MATHÉMATIQUES VISION APPRENTISSAGE

Master M2 MVA

Remote Sensing: from sensor to large scale geospatial data exploitation





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Telecom Paris

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Carlo de Franchis
ENS Paris-Saclay & Kayrros

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ENS Paris-Saclay

Emanuele Dalsasso
Telecom Paris

Practical information on the course

- **Teaching team**
  - ENS Paris Saclay: Gabriele Facciolo, Carlo de Franchis, Enric Meinhardt
  - Télécom Paris: Florence Tupin, Emanuele Dalsasso
- **Web site** https://mvaisat.wp.imt.fr/
- **Practical works**
  - Bring your own computer (colab notebooks)
- **Validation**
  - Practical works (25%)
  - Project (75%)

Overview of the course

Detailed calendar available on the course web site:

- ➢ 9 course sessions with lecture + practical work
- ➢ 2 working sessions on projects
- ➢ final session with projects presentations

Course syllabus:

1. What can be seen from space?
2. Geometric modeling of optical satellites and application to 3D reconstruction
3. Modeling a Synthetic Aperture Radar instrument
4. How to recover 3D information with optical sensors?
5. Sub-pixel matching and super-resolution
6. How to recover 3D information with SAR sensors?
7. Generation and exploitation of 3D data
8. Processing and exploitation of SAR data
9. Optical & SAR time series analysis

Outline of today's session

What can be seen from space? Introduction to Earth Observation

1. Short **history** of remote sensing
2. Satellites **orbits**
3. Satellites **imaging systems**
4. Remote sensing **applications**
5. Coordinate reference systems and images **georeferencing**
6. **Practical work** in Python jupyter notebook

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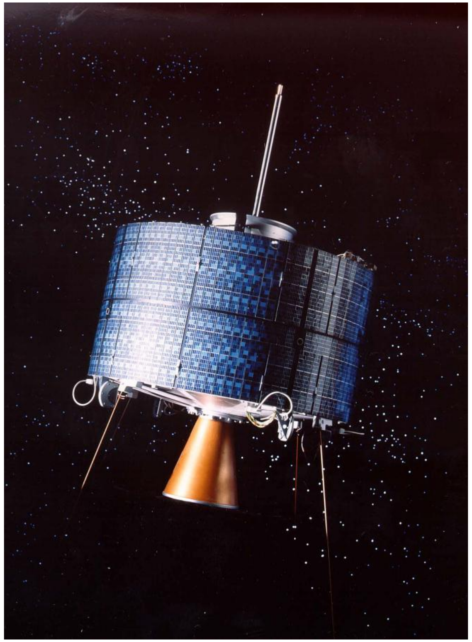
1957 Sputnik 1: first artificial Earth satellite

Launch
4 oct 1957

1960 Tiros 1: first (civilian) image of the Earth

1957: Sputnik 1
1960: Tiros 1



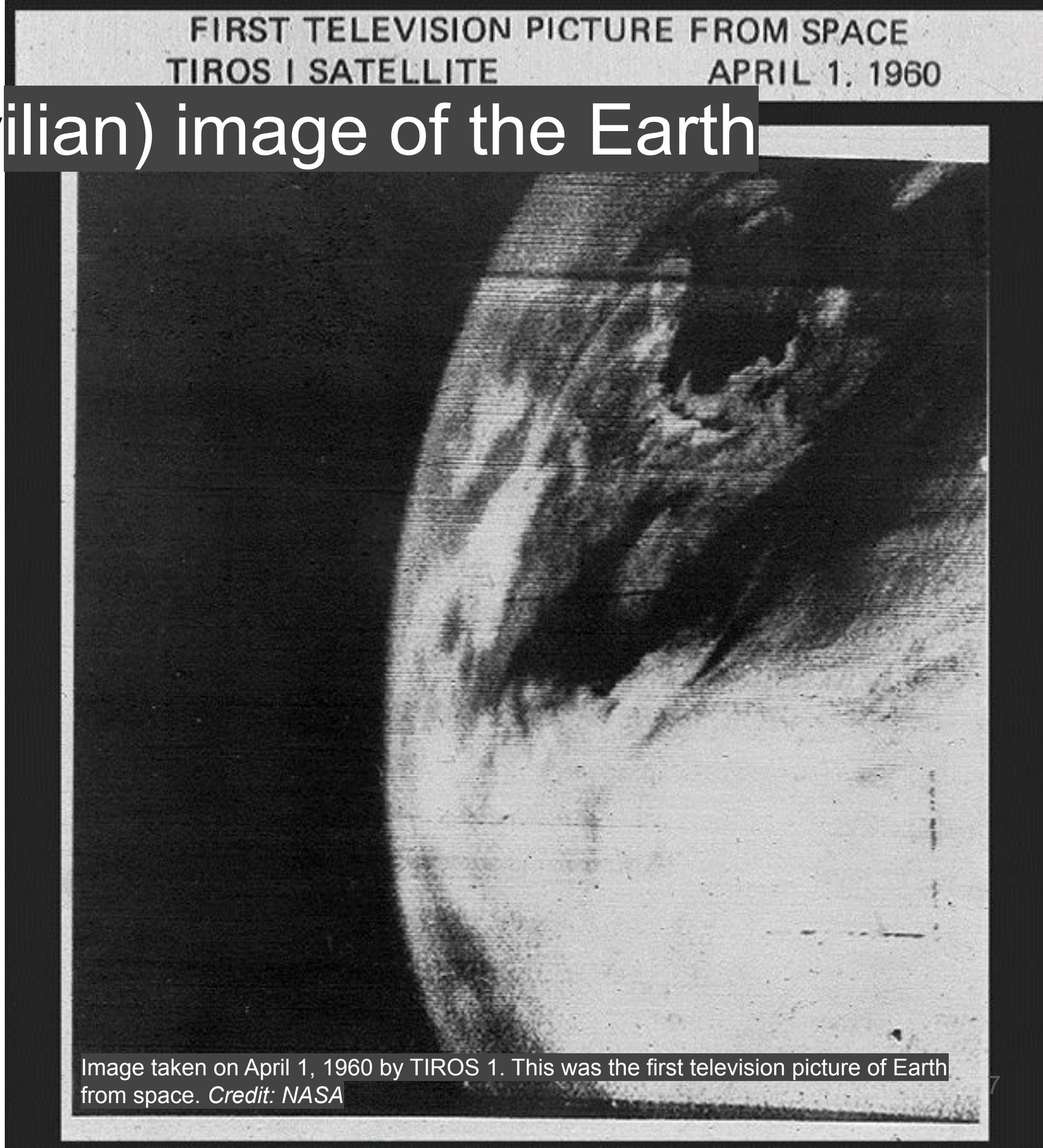


Image taken on April 1, 1960 by TIROS 1. This was the first television picture of Earth from space. *Credit: NASA*

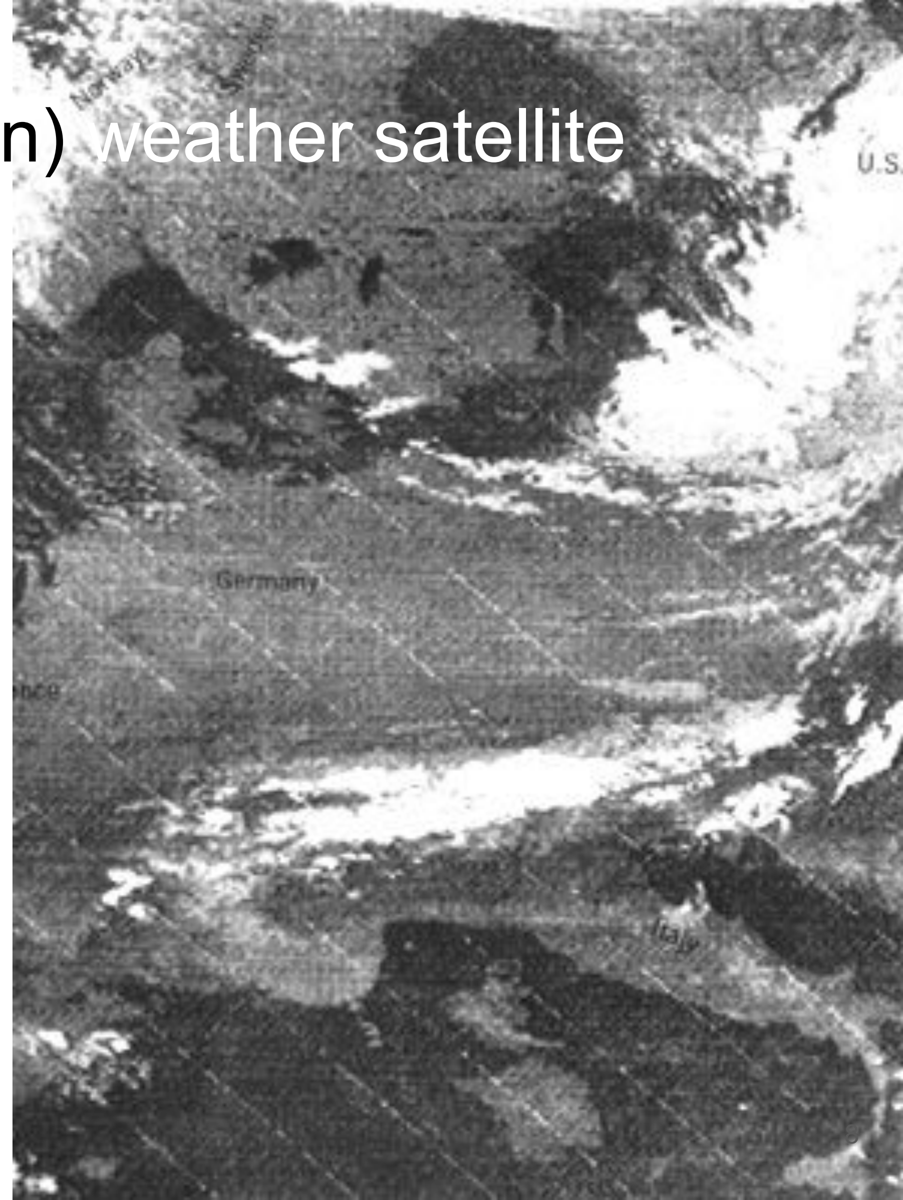
1964 Nimbus 1: first (civilian) weather satellite

1957: Sputnik 1

1960: Tiros 1

1964: Nimbus 1

Sun-synchronous orbit



1972 Landsat 1: regional images at 80m per pixel

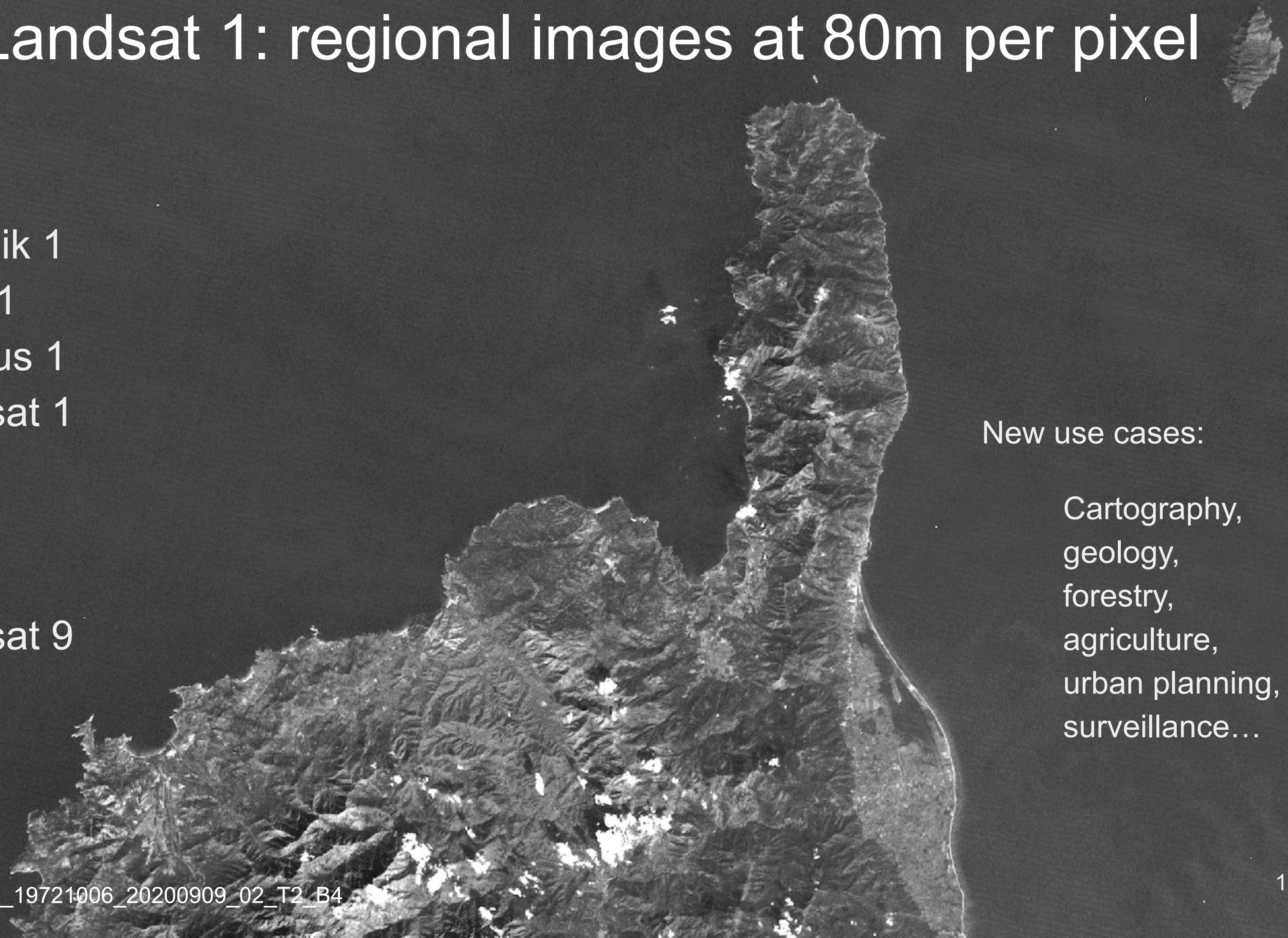
1957: Sputnik 1
1960: Tiros 1
1964: Nimbus 1
1972: Landsat 1
…
…
…
2021: Landsat 9

New use cases:

Cartography,
geology,
forestry,
agriculture,
urban planning,
surveillance…

LM01_L1TP_208030_19721006_20200909_02_T2

1972 Landsat 1: regional images at 80m per pixel



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…
…
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2021: Landsat 9

New use cases:

Cartography,
geology,
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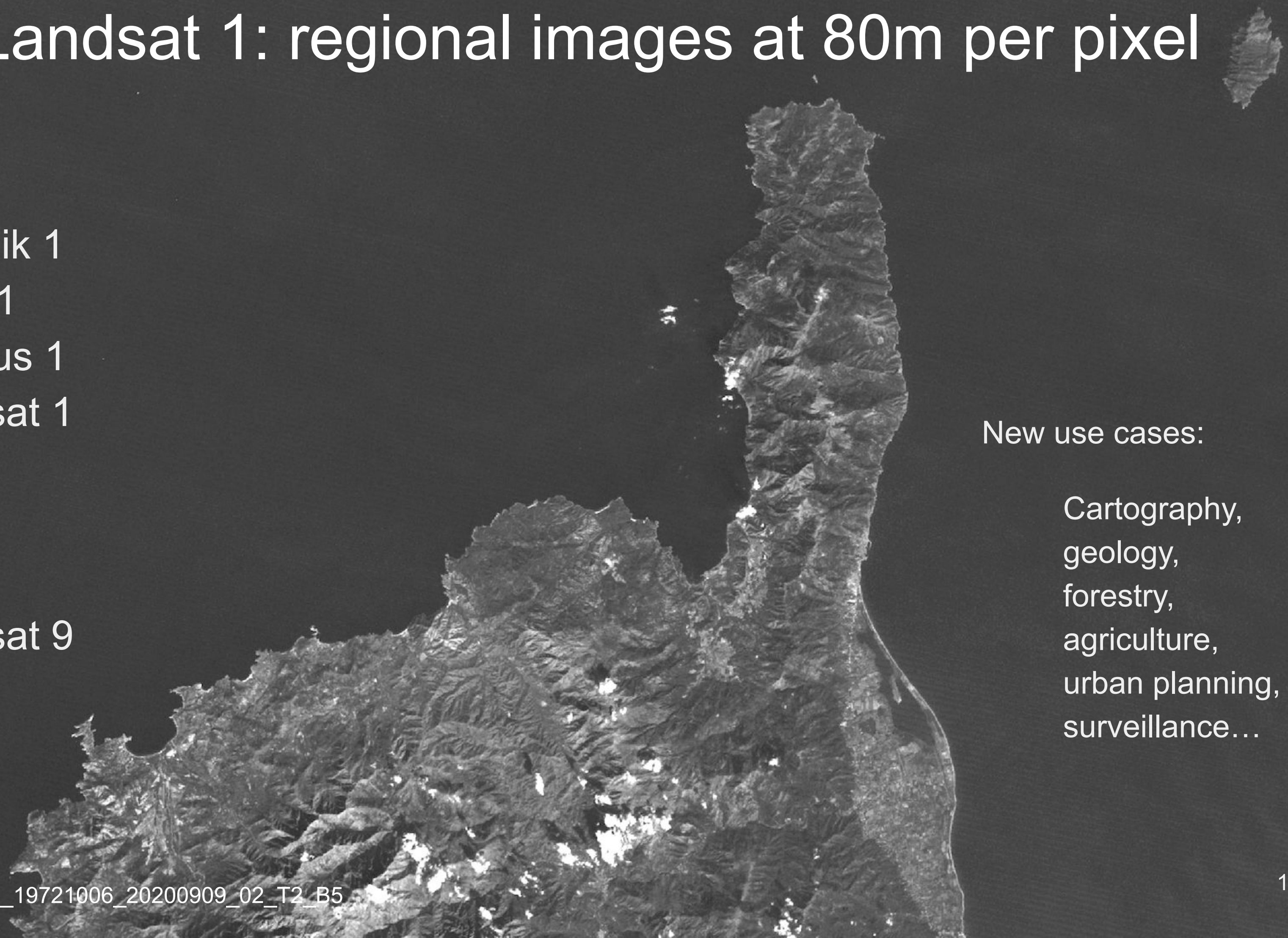
urban planning,
surveillance…

LM01_L1TP_208030_19721006_20200909_02_T2_B4
(green)

1972 Landsat 1: regional images at 80m per pixel

1957: Sputnik 1
1960: Tiros 1
1964: Nimbus 1
1972: Landsat 1
…
…
…
2021: Landsat 9

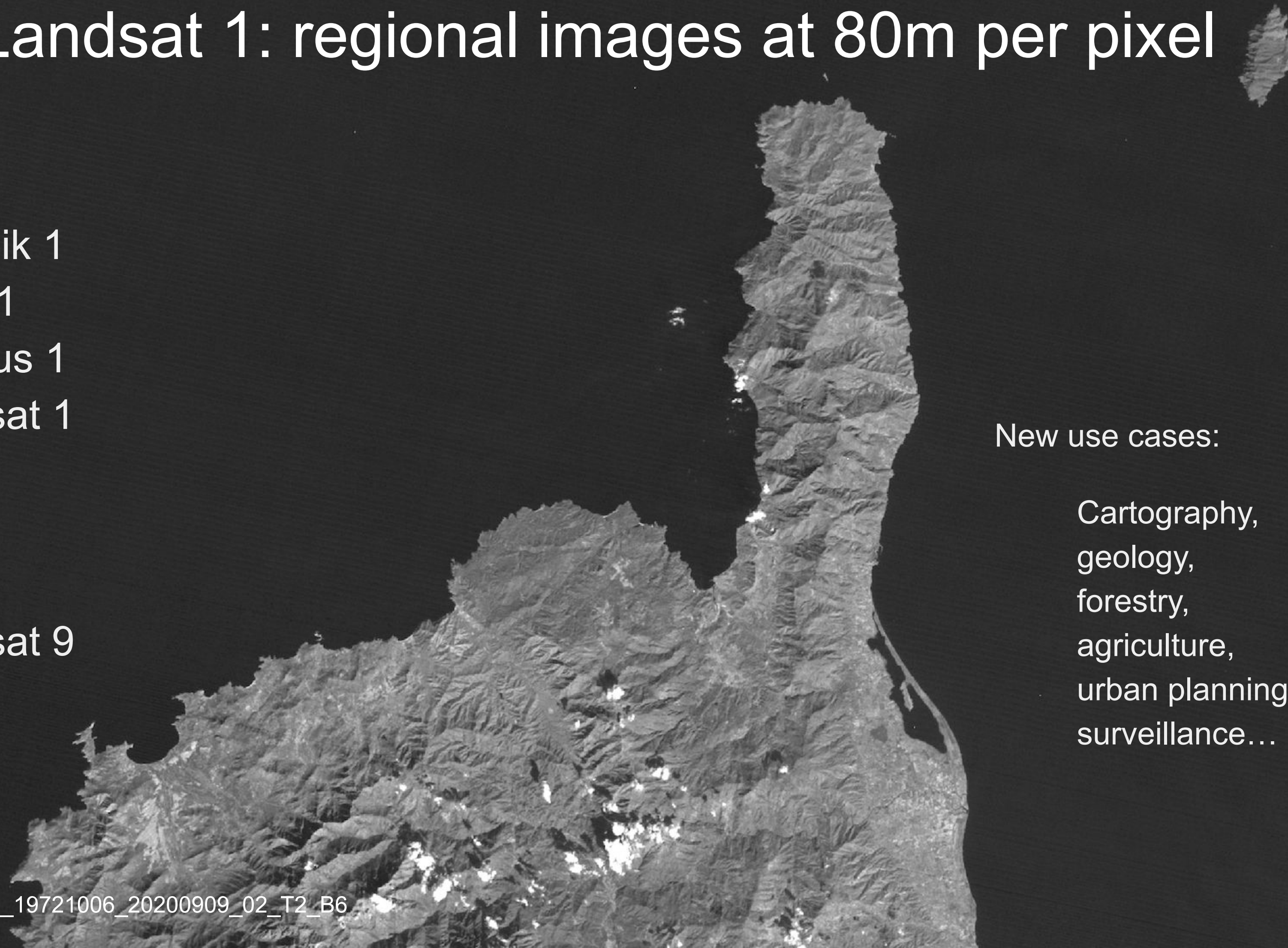


New use cases:

