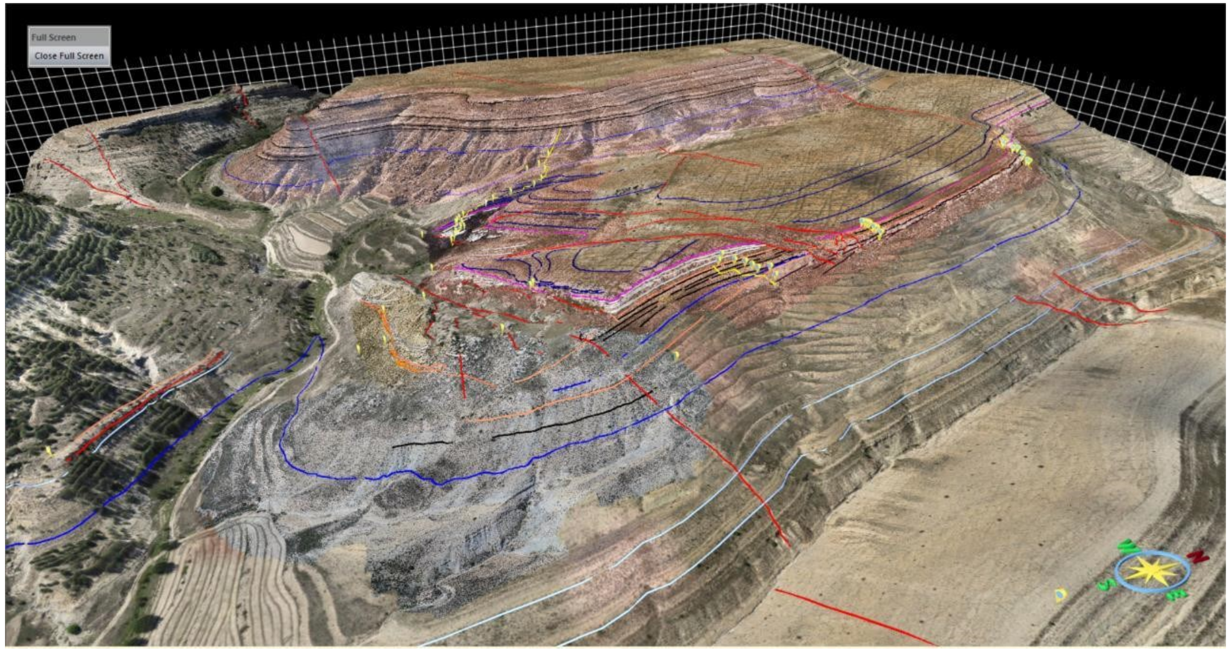
VIRTUAL OUTCROP GEOLOGY



DOCENTI: DOTT. MARCO FRANCESCHI – DOTT. AMERIGO CORRADETTI

CFU: 6

a. a. 2021-2022

VIRTUAL OUTCROP GEOLOGY

Theory:

- Fundamentals of remote sensing
- Fundamentals of photogrammetry
- Photogrammetric systems and procedures for data acquisition
- Positioning systems and use of ground control points
- Point clouds and textured meshes

Laboratory:

- Photo acquisition
- Data processing and model building
- Model interpretation and analysis

Virtual Outcrop Geology

What do you already know about Virtual Outcrop Geology?

What do you need to know and how will you be assessed?

- **Oral examination** on arguments treated in class with the support of a **PC**.
- Present one or more of the models realized during the course (**discuss outcomes**).
- During the course we will ask each one of you to make a 10-15 minutes presentation to the class on how 3D models have been used in a **scientific paper**. Each paper is a subject for the final exam.

VIRTUAL OUTCROP GEOLOGY

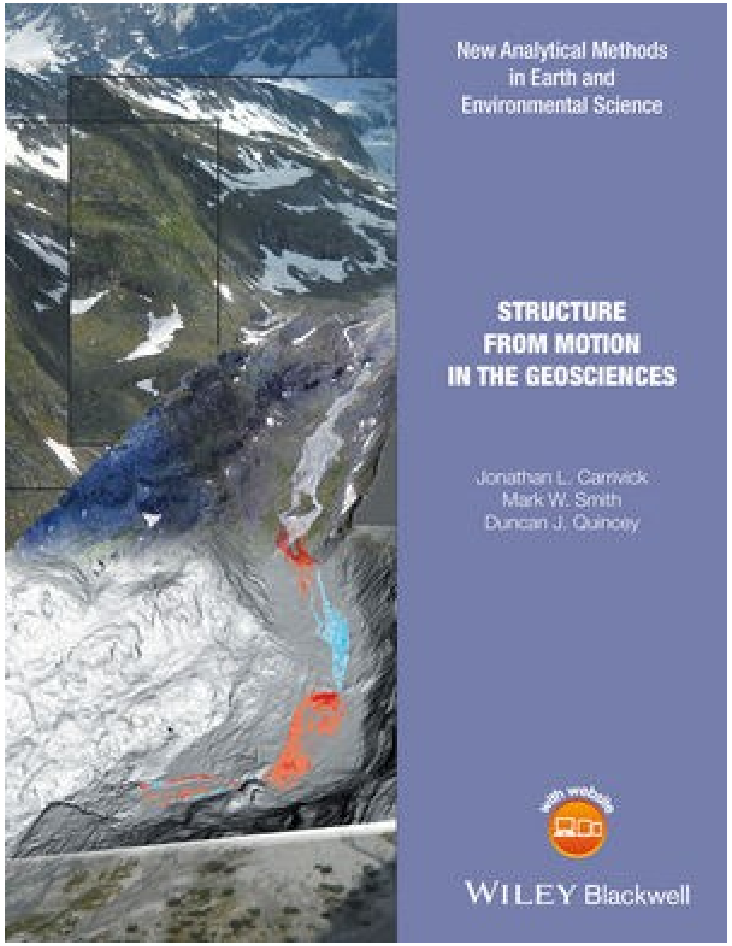
Provisional schedule:

Lesson 1 (Class – 2 hours) – **Introduction to Virtual Outcrop Geology and Remote Sensing**
Lesson 2 (Class – 2 hours) – **Photogrammetry – Theory and basic principles – GCPs**
Lesson 3-4 (Laboratory – 4 hours) – **Preliminary photo acquisitions – Use of Agisoft Metashape – Use of CloudCompare**
Lesson 5 (Field – 6 hours) – **Guided field data acquisition – Use of a gimbal – Use of GCPs – Short video**
Lesson 6-7 (Laboratory – 4 hours) – **Guided data processing and analysis – Use of the OpenPlot to rotate camera orientations**
Lesson 8-9 (Laboratory – 4 hours) – **Orientation data extraction from OpenPlot – Data analysis – Use of mask in photos – Model filtering – Meshing and texturing**
Lesson 10 (Field – 6 hours) – **Semi-guided field data acquisition – Orientation data in the field**
Lesson 11-12-13-14 (Laboratory – 8 hours) – **Semi-guided data processing and analysis – Use of mask in photos – Orthorectified images from models**

Lesson 15 (Laboratory – 4 hours) – **Introduction to other software used in geosciences for model building and interpretation of VOMs – Short seminar by prof. Simon Buckley on the software LIME.**
Lesson 16 (Class – 2 hours) – **Applications of VOMs. Discussion of scientific papers that have involved the use of VOMs (10 minutes each).**
Lesson 17 (Field – 6 hours) – **Data acquisition for the exam**
Lesson 18-19-20-21 (Laboratory – 8 hours) – **Elaboration of final model and analysis**
Lesson 22-23 (Laboratory – 4 hours) – **Open session – Finalization of the models for the exam**

60 hours in total

VIRTUAL OUTCROP GEOLOGY



This book is designed to act as a primer for scientists and environmental consultants working within the geosciences who are interested in using SfM or are seeking to understand more about the technique and its limitations. The early chapters consider SfM as a method within the context of other digital surveying techniques, and detail the SfM workflow, from both theoretical and practical standpoints. Later chapters focus on data quality and how to measure it using independent validation before looking in depth at the range of studies that have used SfM for geoscience applications to date. This book concludes with an outward look towards where the greatest areas of potential development are for SfM, summarizing the main outstanding areas of research.

https://onlinelibrary.wiley.com/doi/book/10.1002/9781118895818

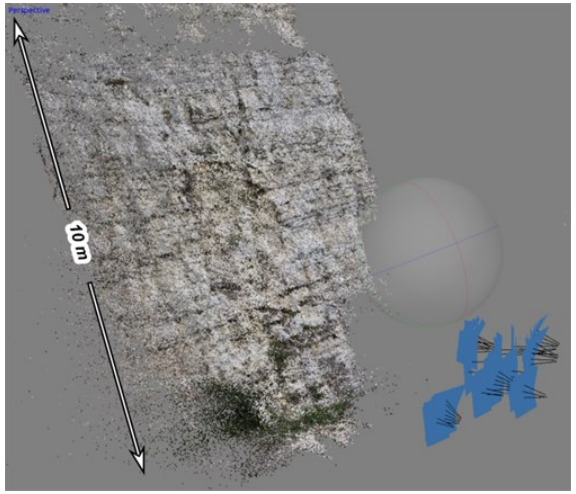
A brief introduction on Virtual Outcrop Geology

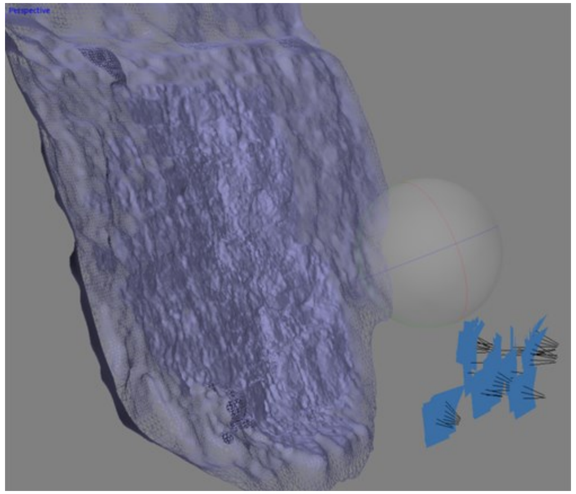
What do we mean by **virtual outcrop geology**?

Virtual outcrop geology is the study of rocks exposures (e.g., their composition, arrangement, and deformation) using 3D models of geological outcrops (or **Virtual Outcrop Models**). Virtual outcrop geology can be considered as a branch of **remote sensing**.

