TELECOM ParisTech

Institut Mines-Télécom

Remote Sensing imaging IMA207

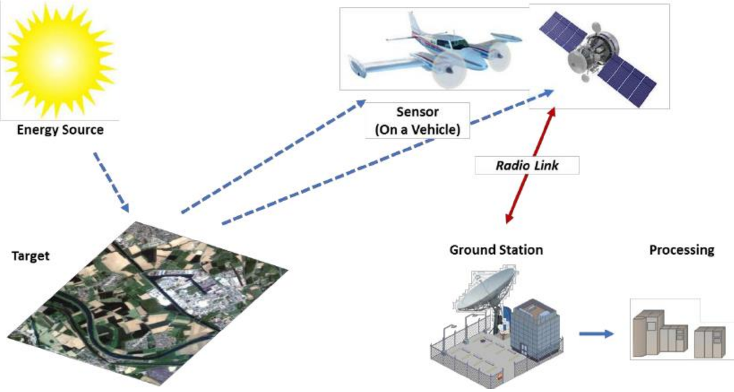
Basics of remote sensing

Florence Tupin, Jean Marie Nicolas

Introduction

- **Remote sensing**
  - « Acquisition of information about an object or phenomenon without making any physical contact with the object in contrast to on site observation»
  - Use of satellite or aircraft based sensor technologies to detect and classify objects on earth

- **Milestones**
  - 1844: first photos from balloons
  - 1900-1960 : aerial photos
  - 1960-: space sensors



The New Space

Bloostar launcher
(**Zero 2 Infinity**)

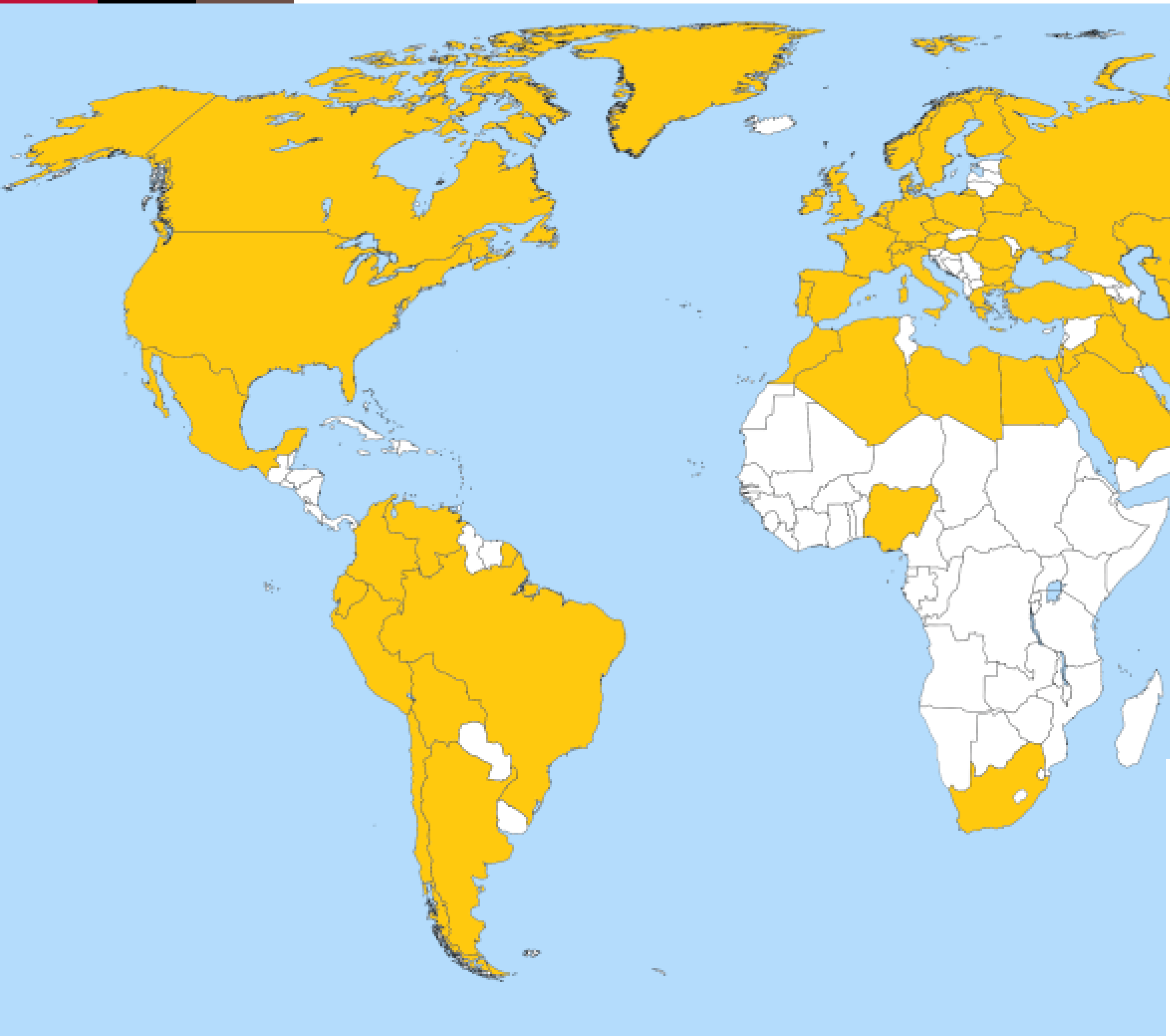
New Shepard for spatial
Tourism (**Blueorigin**)

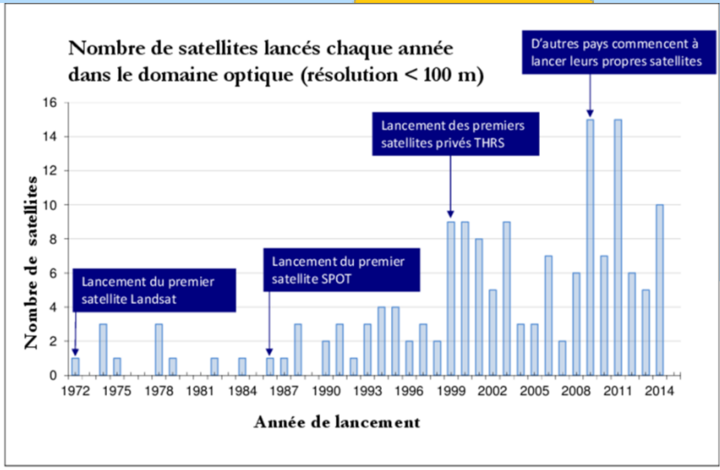
Red Dragon for
Mars Exploratio

Landing of a Flacon-9
(**SpaceX**)

“Congress declares that the general welfare of the United States requires that the Administration seek and encourage, to the maximum extent possible, the fullest commercial use of space. » (2010)

The New Space





1966: 4 countries with satellites, today: 70 countries

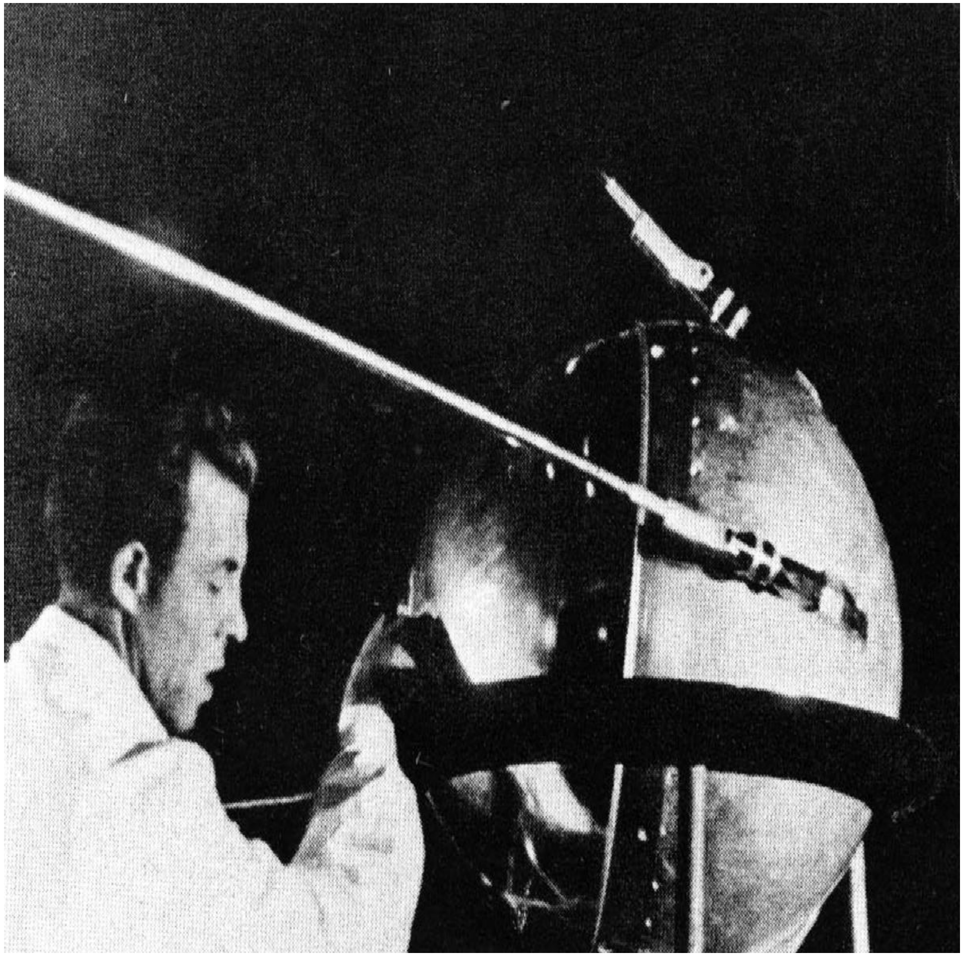

2018 : le bilan des lancements orbitaux
114 lancements orbitaux
deux échecs et deux anomalies
7 pays lanceurs
Chine (39), USA (31), Russie (17), Europe (11), Inde (7), Japon (6) et Nouvelle-Zélande (3)
412 satellites et une voiture rouge mis en orbite
31 autres satellites depuis l'ISS
361 tonnes satellisées
Masse moyenne par satellite : 813 kg
Masse record : 16,5 tonnes
3 vols habités réussis
Un échec au lancement
Equipage récupéré sain et sauf
114 satellites de communication
Observation : 107
Technologie : 93
Multi-mission : 29
www.regard-sur-la-terre.over-blog.com

Overview of the course

- **Short history of remote sensing**
- **Satellites and orbites**
- **Imaging systems**
- **Applications**