Cartography,
geology,
forestry,
agriculture,
urban planning,
surveillance…

LM01_L1TP_208030_19721006_20200909_02_T2_B5
(red)

1972   Landsat 1: regional images at 80m per pixel



1957: Sputnik 1

1960: Tiros 1

1964: Nimbus 1

1972: Landsat 1

…

…

…

2021: Landsat 9

New use cases:

Cartography,
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urban planning,
surveillance…

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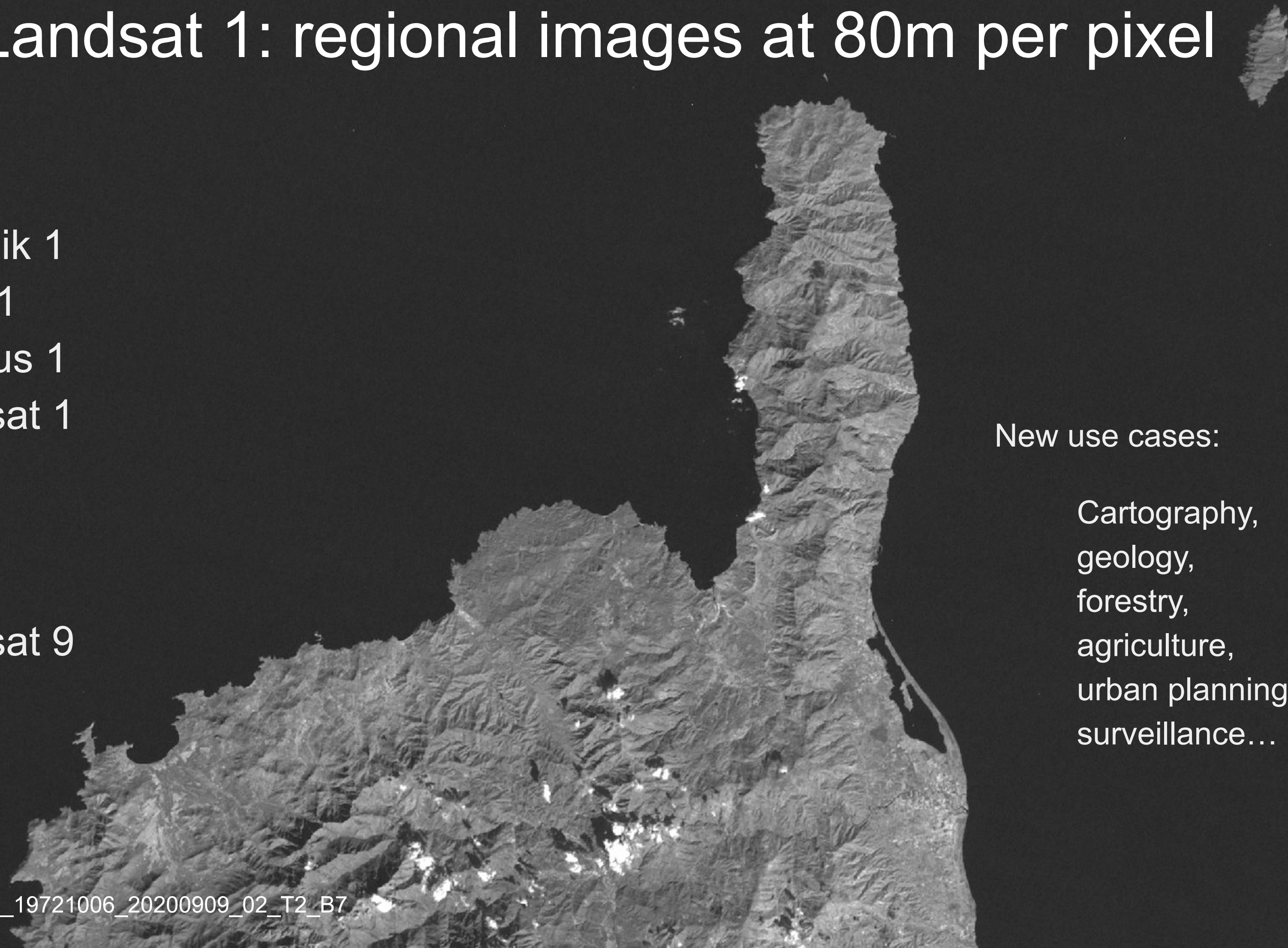
(nir)

1972 Landsat 1: regional images at 80m per pixel

1957: Sputnik 1
1960: Tiros 1
1964: Nimbus 1
1972: Landsat 1
…
…
…
2021: Landsat 9



New use cases:

Cartography,
geology,
forestry,
agriculture,
urban planning,
surveillance…

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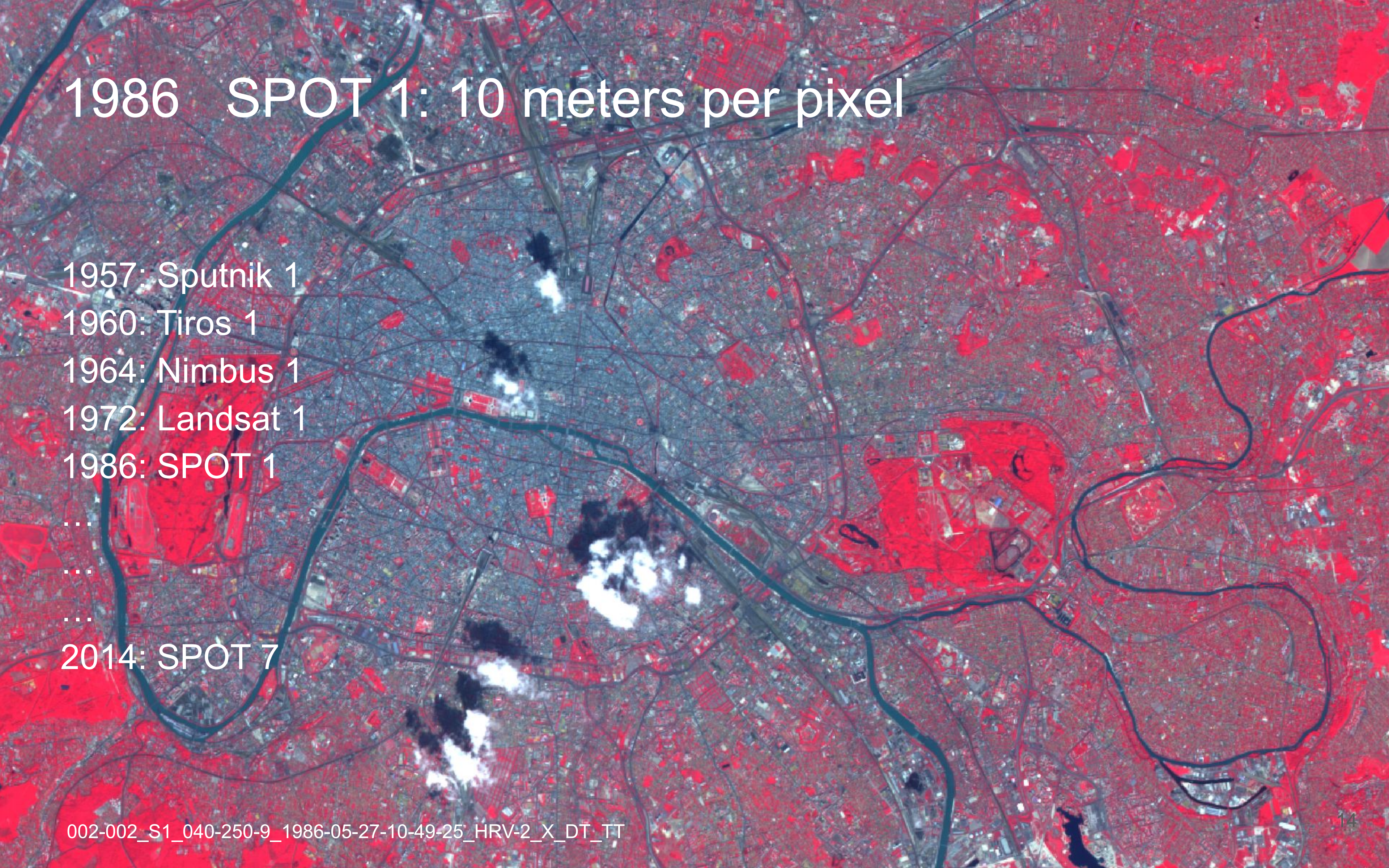
(nir)

1986 SPOT 1: 10 meters per pixel

1957: Sputnik 1
1960: Tiros 1
1964: Nimbus 1
1972: Landsat 1
1986: SPOT 1
…
…
…
2014: SPOT 7



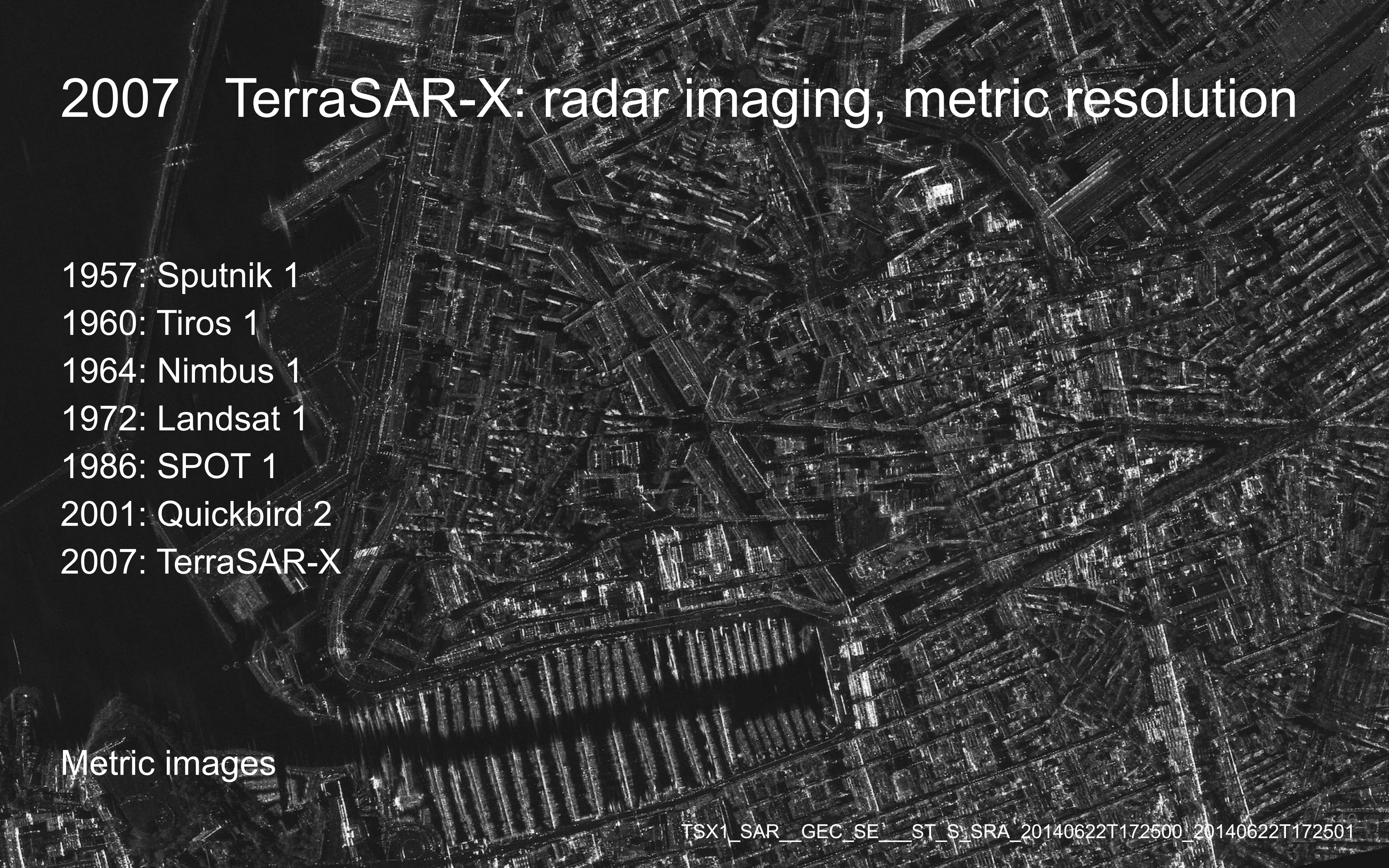
002-002_S1_040-250-9_1986-05-27-10-49-25_HRV-2_X_DT_TT

2001 Quickbird-2: 61 cm per pixel

1957: Sputnik 1
1960: Tiros 1
1964: Nimbus 1
1972: Landsat 1
1986: SPOT 1
2001: Quickbird 2

Metric images

2007 TerraSAR-X: radar imaging, metric resolution



1957: Sputnik 1
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1972: Landsat 1
1986: SPOT 1
2001: Quickbird 2
2007: TerraSAR-X

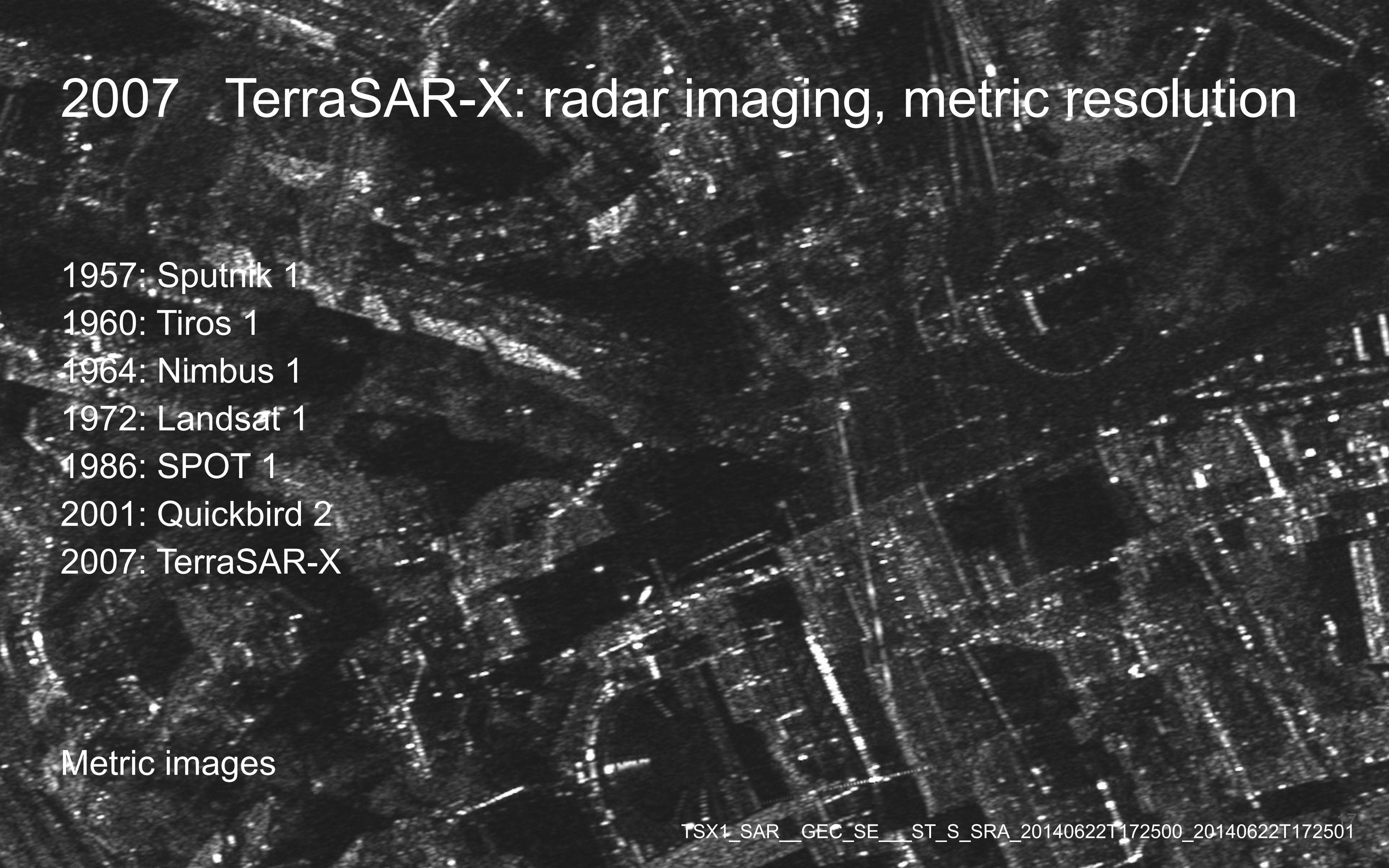
Metric images

TSX1_SAR__GEC_SE___ST_S_SRA_20140622T172500_20140622T172501

2007 TerraSAR-X: radar imaging, metric resolution

1957: Sputnik 1
1960: Tiros 1
1964: Nimbus 1
1972: Landsat 1
1986: SPOT 1
2001: Quickbird 2
2007: TerraSAR-X

Metric images

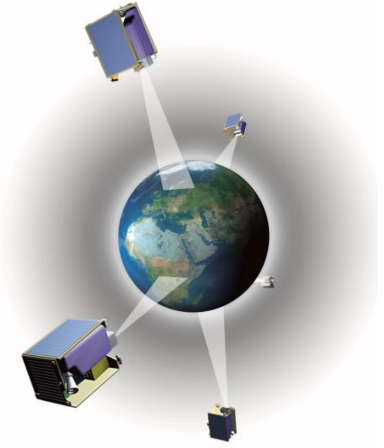


TSX1_SAR__GEC_SE___ST_S_SRA_20140622T172500_20140622T172501

2008 RapidEye: 5 satellites at 6m per pixel

1957: Sputnik 1
1960: Tiros 1
1964: Nimbus 1
1972: Landsat 1
1986: SPOT 1
2001: Quickbird 2
2007: TerraSAR-X
2008: RapidEye

Daily revisit of any point on Earth



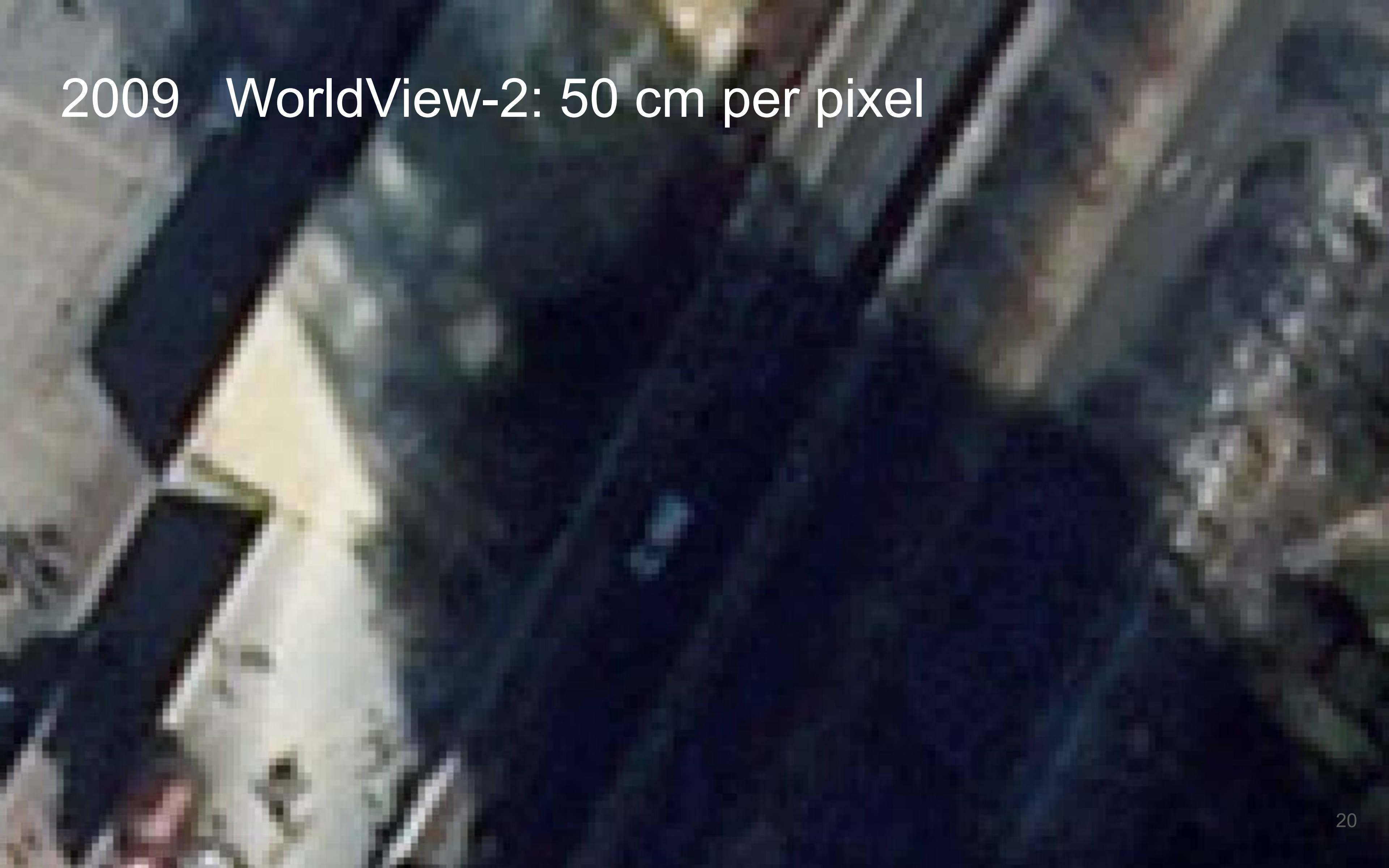
Constellations

2009 WorldView-2: 50 cm per pixel

1957: Sputnik 1
1960: Tiros 1
1964: Nimbus 1
1972: Landsat 1
1986: SPOT 1
2001: Quickbird 2
2007: TerraSAR-X
2008: RapidEye
2009: WorldView-2

