capabilities of optical passive Earth observation methods.

Notes

Summary

10m 51s

Active EO Payloads: Synthetic Aperture Radar

- Measure actual surface altitude
  - Water floods
  - Land subsidence
  - Human and industrial activities

https://www.iceye.com/solutions/insurance/urban-flood-monitoring

Synthetic aperture radars do not only have the ability to see through clouds and at night, but can also measure elevation changes. This is functional to detect and to monitor water floods, as in this example from the startup ICEYE, land subsidence, and human and industrial activities.

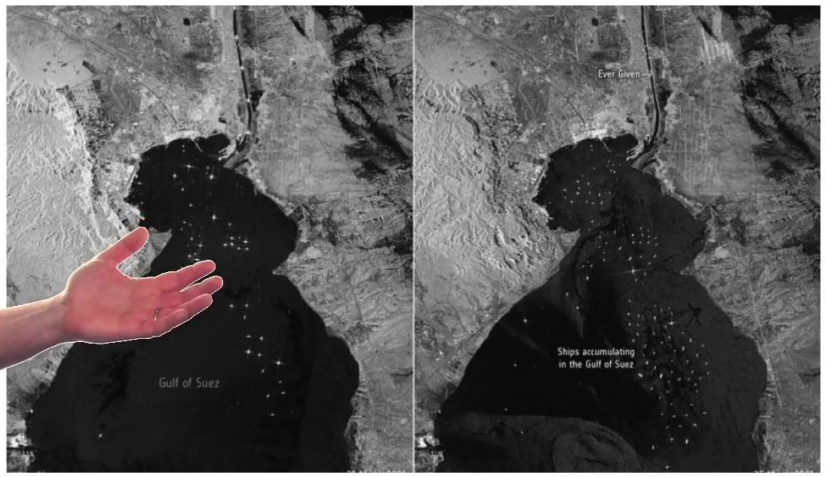
Notes

Summary

10m 59s

Active EO Payloads: Synthetic Aperture Radar

- Establish situational awareness visualization



Ships accumulating at the south entrance of Suez Canal from March 21st to March 25 th Copernicus Sentinel 1. https://www.esa.int/

Here, another example of the ability of synthetic aperture radars to monitor the ship traffic accumulating at the South entrance of the Suez Canal.

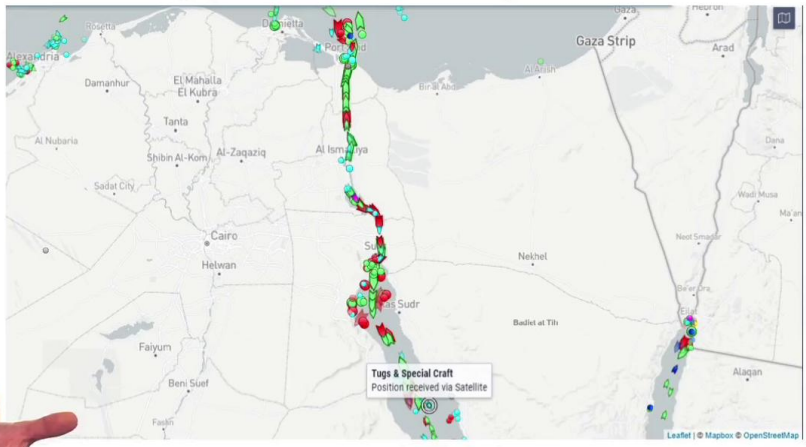
Notes

Summary

11m 22s

Active EO Payloads: Automatic Identification Systems

- Establish situational awareness visualization
  - Active Sensing of Transponders
  - Detecting position and tracking routes



Ship position close to Suez Canal Credit: MarineTraffic.com

A last example of active payloads may be spurious, as it is a crossover between different domains are the automatic identification systems. Instead of monitoring the active signal generated by another satellite, automatic identification systems detect the active signal of aircraft or ship transponders and locate them on the Earth's surface. This technique contributes to monitoring and assessing man-made activities.