First satellite: 83 kg

1957 : Sputnik 1

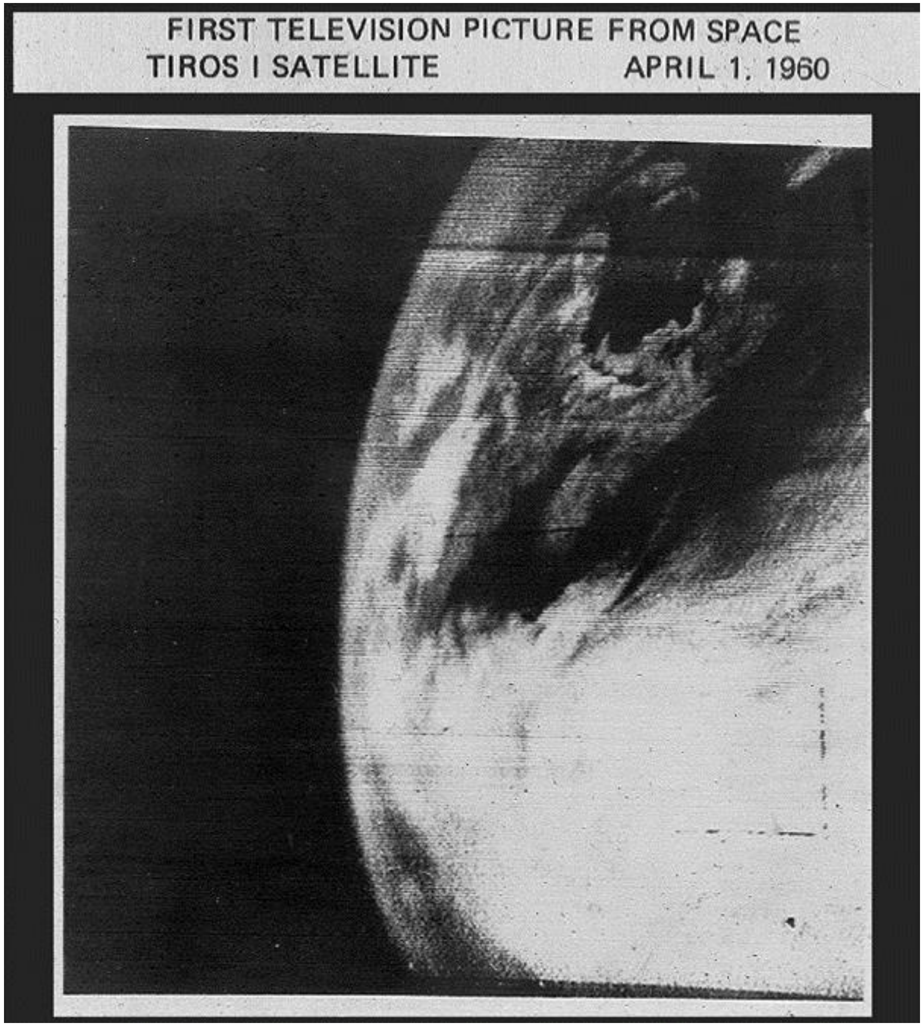


Sputnik-2 : 584 kg

1957 : Sputnik 1
1957 : Sputnik 2

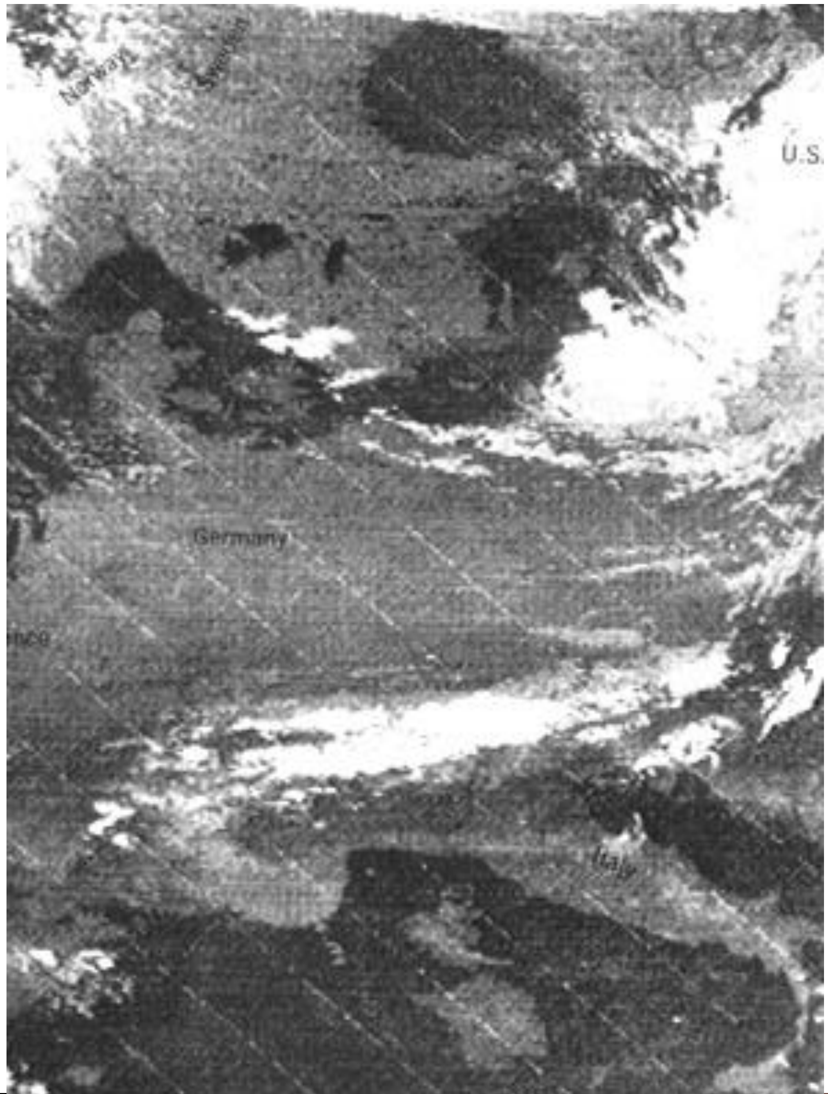
First (civilian) image from the earth (1960)

1957 : Sputnik 1
……
1960 : Tiros 1



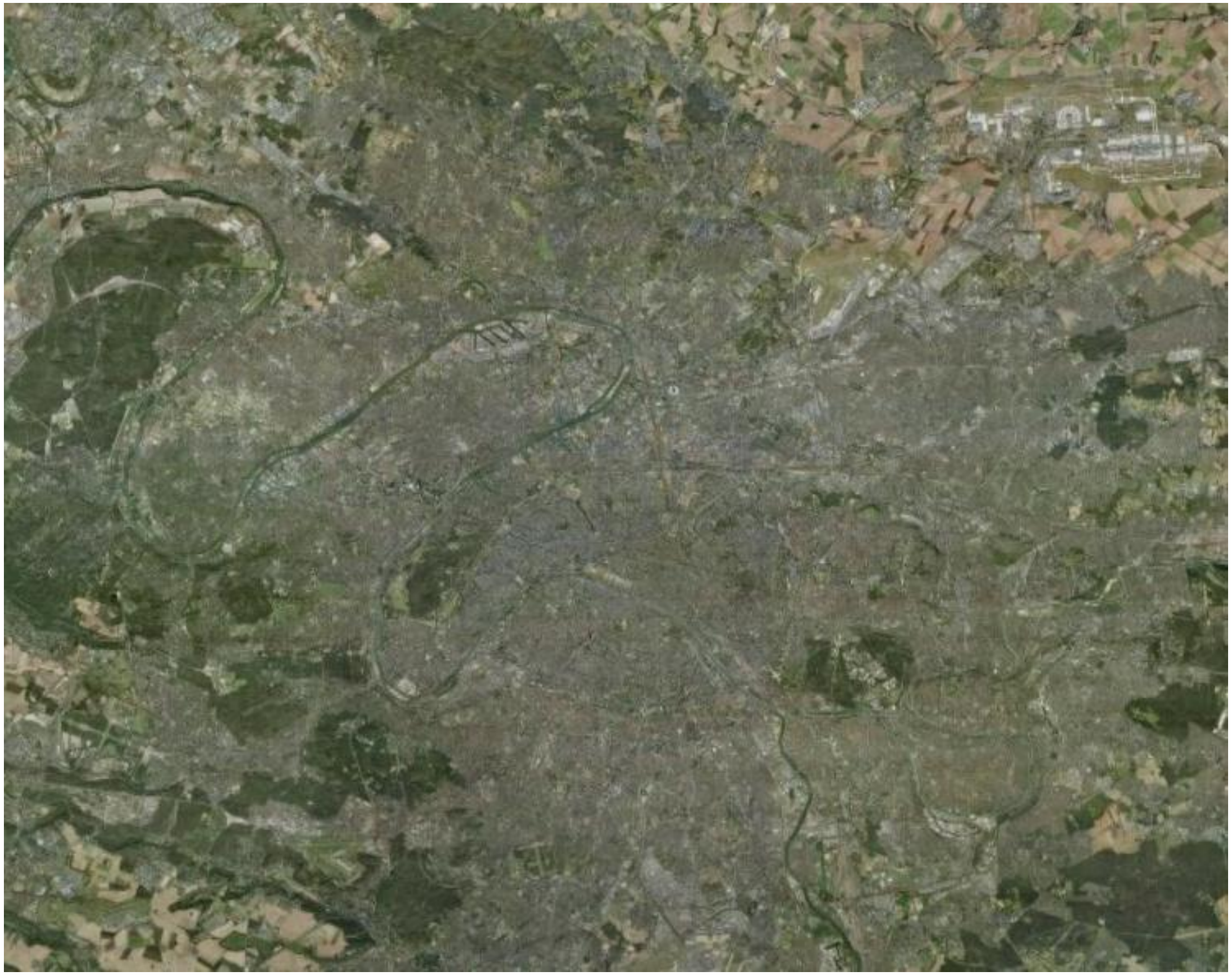
Nimbus (1964): first (civilian) meteorological satellite (sun synchronus)

1957 : Sputnik 1
……
1964 : Nimbus 1



Landsat-1 (1972) : regional images pixel = 30m

1957 : Sputnik 1
……
1972 : Landsat 1



- **Landsat 8 (2013)**

SPOT-1 (1986)
Pixel of 10 m

1957 : Sputnik 1
……
1972 : Landsat 1
……
1986 : Spot 1

- SPOT-7 (2014), pixel of 1,5m

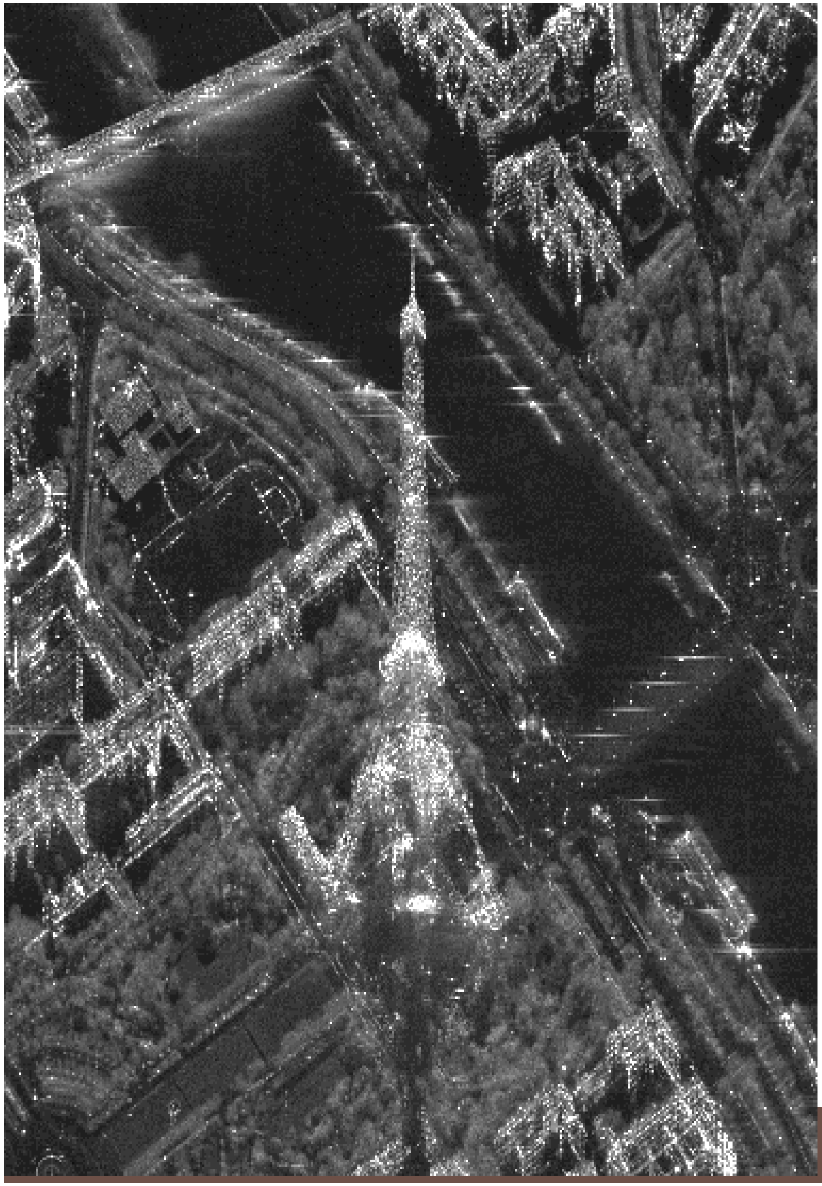
Quickbird-2 (2001)
pixel = 61 cm

1957 : Sputnik 1
……
1972 : Landsat 1
……
1986 : Spot 1
……
2001 : Quickbird 2

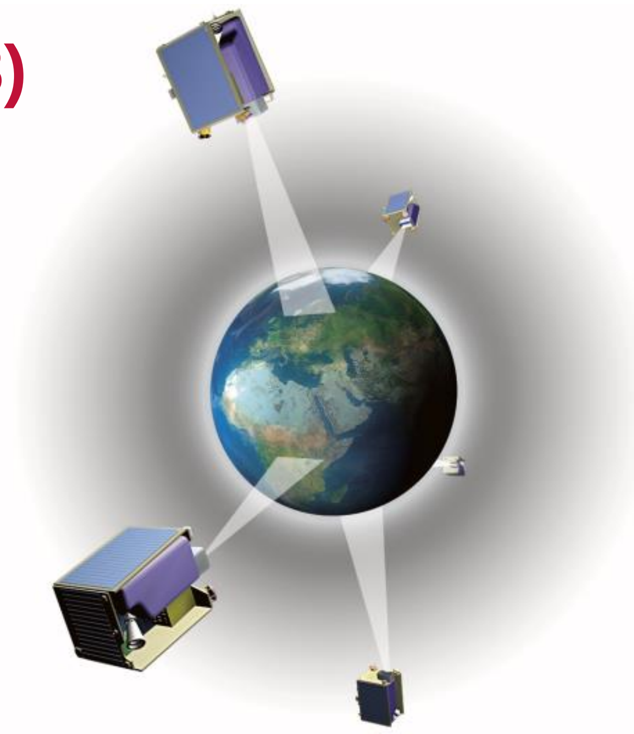
Metric images

TerraSAR-X (2007) : radar imaging
Metric pixel, lateral viewing

1957 : Sputnik 1
……
1972 : Landsat 1
……
1986 : Spot 1
……
2001 : Quickbird 2
……
2007 : Terrasar-X



RapidEye constellation (2008)
5 satellites (pixel ~ 6m)



1957 : Sputnik 1
……
1972 : Landsat 1
……
1986 : Spot 1
……
2001 : Quickbird 2
……
2008 : Rapid Eye