Metric images

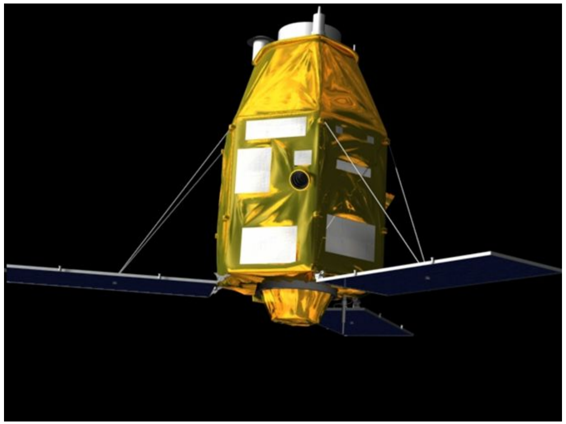
2009 WorldView-2: 50 cm per pixel



2012 Orfeo-Pléiades: 4 SAR and 4 optical sensors

1957: Sputnik 1
1960: Tiros 1
1964: Nimbus 1
1972: Landsat 1
1986: SPOT 1
2001: Quickbird 2
2007: TerraSAR-X
2008: RapidEye
2009: WorldView-2
2012: Orfeo - Pléiades

- Daily image anywhere on Earth
- Metric resolution
- 4 COSMO-SkyMed (radar)
- 2 Pléiades + 2 SPOT 6&7 (optical)



Constellations

2016 WorldView-4: 30 cm per pixel

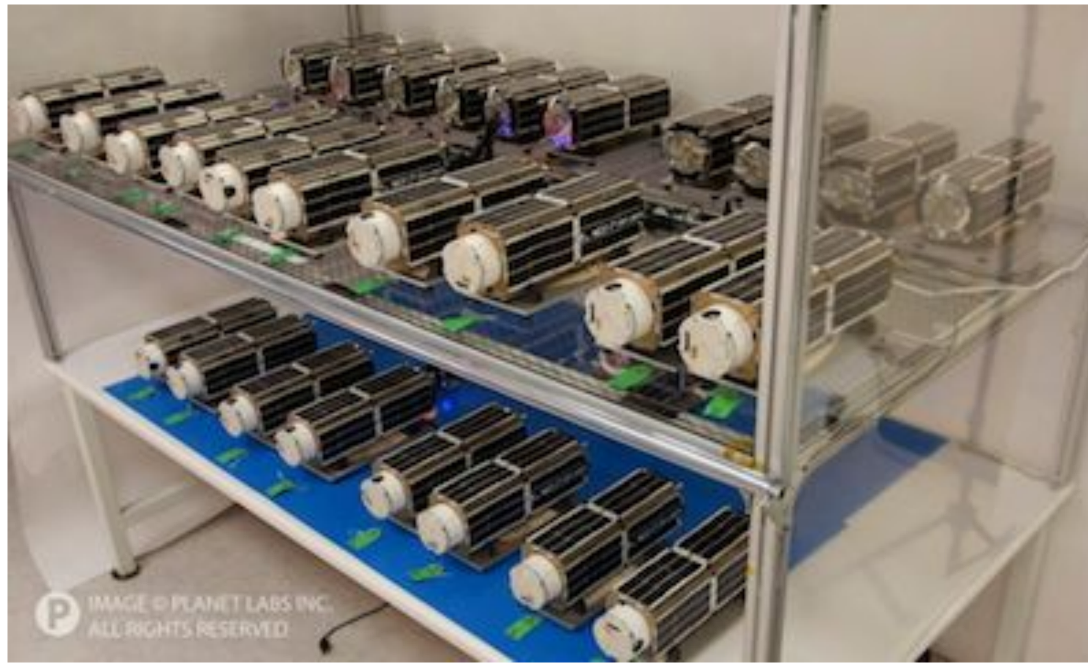
1957: Sputnik 1
1960: Tiros 1
1964: Nimbus 1
1972: Landsat 1
1986: SPOT 1
2001: Quickbird 2
2007: TerraSAR-X
2008: RapidEye
2009: WorldView-2
2012: Orfeo - Pléiades
2014: WorldView-3


2016 WorldView-4: 30 cm per pixel

2017 PlanetScope: daily revisit everywhere

1957: Sputnik 1
1960: Tiros 1
1964: Nimbus 1
1972: Landsat 1
1986: SPOT 1
2001: Quickbird 2
2007: TerraSAR-X
2008: RapidEye
2009: WorldView-2
2012: Orfeo - Pléiades
2017: PlanetScope

Constellations



130+ satellites: https://www.planet.com/our-constellations/

2023 Several new SAR constellations available

- **Capella**
  - first satellite launched in august 2020
  - high resolution (up to 30cm)
  - 8-satellites constellation

- **IceEye**
  - ~20 satellites
  - high resolution (<50cm)

- **Umbra**

- **Spacety**

Space actors

- **From space agencies…**
  - Cost of space missions (1 satellite launch = 100-200 ME)
  - Earth observation thematics :
    - Public issues (meteo, climate, earth survey, disasters management, …)
    - Defense
- **To private industries:**
  - American strategy (supporting US industry in space development)
  - New challenges: spatial tourism, planet exploration and exploitation, …
  - New markets: activity monitoring, agriculture, insurance, finance, energy…

Space actors and data policy

- **Data from space agencies:**
  - Free for scientific programs
  - Fully available and free for ESA's Copernicus program (Sentinel constellation), USGS/NASA Landsat, NOAA VIIRS, …

- **And from commercial providers:**
  - Airbus (Pléiades, SPOT, Pléiades Neo, TerraSAR-X)
  - Maxar (WorldView, GeoEye, QuickBird)
  - Planet (PlanetScope, SkySat)
  - e-Geos (COSMO-SkyMed)
  - Iceye, Capella, ….

Depending on image resolution and size, pricing range from 1 to 100 euros per km^2

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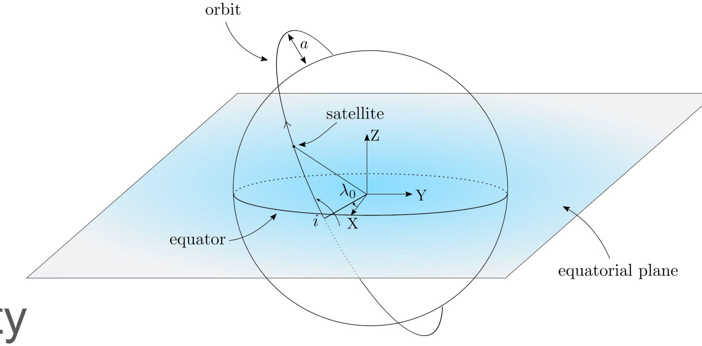
Orbital mechanics



- satellites travel around the Earth thanks to gravity
- if we assume that the Earth mass distribution has spherical symmetry then its gravitational field is equivalent to that of a single point located at its center:

$$F = G\frac{mM}{r^2}$$

- hence the orbit of any satellite is planar (conservation of the angular momentum), and its shape is an ellipse
- without applying force (such as firing a rocket engine), the shape and period of the orbit won't change
- if the launcher releases the satellite with a specific orthoradial initial speed, then the orbit is circular:

$$v = \sqrt{\frac{GM}{r}}$$

Circular orbit parameters

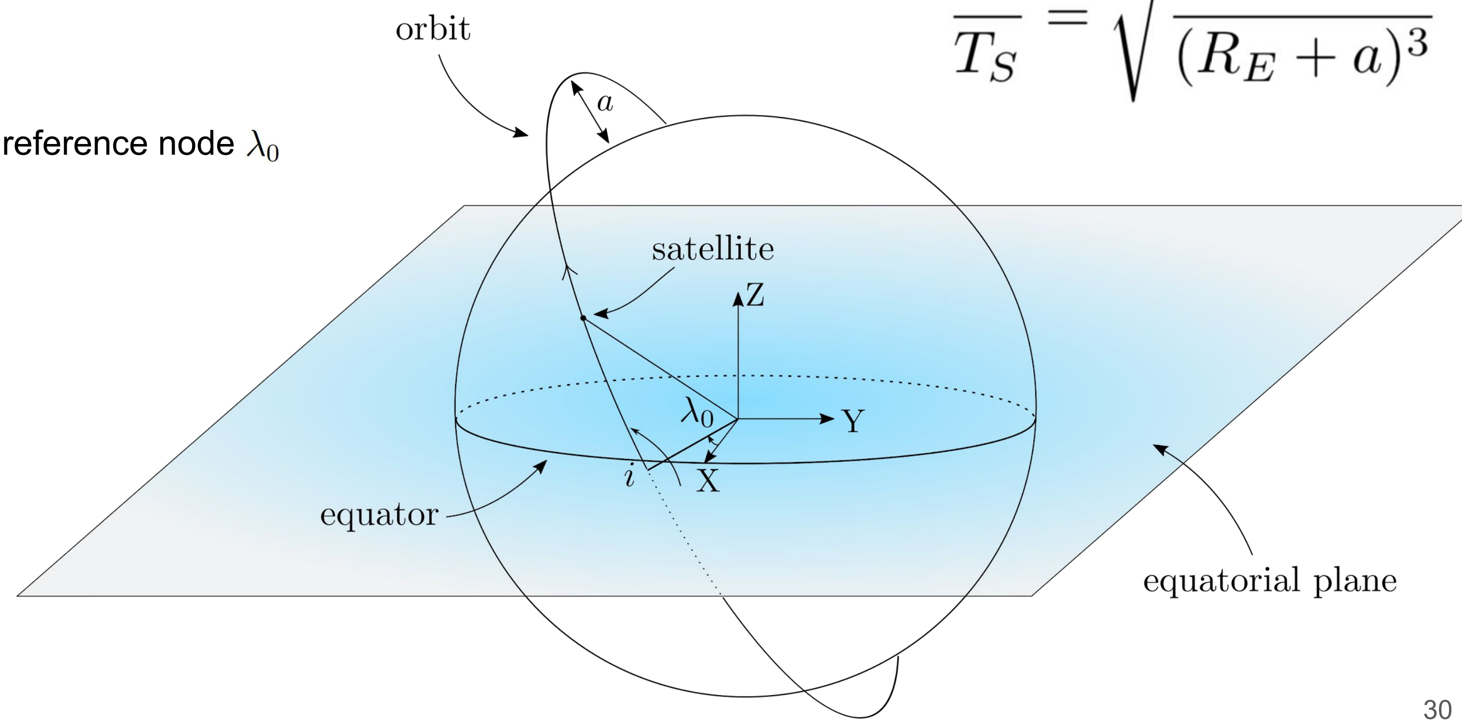
$$v = \sqrt{\frac{GM}{R_E + a}}$$

The radius of a circular orbit determines the (constant) speed and period of the satellites:

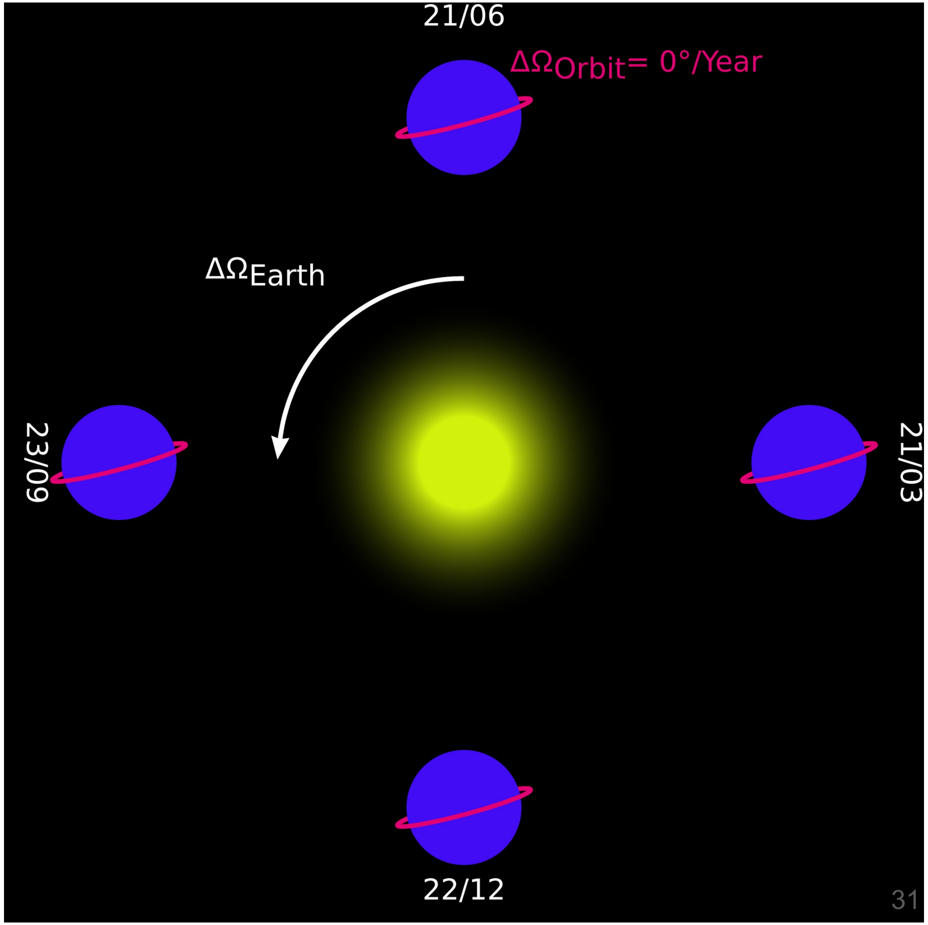
$$\frac{2\pi}{T_S} = \sqrt{\frac{GM}{(R_E + a)^3}}$$

Hence circular orbits depend on only 3 parameters:

- altitude a
- inclination i
- longitude of the reference node λ_0



The Earth moves around the sun!



Sun synchronous orbits

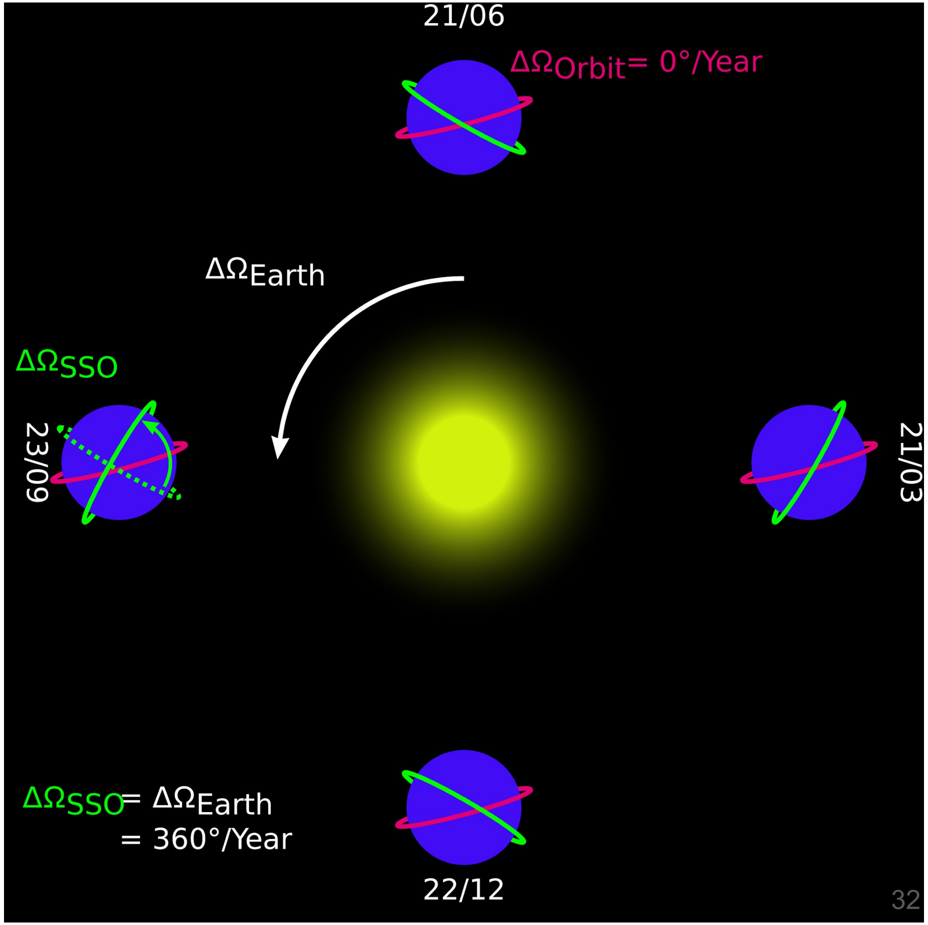
The Earth moves around the sun!

Fortunately the Earth is not a perfect sphere: it's more like an oblate spheroid.

This induces a rotation of the satellite orbital plane around the Earth axis, at this rate

$$\Delta\Omega = -3\pi \frac{J_2 R_E^2}{(R_E + a)^2} \cdot \cos i$$

Knowing the orbit radius, the orbit inclination can be chosen such that the rotation rate is 360 degrees per year.



Sun synchronous orbits

Sun synchronous orbit parameters

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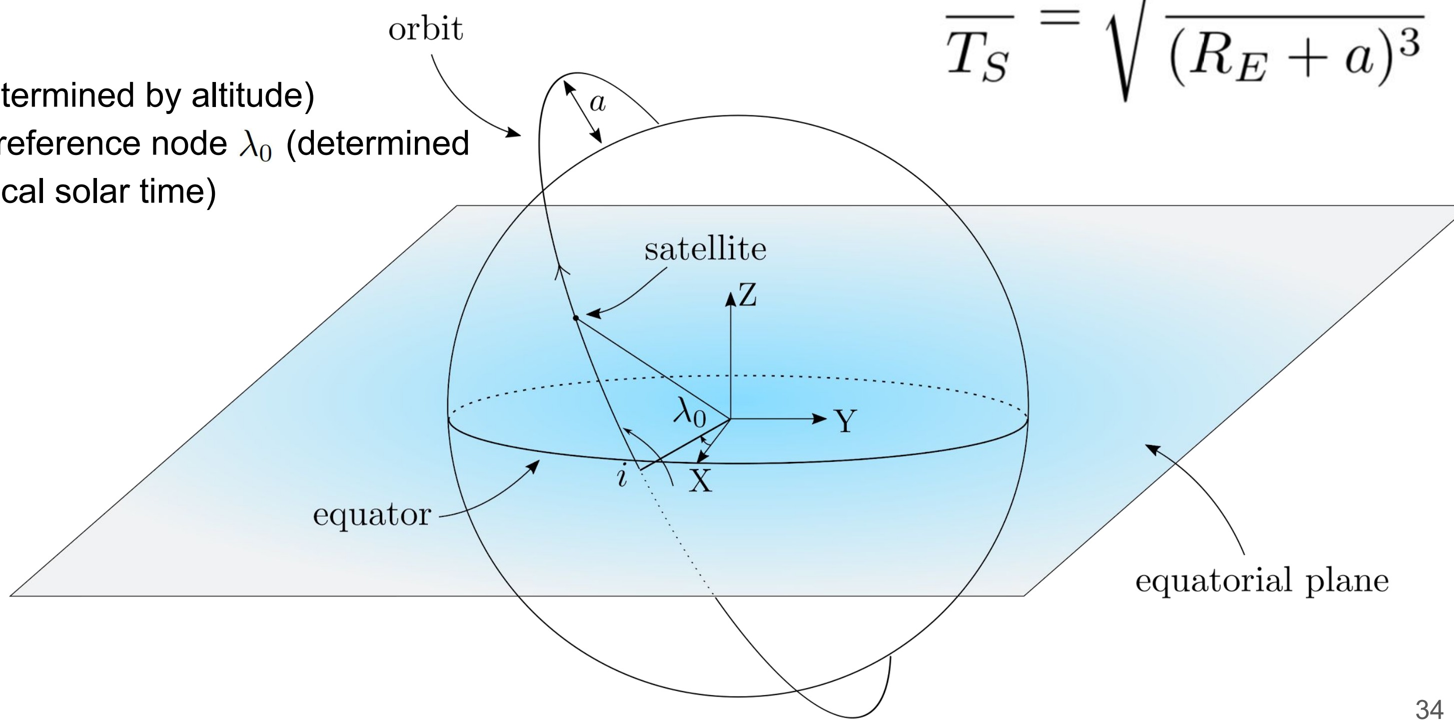
The radius of a circular orbit determines the (constant) speed and period of the satellites:

$$\frac{2\pi}{T_S} = \sqrt{\frac{GM}{(R_E + a)^3}}$$

Hence SSO orbits depend on only 2 parameters:

- altitude a
- ~~inclination i~~ (determined by altitude)
- longitude of the reference node λ_0 (determined by the chosen local solar time)