Notes

Summary

11m 33s

Main Characteristics of EO Payloads and their data

- Ground resolution (or GSD)
- Swath
- Revisit period
- Data quality
- Spectral range
- Spectral resolution
- Radiometric resolution
- Size, Weight and Power (SWaP)

PlanetS. ESA

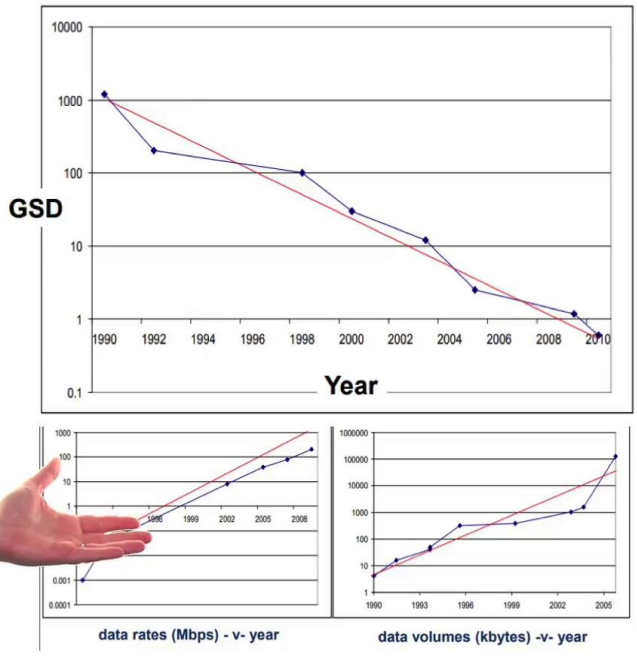
For both passive and active payloads, there are characteristics that define their complexity and cost, and help us to better understand their technical offerings, and to decide which type of data are more helpful for our purposes. These characteristics will be discussed in deep in other modules. Let's focus instead on size, weight, and power. If we want to build and deliver a payload, or if we want to host a payload on our satellite, the location of size, weight, and power is crucial to define the cost of equipment and its performance. Miniaturization of technologies plays an important role. But for Earth observation payloads, laws of physics rule the dimensioning of the equipment. As a rule of the thumb, the larger the payload, the higher the cost of the payload, the better the performance is we can expect. Nevertheless, we should ask ourselves what the targeted end user really seek in terms of data quality.

Notes

Summary

12m 07s

Moore’s Law applied to Earth Observation payloads



Prof. Sir Martin Sweeting: “Microsatellites moving from research to constellations meeting real operational missions”, Tokio, 2010

Over time, the performance of Earth observation payloads has been improving dramatically. Payloads have been able to acquire better resolved, more detailed scenes. At the same time, the ability to download data from satellites and consequently the data rates has been highly increased to cope with increased resolutions.

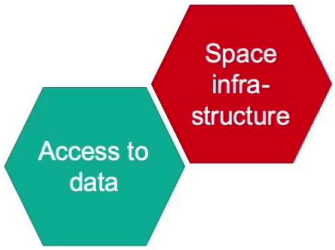
Notes

Summary

13m 18s

The Earth Observation ecosystem

- "Earth Observation (EO) delivers information to enable fact-based decisions."



As we start to talk about data, let's look at how to access them. Access to data is a key enabler of the overall Earth observation ecosystem. We can distinguish two main approaches: the open data policies and the commercial policies.

Notes

Summary

13m 42s

Earth Observation Enablers: Access to Data

- Open Data Policies
  - USGS Open Data Policy (2007)
  - Copernicus Data Policy (2010, 2013, 2014)
  - ESA Data Policy and its revisions (2010)
  - NOAA NESDIS Data Policy (2011)
  - G8 Open Data Charter (2013)

https://mitpress.mit.edu/blog/open-data-global-effort-open-access-satellite-data

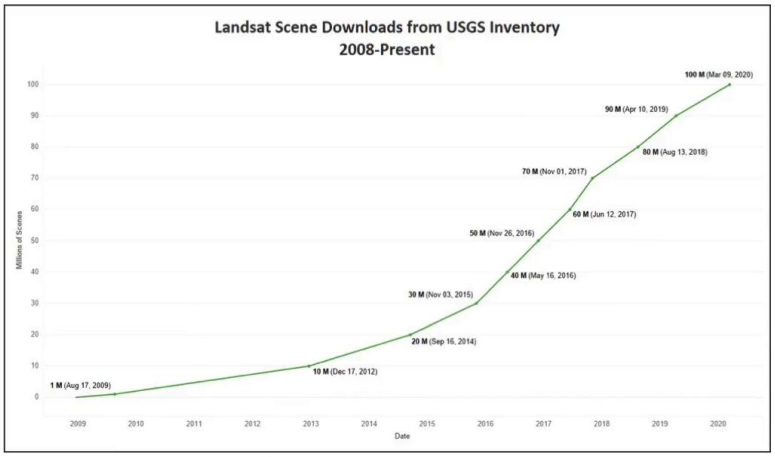
Up to year 2,000, access to satellite data was limited and costly. But since year 2007, a wave of policy changes has been adopted by the main institutional providers of satellite data that initiated free distribution for the majority of users and scopes. Let's take the case of the data managed by the USGS.