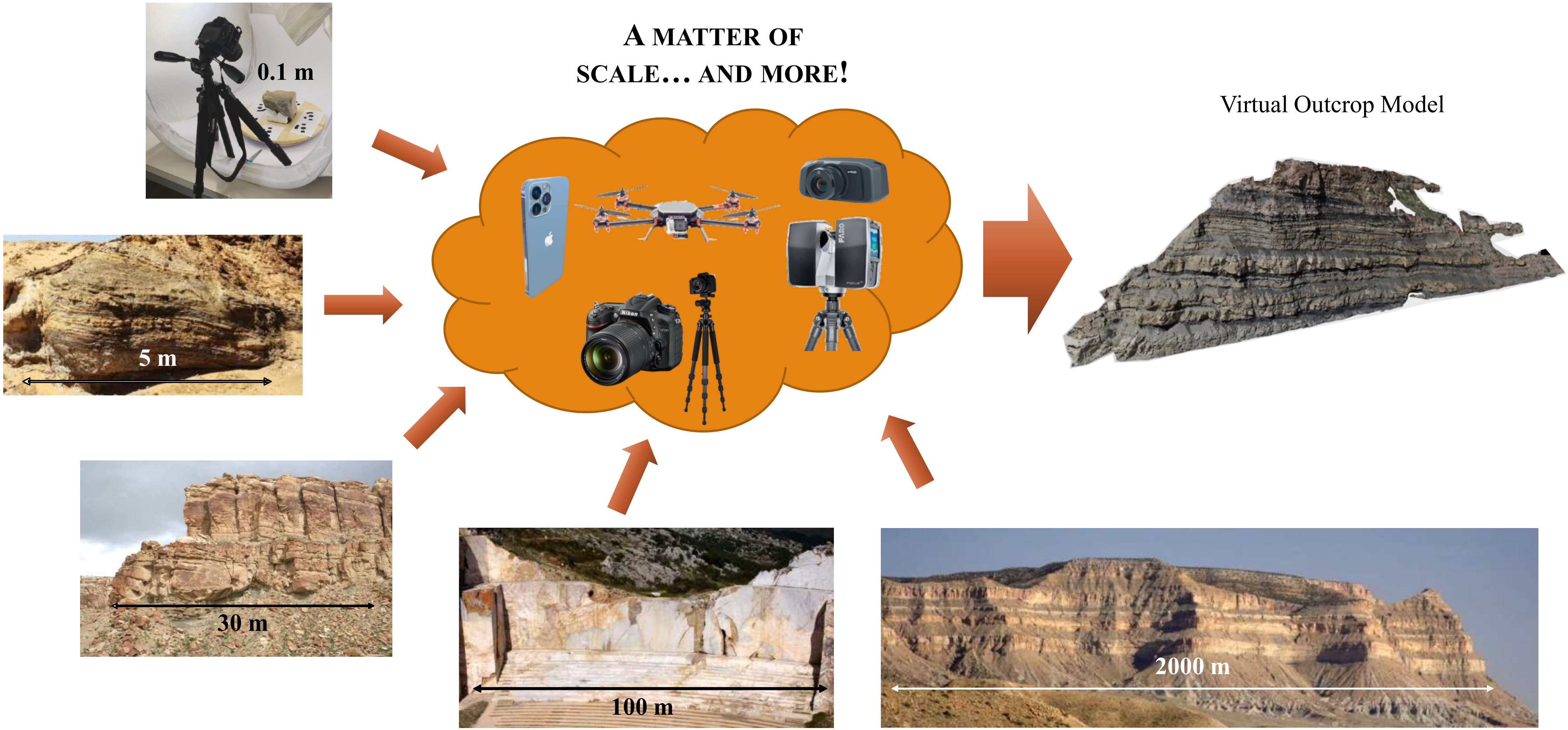
What is a **Virtual Outcrop Model** (VOM)?

A virtual outcrop model (**VOM**) (Xu et al., 1999, 2000), also referred to as digital outcrop model (**DOM**) (Bellian et al., 2005) or photorealistic outcrop model (Buckley et al., 2008), is a 3D representation of the outcrop surface in the form of a (colored) point cloud or a textured polygonal mesh.

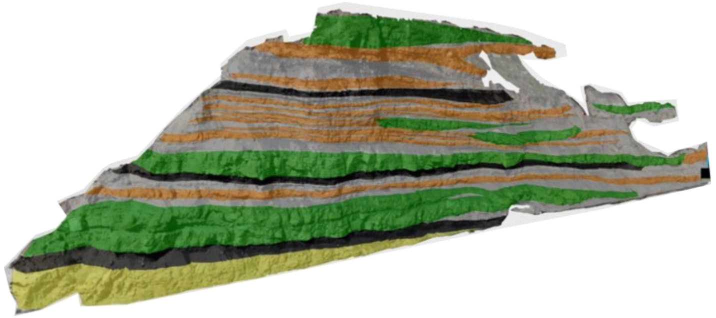


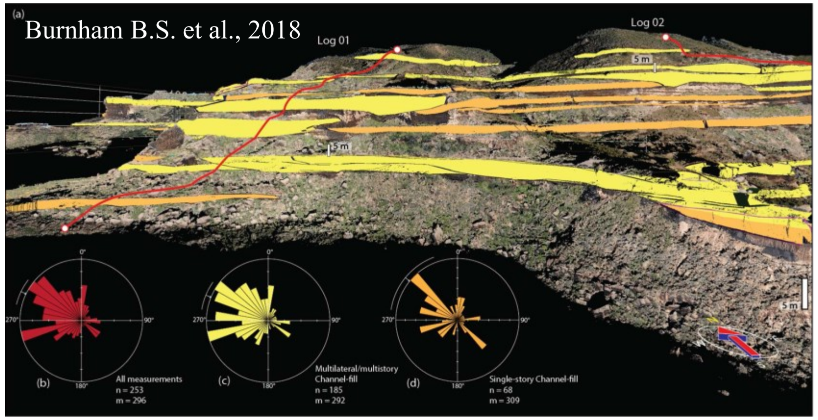


A brief introduction on Virtual Outcrop Geology



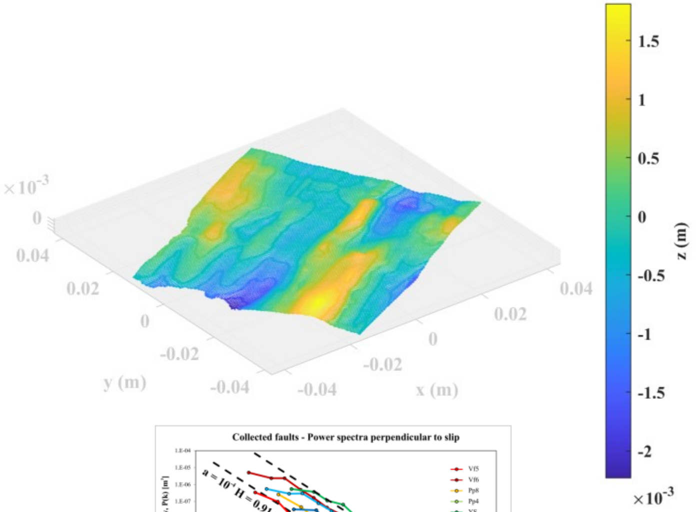
A brief introduction on Virtual Outcrop Geology

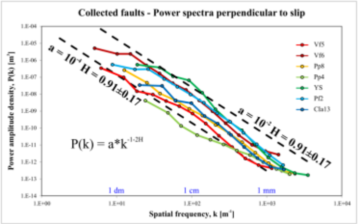


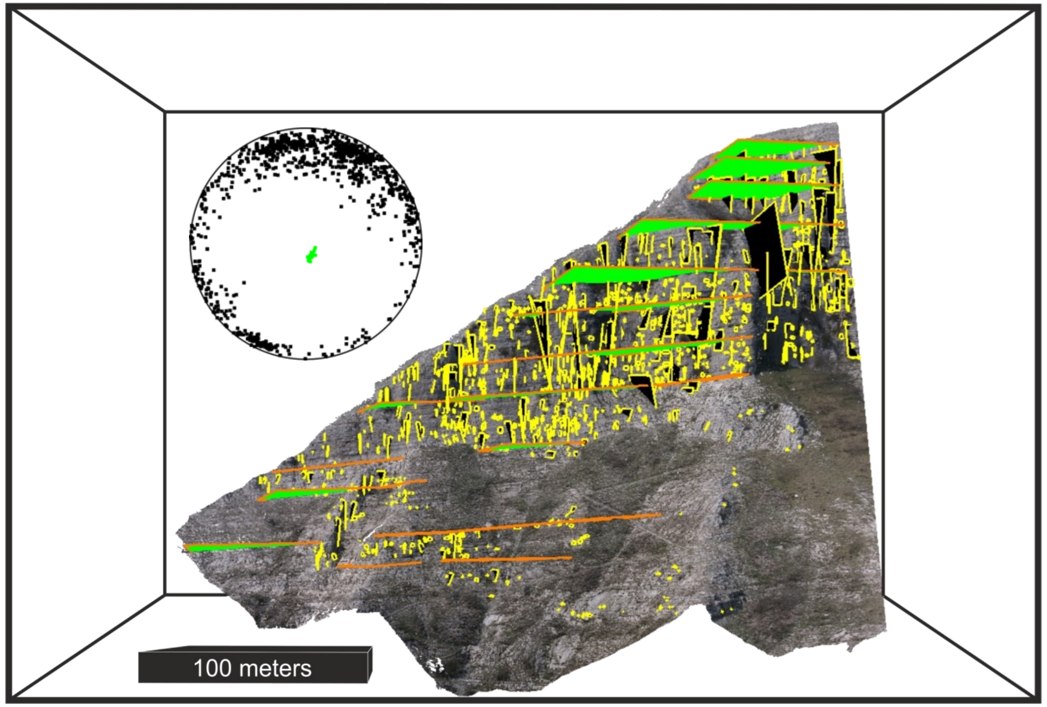


3D MODELS ARE QUANTITATIVE OBJECTS

3D digitization makes the study of outcrops statistically relevant providing quantitative and hence fully interrogable objects.