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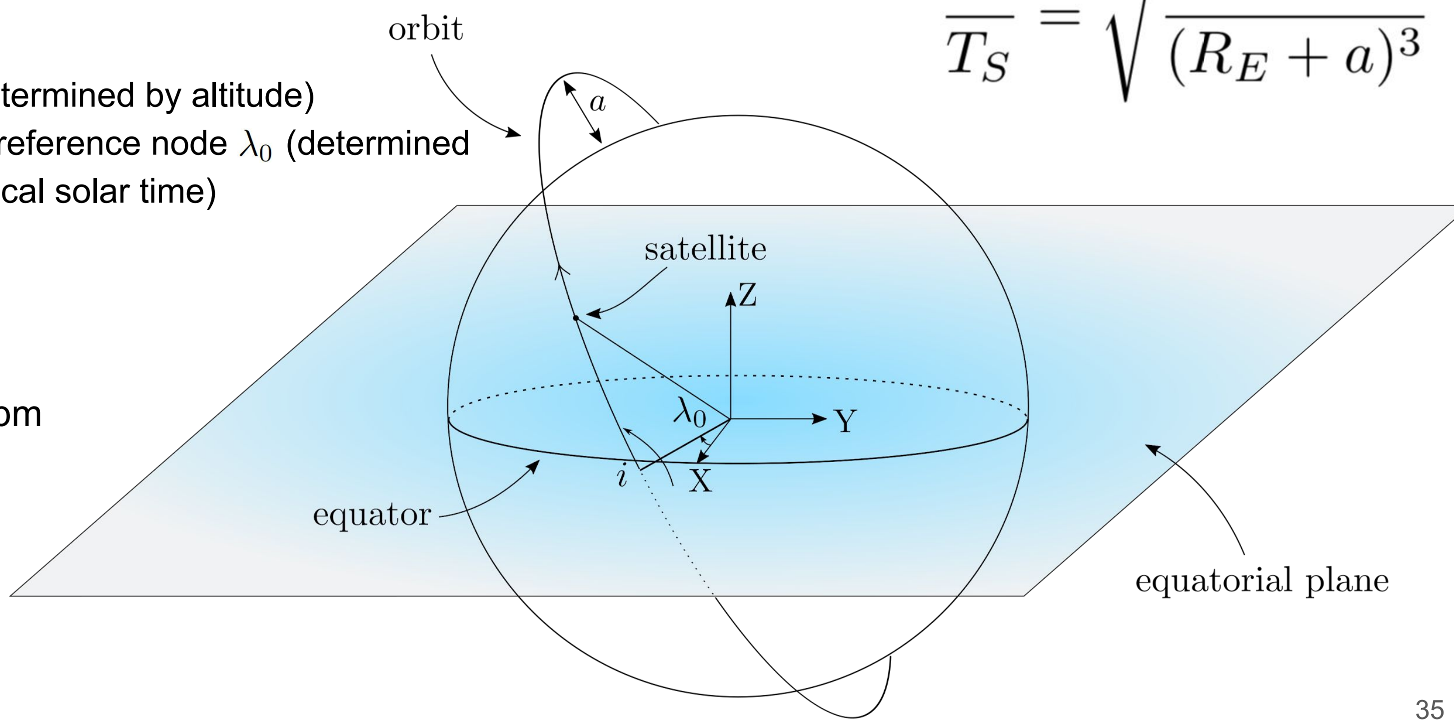
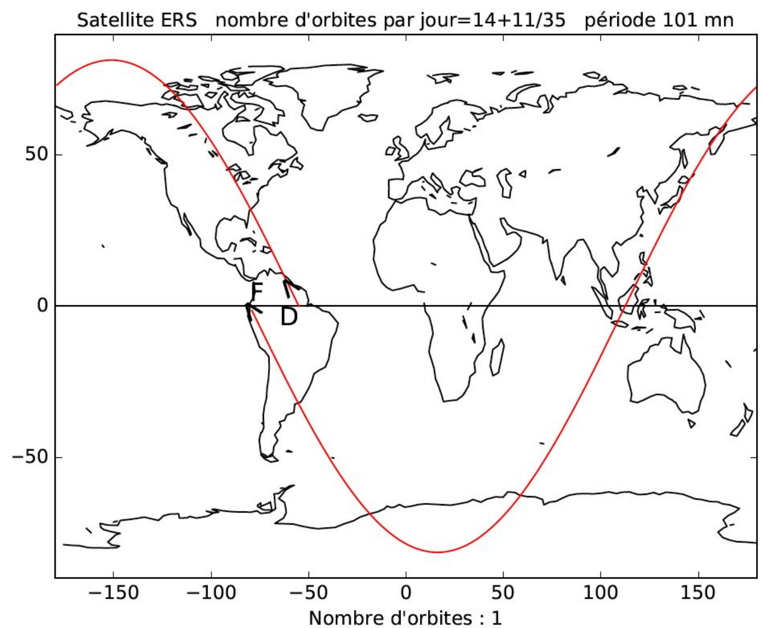


Crazy consequence:
- Optical: 10am
- SAR: 6am & 6pm

Does the orbit have a repeat cycle?

Let T be the orbit period. For orbit altitudes of about 500 to 1000 km, T varies from 94 to 105 minutes, ie the satellite circles the Earth 13.7 to 15.3 times per day.

The Earth rotates: after completing one orbit, the satellite faces another location.



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If there exist two integers n and p such that

$$n \times T = p \times 24 \text{ hours}$$

then after p days the satellite is back in the exact same position with respect to the ground. Is this case the satellite is said to have a **repeat cycle** of p days.

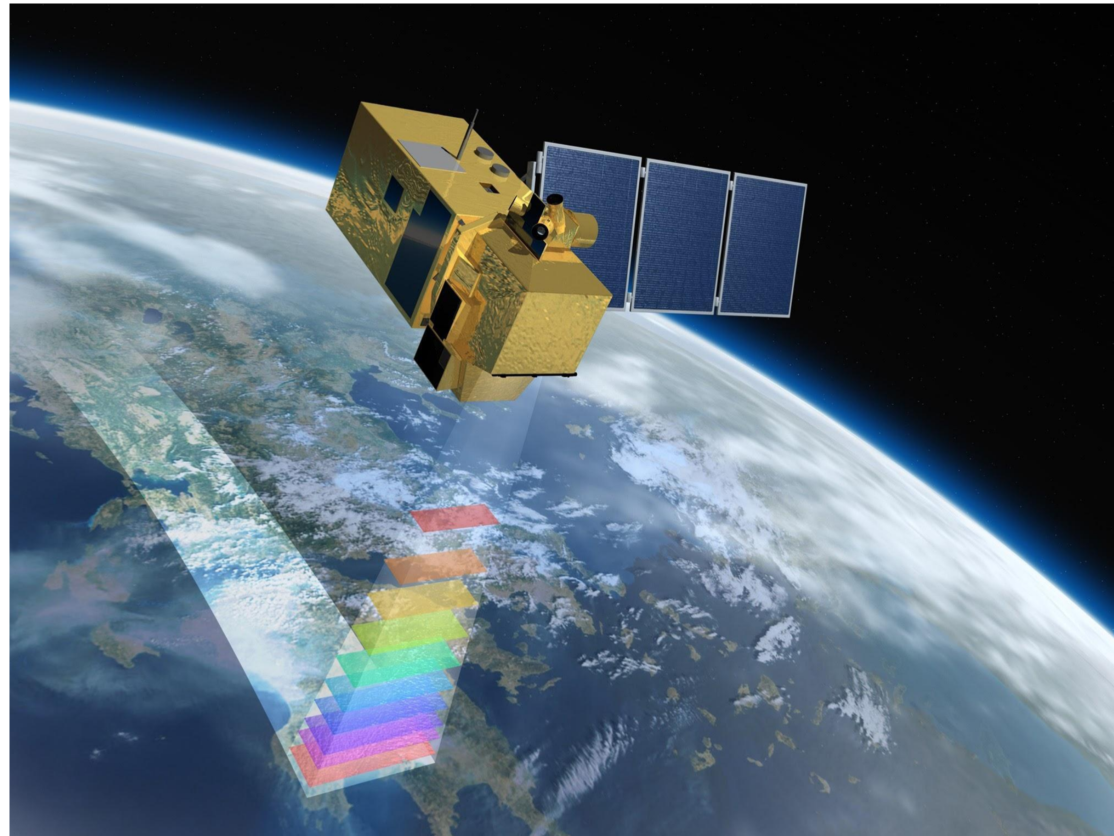
Having a repeat cycle is crucial for some applications (radar interferometry).

Mission	Altitude	Période en minutes	Orbites par jour	Cycle en jours	Orbites par cycle	Distance minimale entre orbites à l'équateur	Décalage journalier	Inclinaison de l'orbite
	h	T	p	q	N	$D_{\min}$	d	i
Landsat-1	917 km	103.81	$13 + \frac{17}{18}$	18	251	159 km	159 km	99.1°
Formosat	888 km	102.74	14	1	14	2 857 km	0 km	98.99°
SPOT	832 km	102.01	$14 + \frac{5}{26}$	26	369	108 km	540 km	98.7°
ADEOS-2	804 km	101.05	$14 + \frac{1}{4}$	4	57	615 km	2800 km	98.64°
ERS, ENVISAT	781 km	100.60	$14 + \frac{11}{35}$	35	501	80 km	1920 km	98.52°
Landsat-4	705 km	98.9	$14 + \frac{9}{16}$	16	233	171 km	171 km	98.2°
TerraSAR-X	515 km	95.38	$15 + \frac{2}{11}$	11	167	240 km	480 km	97.4°

Swath size

The stripe of land that the satellite is able to capture during a single pass is called the **swath**.

The swath size depends both on the **instrument aperture** and the **orbit altitude**.

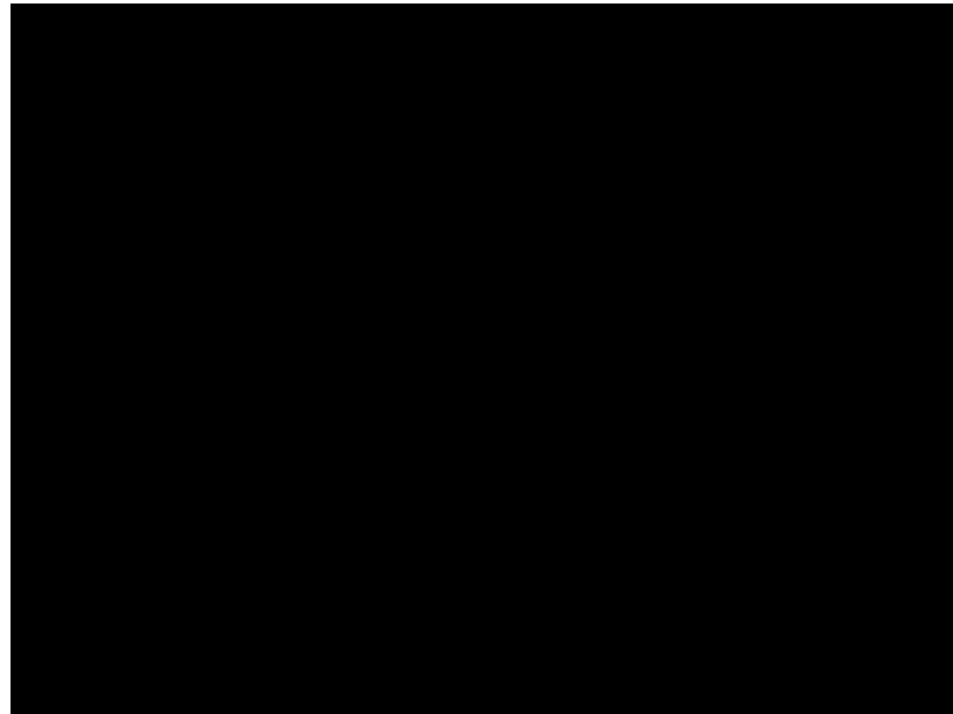


Swath and repeat cycle

The orbit altitude must be chosen such that the swath size and number of orbits per cycle ensure a **complete coverage** of the Earth surface.

To lower the repeat cycle, one can add satellites on the same orbit.

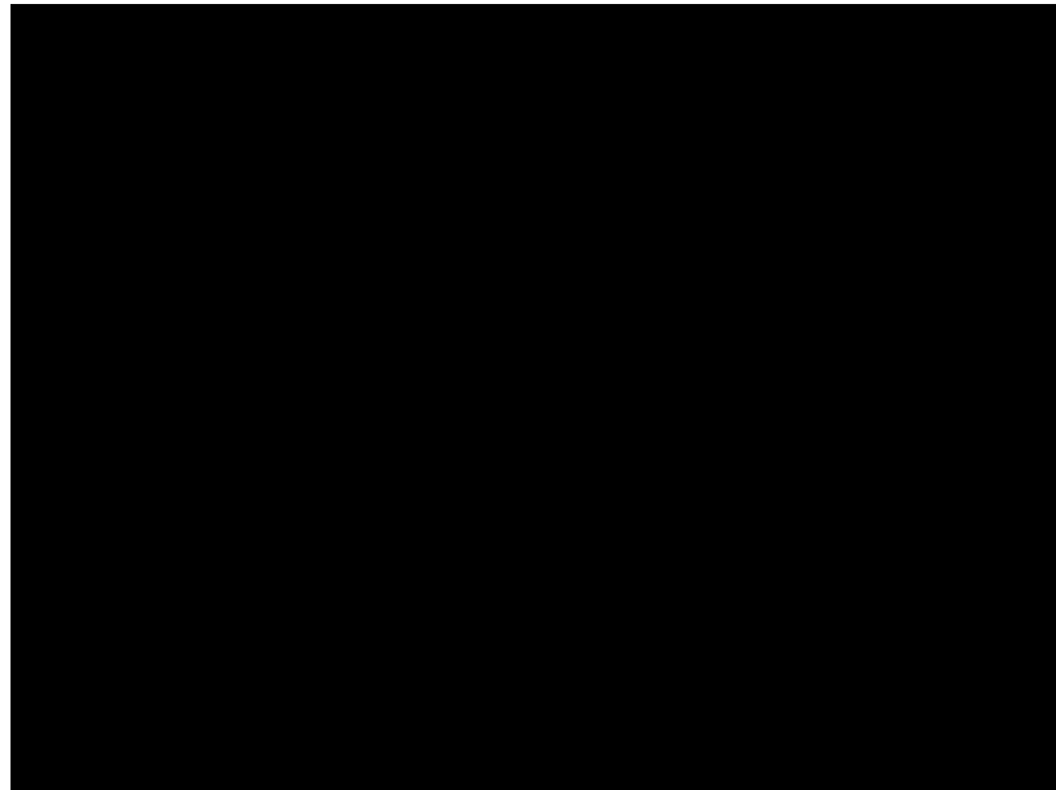
Revisit time (≠ repeat cycle) is lower at the poles as swaths overlap.



Tasking

On Very High Resolution (VHR) sensors, the swath width is too small to ensure global coverage with a reasonable repeat cycle.

Hence the satellites carrying these sensors are **agile**: they can point on-demand at desired targets.



Quick recap about Earth observation satellites orbits

Most Earth monitoring satellites fly on sun-synchronous orbits:

- solar time of the scene is constant
  - usually 10 am for optical, 6 am / 6 pm for radar
  - with only 1 orbital plane, minimal revisit time is 1 day
- altitude: between 500 and 1000 km above the ground
  - speed: about 7 km / s
  - orbital period: about 100 minutes
  - orbits per day: about 15 orbits per day
  - inclination: about 98 degrees
- there’s a tradeoff between spatial resolution and temporal revisit

Some Earth monitoring satellites fly on different orbits, such as the geostationary orbit (weather satellites).

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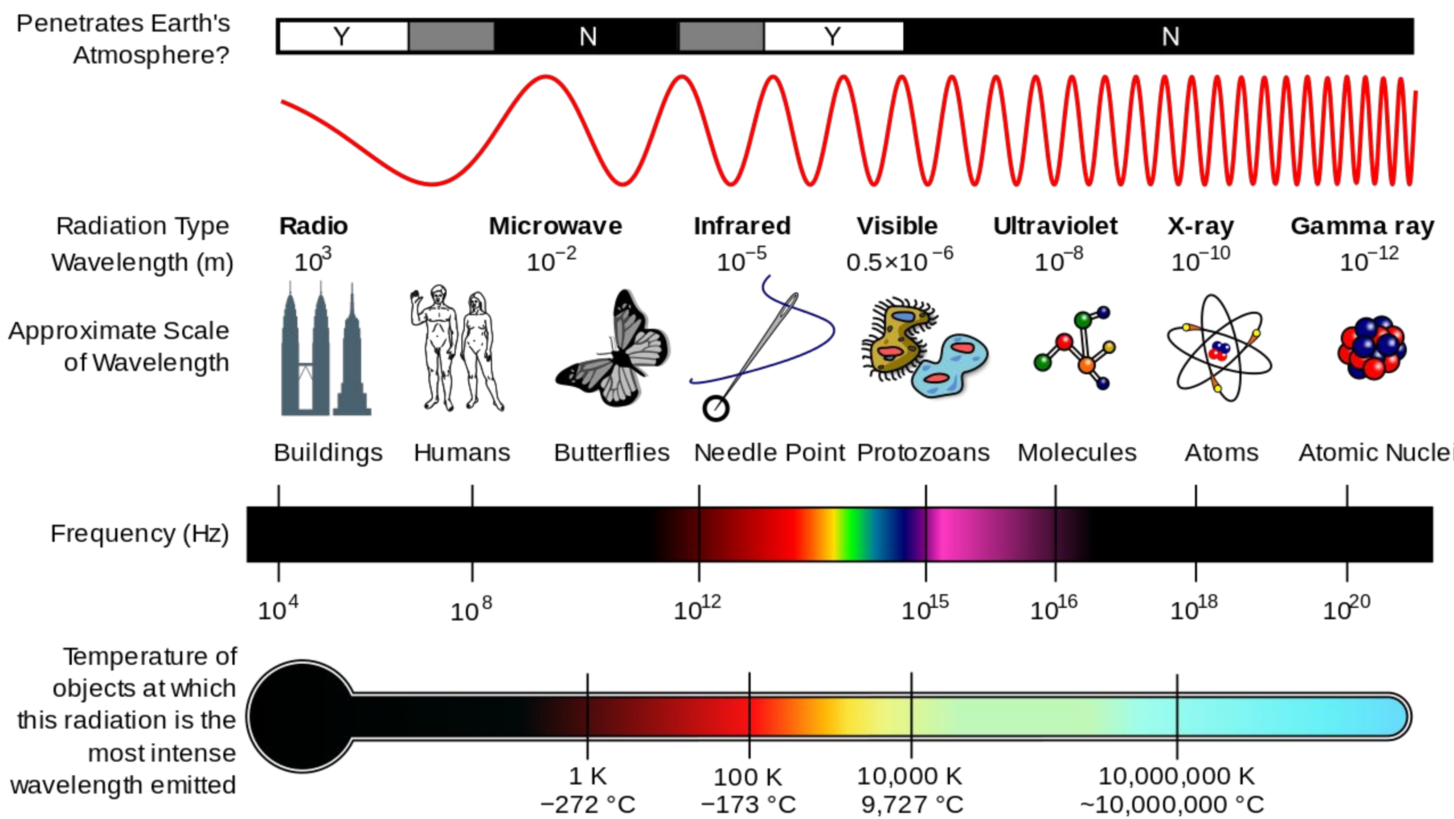
Sensors

All sensors measure the energy of some specific electromagnetic wavelenghts.



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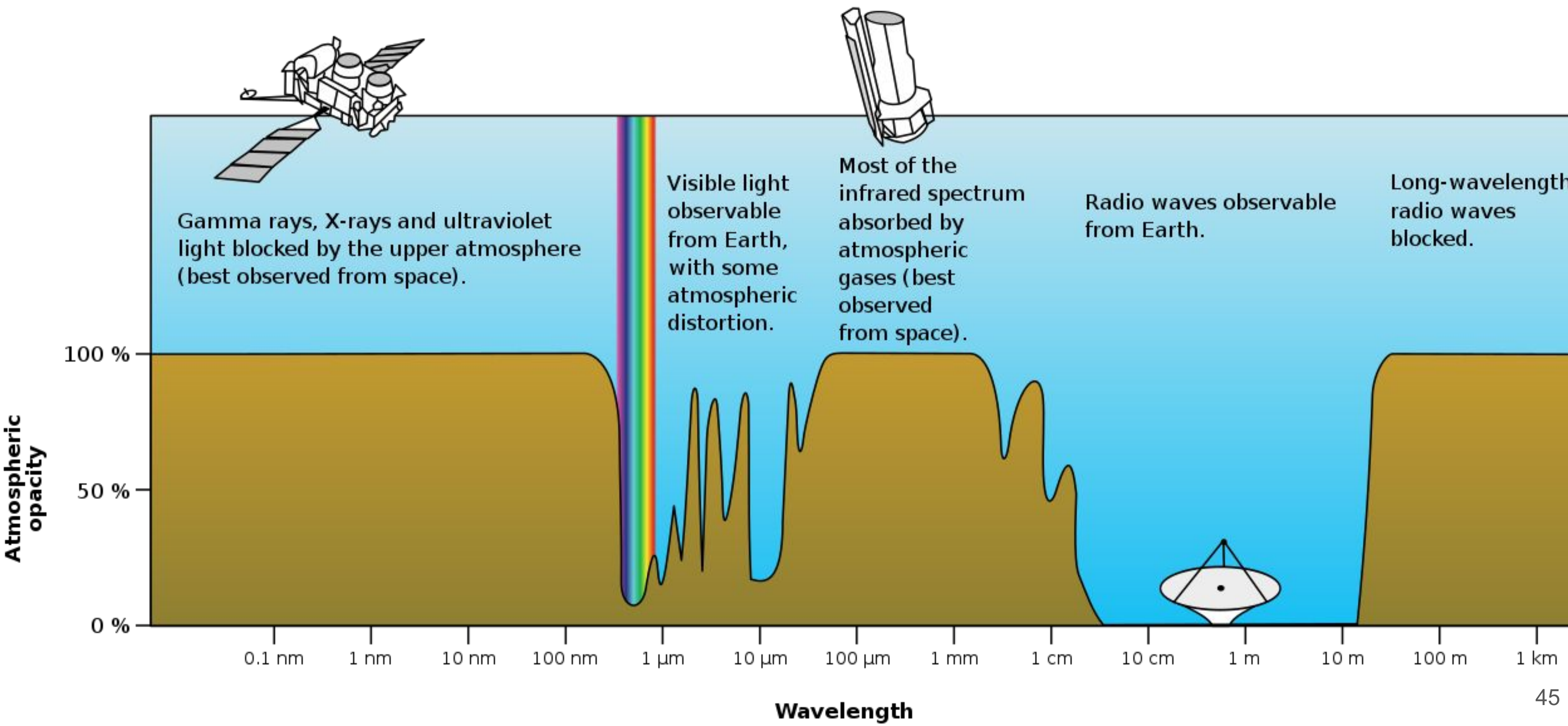


Sensors

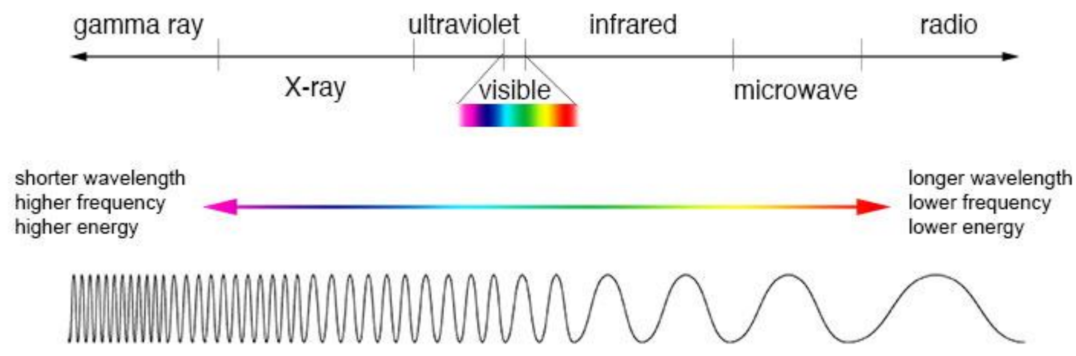
All sensors measure the energy of some specific electromagnetic wavelenghts.