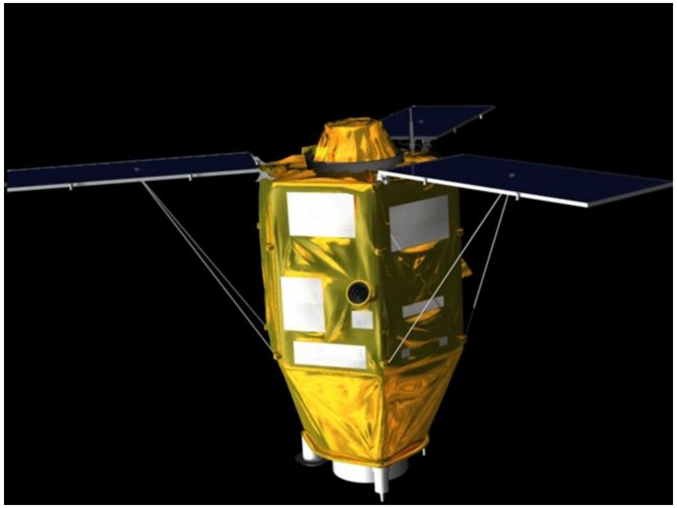
Constellations

- **Daily visit of any point on earth**

Constellation Orfeo-Pleiades
4 radar sensors (CSK), 2 (+2) optic sensors

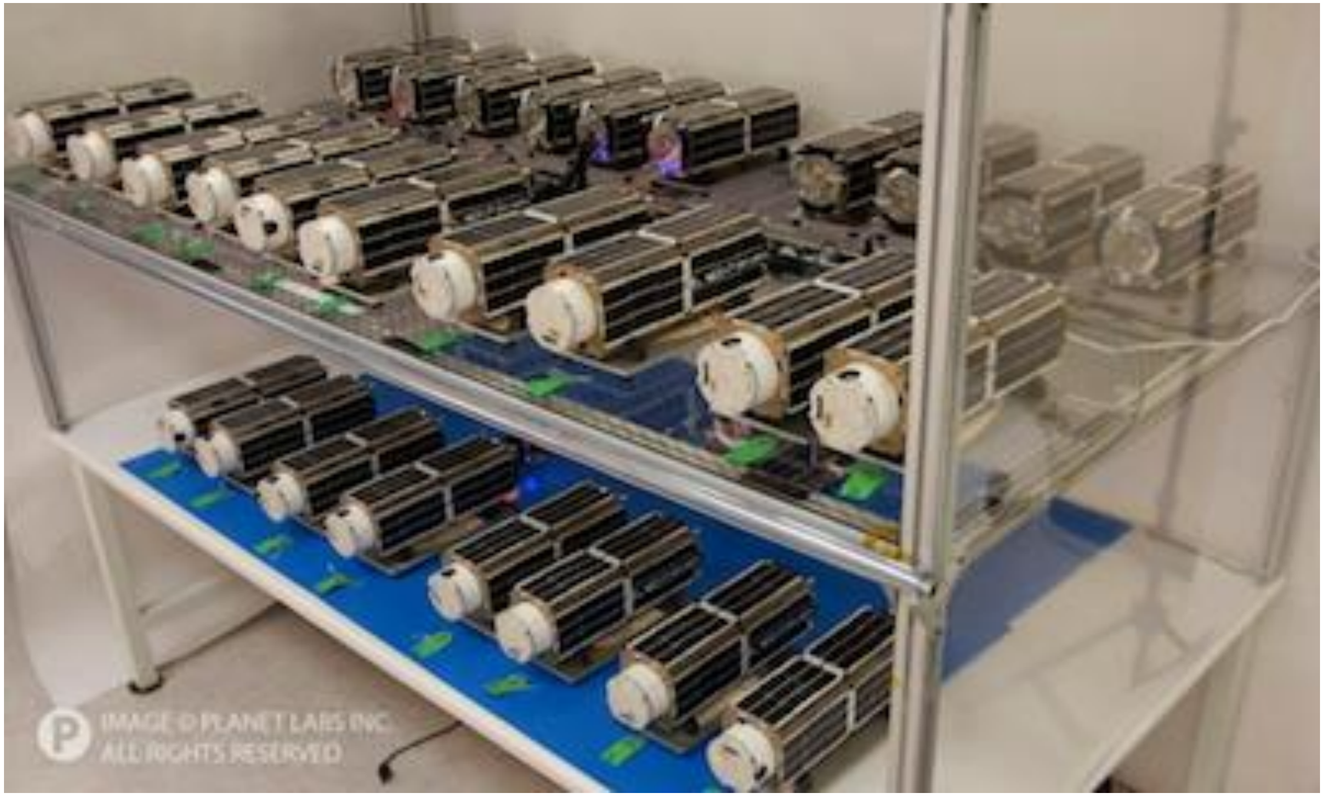
- **Daily image anywhere on earth**
- **Metric resolution**

1957 : Sputnik 1
……
1972 : Landsat 1
……
1986 : Spot 1
……
2001 : Quickbird 2
……
2007 : Terrasar-X
……
2012 : Orfeo Pleiades



2017: hyperconstellations
Planet (> 300 microsatellites, 5 kg)

1957 : Sputnik 1
……
1972 : Landsat 1
……
1986 : Spot 1
……
2001 : Quickbird 2
……
2007 : Terrasar-X
……
2012 : Orfeo Pleiades
…….



Space actors

- **From space agencies…:**
  - Cost of space missions (1 launched satellite = 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 developement)
  - New challenges: spatial tourism, planet exploration and exploitation, …
  - New markets: activity monitoring, agriculture, …

Space actors and data policy

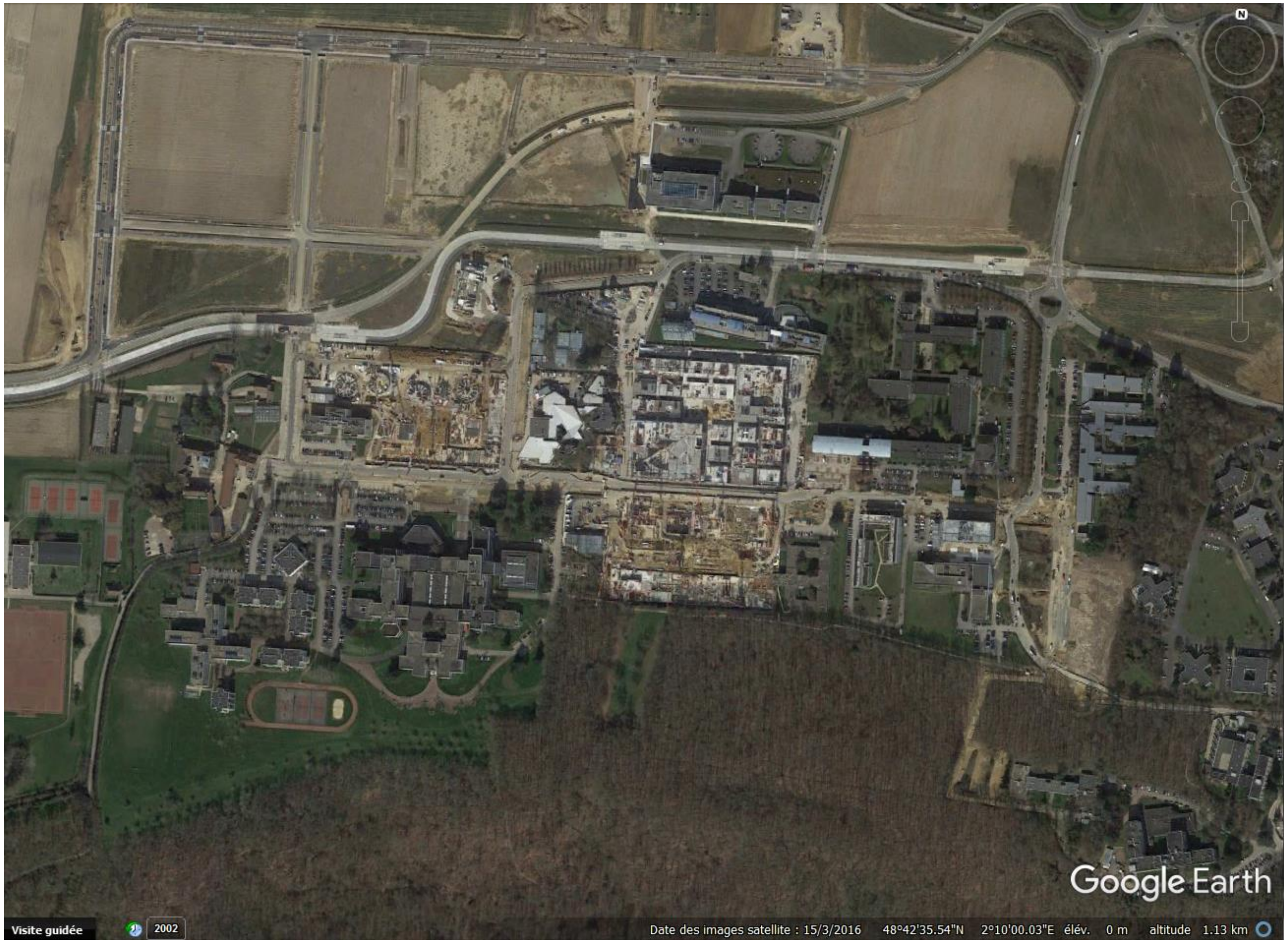
- **Data from space agencies:**
  - Free for scientific programs
  - Fully available and free for Copernicus program of ESA

- **To private industries:**
  - Paying data
    - CSK radar (1m) : 100 km^2 pour 6000 Euros
    - DigitalGlobe 50 cm : ~50 Euros par km^2
    - RapidEye : 1 Euros par km^2
  - Public access for some study areas

Google Earth (2005-….)

- **Widely used**
- **Metric images (from different sensors)**

- Google earth Engine



TELECOM ParisTech

Geoportail of IGN (2006-….)
Professionnal and public software
Images + maps

Overview of the course

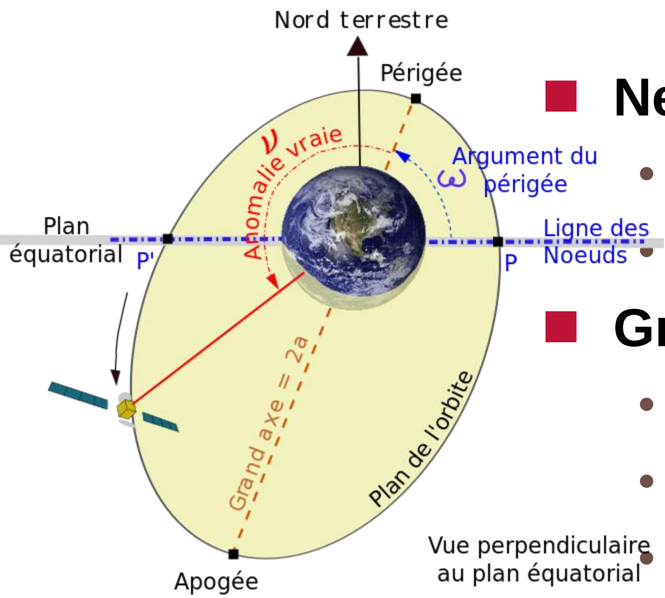
- Short history of remote sensing
- Satellites and orbites
- Imaging systems
- Applications

Basics of Kepler mechanics

- **Kepler :**
  - Orbits of planets are ellipses (with the sun as one of the two foci)
  - A line segment joining a planet and the Sun sweeps out equal areas during equal intervals
- **Newton :**
  - Potential
  - Force in $1/r^2$
- **Gravitational constant:**
  - $G=6{,}672\ 10^{-11}$
  - $M_T = 5{,}597\ 10^{24}$ kg
  - $\mu=GM_T=3{,}986\ 10^{14}$

$$U = -\frac{\mu m}{r}$$

$$\vec{F} = -\frac{\mu m}{r^2}\frac{\vec{r}}{r}$$



@wikipedia

Punctual and homogeneous earth :

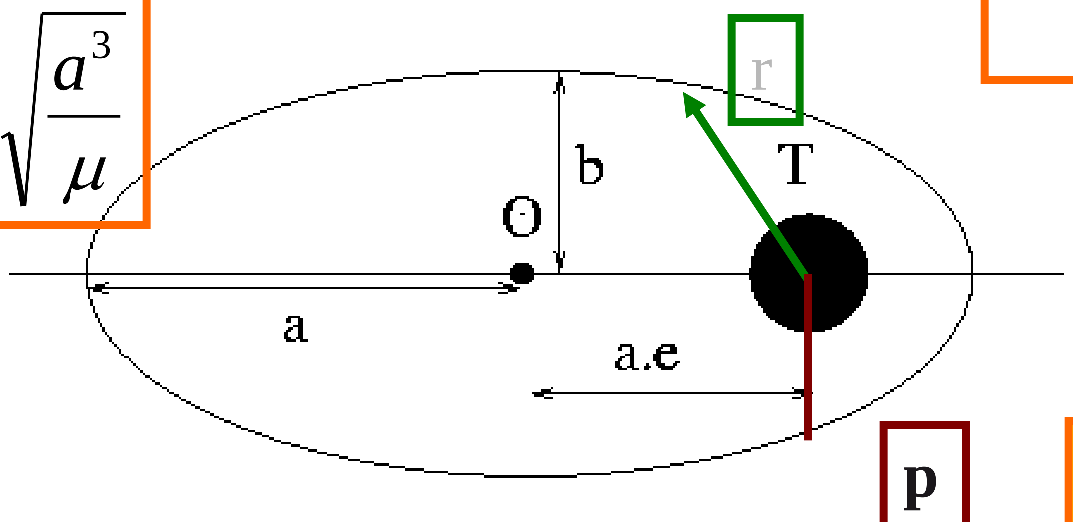
$$U = -\frac{\mu\, m}{r}$$

- **Elliptic trajectories for satellites**
- **Earth is in the orbital plane and one of the foci**
- **Ellipse parameters:**
  - Semimajor axis: a
  - Seminimor axis: b
  - Eccentricity: e

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = Cste$$

$$r = \frac{p}{1 + e\cos(\theta - \theta_0)}$$

$$T = 2\pi\sqrt{\frac{a^3}{\mu}}$$

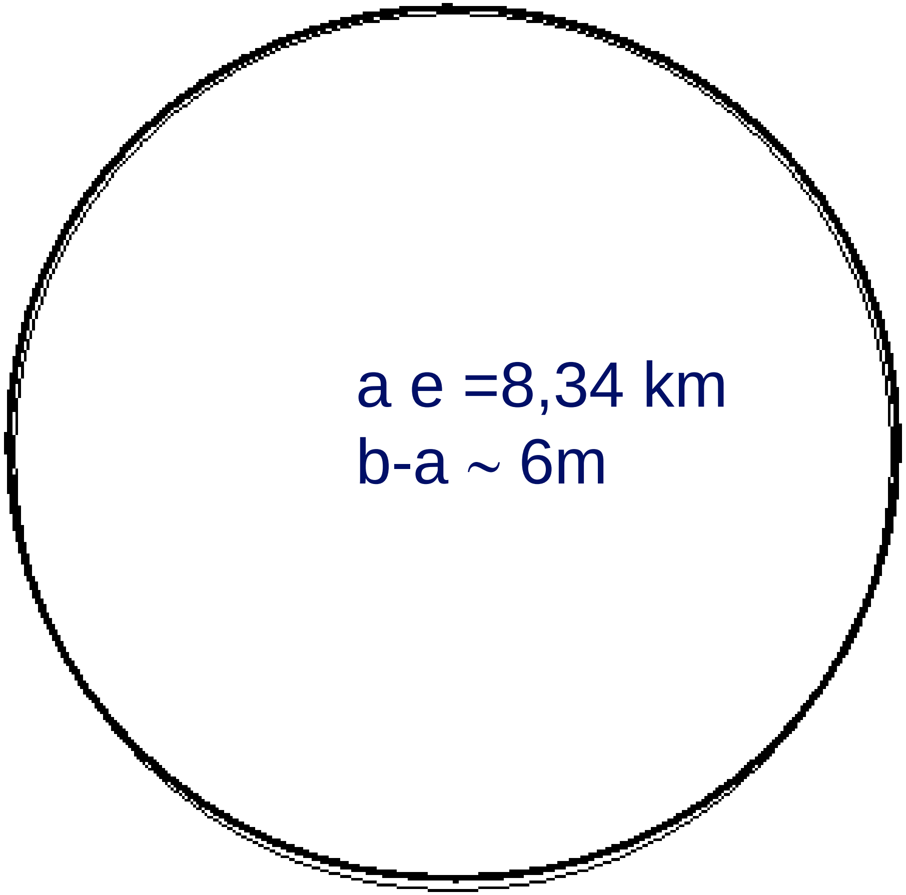


$$e^2 = 1 - \left(\frac{b}{a}\right)^2$$

$$p = a\left(1 - e^2\right)$$

Orbites of remote sensing satellites

- **Almost circles**
- **Earth no exactly in the center:**
  - Small eccentricity
  - Error of around 8 km
  - Shape of a circle
- **Satellite speed varies along the trajectory:**
  - Faster for low altitude
  - Slower for high altitude