Notes

Summary

14m 02s

Earth Observation Enablers: Access to Data



- User enquiry shift to multi-years scenes at same location
- Data delivered to 186 countries (2013)
- From 25’000 scenes/year in 2001 to 25’000 scenes/month in 2012
- From <1 M scenes by 2008 to >100M scenes by 2020

https://www.usgs.gov/core-science-systems/nli/landsat/march-11-2020-landsat-downloads-top-100-million

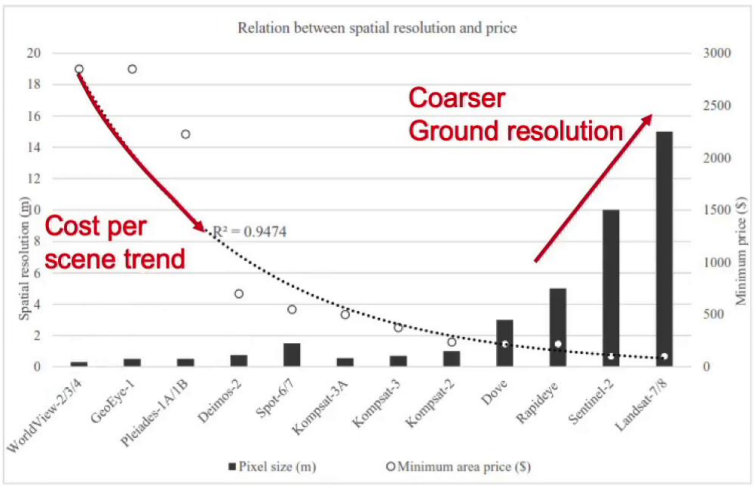
Up to year 2007, the accumulated amount of scenes distributed for the Landsat satellites against the fee was less than one million overall. But in year 2020, more than 100 million scenes accumulated were distributed, serving users from more than 186 countries. Users also started to change the behaviour from a single scene to multiple scene coverage at multiple times for the same location.

Notes

Summary

14m 27s

Access to Data: dependance on GSD



Sozzi, Marinello, Pezzuolo, Sartori "Benchmark of Satellites Image Services for Precision Agriculture" (2018)

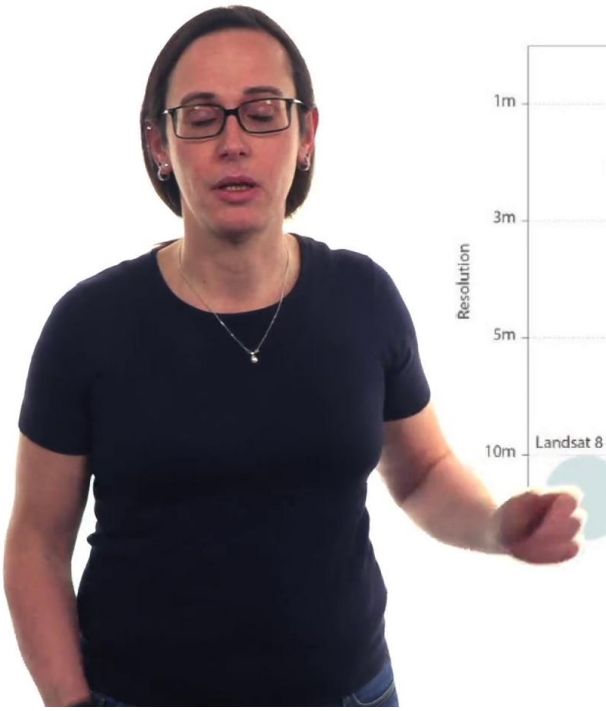
But the open data policies are not the only way to access satellite data. Multiple commercial operators distribute satellite scenes, and we can identify three major drivers for the costing. The smaller the pixel size, that is, the better the resolution, the higher the cost.