Optical visible: the most common

- regular photos, easy to interpret
- usually 3 or 4 channels (RGB or RGBI)
- broad range of spatial resolutions available: from 30cm/px (Pléiades Neo) to 1km/px (MODIS)

Infrared: very near (VNIR), short wave (SWIR), thermal (TIR). To detect heat and some materials that have a specific emissivity (e.g. chlorophyll index). Low resolution.

Hyperspectral: hundreds of narrow spectral bands. Monitor atmospheric gas concentration in air columns. Topomi (S5P), AIRS (Acqua). Low resolution.



Source: Comparison of wavelength, frequency and energy for the electromagnetic spectrum." Digital image. The Electromagnetic Spectrum. March 2013.

Sensors

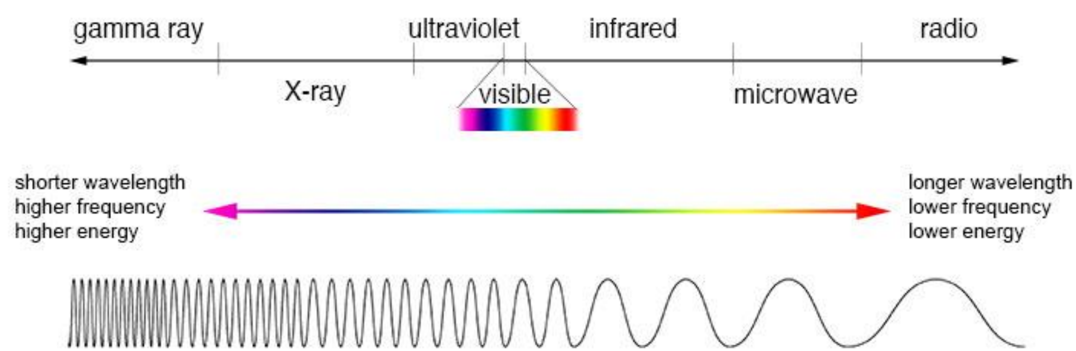
All sensors measure the energy of some specific electromagnetic wavelenghts.

Radar: the most reliable

- sees through clouds and at night
- visually hard to interpret
- very noisy
- broad range of spatial resolutions available

Others: lidar-doppler (Aeolus),

...



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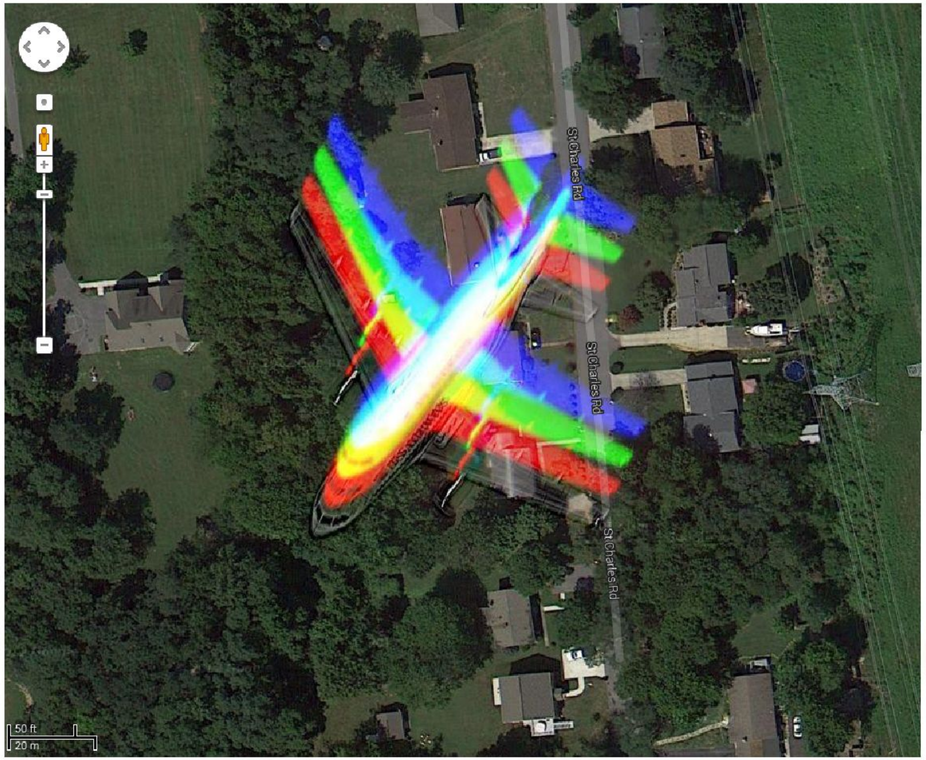
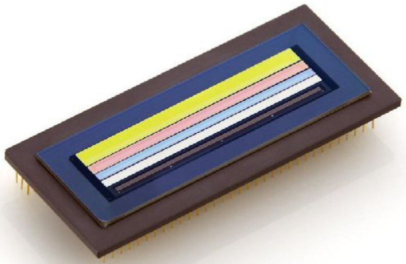
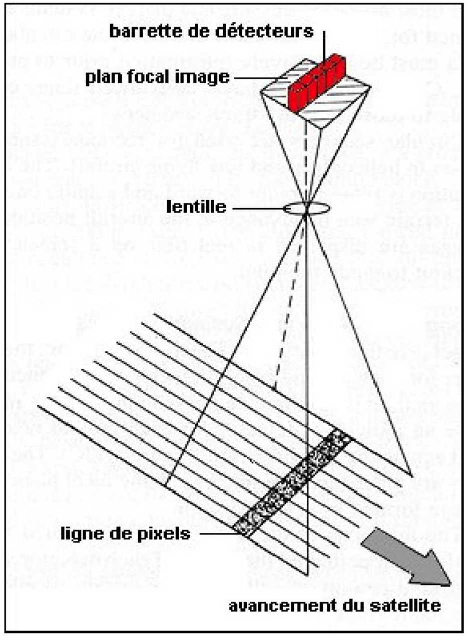
Optical sensors: frame vs pushbroom cameras







Vehicles speed estimation with WorldView-3

Vehicles speed estimation with WorldView-3

Optical sensors

Landsat-8/9

- resolution 15 m
- repeat cycle 16 days
- 12 bands

Sentinel-2

- resolution 10 m
- repeat cycle 5 days (2 satellites)
- 13 bands

Planet Doves

- resolution 3 m
- no repeat cycle, revisit 1 day (150 sats)
- 4 bands

RapidEye

- resolution 6.5 m
- repeat cycle 5 days (5 sats)
- 5 bands

WorldView-3

- resolution 31 cm
- revisit 1 day
- 1 PAN + 8 XS + 8 SWIR bands

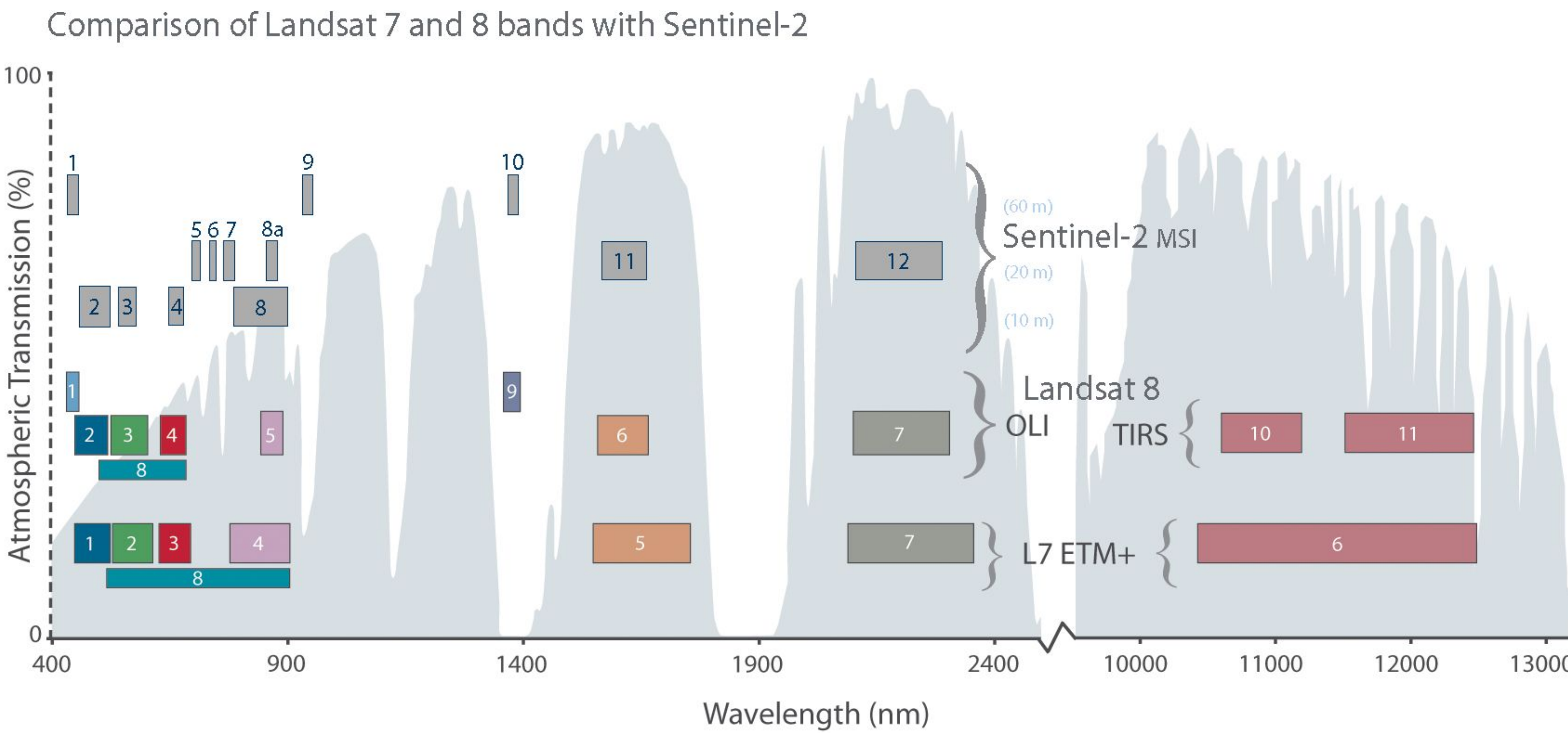
Pléiades

- resolution 70 cm
- repeat cycle 13 days (2 sats)
- revisit 1 day
- 1 PAN + 4 XS bands

SkySat

- resolution 72 - 86 cm
- revisit 0.5 day
- 1 PAN + 4 XS bands
- video mode

Multimodal : visible, NIR, SWIR sensors



By **Earth Resources Observation and Science (EROS) Center**, USGS


2017-06-23_S2A_orbit_027_tile_11SLU_L1C

2017-06-23_S2A_orbit_027_tile_11SLU_L1C

Viedma glacier, Argentina, seen by Sentinel-2

Viedma glacier, Argentina, seen by Sentinel-2

SkySat Imaging HD Video of Burj Khalifa

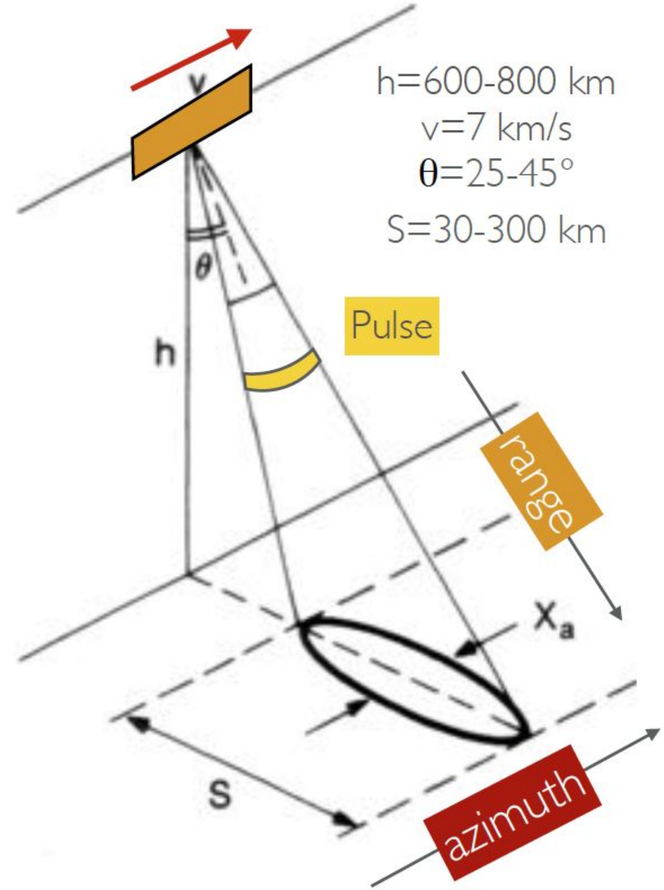
Radar sensors

Active system:

- sends radio waves to the ground and listen for the waves that bounce back
- measures the time of flight and derive the distance (range)
- The image pixel values are the amplitude and phase of the waves that came back

Metallic structures usually are strong reflectors.

It can see through clouds and at night!



Radar sensors have several acquisition modes

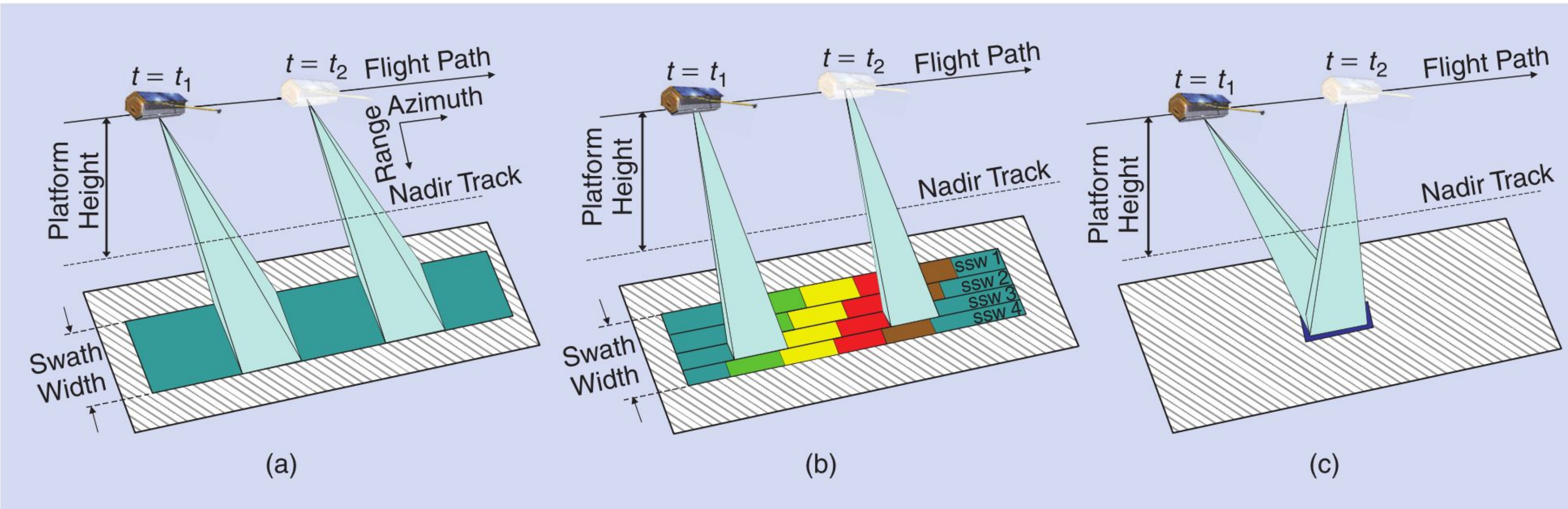


FIGURE 6. Illustration of different SAR operation modes which are used to increase the swath width (ScanSAR) or improve the azimuth resolution (Spotlight) compared to the Stripmap mode. (a) Stripmap. (b) ScanSAR. (c) Spotlight.

Radar sensors

Sentinel-1

- TOPS resolution 14 x 3.2 m
- repeat cycle 6 days (2 satellites)
- systematic coverage (no tasking)

COSMO-SkyMed

- resolution 3 m (stripmap), 1 m (spotlight)
- repeat cycle 1-3-4-8 days (4 satellites)

TerraSAR-X / TanDEM-X

- resolution 3 m (stripmap), 0.24 x 1 m (spotlight)
- repeat cycle 11 days
- single pass interferometry (2 satellites)

Capella

- resolution 3 m (stripmap) 1.5 m (spotlight)
- repeat cycle 5 days
- 36 sats, 12 orbital planes

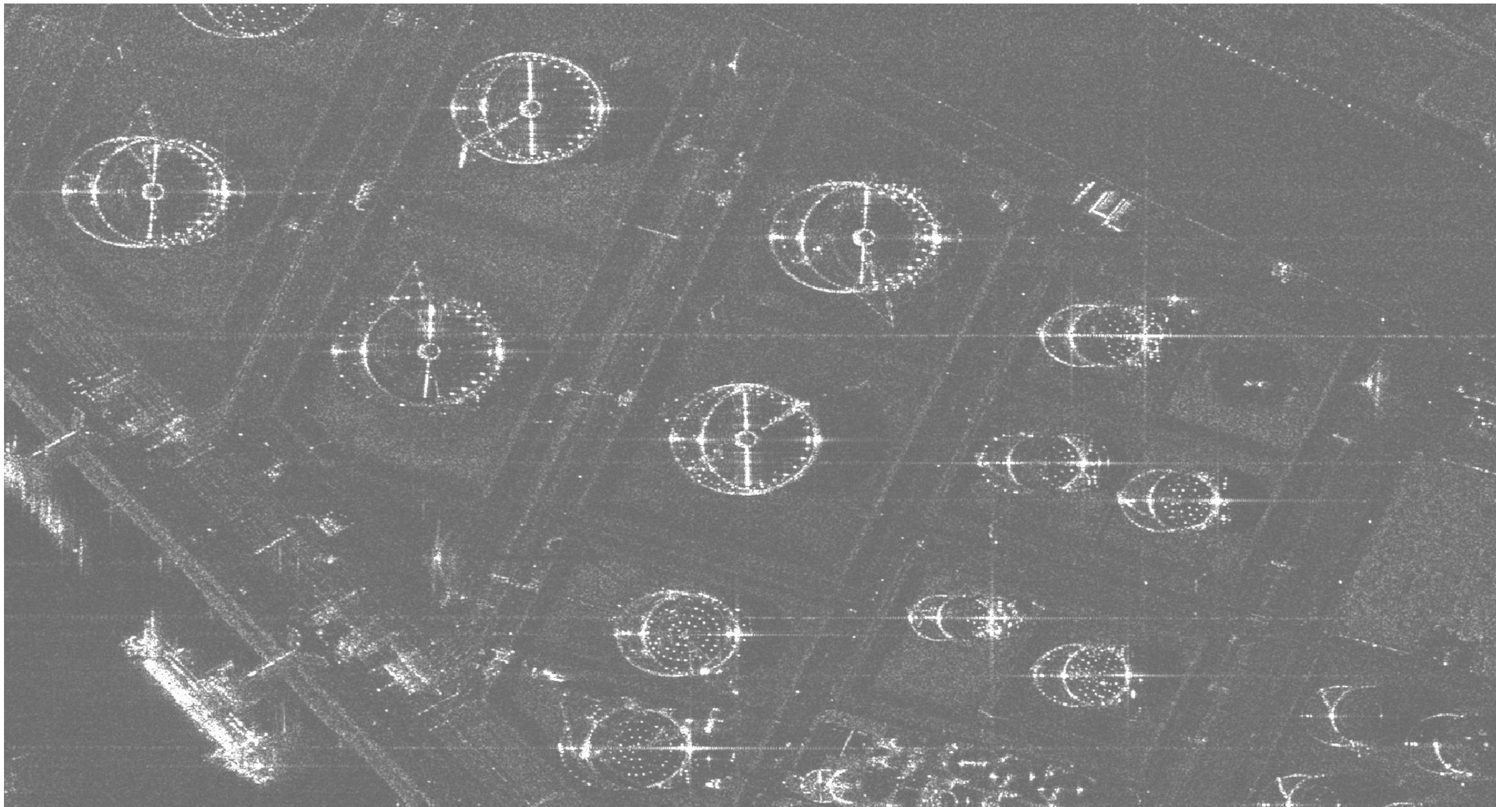
Iceye

- resolution 10 m, 3 m
- launched first satellite in 2018

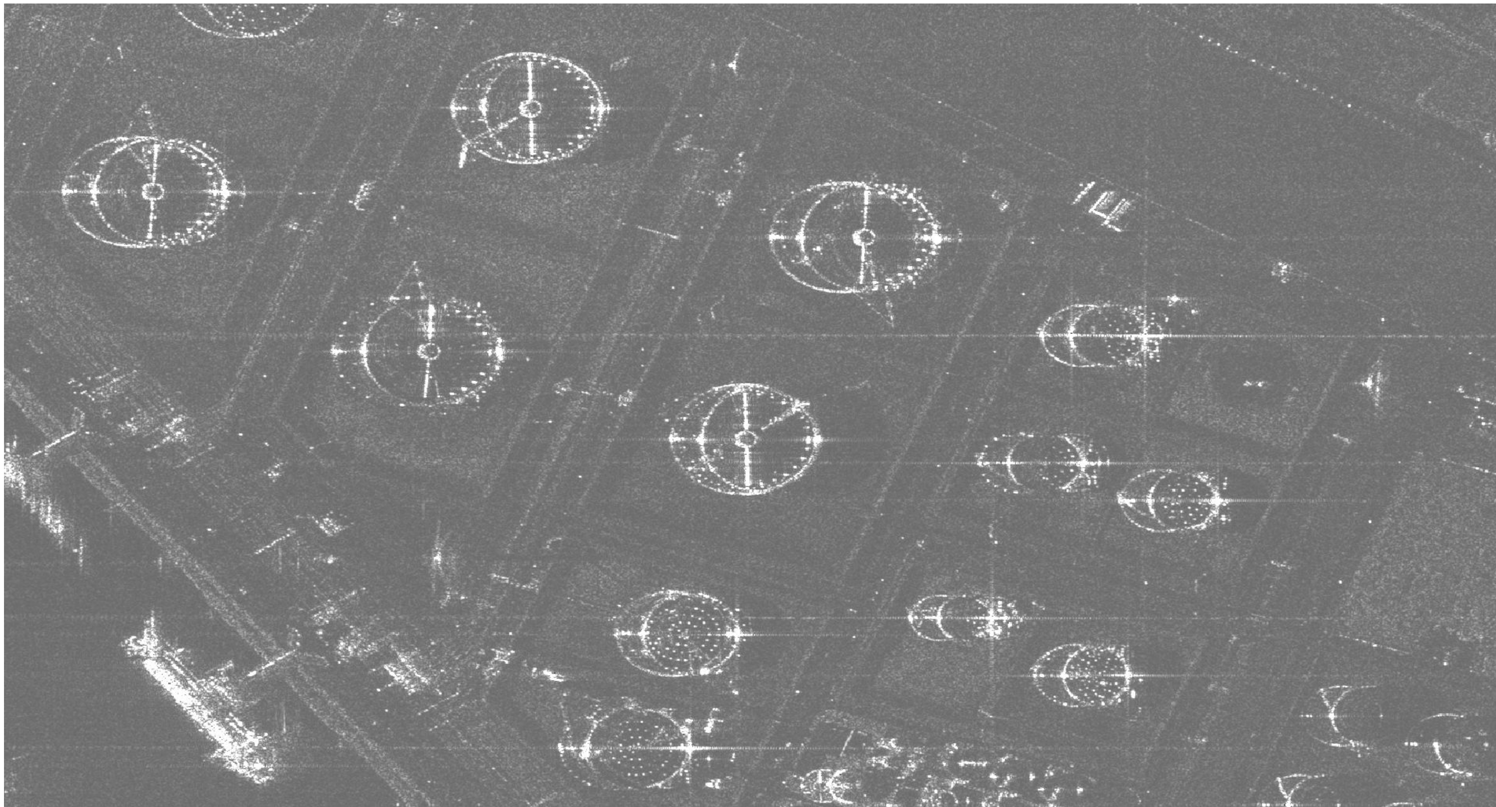
ArrowSAR (Airbus DS)