Example of ERS : e=0.001165

Examples

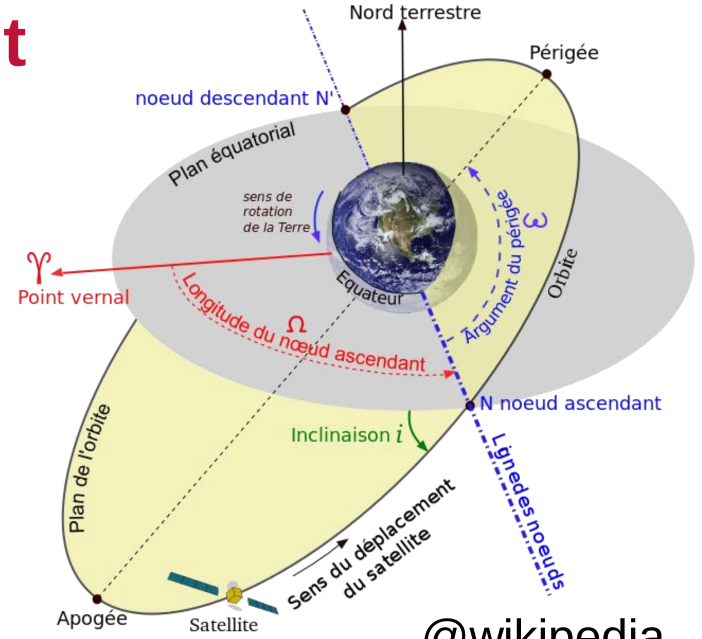
$$T = 2\pi\sqrt{\frac{a^3}{\mu}}$$

	Period	Altitude	Orbit/day
FORMOSAT	102,8’	891 km	14
SPOT	101,4’	832 km	14+5/26
RADARSAT	100,6’	798 km	14+7/24
ERS	100’	785 km	14+11/35
Landsat 7	98,5’	705 km	14+9/16
Ikonos	98’	681 km	
Terrasar-X	95’	515 km	15+2/11
Quickbird	93,5’	450 km	

Earth gravitational field
Analysis of Sputnik 2 orbit

- **Earth flattening ≅ 1/298**
- **Coefficient J_2 in the terrestrial field**

$$U = -\frac{\mu m}{r}\left(1 + J_2\left(\frac{R_T}{r}\right)^2 P(\varphi)\right)$$

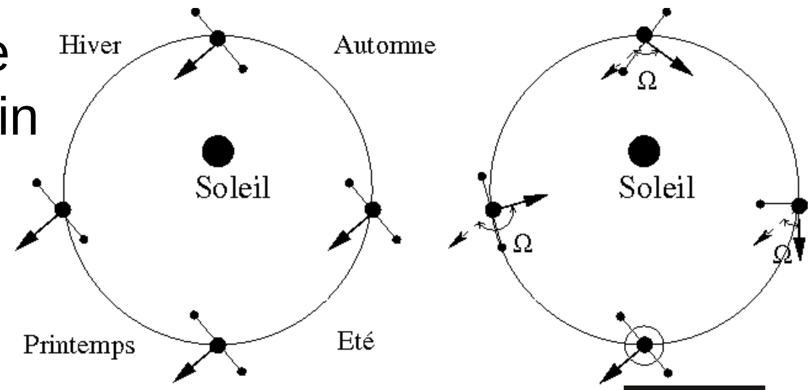


@wikipedia

- **Sun-synchronus trajectories :**
  - Choice of an inclination i such that the the rotation of the orbit plane is 360° in one year

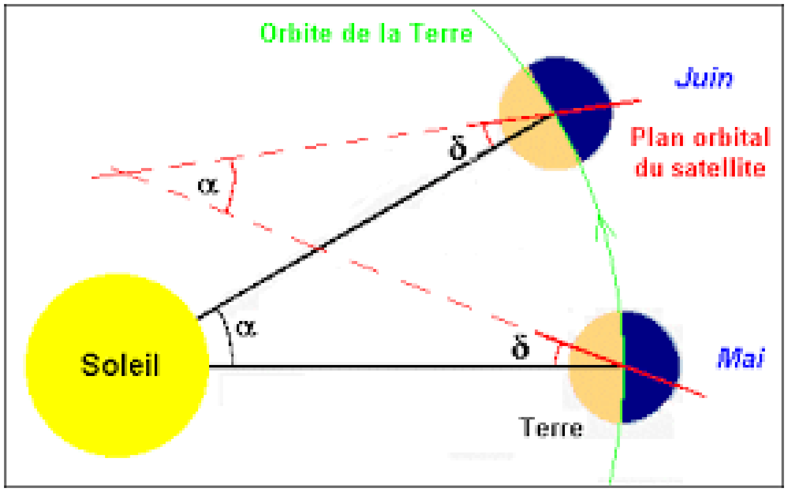
    (one altitude -> one inclination)

  For altitudes in [400,800]km, inclinations in [97°,99°]



TELECOM ParisTech

Sun-synchronus orbits



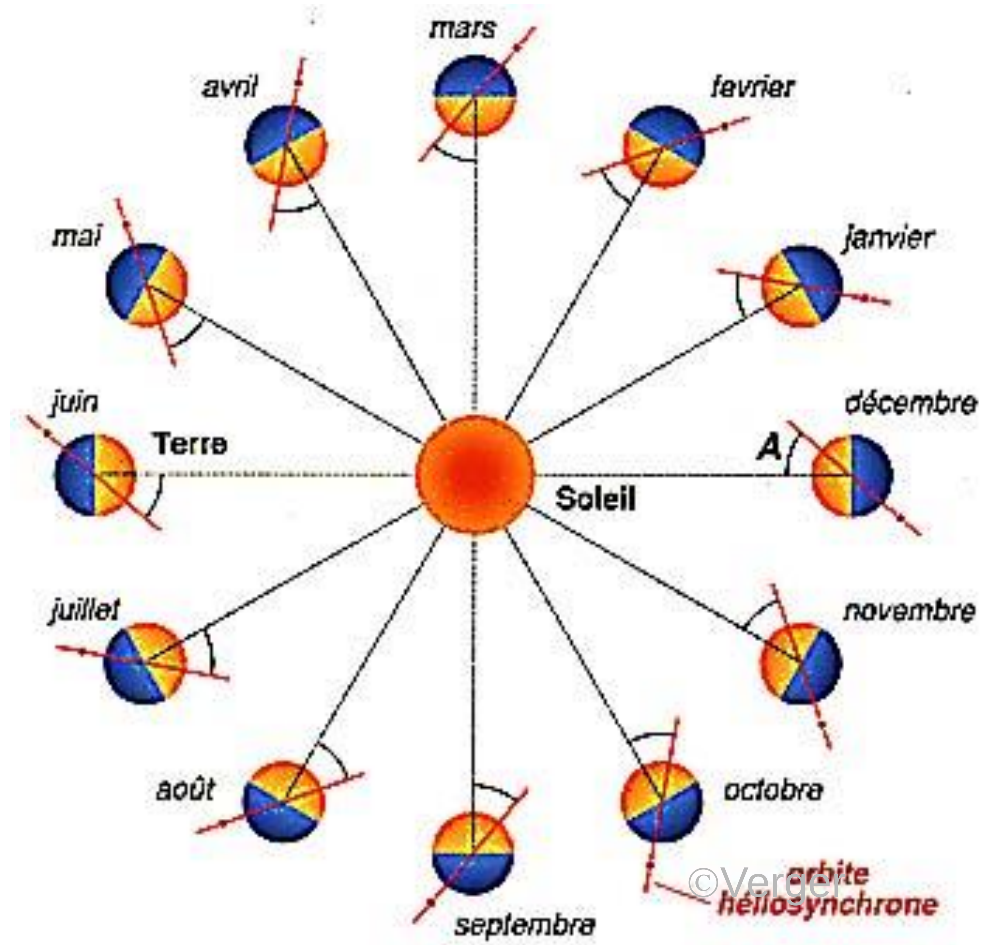
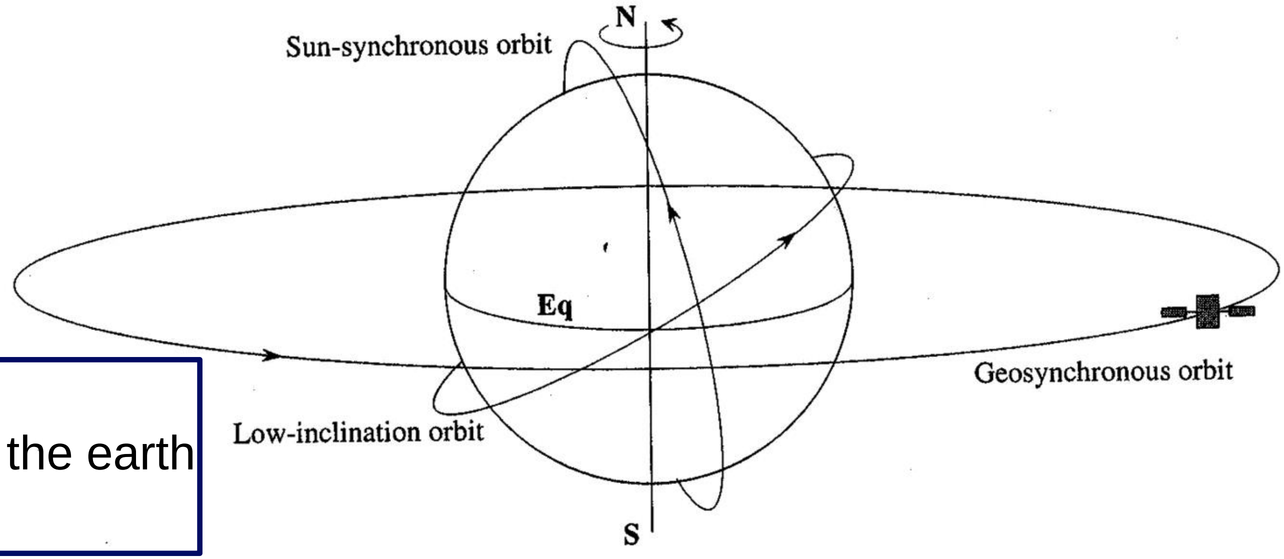
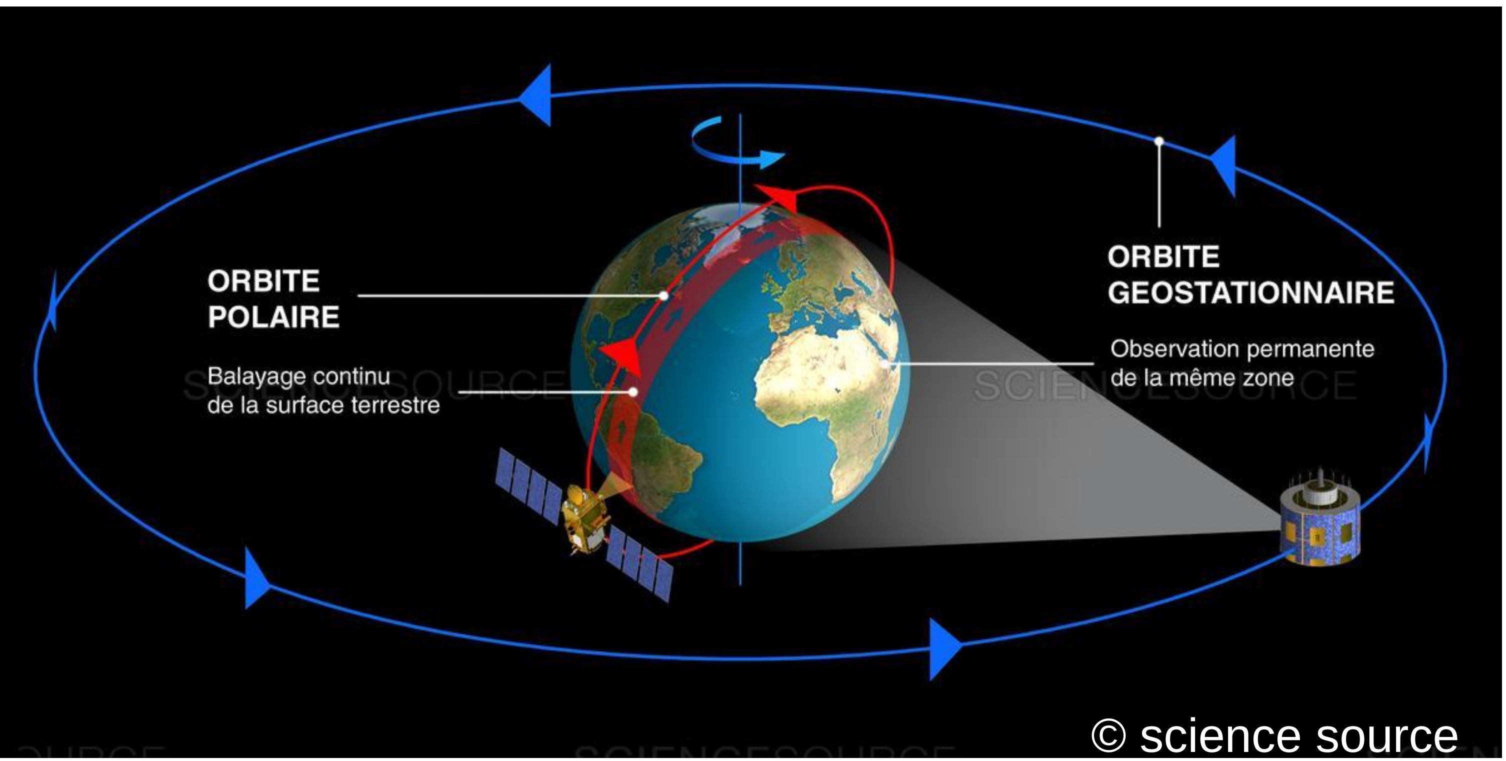