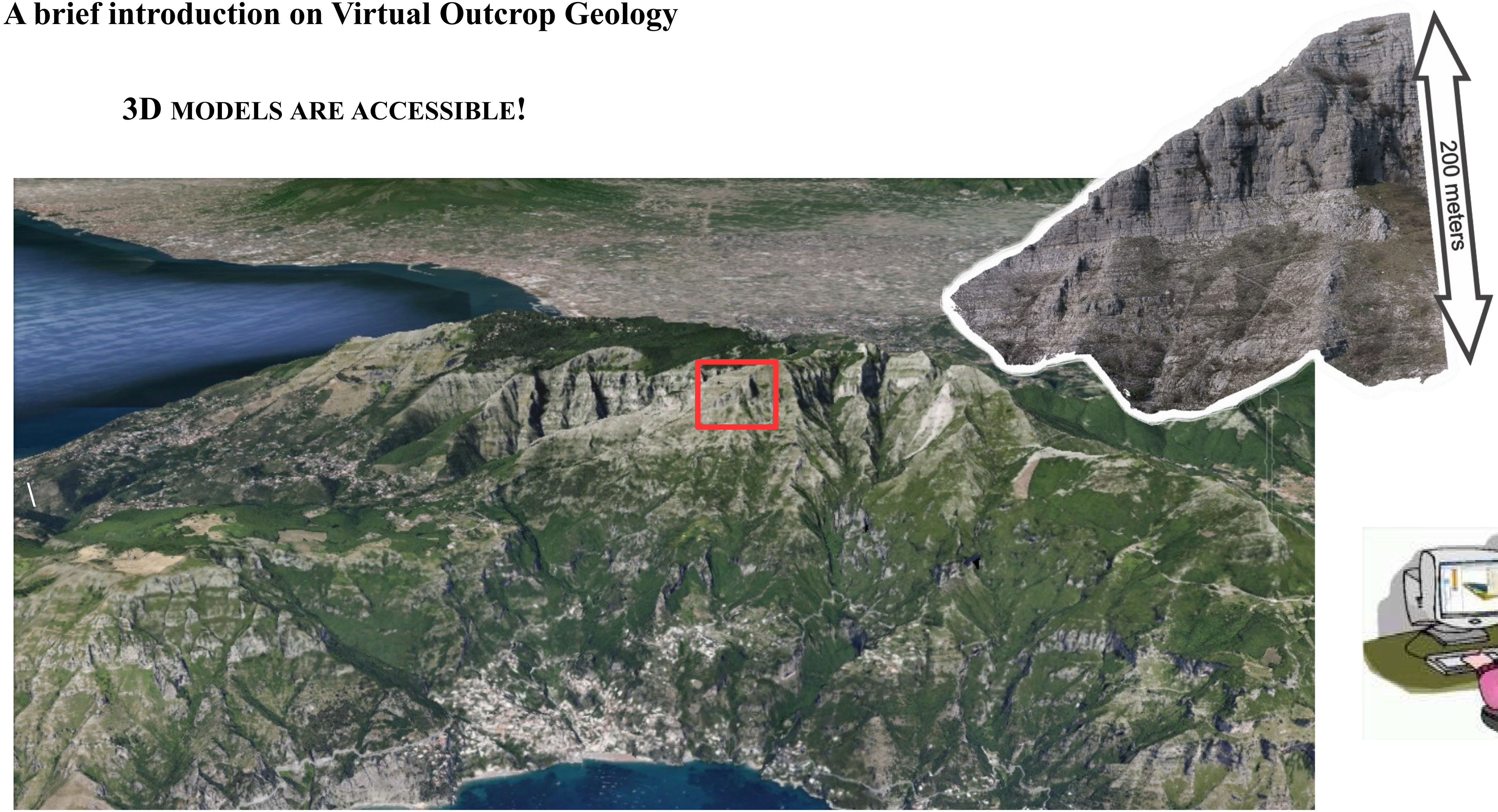






A brief introduction on Virtual Outcrop Geology

3D MODELS ARE ACCESSIBLE!

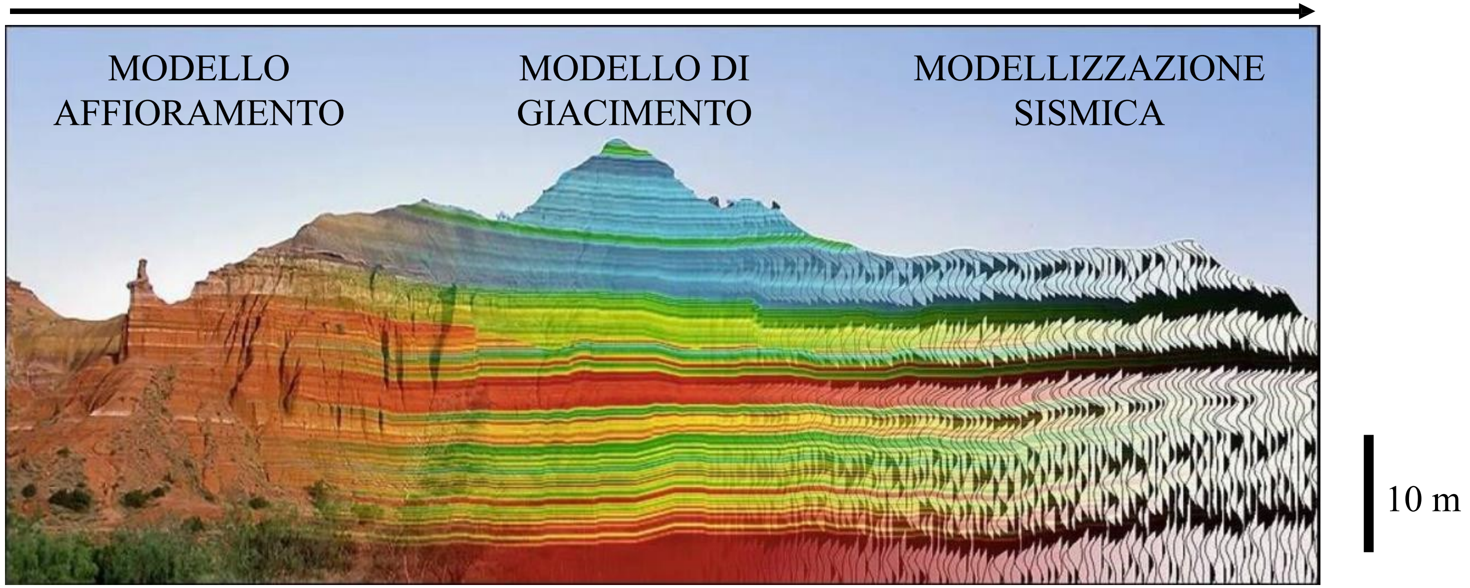


A brief introduction on Virtual Outcrop Geology

3D MODELS CAN COVER THE OBSERVATION SCALE BETWEEN OUTCROPS AND RESERVOIRS AND CREATE THE DIGITAL LINK BETWEEN FIELD ANALOG OBSERVATIONS AND DIGITAL SUBSURFACE MODELS.

MICRO-SCALE	***OUTCROP-SCALE***	***GAP***	***SEISMIC-SCALE***

VIRTUAL OUTCROPS

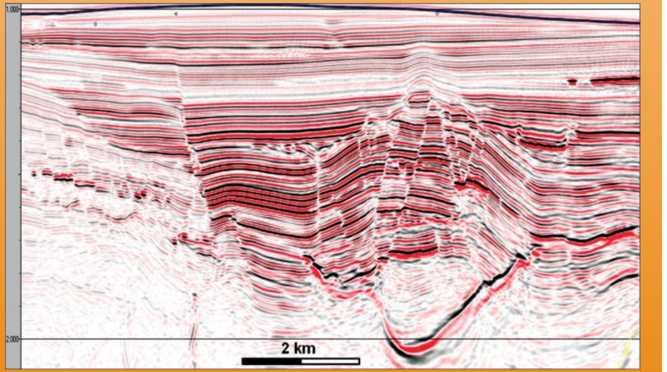


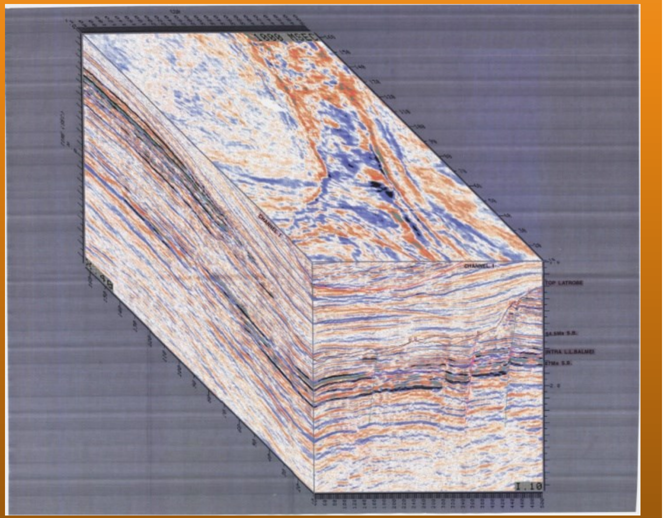
Source: Grelaud, 2018

A brief introduction on Virtual Outcrop Geology

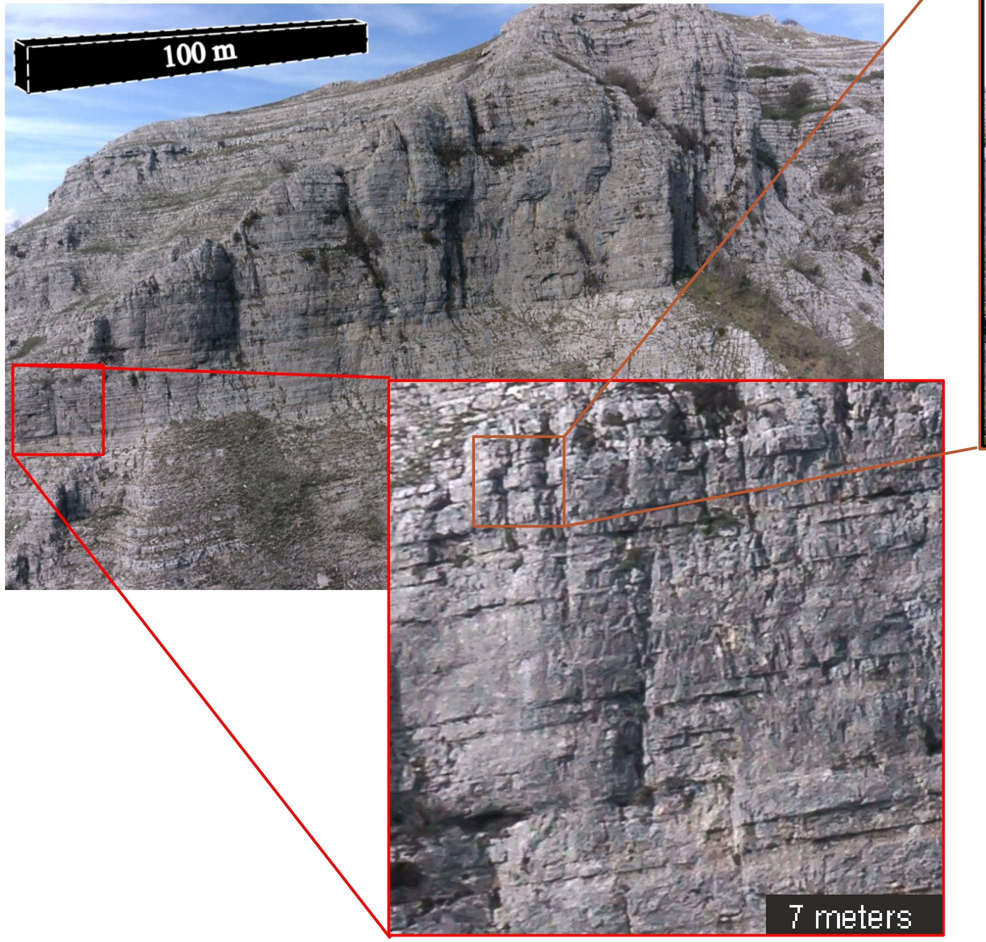
The importance of outcrops (and VOMS) in exploration and underground fluid management