- planned constellation of 16 satellites

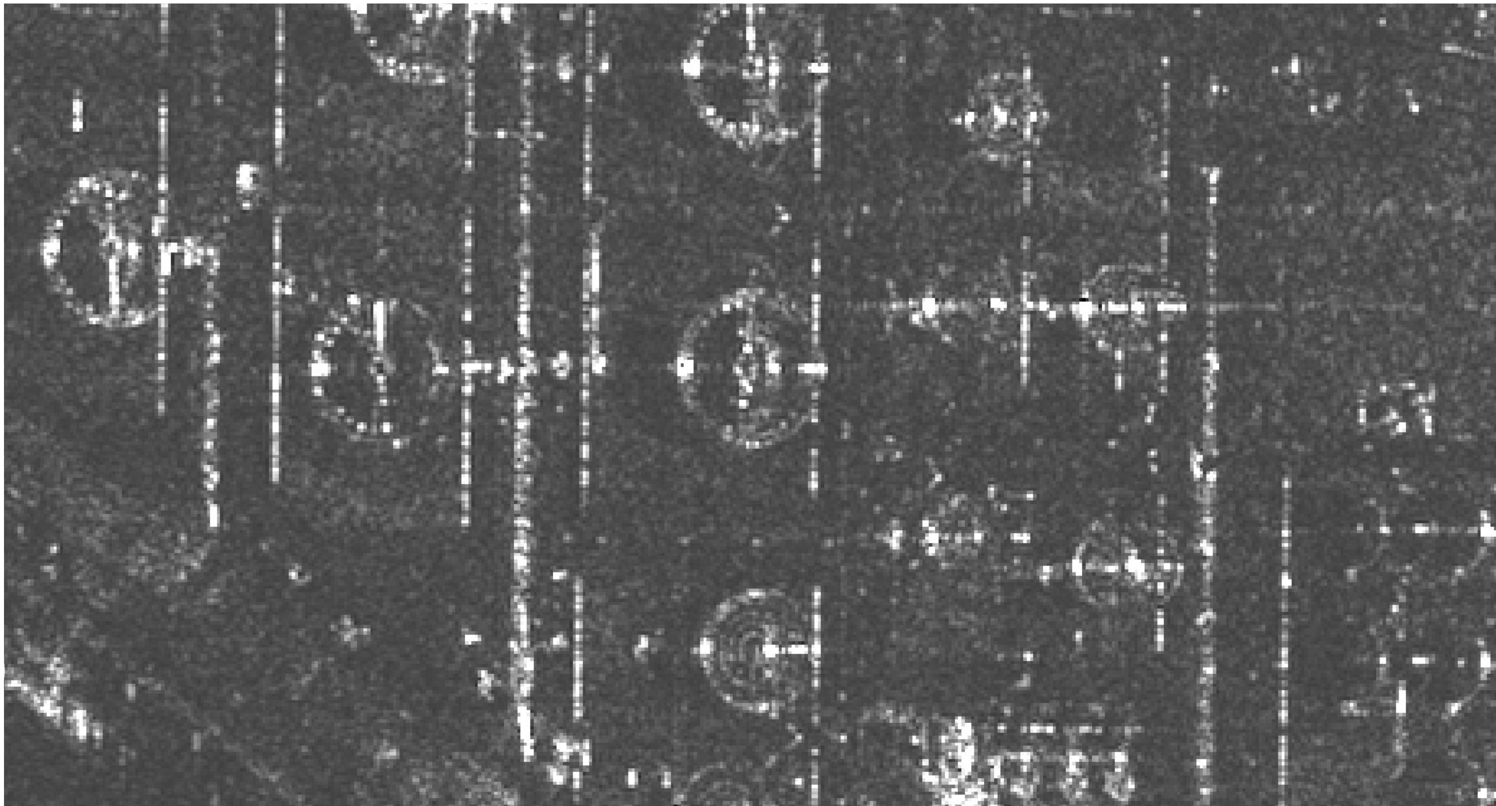
COSMO-SkyMed SpotLight (1m / px), Europoort



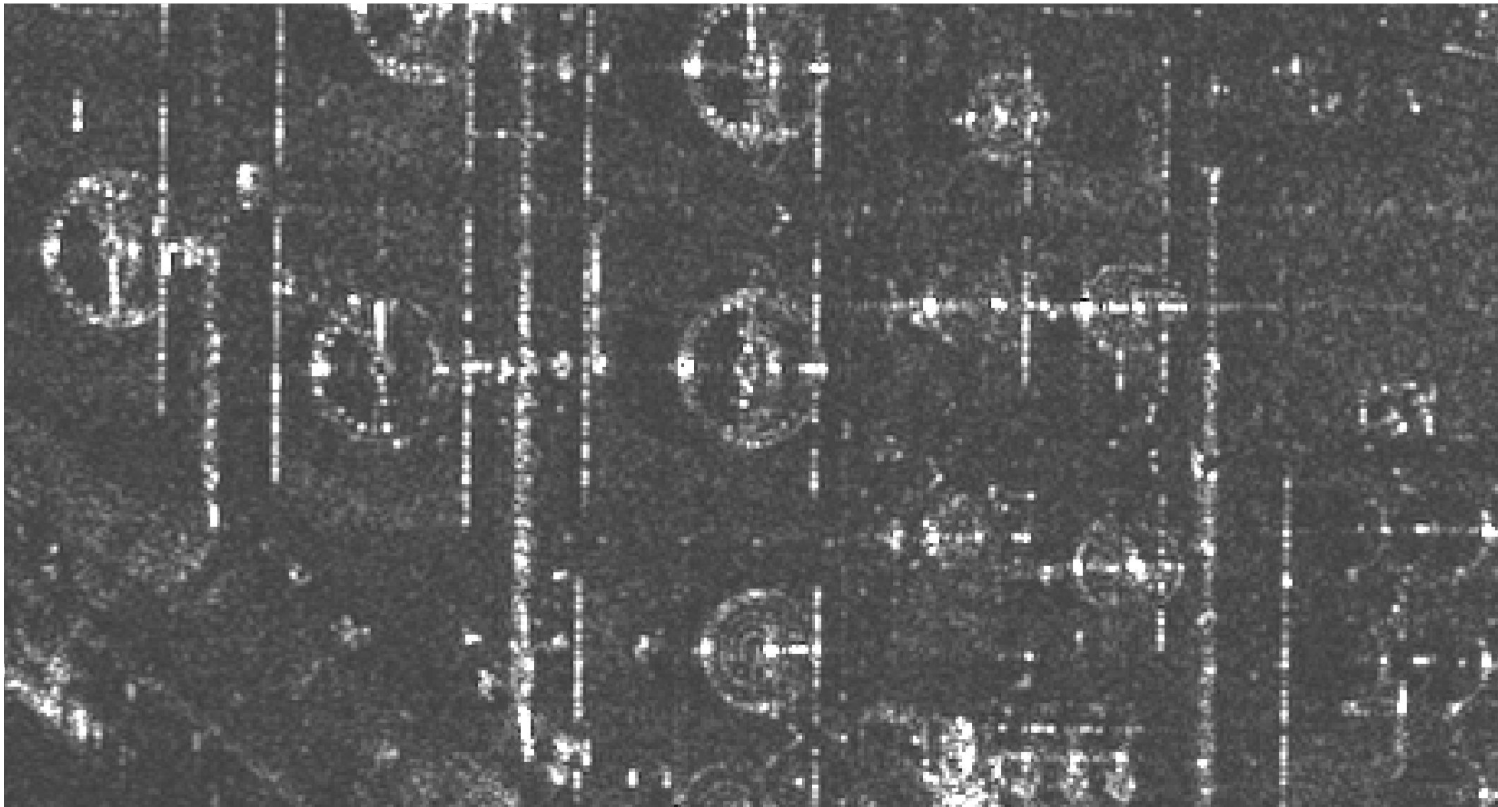
COSMO-SkyMed SpotLight (1m / px), Europoort



COSMO-SkyMed StripMap (3m / px), Europoort



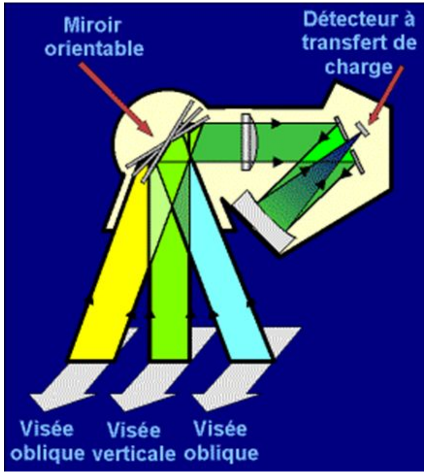
COSMO-SkyMed StripMap (3m / px), Europoort

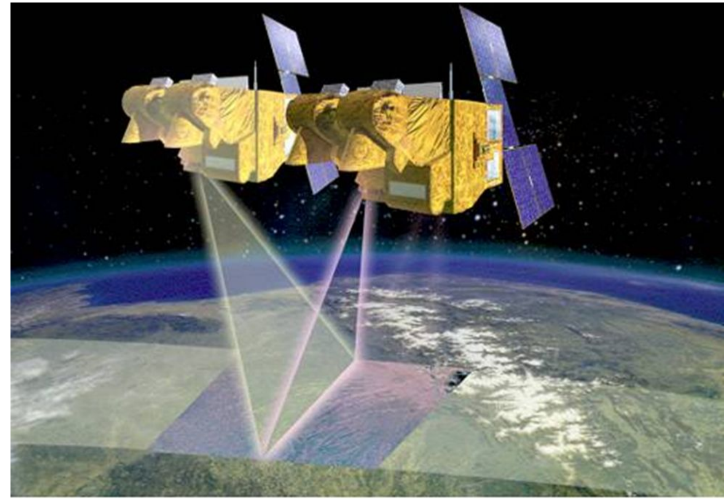


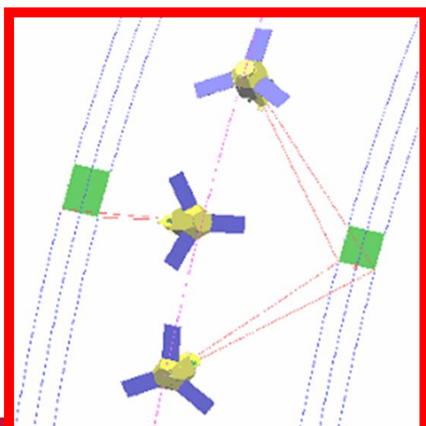
Sensor and satellite

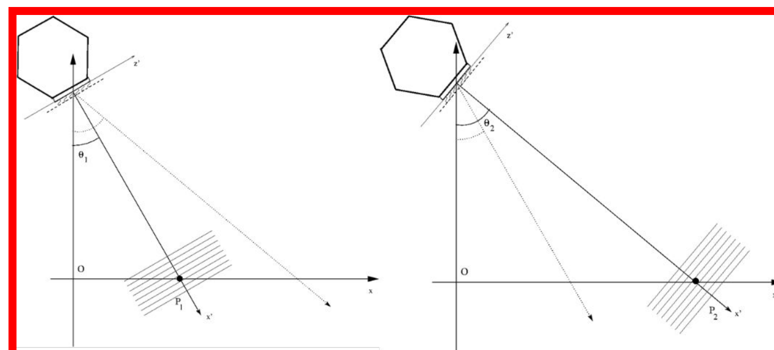
- **Satellite:**
  - → Orbital cycle: **time of the cycle**
  - Identical geometry viewing for each cycle
- **Satellite + sensor agility:**
  - → **Revisit time**
  - Sensor geometry different for each acquisition
- **Temporal resolution:**
  - satellite constellations + sensor agility !

Sensor agility









©CNES

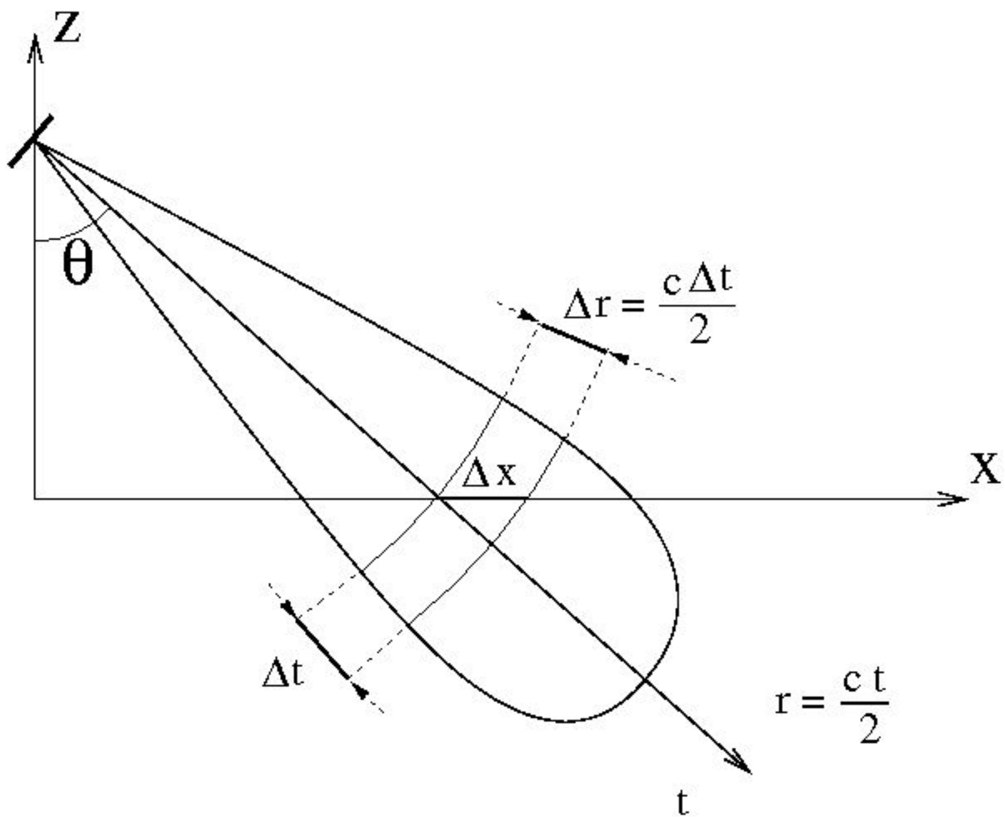
Revisit time: Pleiades

- Sensor agility
- Angular variations

Authorized angular variation	1 satellite	2 satellites
5°	25 days	13 days
20°	7 days	5 days
30°	5 days	4 days
45°	2 days	1 day
47°	1 day	1 day

Pleiades

Radar: lateral viewing



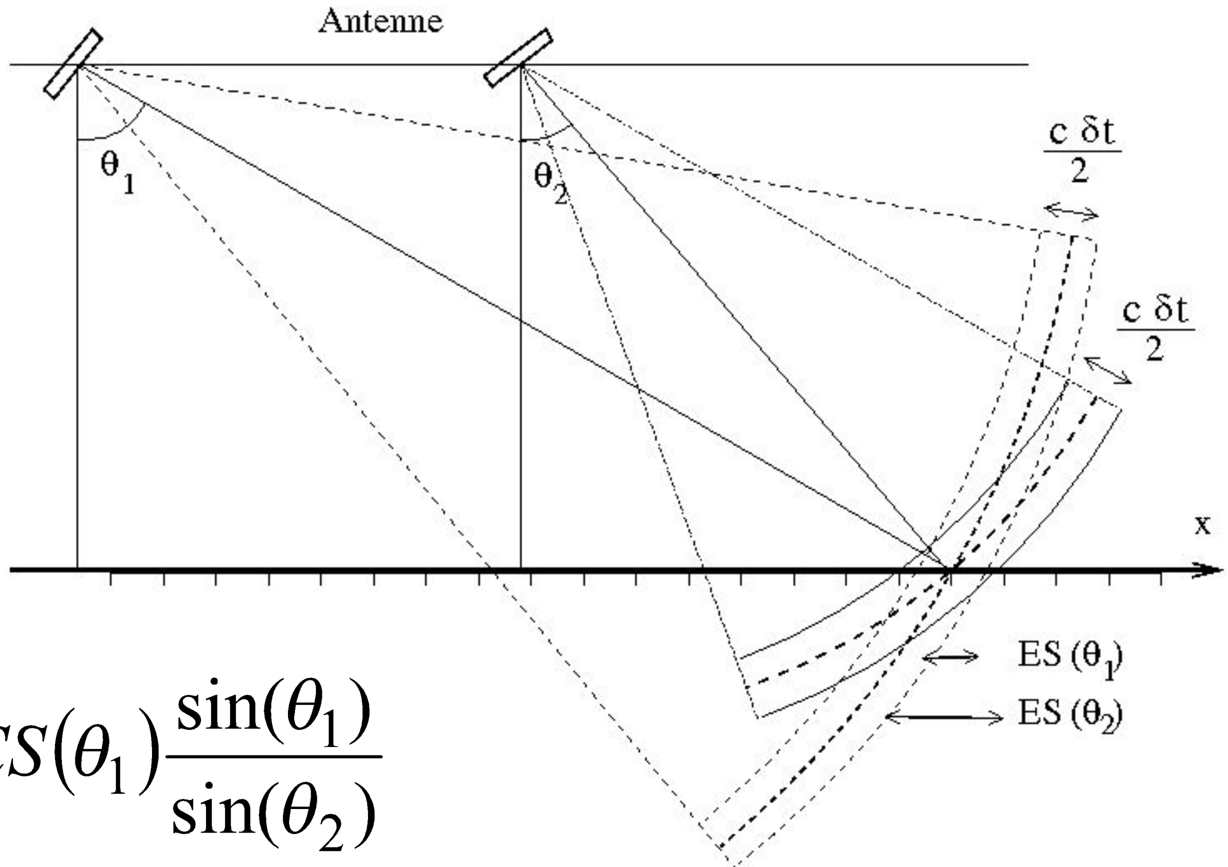
$$CS = \Delta x = \frac{\Delta r}{\sin(\theta)}$$