*Fig. 28 - **Principe de l'héliosynchronisme.** L'angle A formé par le plan de l'orbite et la direction Terre - Soleil demeure constant au cours de l'année.*

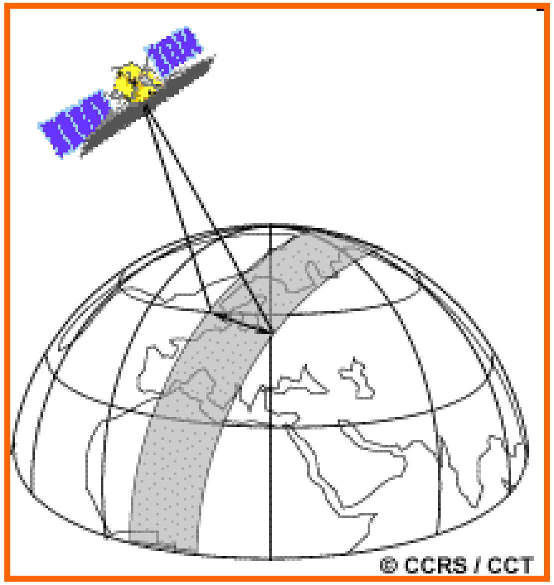


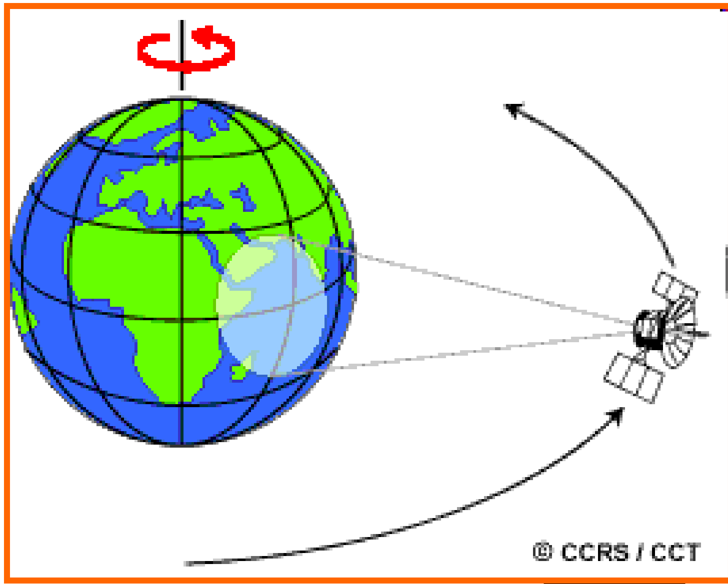
Sun-synchronous orbit:
Illumination of a point on the earth at the same local time



Choice of orbits for satellites

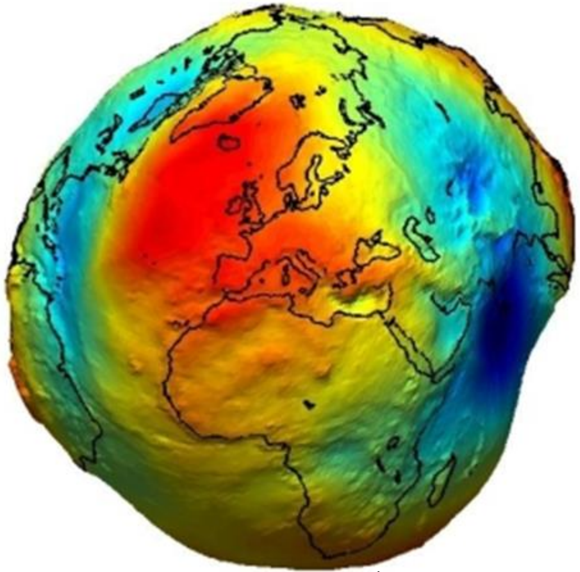
- **Low orbits (500 km – 1000 km)**
  - LEO (Low Earth orbit)
  - Sun synchronous (near polar orbit - for stability of acquisition conditions)
  - Altitude chosen for a given cycle (period depends on altitude, cycle depends on period)
  - For altitude < 400 km, fast destruction due to rubbings
- **Geostationnary orbits**
  - High geostationary orbit
    altitude 35 683km)
  - Orbital plane in equatorial plane: motionless satellite from earth
  - Visibility of a fixed area of the earth (42%)





Improving earth shape: DORIS experiments (1990)

- **Emission on earth of known signals (2036.25 MHz et 401.25 MHz)**
- **Doppler shift analysis on board**
  - Determination of the satellite speed (0,06 mm/s)
  - Knowledge of TCA (Time of Closest Approach)
- **Recomputation of orbital trajectories:**
  - Accuracy of the satellite position:
    - 10 cm after 3 heures
    - 4 cm after 3 jours
    - 2,5 cm after 30 jours
    - Aim: < 1 cm



Improving earth shape 2017…

$$U = -\frac{\mu}{r}\left(1 + \sum_{n=2}^{\infty}\left(\frac{R_T}{r}\right)^n J_n P_n(\cos\phi) + \sum_{n=2}^{\infty}\sum_{q=1}^{\infty}\left(\frac{R_T}{r}\right)^n J_{n,q} P_{n,q}(\cos\phi)\cos(q(\lambda-\lambda_0)) \right)$$

- **2017 : 5 10^6 coefficients (available on the WEB)**
- **Excellent positionnement des satellites (GPS+centrales inertielles)**

Orbit plane, earth without rotation

A satellite and a rotating earth

T=0'

T=3'

T=6'

T=9'

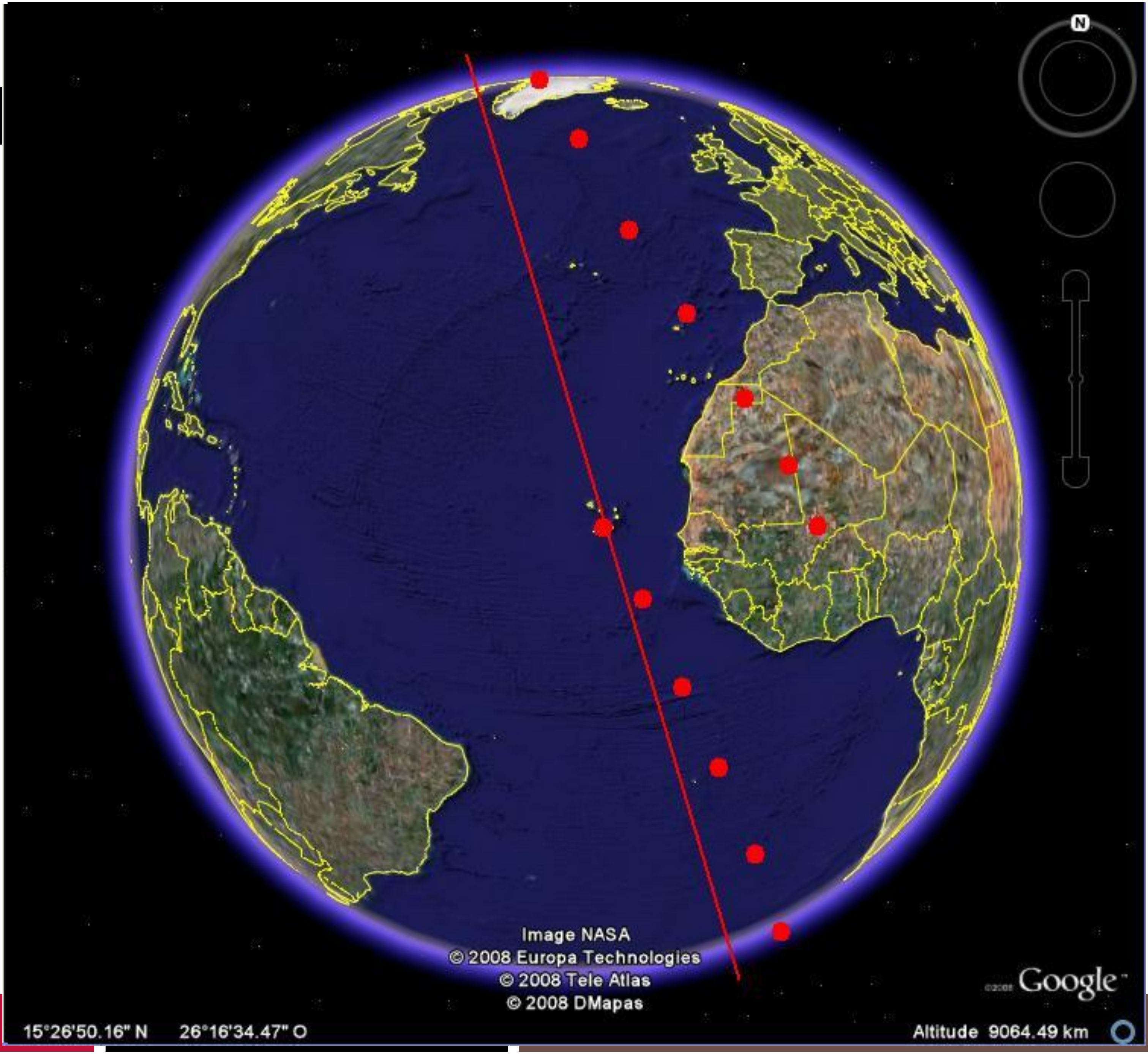
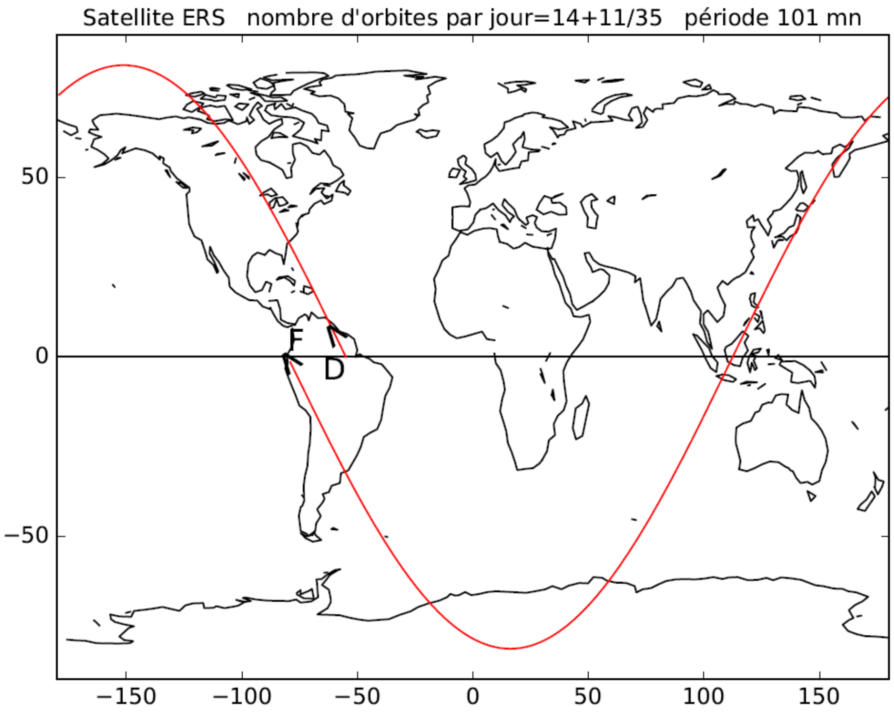


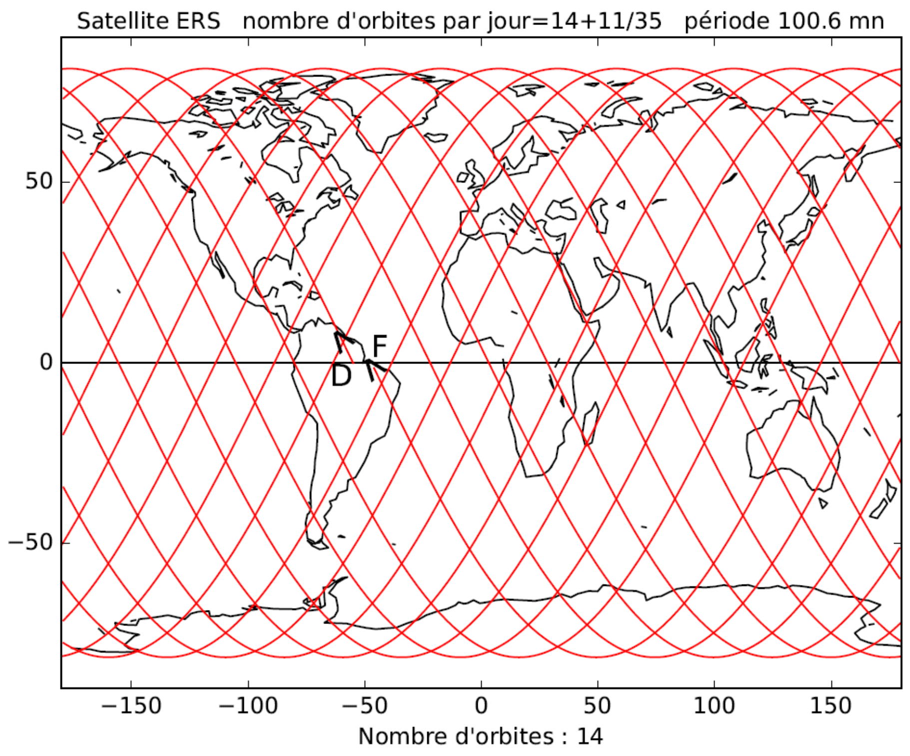
Image NASA
© 2008 Europa Technologies
© 2008 Tele Atlas
© 2008 DMapas
Google
15°26'50.16" N 26°16'34.47" O
Altitude 9064.49 km