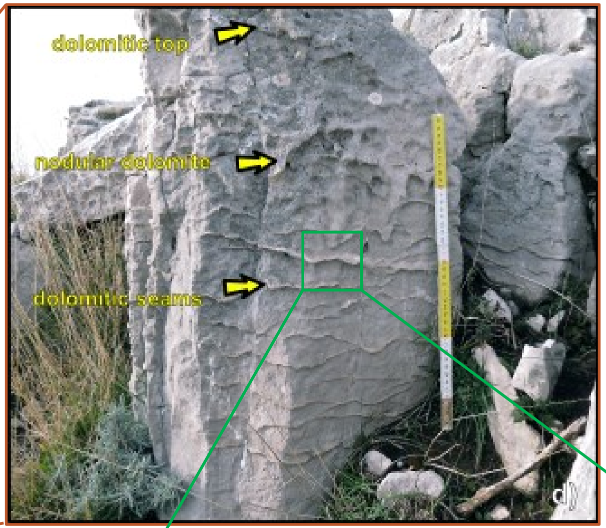
The subsurface we know…

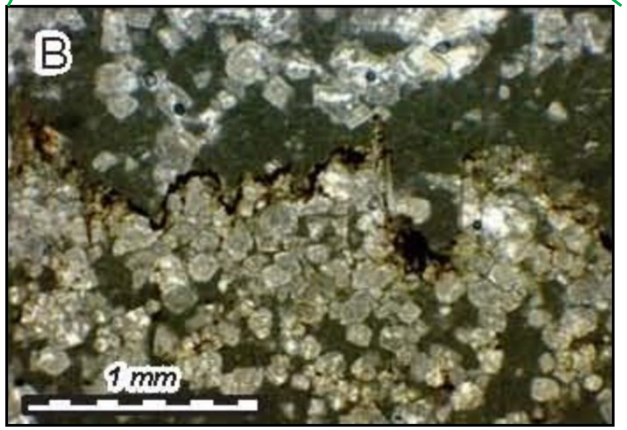




…and how really is!



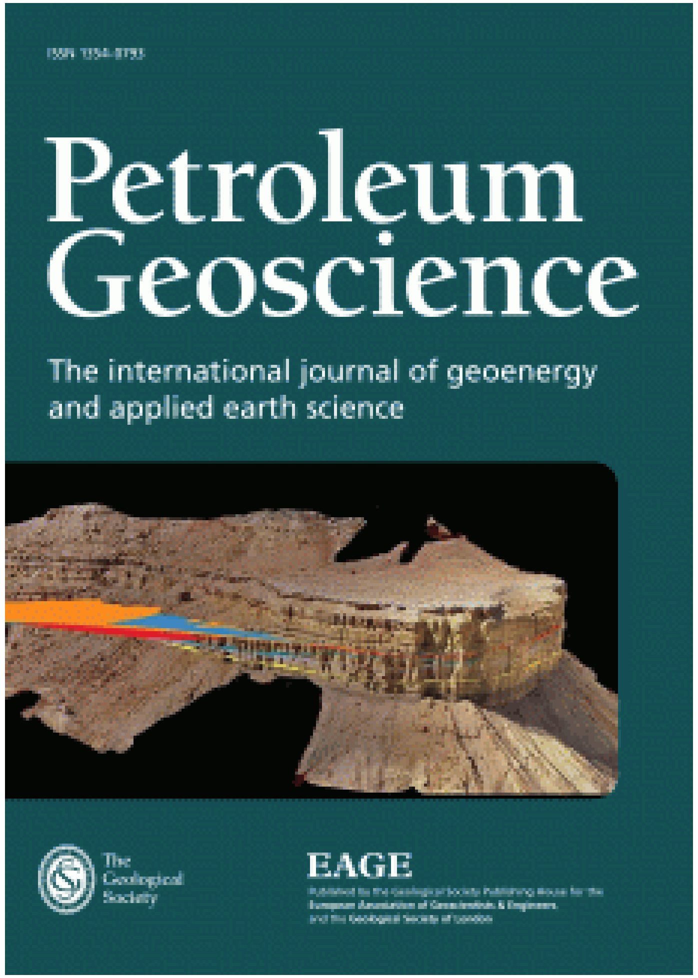




A brief introduction on Virtual Outcrop Geology

The importance of outcrops (and VOMs) in exploration and underground fluid management

The latest front cover of the Petroleum Geoscience Journal Feb. 2022, Vol. 28, Issue 1



Source: Mullins et al., 2021 (doi:10.1144/petgeo2020-012)

In this study, a reservoir modeling methodology was presented that addresses the problem of constraining process-based models of depositional systems to subsurface data such as well logs or seismic information.

Through this approach quantitative 3D architectural trends can be extracted and potentially combined to condition simulations with Multi-Point Statistics (MPS).

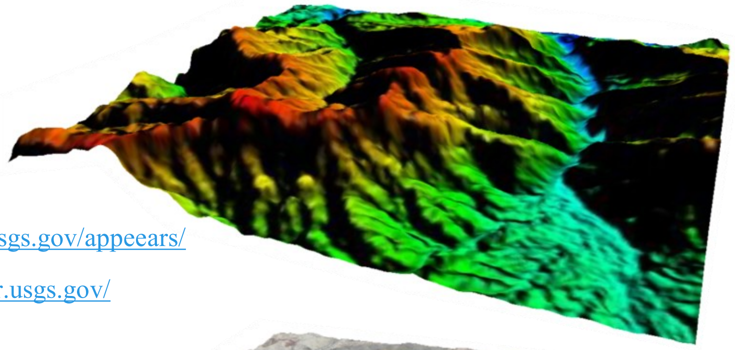
Artificial Intelligence (AI) and Machine Learning (ML) applied to the study of Virtual Outcrop Models will probably play a fundamental role in the next future.

A brief introduction on Virtual Outcrop Geology

3D MODELS CAN BE GENERATED FROM UNVISITED/REMOTE PLACES

Orthophoto

+



DEM

=

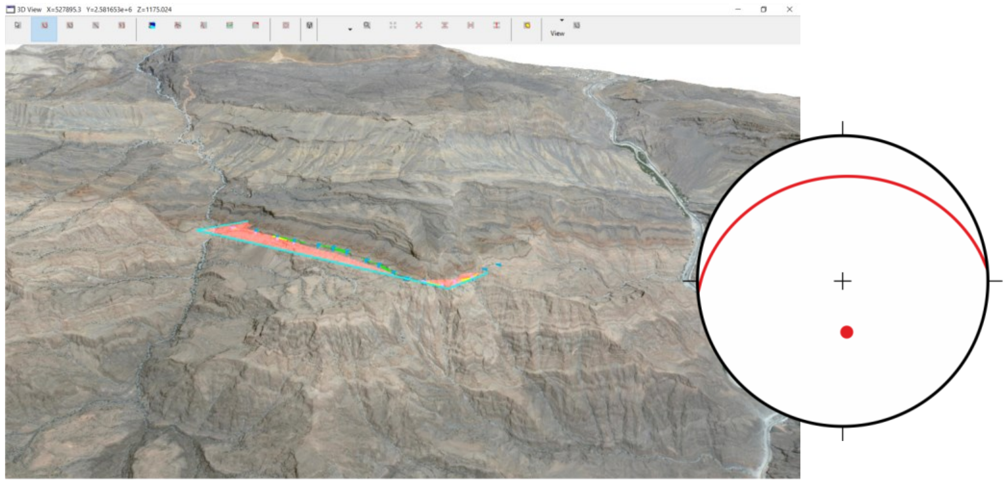
VOM

https://lpdaacsvc.cr.usgs.gov/appeears/

https://earthexplorer.usgs.gov/

Source: doi:10.1017/S0016756819001250

Geological information can be extracted from a VOM that has never been visited!



[Examples from Sketchfab]

A brief introduction on Virtual Outcrop Geology

3D MODELS AS REPOSITORIES FOR DATA SHARING AND VIRTUAL FIELD TRIPS TO PROMOTE OPEN SCIENCES AND INCLUSIVITY.

https://sketchfab.com

https://www.e-rock.co.uk/

https://v3geo.com/

https://www.vrgeoscience.com/geotour3d/

https://geobase-wustl.herokuapp.com/outcrops

https://www.svalbox.no/

A brief introduction on Virtual Outcrop Geology

Advantages summary!

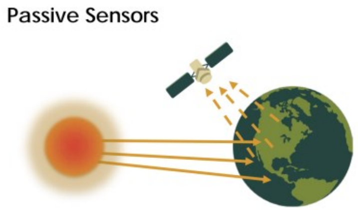
- Virtual outcrop models offer the opportunity for taking **extensive measurements** (i.e., extended area coverage and a larger number of measurements), at **different scales** and even from partly/fully **inaccessible outcrops**.
- Data extracted from a georeferenced VOM are themselves **georeferenced**, allowing the merging of multiple datasets in a single **multi-scale model**.
- 3D models allow working on "outcrops" at **any time** (despite weather conditions, safety concerns, and time/money available for fieldwork).
- 3D models enhance **accessibility and inclusion** in education and data sharing.

Remote sensing introduction

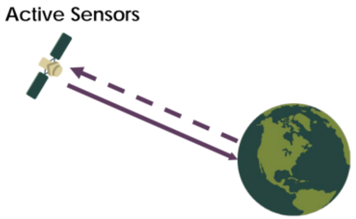
Traditionally, the term **remote sensing** is specifically referred to as the process of ***detecting and monitoring the physical characteristics of an area by measuring its reflected electromagnetic spectrum*** from **satellites** or **air vehicles**. In this sense, **aerial photogrammetry** (images taken from the air) is at all means a subset of remote sensing that primarily involves visible light waves of the electromagnetic spectrum.

More **general meaning of remote sensing** is given to all scientific methods of ***gathering information from remotely sensed data***. Thus, remote sensing methods are any methods where data is obtained by identifying, observing, and measuring an object without coming into direct contact with it.