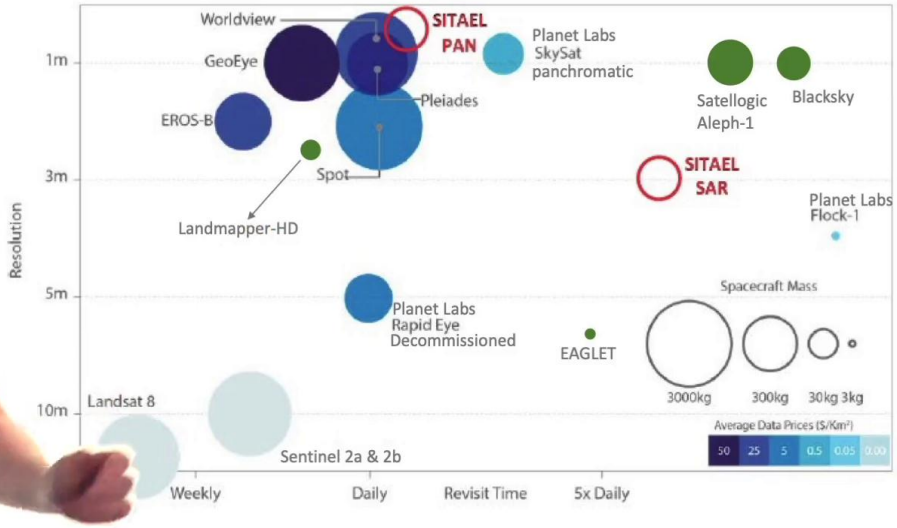
Notes

Summary

15m 01s

Access to Data: dependance on revisit time





Elaborated from Stanzione V. et al "Earth Observation In New Space Economy: Constellations Of Small Satellites", Italian Association of Aeronautics and Astronautics, XXV International Congress, 9-12 September 2019 Rome, Italy

At the same time, a course correlation is existing between frequency of the light or constellation revisit time, ground resolution, and price per scene.

Notes

Summary

15m 23s

Earth Observation Enablers: Access to Data

- Open Data Policies
- Commercial Data Policies
  - Dependency on GSD
  - Dependency on Revisit time
  - Corporate specific policies
  - Broker

Finally, each commercial entity has a corporate specific policy that may ease or make more complicated the access to a specific data set of interest. Having to deal with different data providers can be very cumbersome. The role of satellite data brokers is arising as a middleman between the commercial entities and the users.

Notes

Summary

15m 35s

The EO ecosystem: the data growth rate

- Increase rate of EO raw data
  - 20+ TB/day downloaded by the Sentinel 1,2,3 fleet (2018)
  - 100+ TB/day downloaded by commercial EO satellites (2020)
- ~45 Petabytes/year (45000 TB/year) of imagery stored in servers.

https://datacenterfrontier.com/terabytes-from-space-satellite-imaging-is-filling-data-centers/ (2020)
"Big Earth data: disruptive changes in Earth observation data management and analysis?" (2018)

Earth observation data are growing at an incredible pace. Institutional constellations as the Sentinels is downloading more than 20 terabytes of data every day. Commercial Earth observation satellites are estimated to download more than 100 terabytes of data each day. This translates into petabytes of raw data stored each year on public and private servers, data that needs to be backed up, calibrated, processed, scrutinized, analyzed.

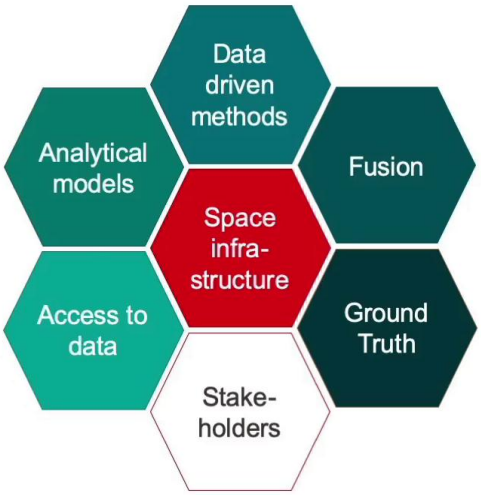
Notes

Summary

15m 59s

The EO ecosystem

- "Earth Observation (EO) delivers information to enable fact-based decisions."