T=0’

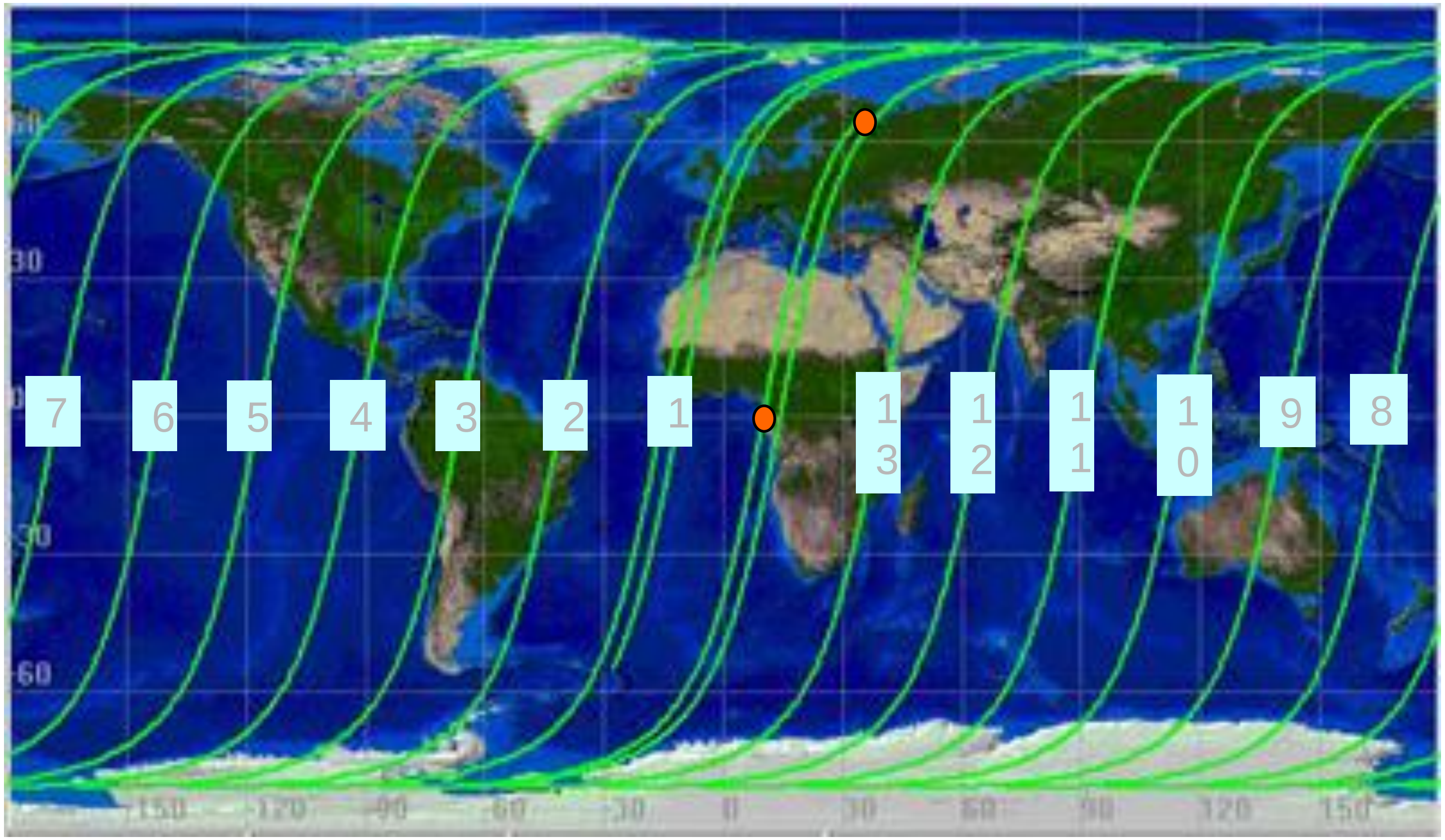
T=97’

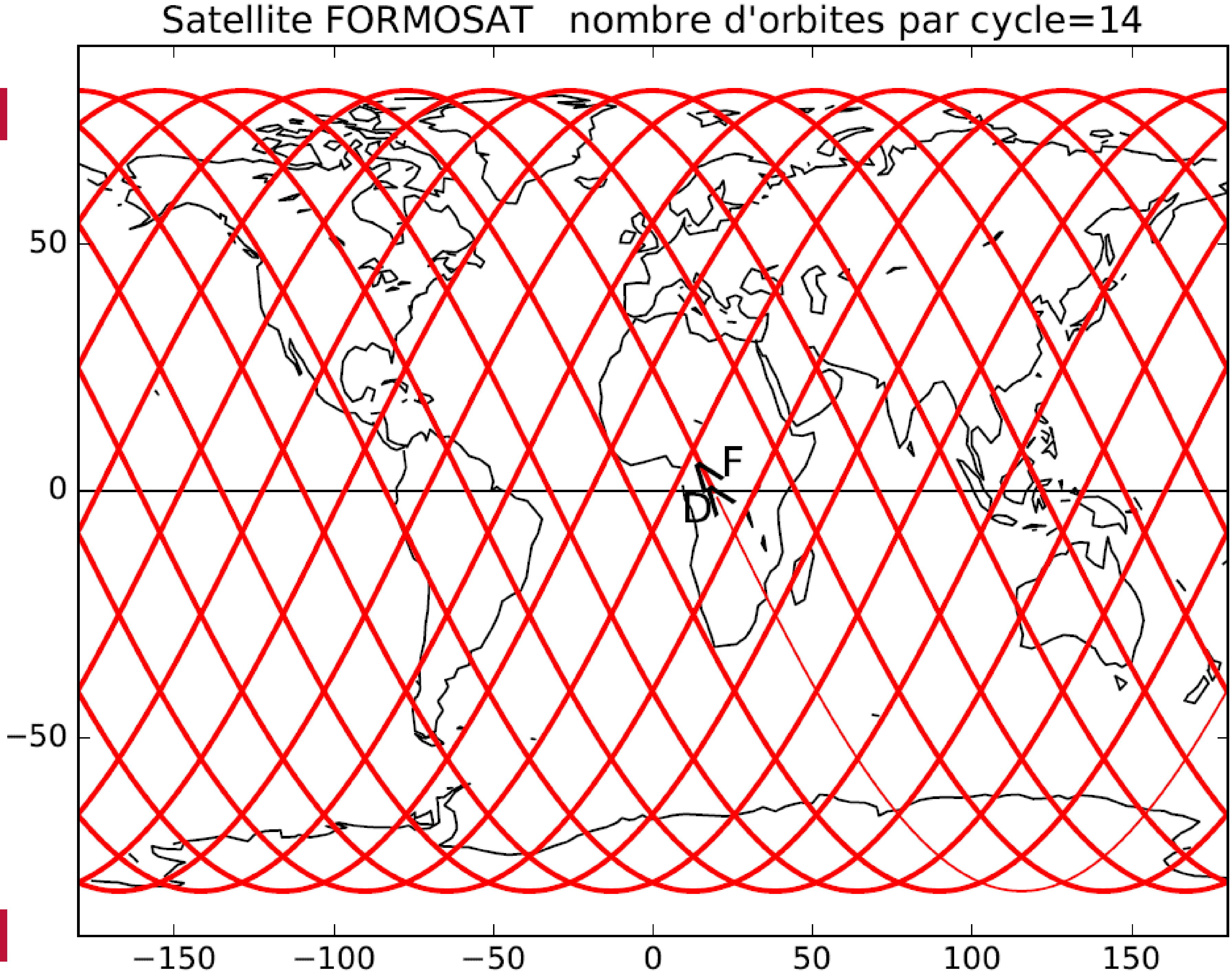
One orbit
One day of orbits



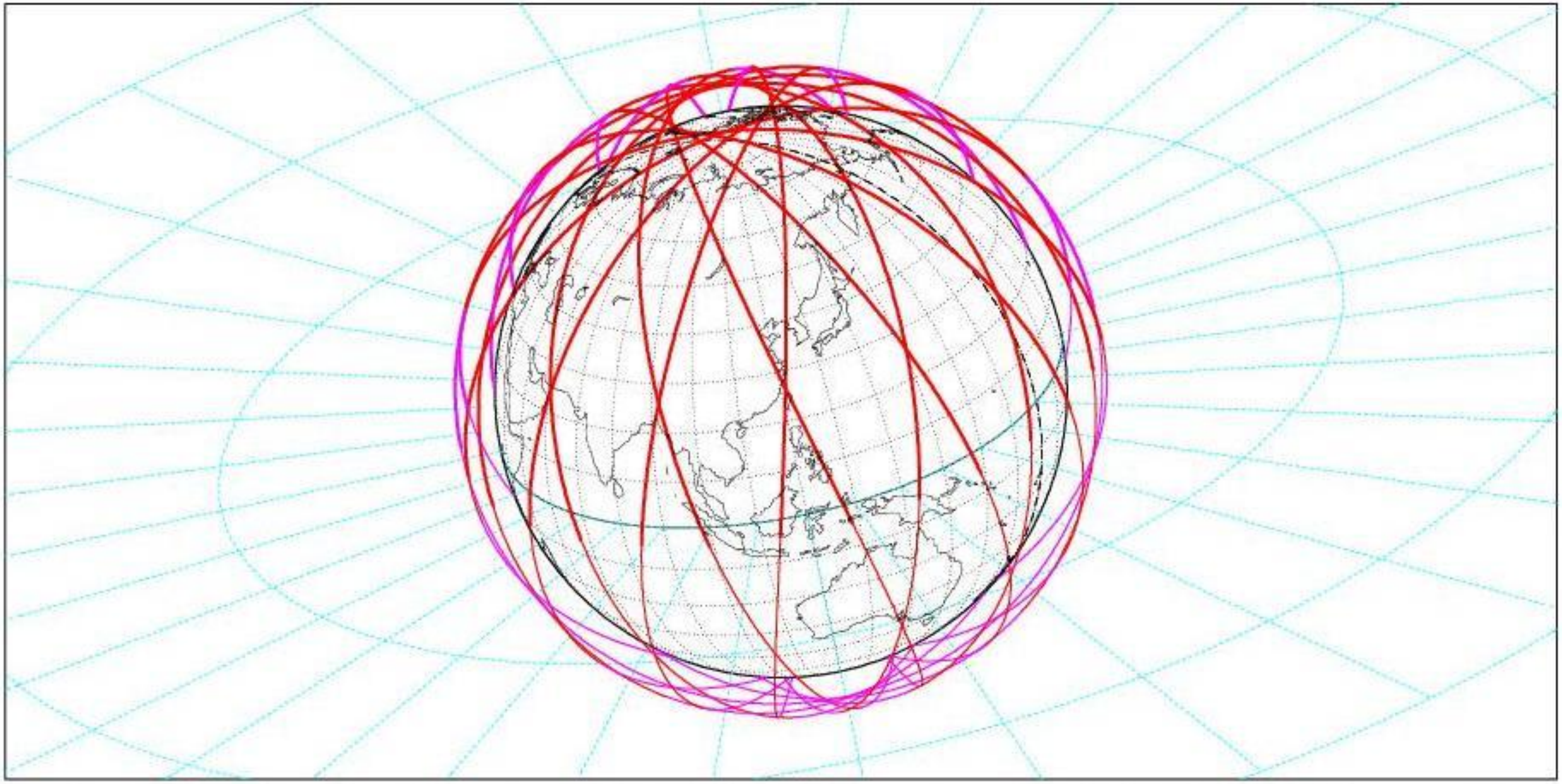


ERS : descending tracks




Satellite FORMOSAT   nombre d'orbites par cycle=14
50
0
−50
−150
−100
−50
0
50
100
150
D
F

1 day with Formosat : 14 orbits per day



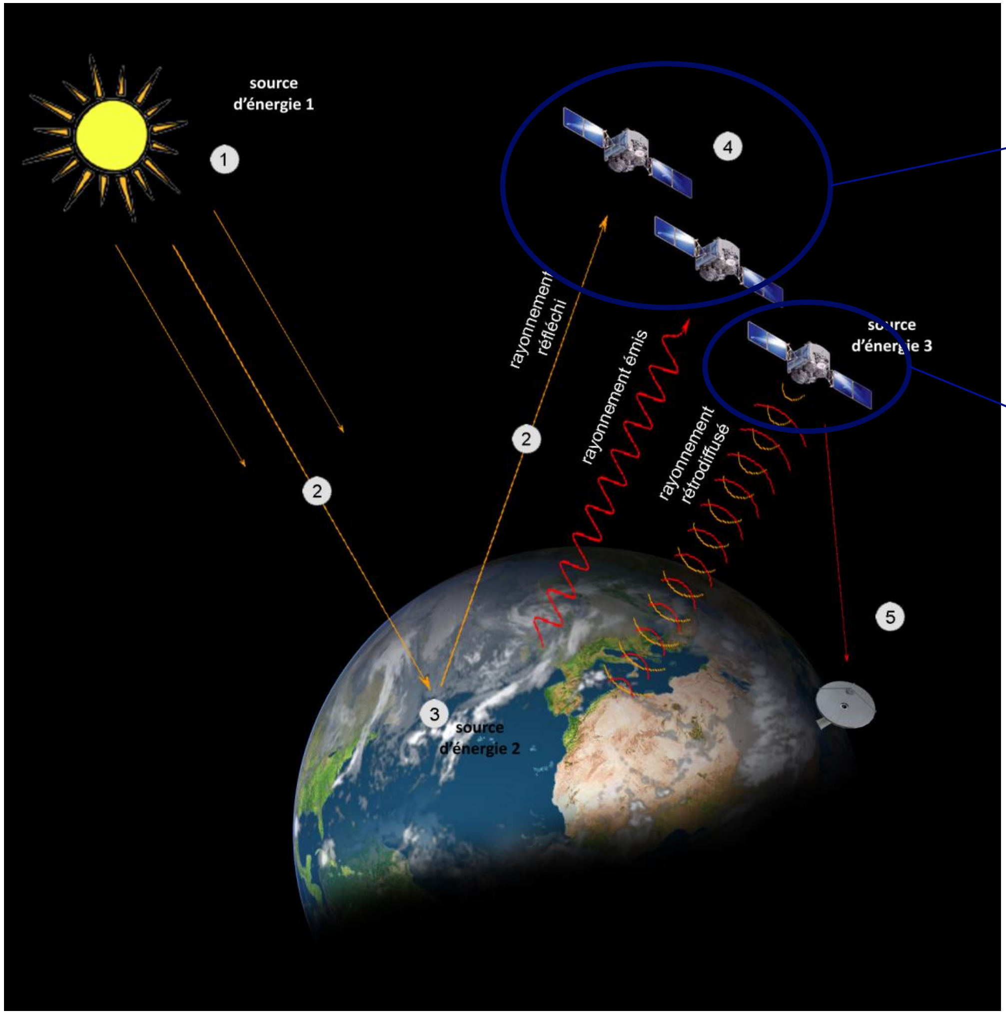
Examples of cycles

1 day	FORMOSAT	14
10 days	Sentinel-2	14+3/10
11 days	Terrasar-X	15+2/11
16 days	LANDSAT 7, Terra	14+9/16
24 days	RADARSAT	14+7/24
26 days	SPOT	14+5/26
35 days	ERS	14+11/35
46 days	ALOS	