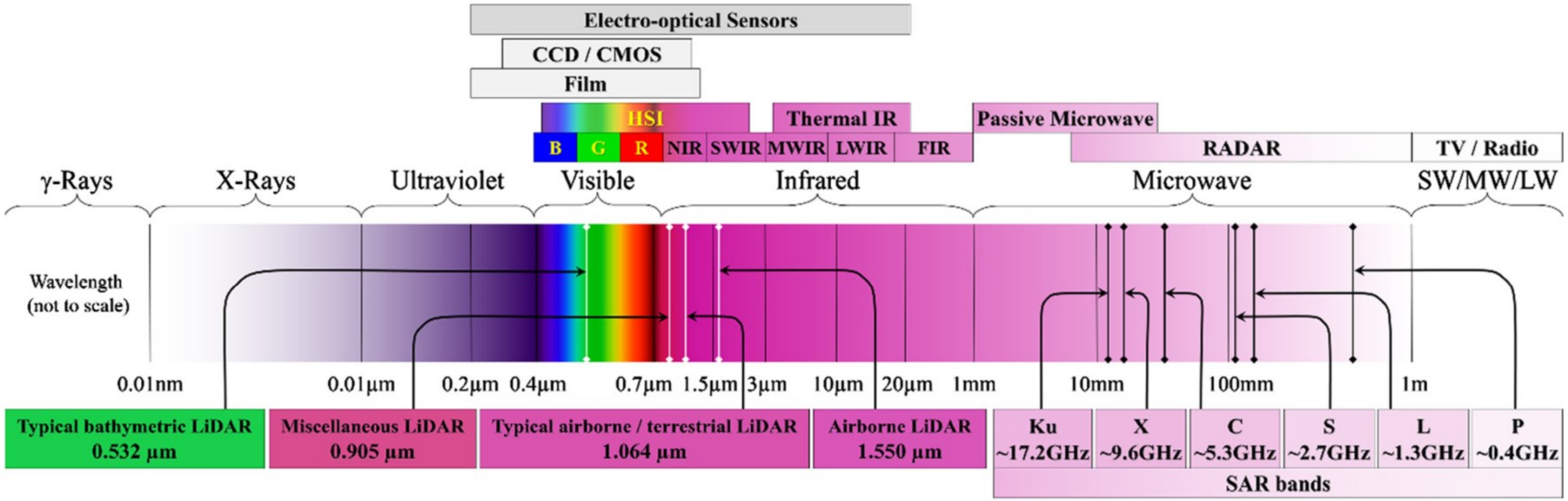
Passive sensor methodologies
Photogrammetry – Terrestrial, aerial and spaceborne photography – Multispectral (3-10 bands) or hyperspectral radiometer sensors (narrower bands with hundreds or thousands of bands).



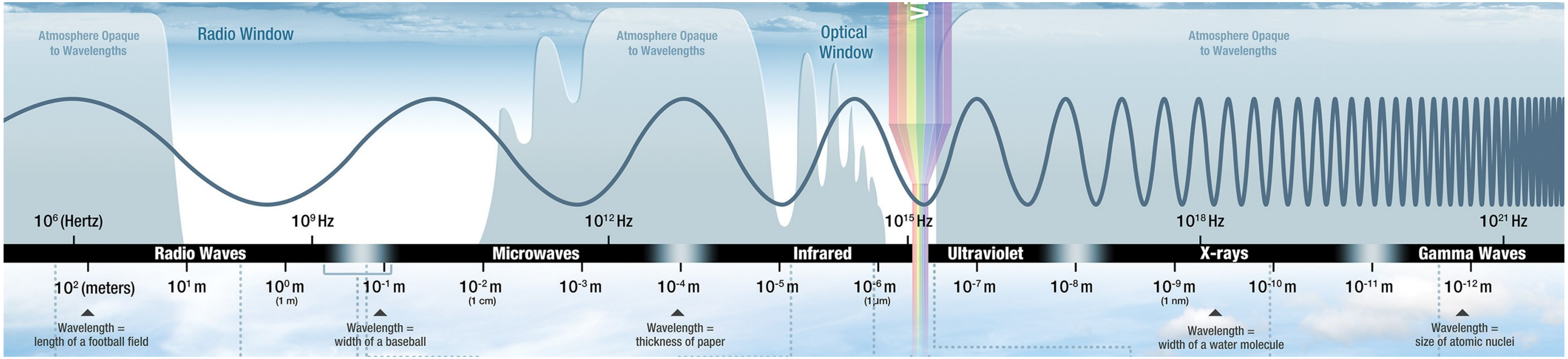
Active sensors methodologies
RADAR – SONAR – LIDAR



NASA Applied Remote Sensing Training Program



Toth and Jozkow, 2016.

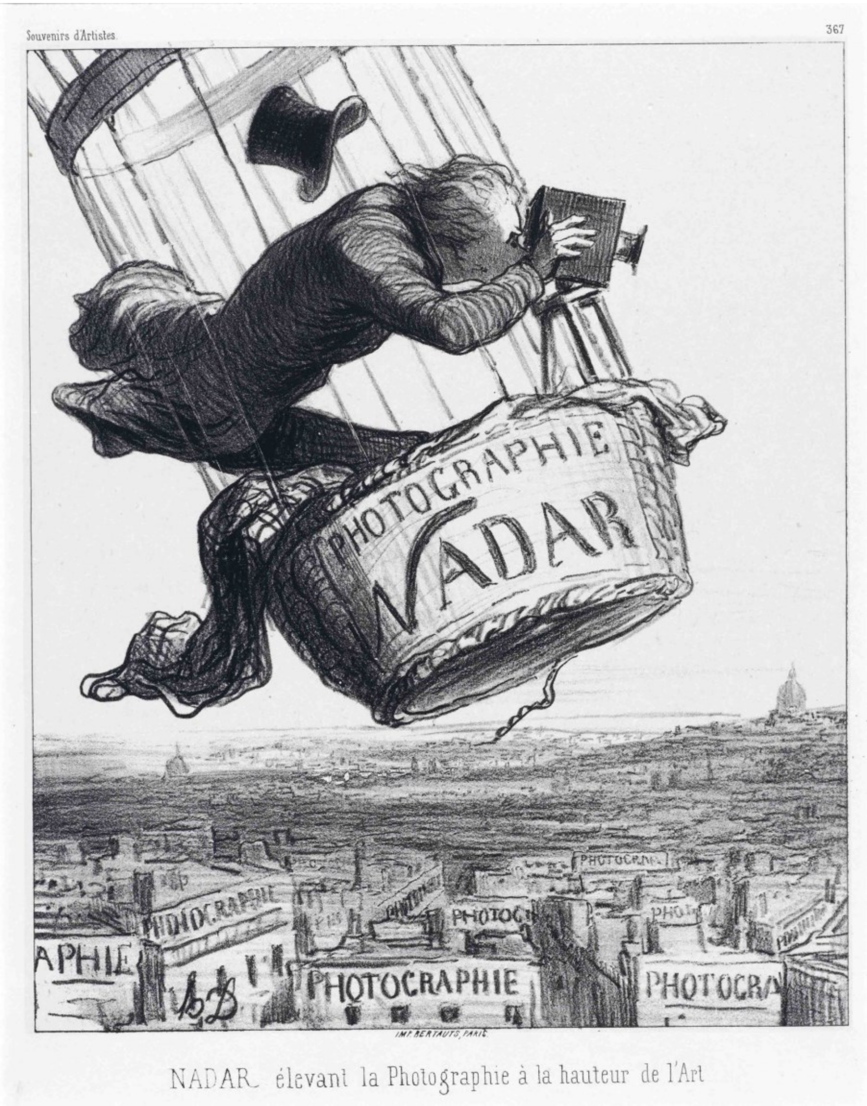


https://earthdata.nasa.gov/learn/backgrounders/remote-sensing

Remote sensing history

The first **aerial photograph** was made by Nadar (Gaspard-Félix Tournachon) from an air balloon basket in Paris in 1858.

In 1855 he had patented the idea of using aerial photographs in **mapmaking** and **surveying**, but it took him 3 years of experimenting before he successfully produced the very first aerial photograph.

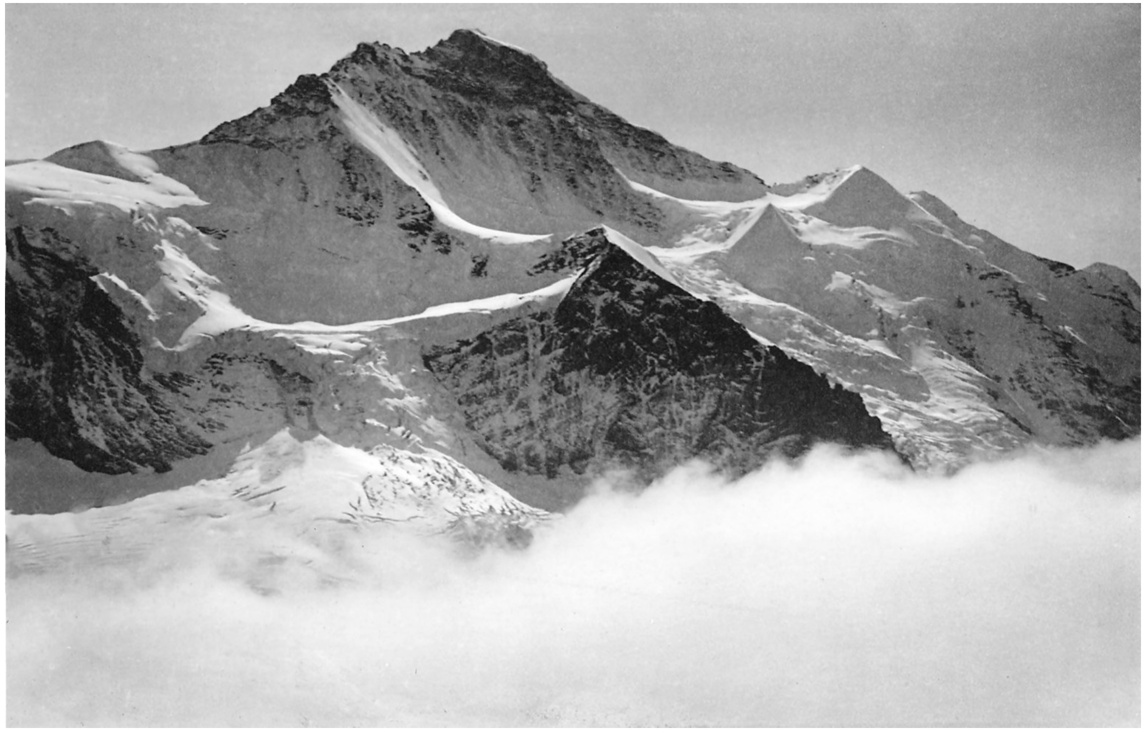



Paris 1866. Nadar.