Radar near range versus far range

θ=6°, dx

θ=60°, dx/10

Variation of the ground cell with the local incidence angle



$$CS(\theta_2) = CS(\theta_1)\frac{\sin(\theta_1)}{\sin(\theta_2)}$$

$CS(\theta_1)$

$CS(\theta_2)$

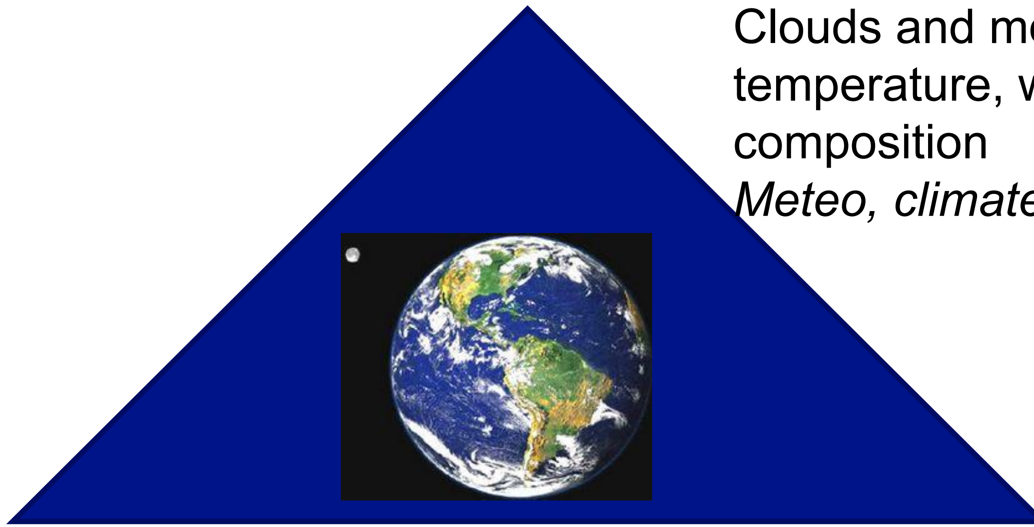
Outline of today’s session

What can be seen from space? Introduction to Earth Observation

1. Short **history** of remote sensing
2. Satellites **orbits**
3. Satellites **imaging systems**
4. Remote sensing **applications**
5. Coordinate reference systems and images **georeferencing**
6. **Practical work** in Python jupyter notebook

Remote sensing applications

ATMOSPHERE



Clouds and movements, temperature, water content, composition

Meteo, climate change, pollution

OCEAN

Temperature, color, tides, sea levels, ice sheets and movements

Ocean survey, climate change, pollution

LAND

Urban and land use, topography

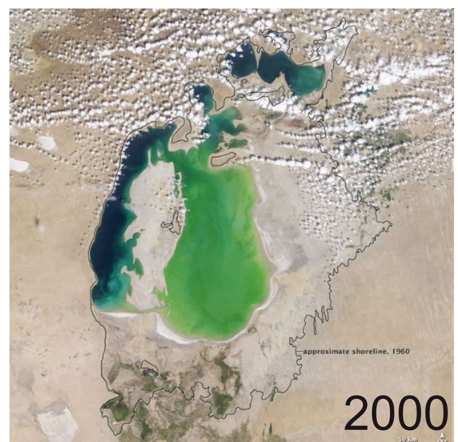
Emergency reponse, land or urban mapping and monitoring,

LAND applications

- **Environmental applications**
  - Vegetation and hydrology survey
  - Agriculture monitoring
  - Urban monitoring
  - Snow / glacier monitoring
  - DTM / DSM
- **Security applications**
  - Ground movement monitoring
  - Disaster management
- **Defense applications**
  - Land survey
  - Activity area detection

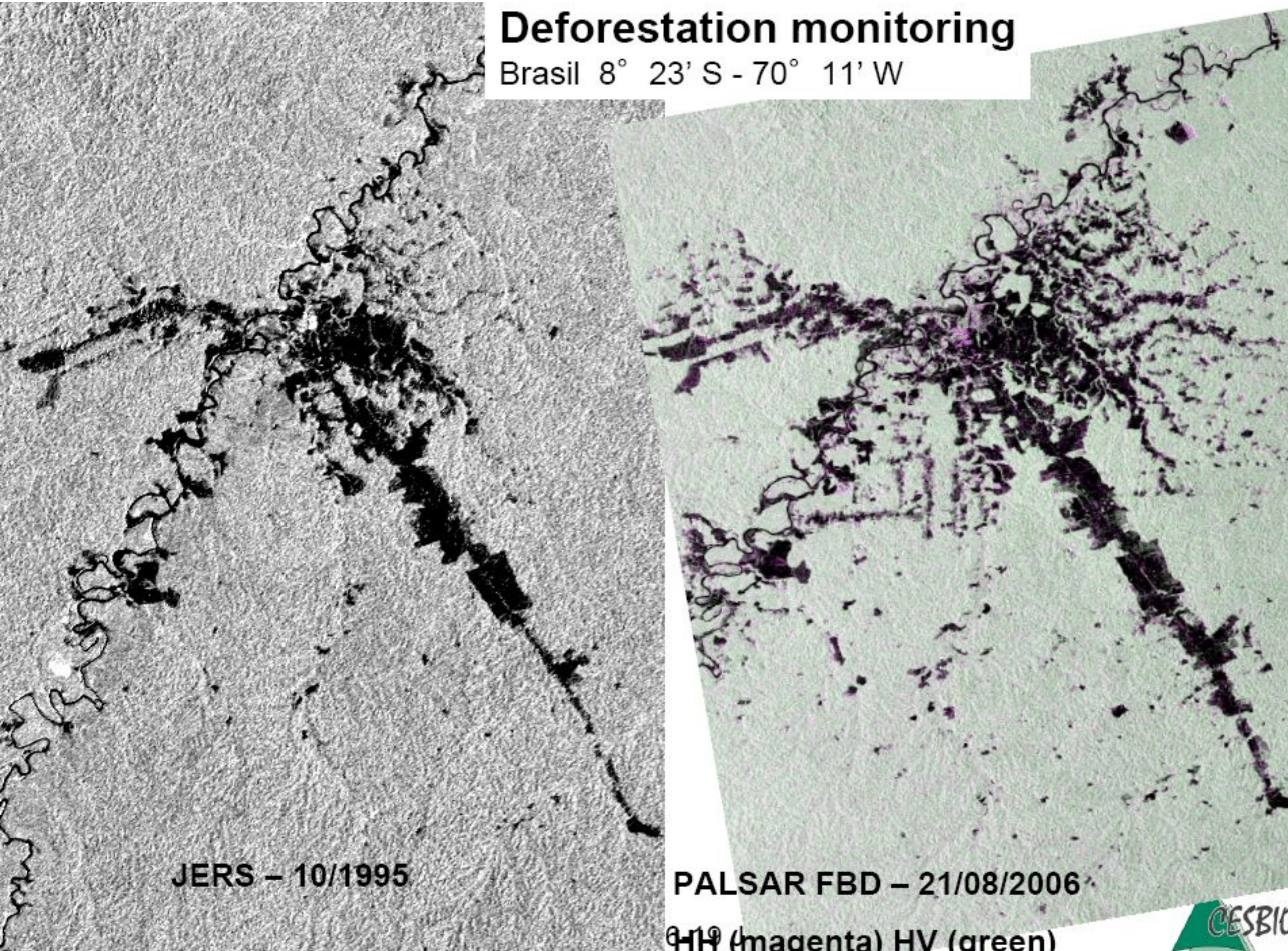
Environment monitoring (mer d'Aral)

50 km



Deforestation monitoring

Brasil 8° 23' S - 70° 11' W



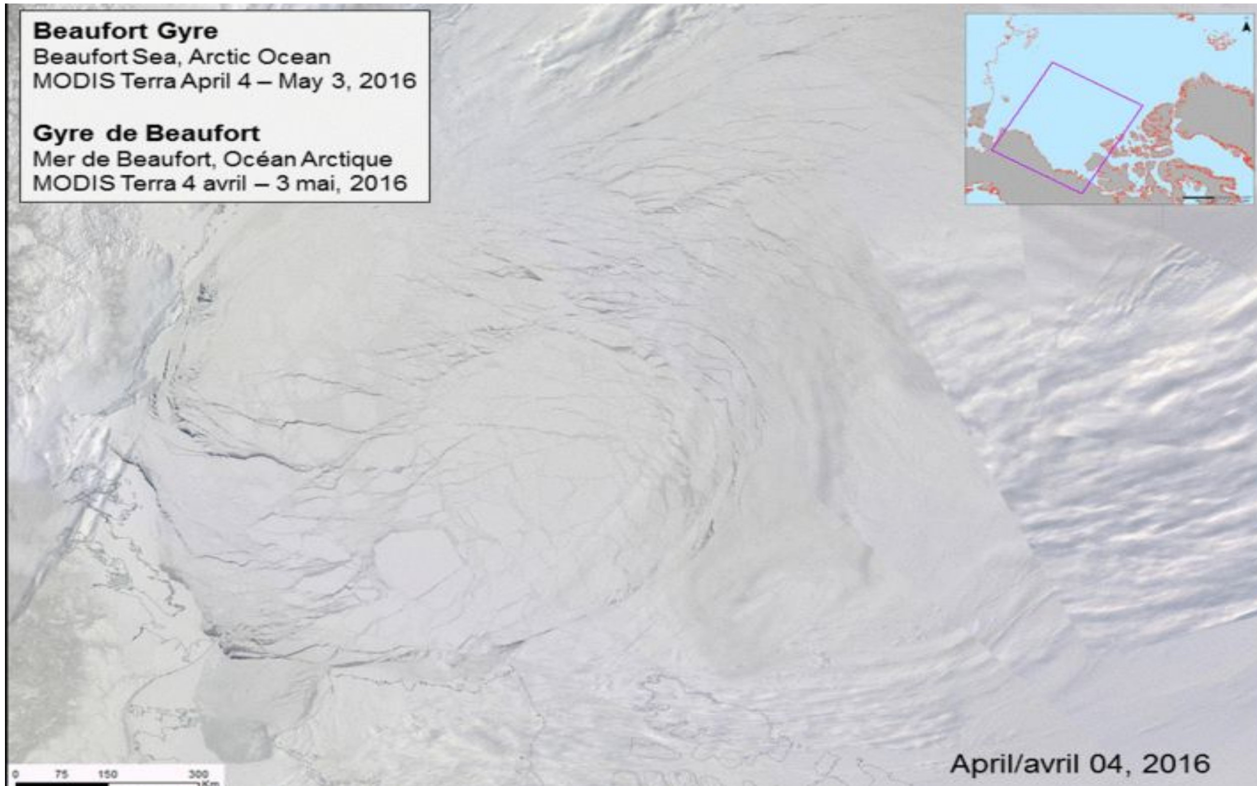
CESBIO

TELECOM ParisTech

Agriculture monitoring (polarimetry)

TELECOM ParisTech

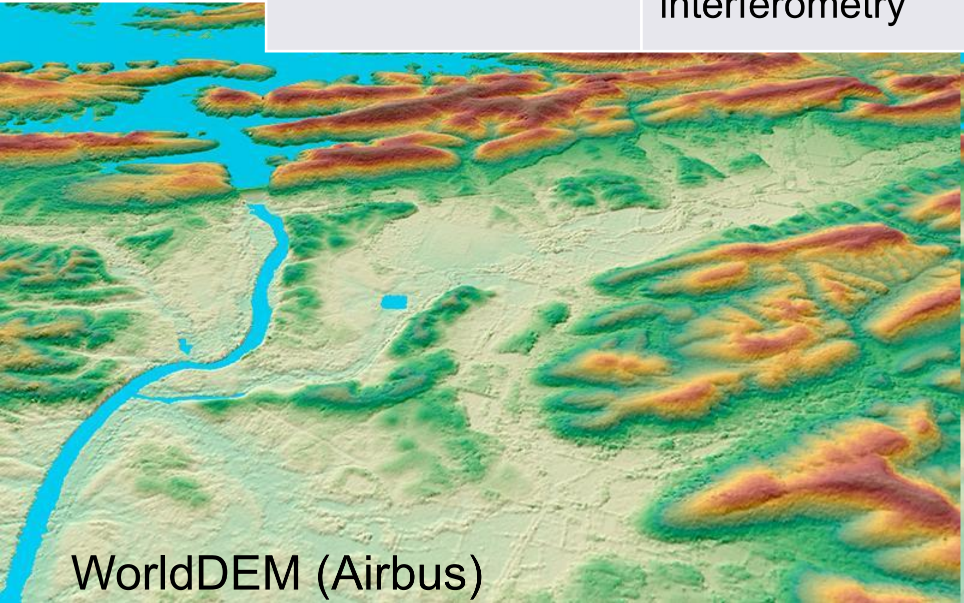
Gyre of Beaufort, Terra satellite between 4/04/2016 and 3/05/2016



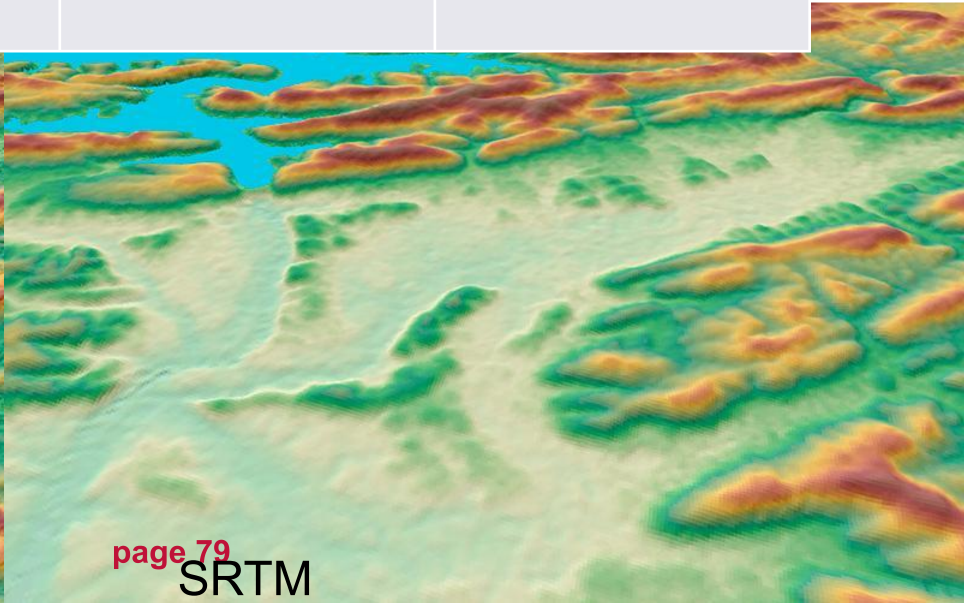
TELECOM ParisTech

3D Reconstruction - DEM

Mission	mode	Planimetric accuracy	Altimetric accuracy
SRTM (2000)	Bande X Single-pass interferometry	60m (30m)	16m abs. 10m rel.
TanDEM-X WorldDEM	Single-pass + mult-pass interferometry	12m	4m abs. 2m rel.



WorldDEM (Airbus)



SRTM

Application of optical images: 3D modeling

Input: Multiple views

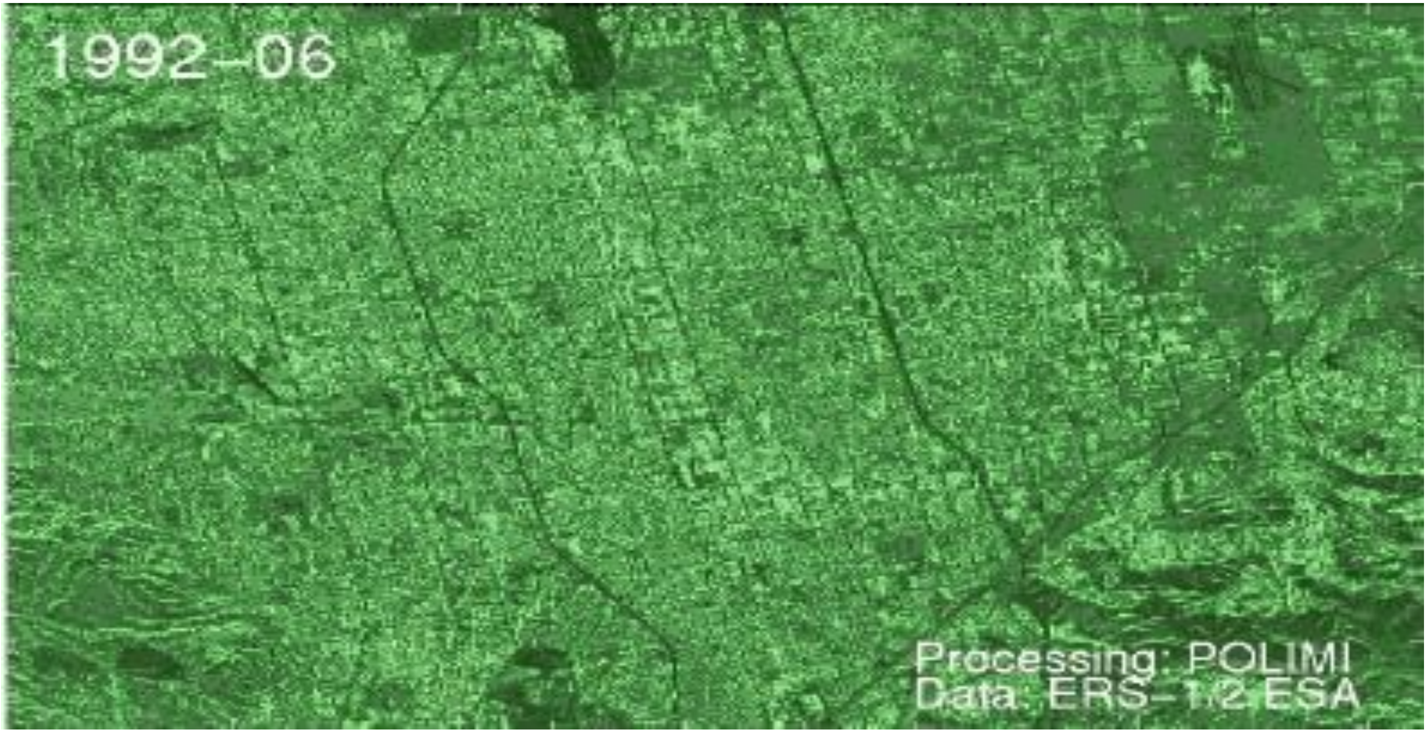
Output: 3D reconstruction

Application of optical images: 3D modeling

Input: Multiple views

Output: 3D reconstruction

Subsidences by radar interferometry: ERS-1



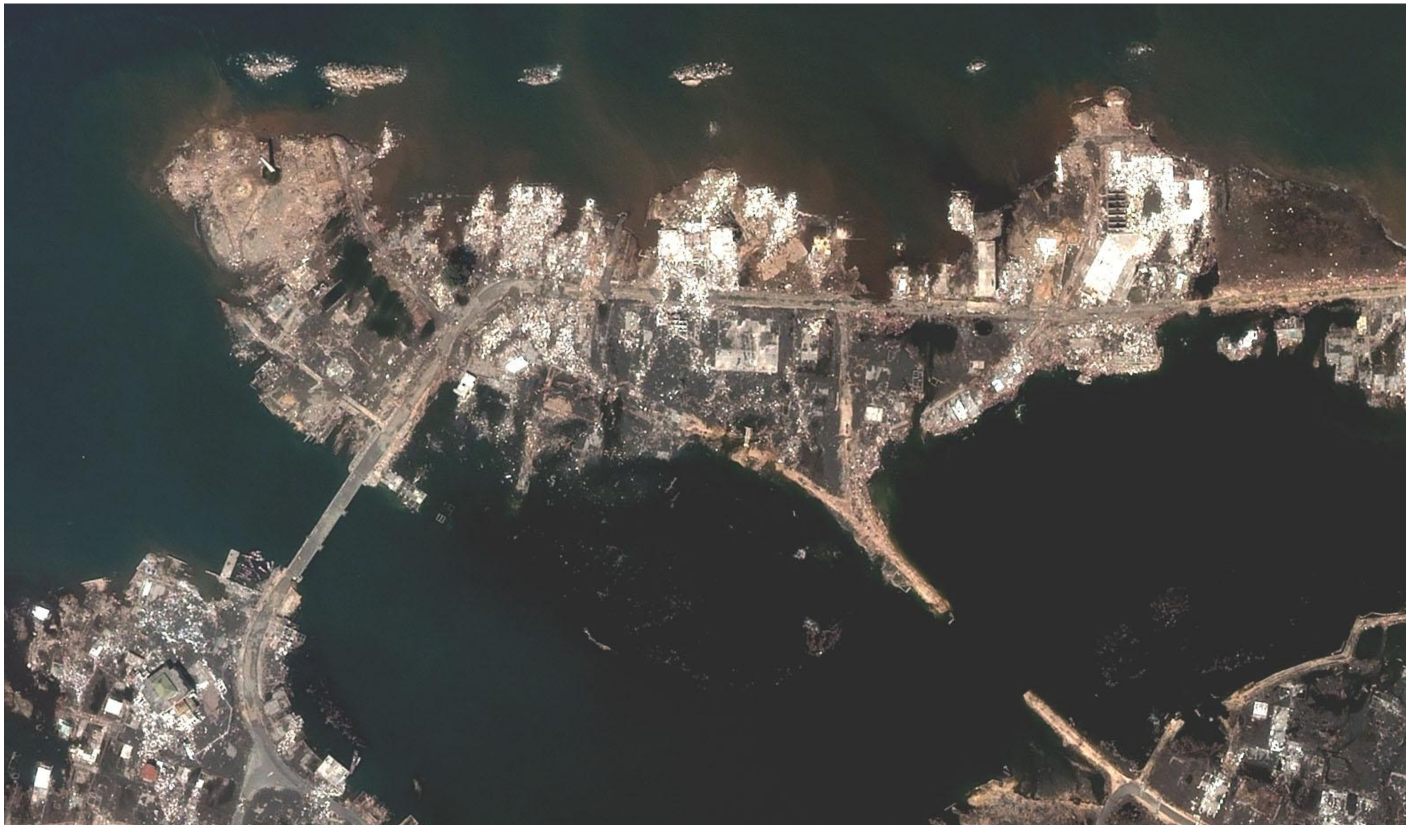
Pomona subsidence: animation of Politechnico di Milano