Overview of the course

- **Short history of remote sensing**
- **Satellites and orbites**
- **Imaging systems**
- **Applications**

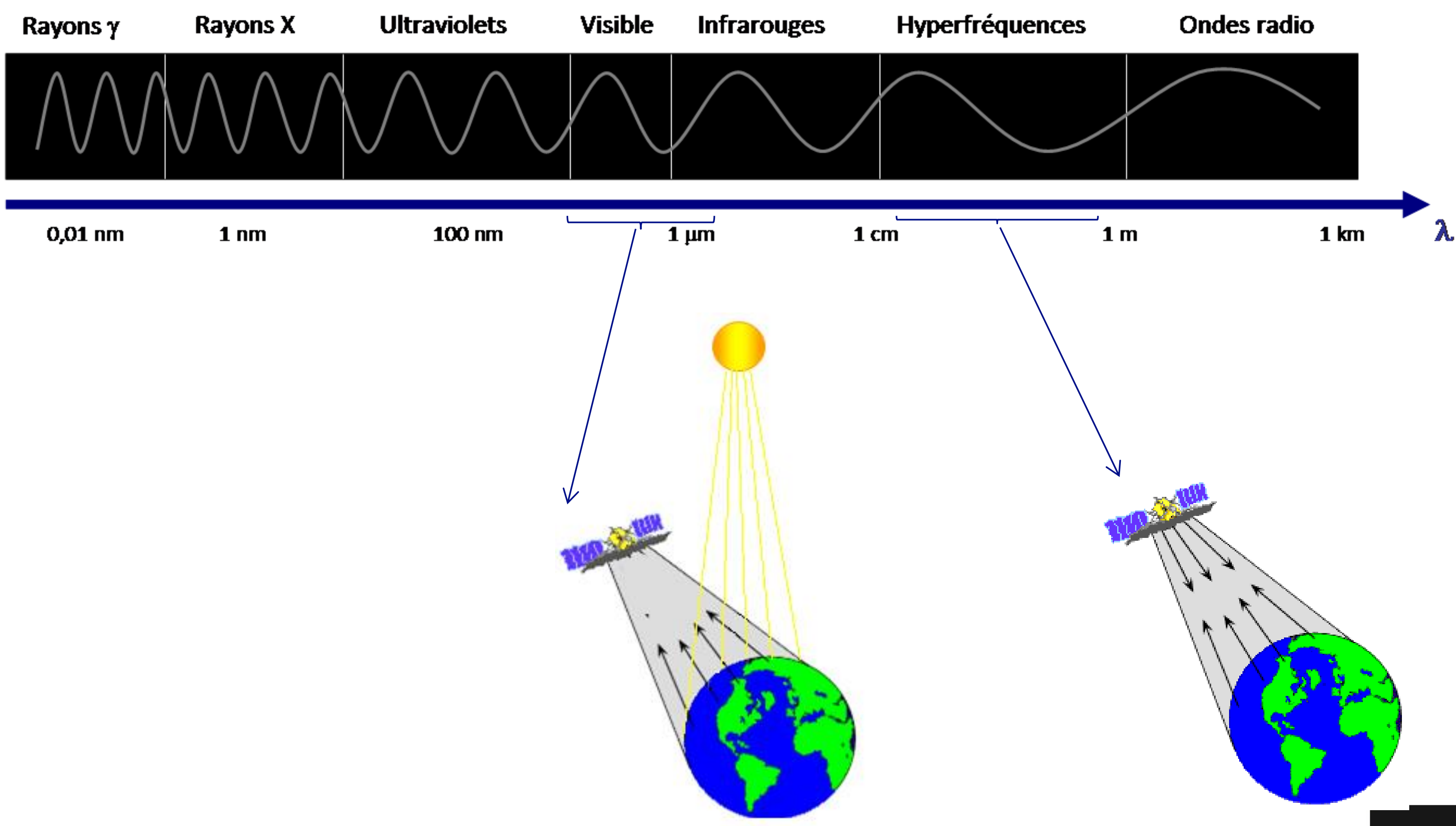
Physics of electromagnetic radiations



Passive sensors
- Optic domain
- Infra red

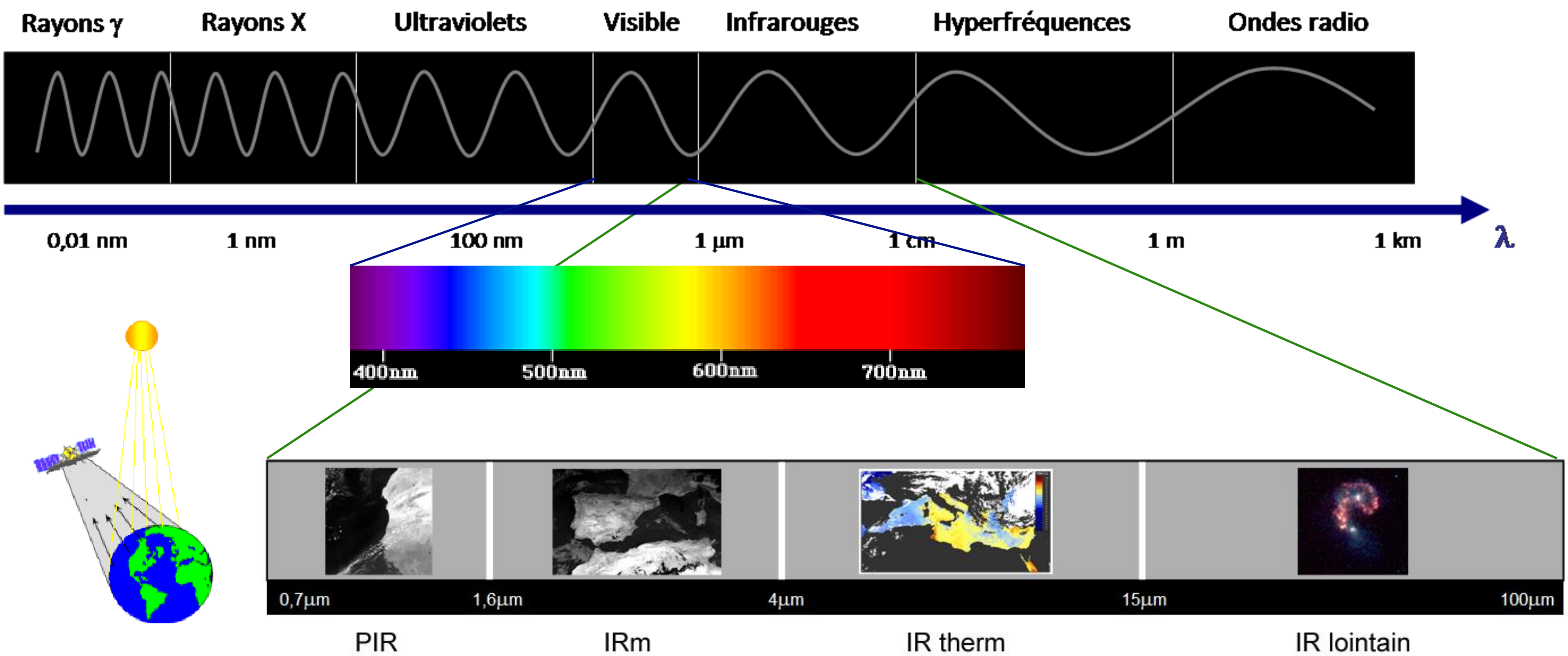
Active sensors
- radar
- lidar

Physics of electromagnetic radiations



Source figure ENVCAL

Physics of electromagnetic radiations



Vegetation

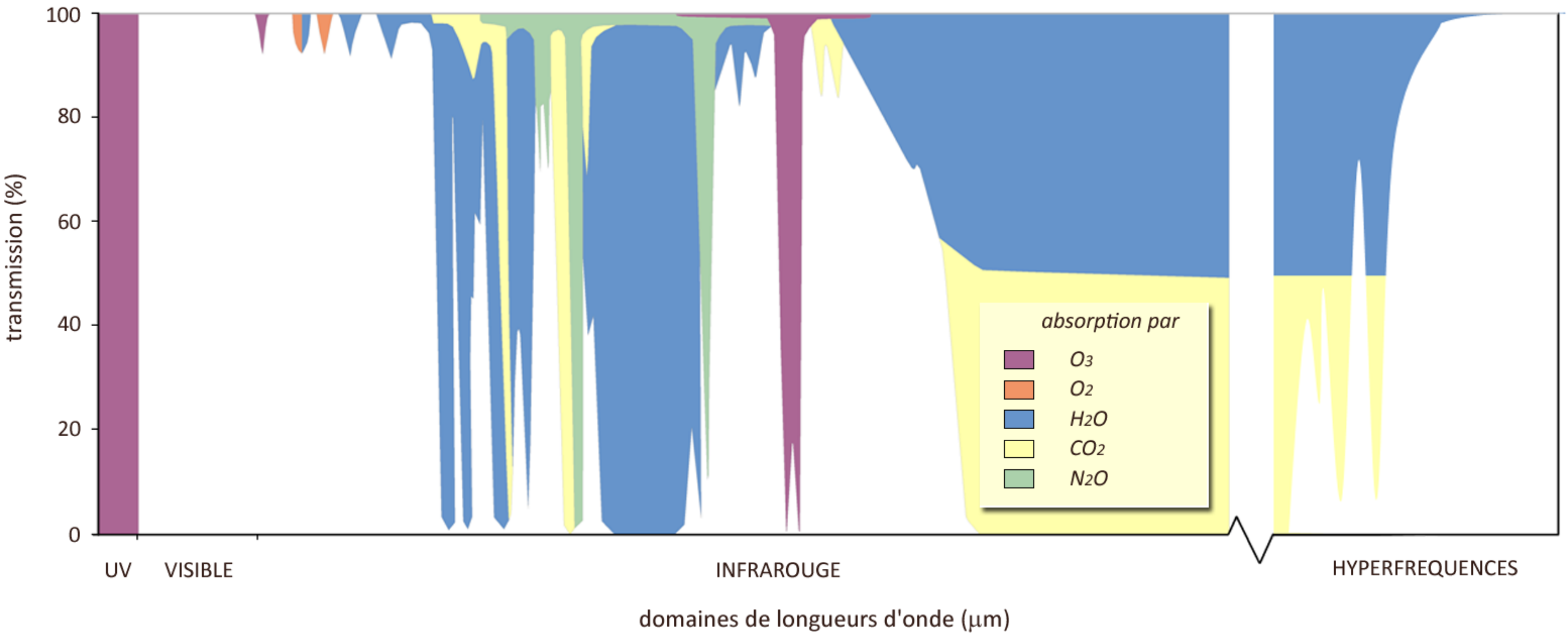
Water content

Surface emissivity temperature

Radiations of heavenly bodies

Source figure ENVCAL

Atmospheric windows



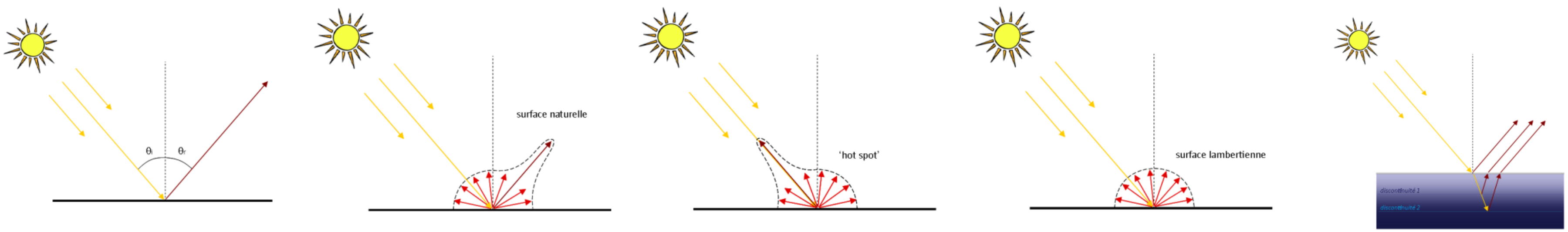
Visible senors

IR sensors
(3,5 – 3,9 µm)
(10,5 – 12,5 µm)