Lithograph by Honoré Daumier, Nadar Elevating Photography to the Height of an Art, 1862. Souvenirs d'Artistes, 44.8 × 30.9 cm (National Gallery of Art)

Remote sensing history

Giza pyramid complex, photographed from Eduard Spelterini's balloon on November 21, 1904

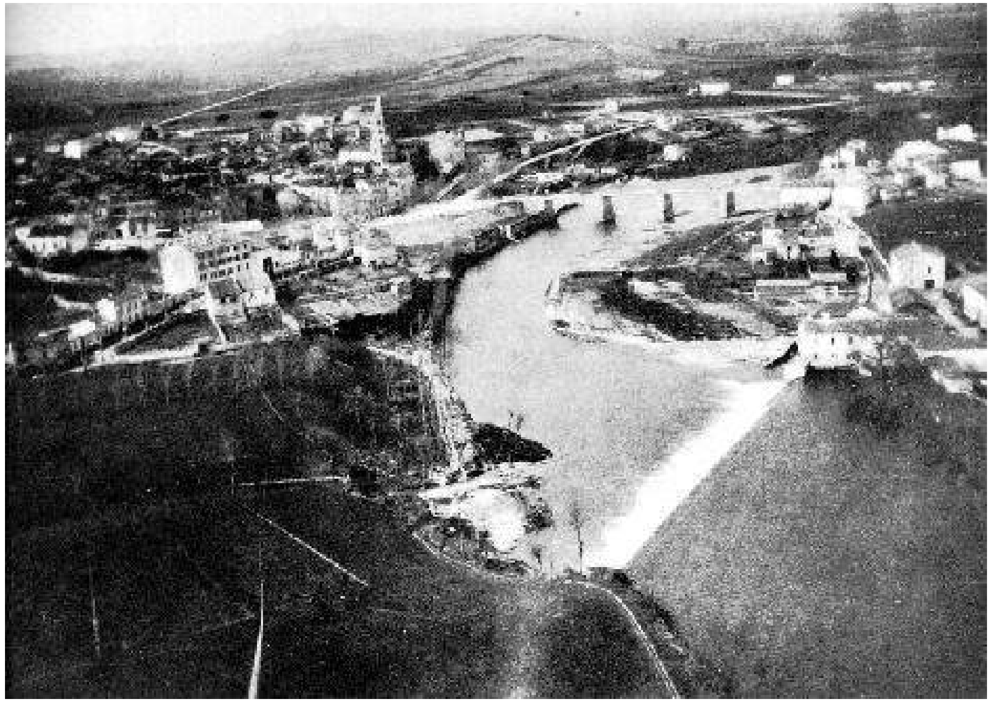


The north face of the Jungfrau, 20 September 1904.
Eduard Spelterini.

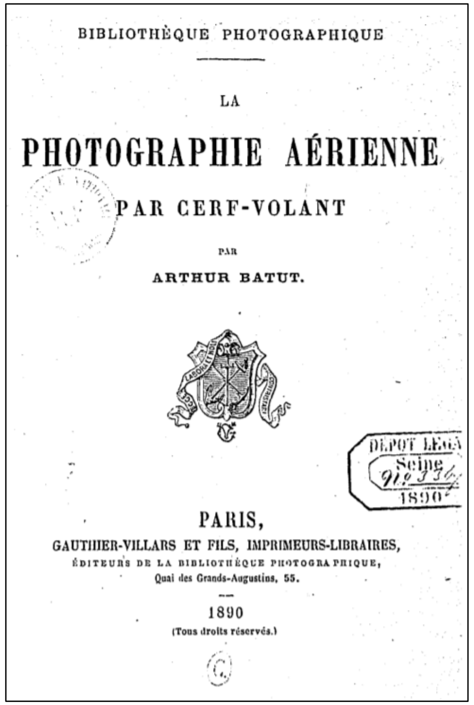
Albert Heim

Remote sensing history

Following photographic technology improvements (roll film, lighter cameras, and long shutter releases), cameras were also mounted on unmanned flying objects like tethered **kites**, **pigeons**, and **rockets**.



Labruguière photographed by **Arthur Batut**'s kite in 1889.



BIBLIOTHÈQUE PHOTOGRAPHIQUE

LA

PHOTOGRAPHIE AÉRIENNE

PAR CERF-VOLANT

PAR

ARTHUR BATUT.

PARIS,

GAUTHIER-VILLARS ET FILS, IMPRIMEURS-LIBRAIRES,

ÉDITEURS DE LA BIBLIOTHÈQUE PHOTOGRAPHIQUE,

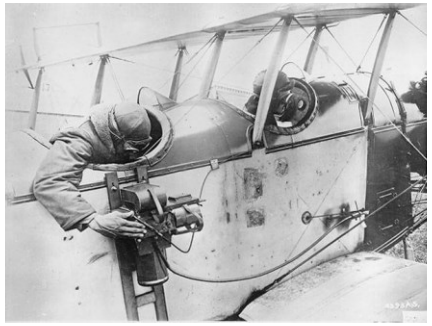
Quai des Grands-Augustins, 55.

1890

(Tous droits réservés.)

Remote sensing history

Following photographic technology improvements (roll film, lighter cameras, and long shutter releases), cameras were also mounted on unmanned flying objects like tethered **kites**, **pigeons**, and **rockets**.



The **first aerial photograph** taken from an airplane was in 1909 by Wilbur Wright.

In 1907 Julius Neubronner filed a patent for miniature **cameras for pigeons**.

After 1917 the **Fairchild's camera** was invented by Sherman M. Fairchild. His camera major improvement was a shutter located inside the lens, able to significantly reduce image distortion caused by slow shutter speeds and becoming the standard camera system for many decades.

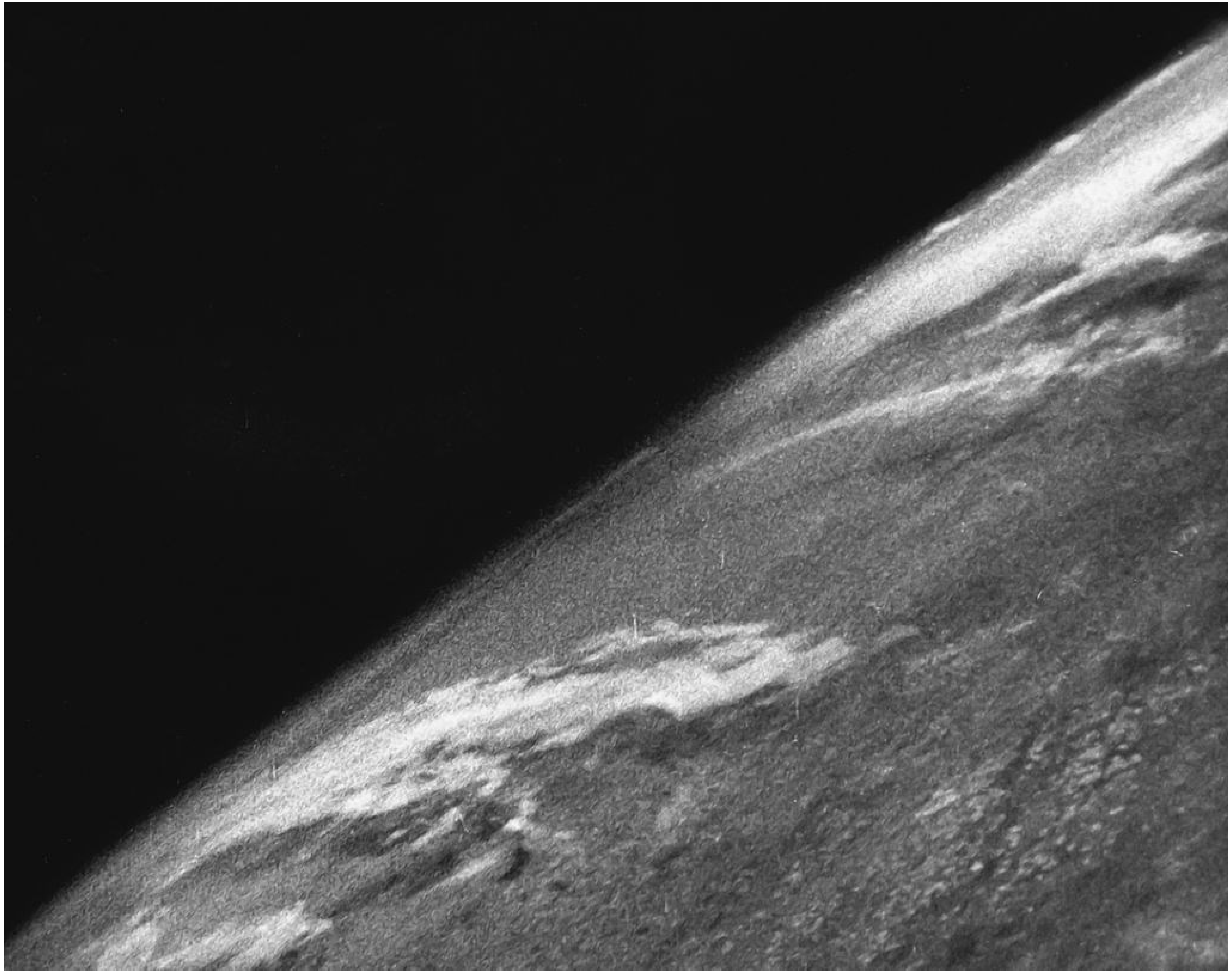
WWI gave a major push to develop aerial photography and after the war, the technology was in place to begin large-scale aerial surveys.

Remote sensing history

The **first image from space** was taken on the sub-orbital V-2 No. 13 **rocket flight** launched by the U.S. on October 24, 1946.

https://youtu.be/Sykfqa3MKAg

DeVry-35mm Cine Camera



Non photographic remote sensing (active sensors)

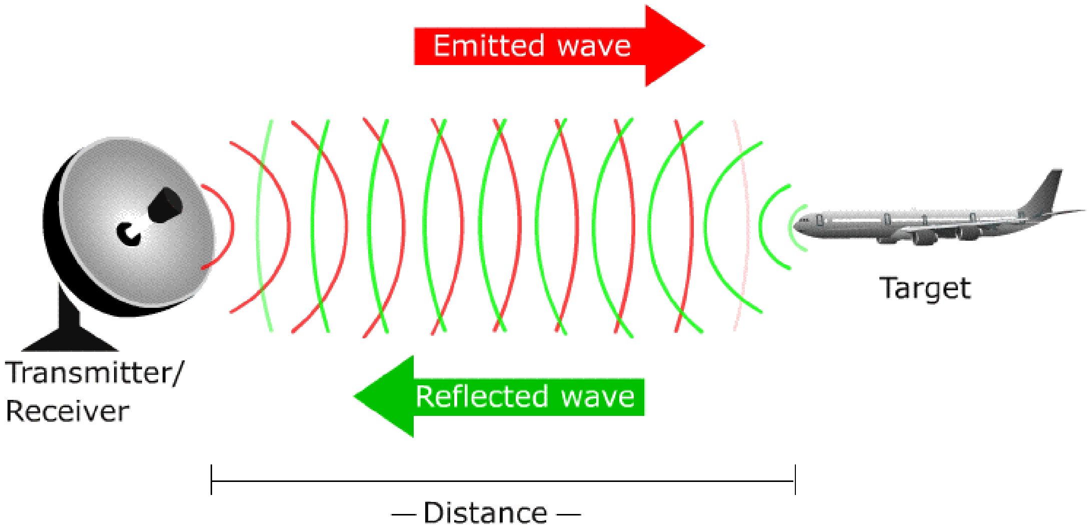
The origin of non-photographic remote sensing can be traced to WWII, with the development and improvement of **RADAR** (RAdio Detection And Ranging), and **SONAR** (SOund NAvigation Ranging).