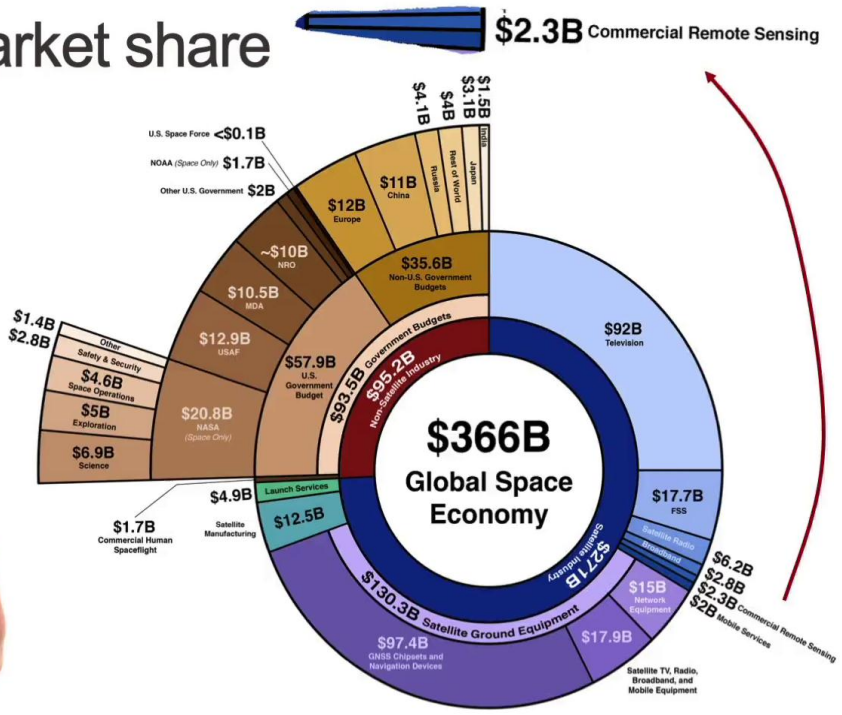
Here lies the relevance of the Earth observation ecosystems, complemented by analytical models, data-driven models, and data fusion approaches in order to deliver the stakeholder's sensible, concise, and understandable information.

Notes

Summary

16m 31s

Earth Observation market share



Bryce Space and Technology – 2019 Global Space Economy at a Glance

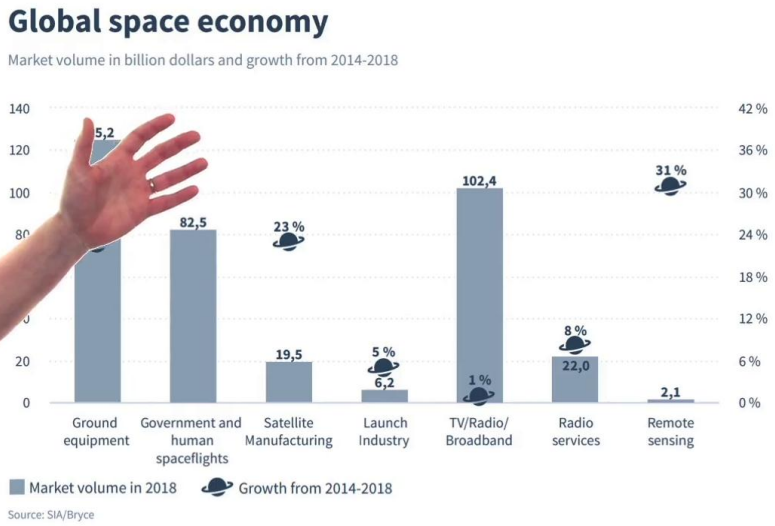
We conclude on the financial volume generated by the Earth observation enterprises. We only focus on those companies whose products and services are based on Earth observation data. This was totaling in 2019 to about $2.3 billion, and this is indeed a small market share considering the overall investment performed to establish the satellite constellations, and to manage them and to manage the data. But we shall have a look at the rate of growth.

Notes

Summary

16m 48s

Earth Observation market share



Institut der deutschen Wirtschaft "Kurzbericht 43/2019 Space Economy" from SIA Bryce data

In this representation, we can see how between 2014 and 2018, the Earth Observation share has been one of the most growing segments of the overall space economy.

Notes

Summary

17m 26s

The Earth Observation infrastructure: conclusions

- Earth Observation delivers information to enable fact-based decisions
- Earth Observation is an ecosystem centered on space infrastructure, but not only
- The added value of Earth Observation is to reveal more than what meets the eye.

Let's recap together. Earth observation delivers information to enable fact-based decisions. Earth observation is an ecosystem based on space infrastructure and is complemented by additional expertise and competencies. The added value of Earth observation is to reveal more than what meets the eye. The final thought, whereas Earth observation has been used widely by institutions and governments to set and monitor policies, an increasing amount of business agencies are using Earth observation products and services for their commercial and financial use. Thank you very much for your attention. Goodbye.

Notes

Summary

17m 39s