Banda Aceh, summer 2004

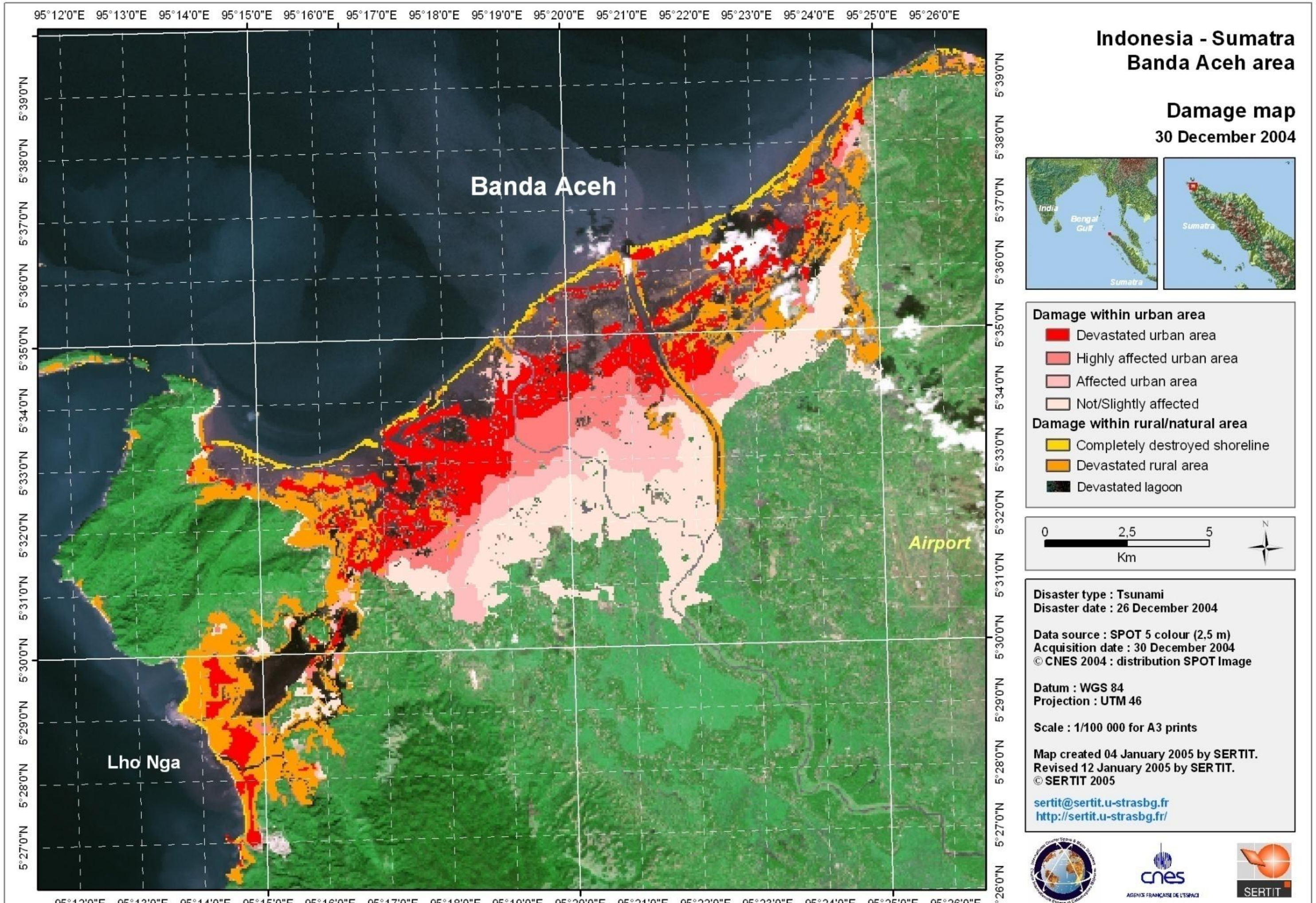
Image Orbview3
©DigitalGlobe

Image Orbview3
©DigitalGlobe

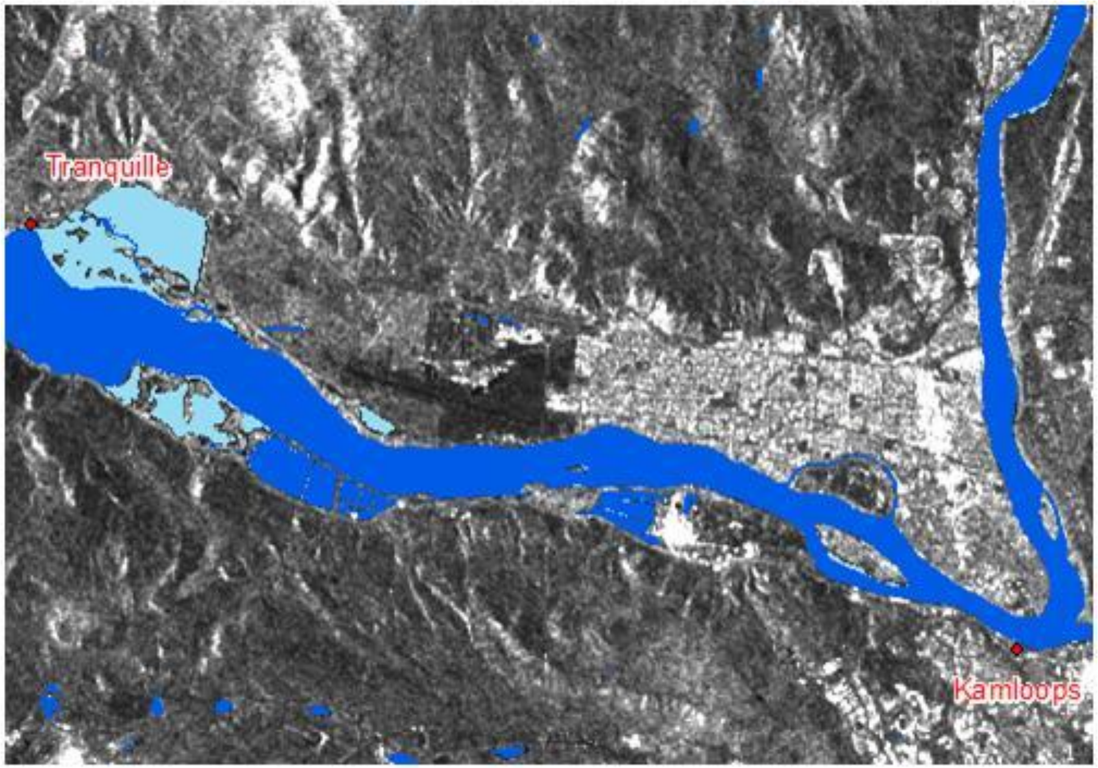
Banda Aceh on 28 december 2004



International charter: Space and Major Disasters (17 space agencies)

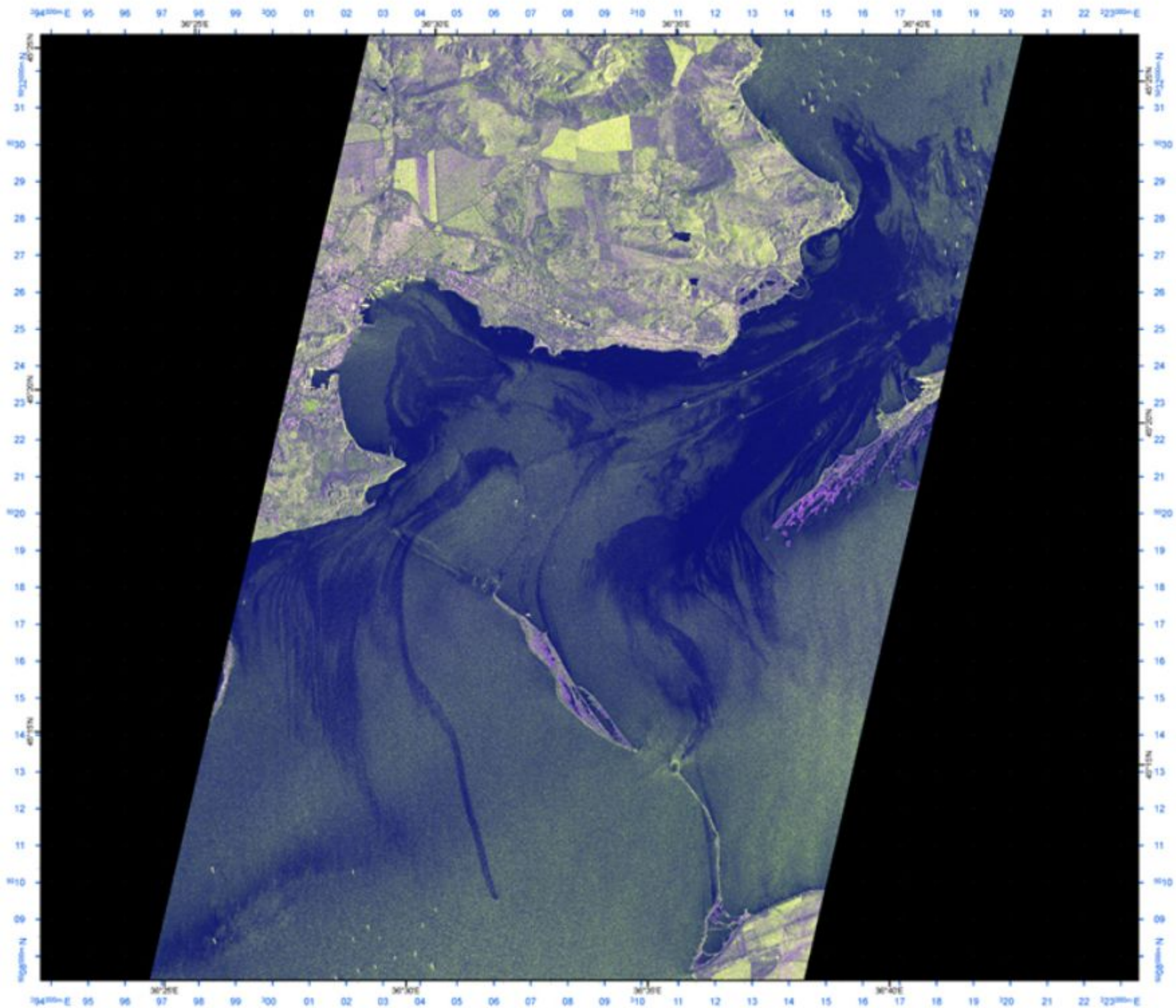

Indonesia - Sumatra
Banda Aceh area
Damage map
30 December 2004
Banda Aceh
Lho Nga
Airport
Damage within urban area
Devastated urban area
Highly affected urban area
Affected urban area
Not/Slightly affected
Damage within rural/natural area
Completely destroyed shoreline
Devastated rural area
Devastated lagoon
0 2,5 5
Km
Disaster type : Tsunami
Disaster date : 26 December 2004
Data source : SPOT 5 colour (2,5 m)
Acquisition date : 30 December 2004
© CNES 2004 : distribution SPOT Image
Datum : WGS 84
Projection : UTM 46
Scale : 1/100 000 for A3 prints
Map created 04 January 2005 by SERTIT.
Revised 12 January 2005 by SERTIT.
© SERTIT 2005
sertit@sertit.u-strasbg.fr
http://sertit.u-strasbg.fr/

Flood monitoring



©RadarSat-2

Eastern Crimea (Ukraine) - Oil Spills



TerraSAR-X StripMap Acquisition

Location of Crimea:

Satellite Information

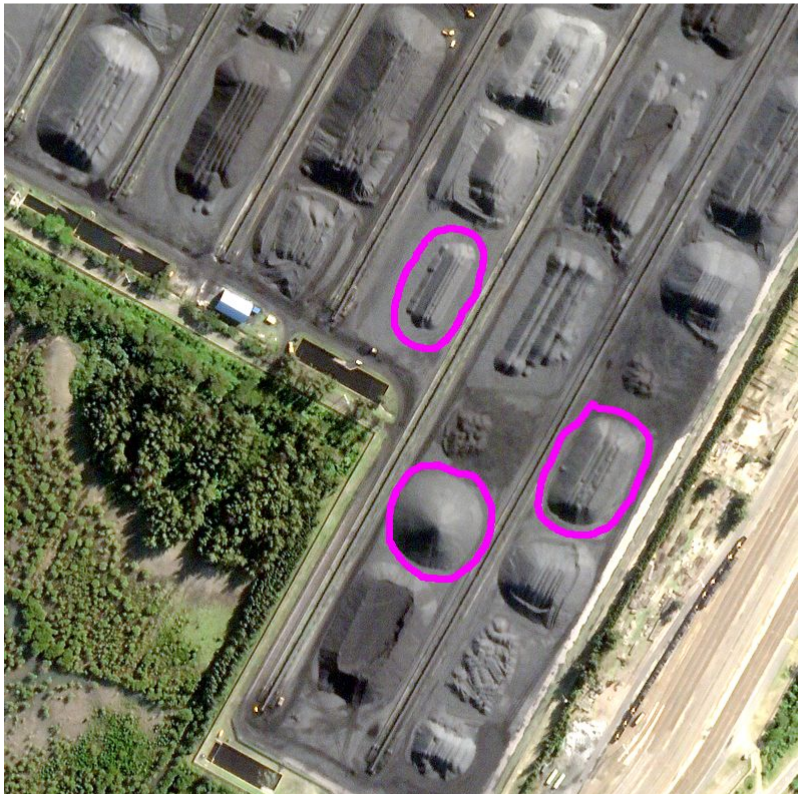
Satellite:	TerraSAR-X
Imaging Mode:	StripMap
Slant Range Res.:	3m
Polarisation:	HH+VV
Pass Direction:	Descending
Acquisition Date:	2007-11-16, 03:52:06 to 03:52:14 UTC
Product Type:	Geocoded Ellipsoid Corrected
Resolution Mode:	Spectrally Enhanced

0 1 2 4 6 8
Kilometers

Map Projection

Geographic	**Universal Transverse Mercator**
Ellipsoid: WGS 84 Datum: WGS 84	Ellipsoid: WGS 84 Datum: WGS 84 Zone: 37N

Global coal stockpile monitoring



Input

Output

Global crude oil storage monitoring

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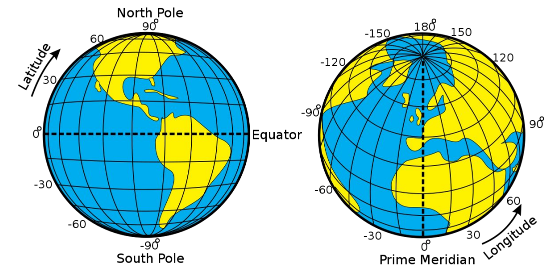
Coordinate reference systems (CRS)

Provide a standardized way of describing locations

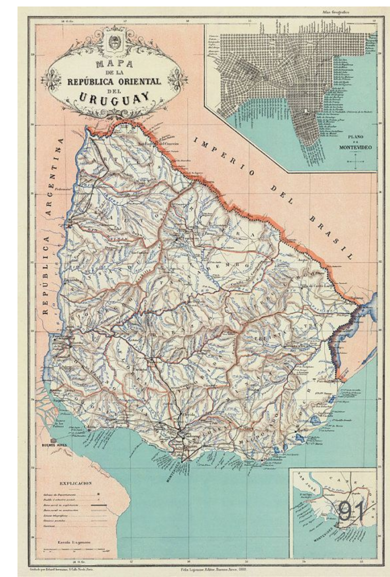


- **Geographic** reference systems:

  describe 3D points relative to a reference ellipsoid using latitude, longitude, and altitude

- **Projected** reference systems:

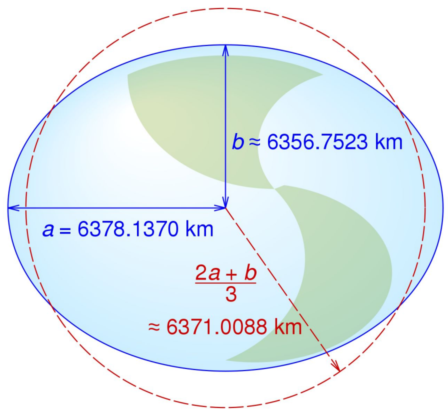
  transform the ellipsoidal earth into a flat surface e.g. UTM, Lambert...

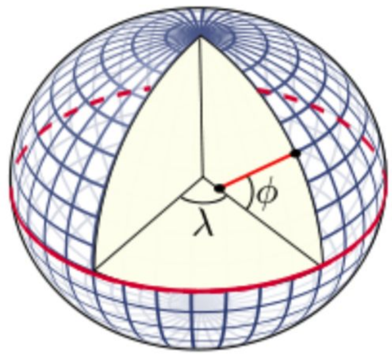


Geographic reference systems

The **World Geodetic System (WGS84)** is a standard for use in cartography, geodesy, and navigation including GPS. It comprises:

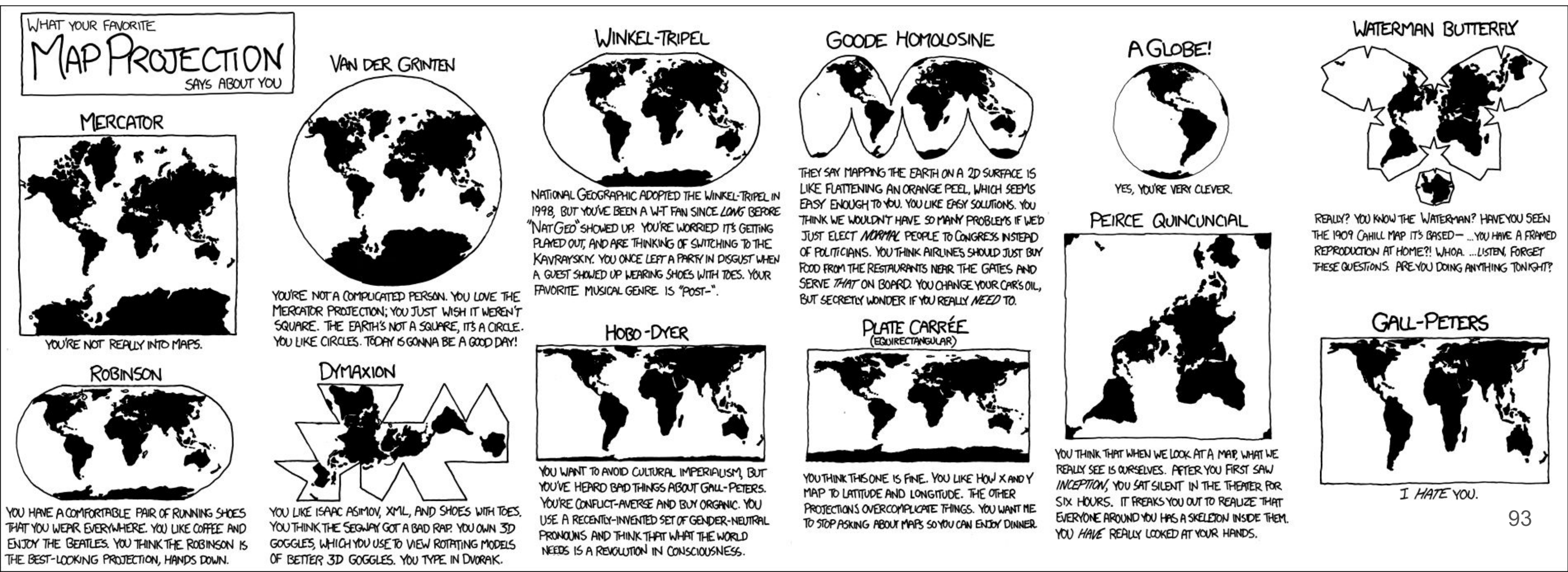
- **reference ellipsoid**
- gravitational equipotential **geoid** that defines the nominal sea level
- Coordinates: **latitude** and **longitude** wrt the reference ellipsoid
- **Altitude**: normal to the ellipsoid
- **Datum**: defines origin and direction of the coordinate axes (Equator, Greenwich)





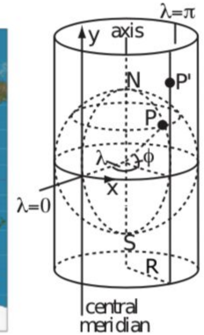
Projected reference systems

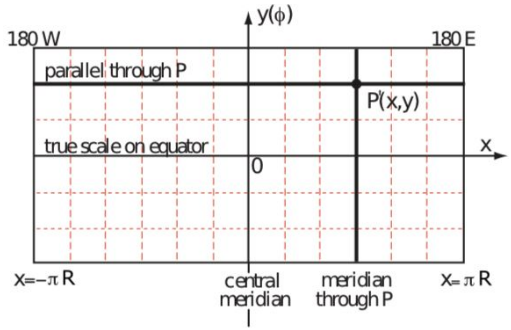
Projections aim at transforming the ellipsoidal earth into a flat surface.
This cannot be done without distortion and results in trade-offs between area, direction, shape, and distance.



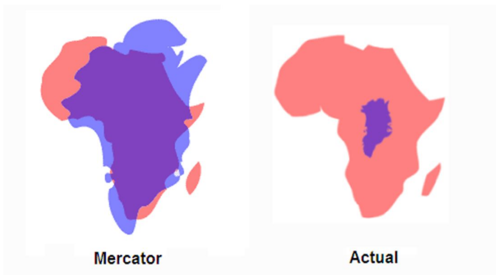
Mercator projection

- **cylindrical** conformal map (preserves angles and small shapes)





- the projection is **“exact” at the equator**
- **does not preserve sizes**



Universal transverse mercator (UTM)

UTM system divides the Earth into **sixty zones**, each a six-degree band of longitude, and uses a **secant transverse Mercator** projection in each. Within an UTM zone the coordinates are expressed as **easting** and **northing**.

- **easting**: eastward distance (in meters) from the central meridian of the UTM zone, which is assigned a value of 500000m
- **northing**: for the north (resp south) hemisphere, number of meters north of the equator (resp. south pole)

i.e. UTM (WGS84) Zone 31U
E: 450504.27 N: 5408937.43

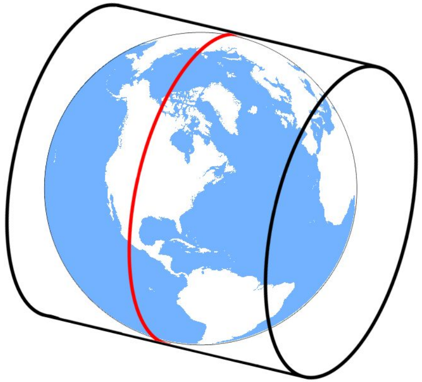


Image metadata, formats and conventions

Images are associated to different types of metadata

- acquisition date&time
- georeferencing information (different conventions)
- cloud masks
- resolution on the ground

Satellite images are very variate

- file formats
- multiple spectral bands → indices e.g. NDVI
- different levels of radiometric and geometric processing

GDAL reads all image formats and handles conversion between all coordinate systems (reprojection)

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