RADAR is a sensor assisting in ranging with radio and microwave signals.

Its specific feature is the antenna emitting impulses.

When the energy flow in radar active remote sensing meets an obstacle, it scatters back to the sensor to some degree.

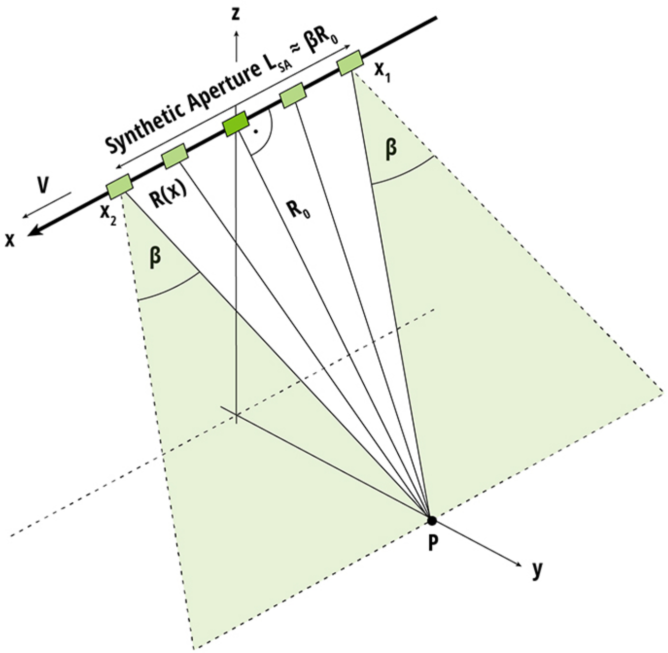
Based on its amount and traveling time, it is possible to estimate how far the target is.



https://www.skyradar.com/blog/radar-principle

Non photographic remote sensing (active sensors)

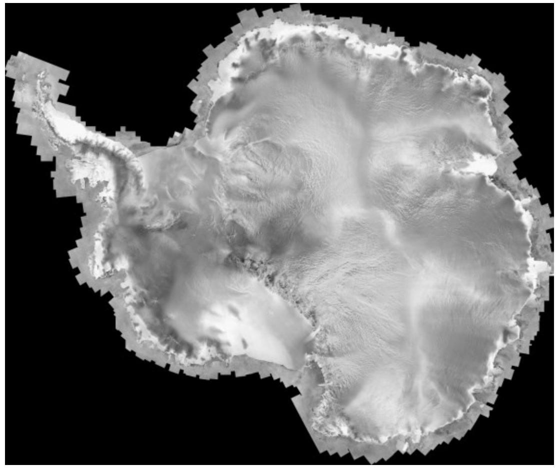
The origin of non-photographic remote sensing can be traced to WWII, with the development and improvement of **RADAR** (RAdio Detection And Ranging), and **SONAR** (SOund NAvigation Ranging).



NASA SAR Handbook

An important application of the RADAR system in the field of remote sensing is the **Synthetic-Aperture Radar (SAR)** that can be used to generate 2D images or 3D reconstructions of landforms.

The synthetic aperture is a strategy of acquisition working in sequence to simulate the effect of a larger antenna providing higher resolution data.



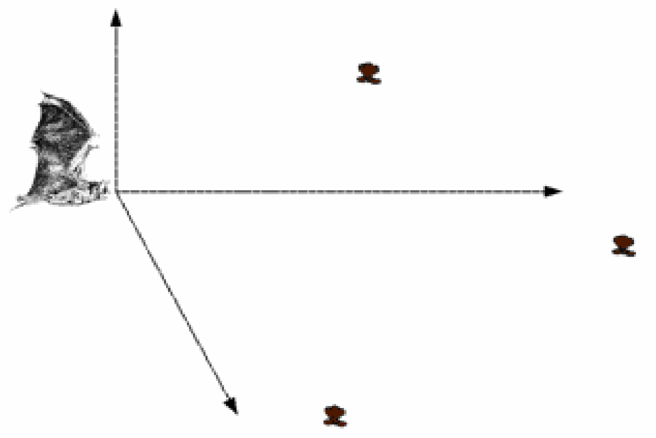
Mosaics of RADARSAT-1 imagery processed by ASF 1997-2000

Non photographic remote sensing

SOund **NA**vigation **R**anging (**SONAR**) instead of electromagnetic waves uses **sound waves**. In remote sensing, SONAR is used underwater to sense seafloor morphology.

https://www.hydro-international.com/content/article/the-study-of-mapping-the-seafloor

$$v = \sqrt{\frac{B}{\rho}}$$



https://acoustics.org/pressroom/httpdocs/154th/aytekin.html

A natural form of sonar is present in bats. **Bats** emit short, loud 'chirps' and receive an **echo** through their ears in the form of two antennae. This provides the bat with a three-dimensional view of the surrounding area.

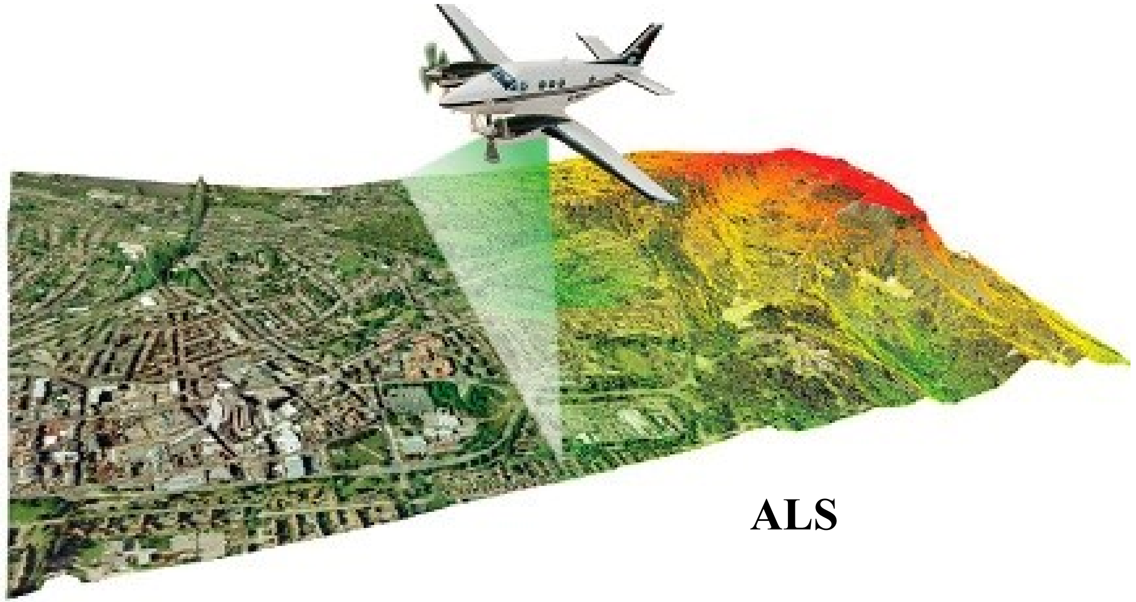
Matt Murdock/Daredevil (Marvel Comics)
https://powerlisting.fandom.com/wiki/Sonar

LiDAR (Light Detection And Ranging)

LiDAR is a method for determining distances with a laser and measuring the time for the **reflected light** to return to the receiver. LiDAR can work with **ultraviolet**, **visible**, or **near-infrared light**. It can target a wide range of materials, including rocks, rain, chemical compounds, aerosols, clouds, etc.

The surveying instrument that utilizes the LiDAR technology is called **laser scanner**. Depending on whether the scanner is mounted on an aircraft or on a tripod on the ground we can distinguish **ALS (Airborne Laser Scanning)** and **TLS (Terrestrial Laser Scanning)**.

TLS



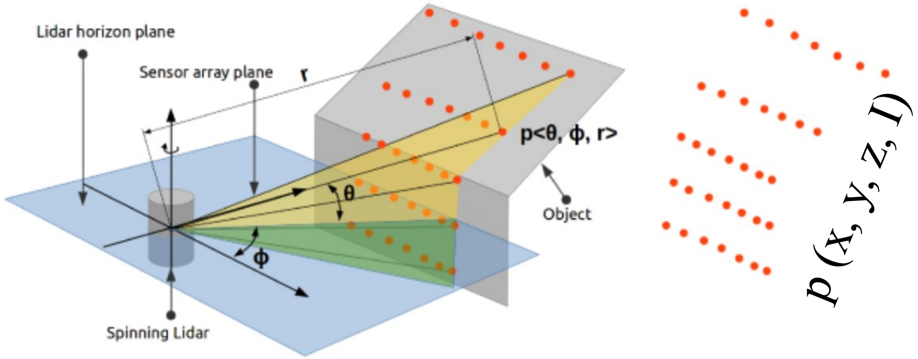
ALS

Surveying techniques and instruments

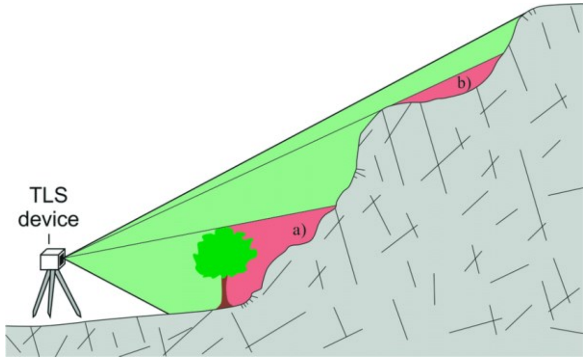
TLS – Terrestrial Laser Scanners

TLSs are optimized for **precision at a given range** because the **laser beam spreads** (i.e. has a larger footprint) with increasing distance from the instrument. Largely as a consequence of the laser required to achieve this range, **the speed, point accuracy, and other properties of the data from the TLS can vary markedly**.

TLSs are nowadays integrated with a **camera** to attribute an **RGB value** to each point.



Mukherjee, Aritra, et al. "Fast geometric surface based segmentation of point cloud from lidar data." International Conference on Pattern Recognition and Machine Intelligence. Springer, Cham, 2019.



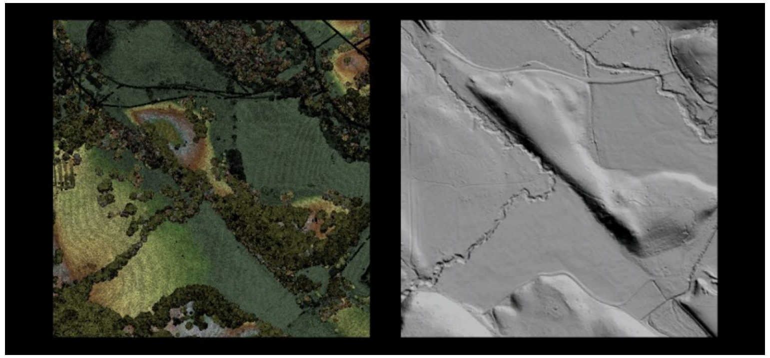
Multiple scan positions are likely to be necessary, not only to avoid blind spots behind obstacles but also to gain the spatial coverage required.

Keilig, Klaus, A. Dietrich, and M. Krautblatter. "How to effectively monitor geomorphic changes in debris-flow channels. 5th International Conference on Debris Flows: Disasters, Risk, Forecast, Protection. At: Tbilisi, Georgia. 2018.

Surveying techniques and instruments

ALS – Airborne Laser Scanners

The **accuracy** of ALS is generally between 0.1 and 0.15 m in the **vertical direction** and between 0.1 and 0.5 m in the **horizontal**. The accuracy depends on **intrinsic components**, such as the dGPS and the inertial measurement unit systems (IMU), and **external factors** such as object reflectance, atmospheric conditions, landform slope angle, or density of vegetation cover.

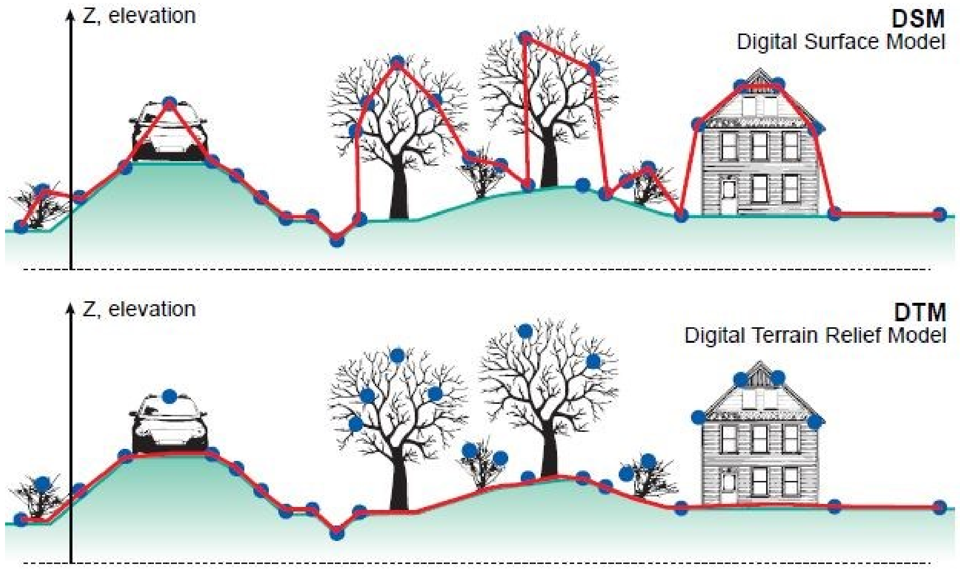


A key advantage of ALS is that some laser pulses are **able to penetrate through sparse vegetation** enabling both vegetation height and **"bare-earth"** to be determined.

Multiple returns can detect the elevations of several objects within the laser footprint of an outgoing laser pulse. The intermediate returns, in general, are used for vegetation structure, and the last return for **bare-earth terrain models**.

DEM vs DTM vs DSM

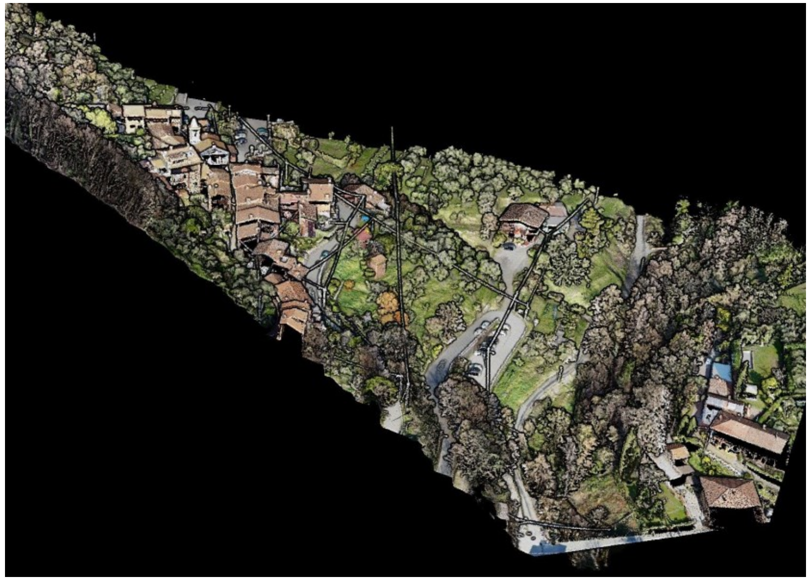
A **Digital Elevation Model (DEM)** is a digital 2.5D or 3D statistical representation of the Earth's surface, in which, for a finite number of x and y coordinates there is an associated elevation (altitude) value z (x,y).
The term is sometimes equalized to one between **Digital Terrain Model (DTM)** or **Digital Surface Model (DSM)**.
Most of the time the term DEM is used with a generic connotation to indicate both.



https://3dmetrica.it/dtm-dsm-dem/

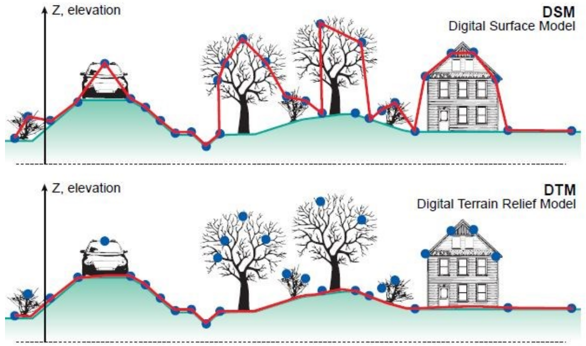
Digital Elevation Models (DEMs) can be derived through a variety of techniques, such as digitizing contours from existing topographic maps, topographic leveling, differential GPS measurements, (digital) photogrammetry, Radar remote sensing (InSAR), and Light Detection and Ranging (LiDAR).

DEM vs DTM vs DSM

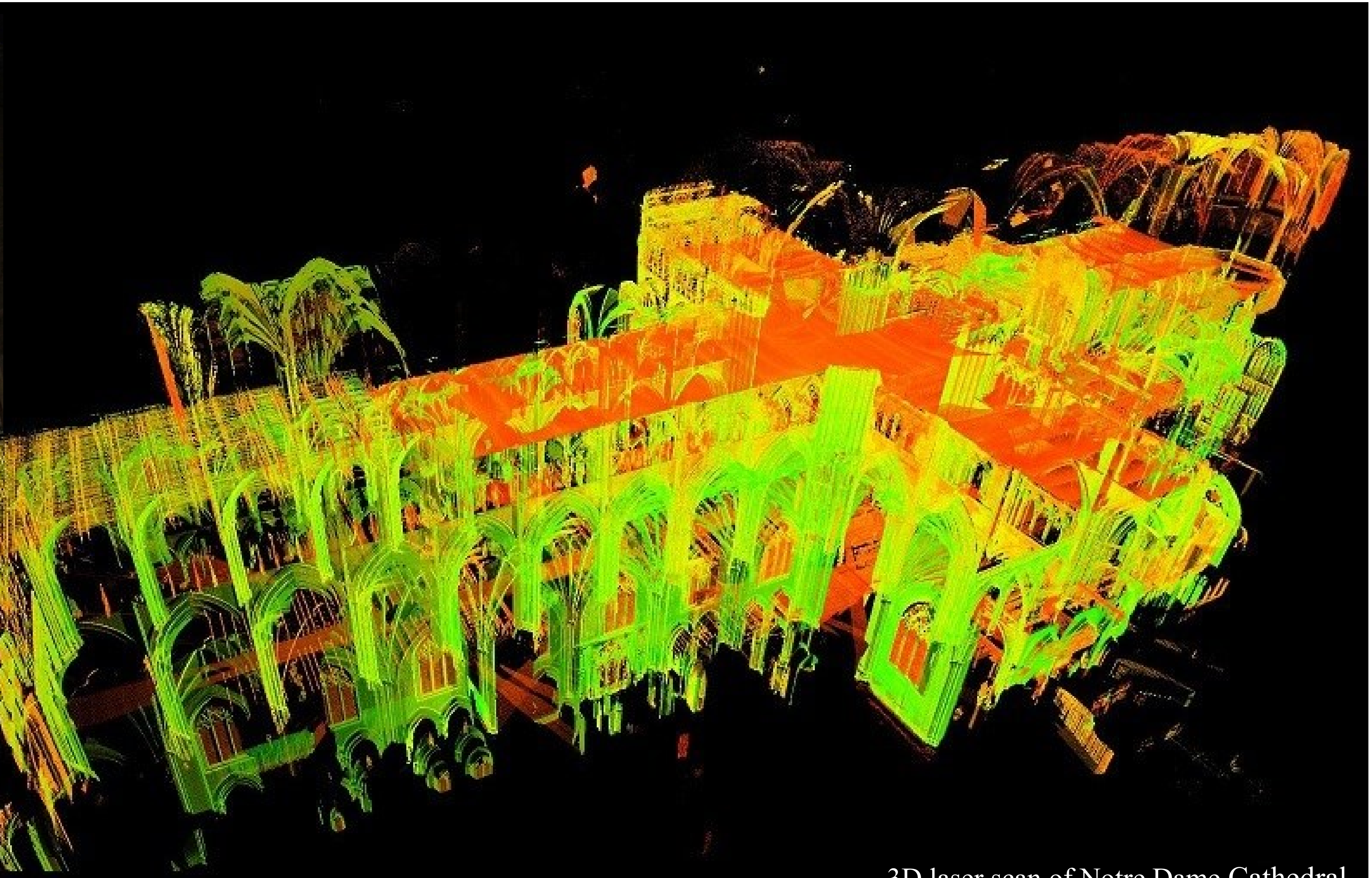


Source: Paolo Corradeghini LinkedIn page

Filtering by point classification



https://3dmetrica.it/dtm-dsm-dem/



3D laser scan of Notre Dame Cathedral.
Andrew Tallon.