Active sensors

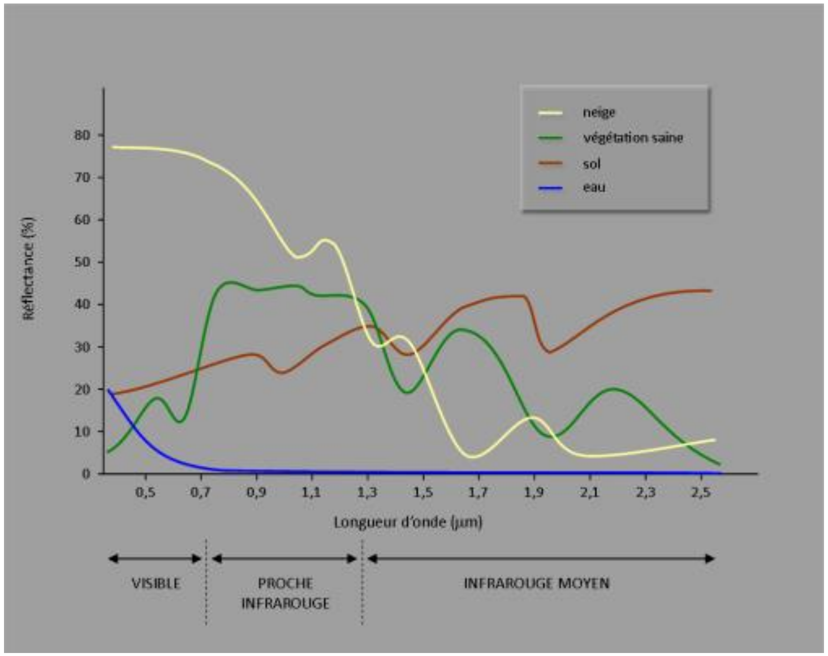
Electro-magnetic radiations and matter

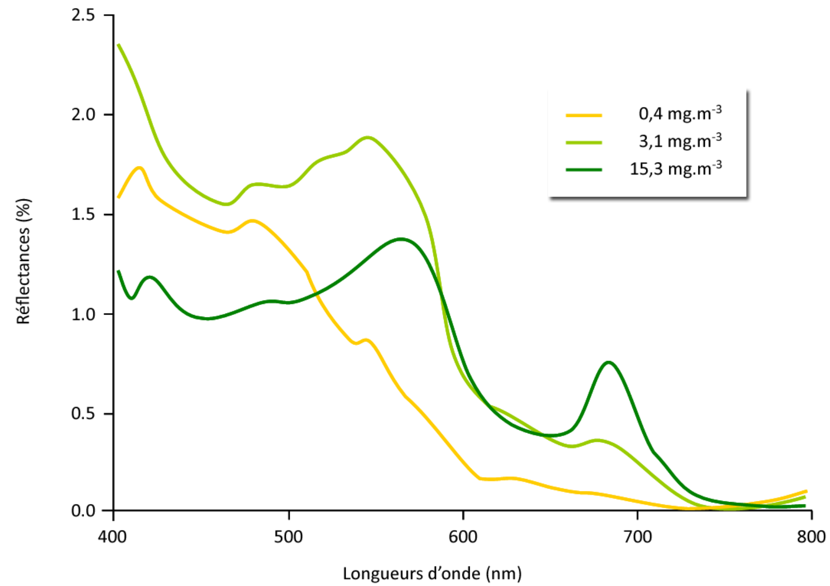
- **Interaction**
  - Absorption / reflexion / transmission
- **Reflexion**



- **Absorption**
  - Atmosphere, natural surfaces
- **Transmission**
  - Transparent media for some wavelengths
- **Measurements: luminance, radiance**
  - Radiometric calibration: sensor measurement to physical quantity (from DN to radiance)

Spectral signatures of media

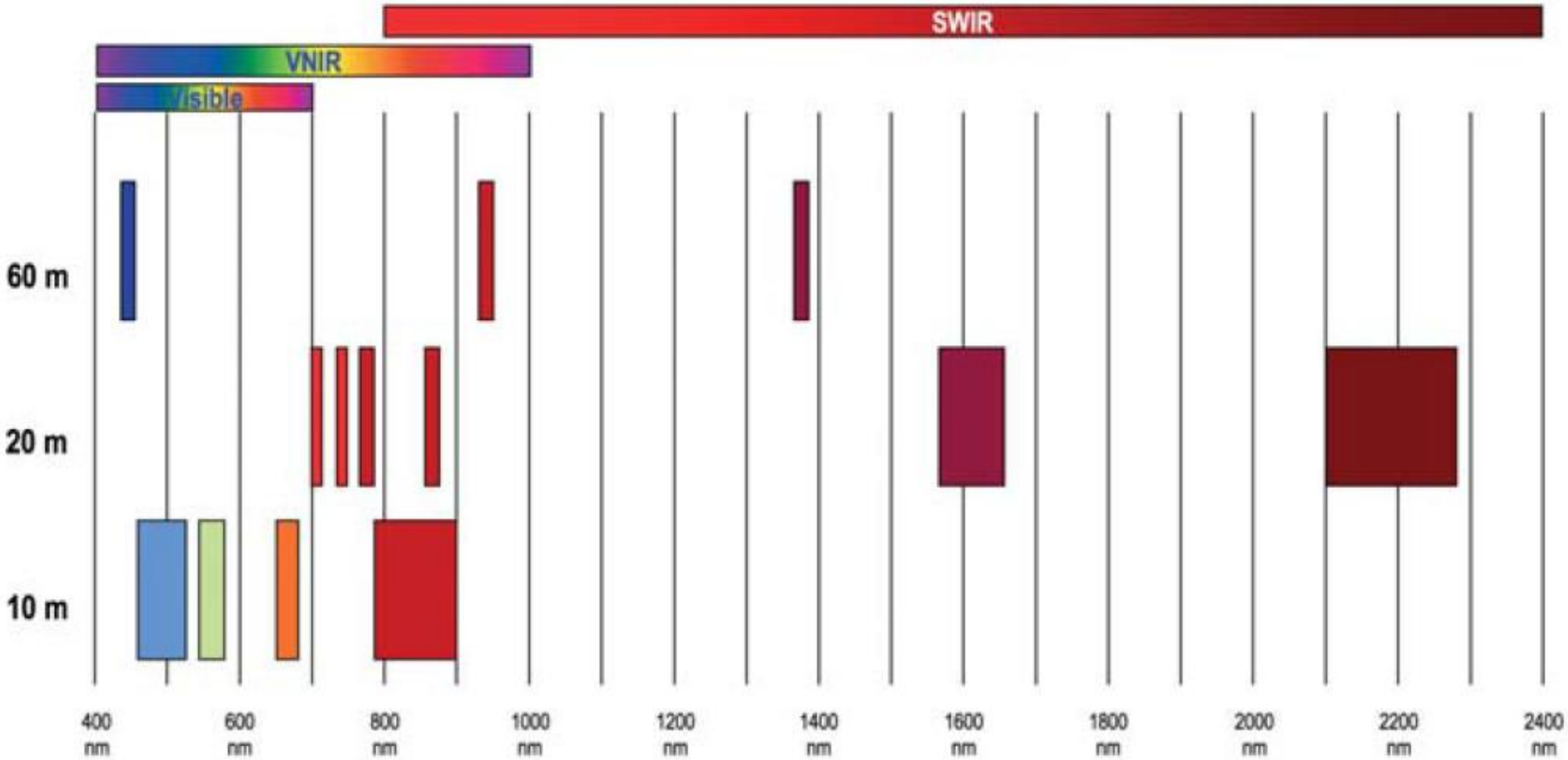




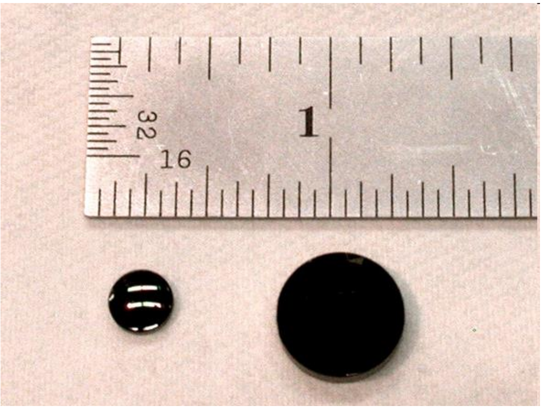
Spectral signatures of natural surfaces
Identification with multi/hyper spectral imagery

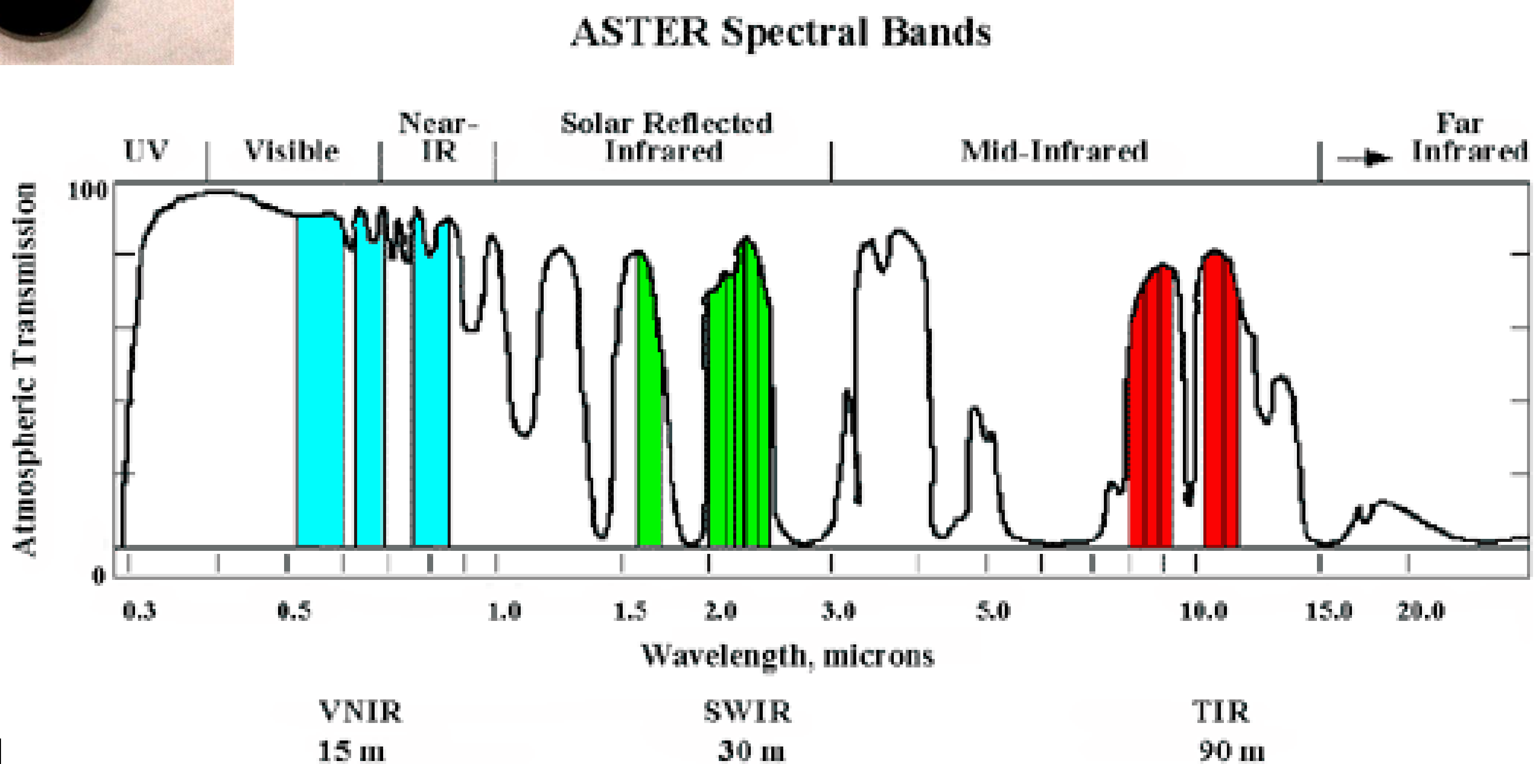
Spectral signature of water depending on its chlorophyle content
It depends also on its turbidity (content of sedimentary materials)

Multimodal : visible, NIR, SWIR
Sentinel-2 sensor



TIR (Thermic Infra Red) senors



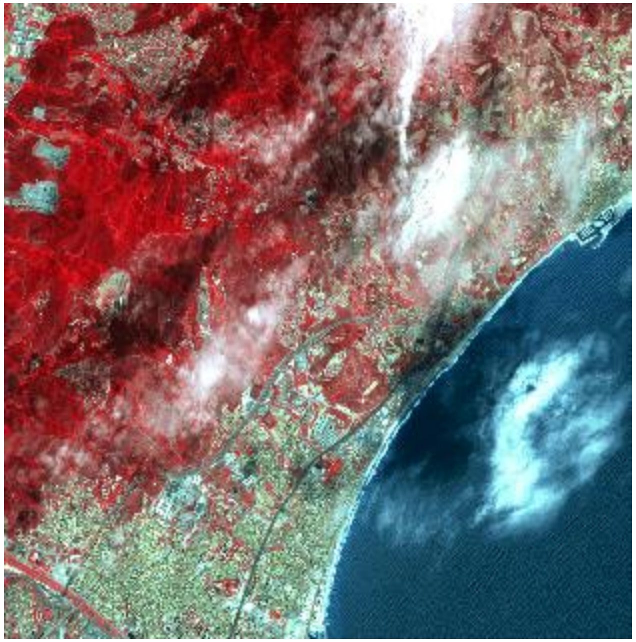






440-510
520-590
630-685
690-730
760-850

False color images

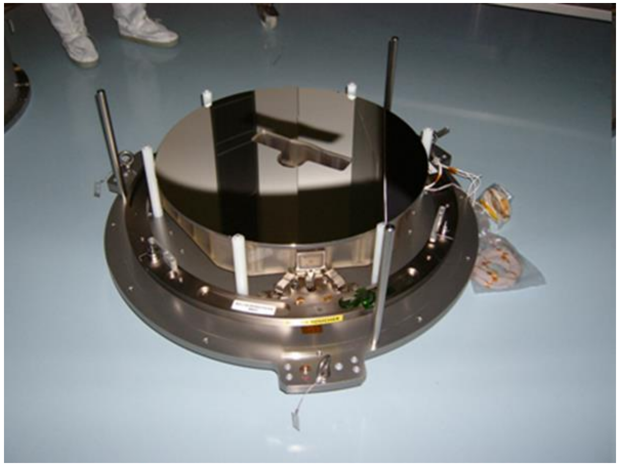


- Left: B+G+R channels (1, 2 and 3)
- Right: B+G+MIR channels (2, 3 and 4)

Optical systems
Aperture and resolution

μ+φ

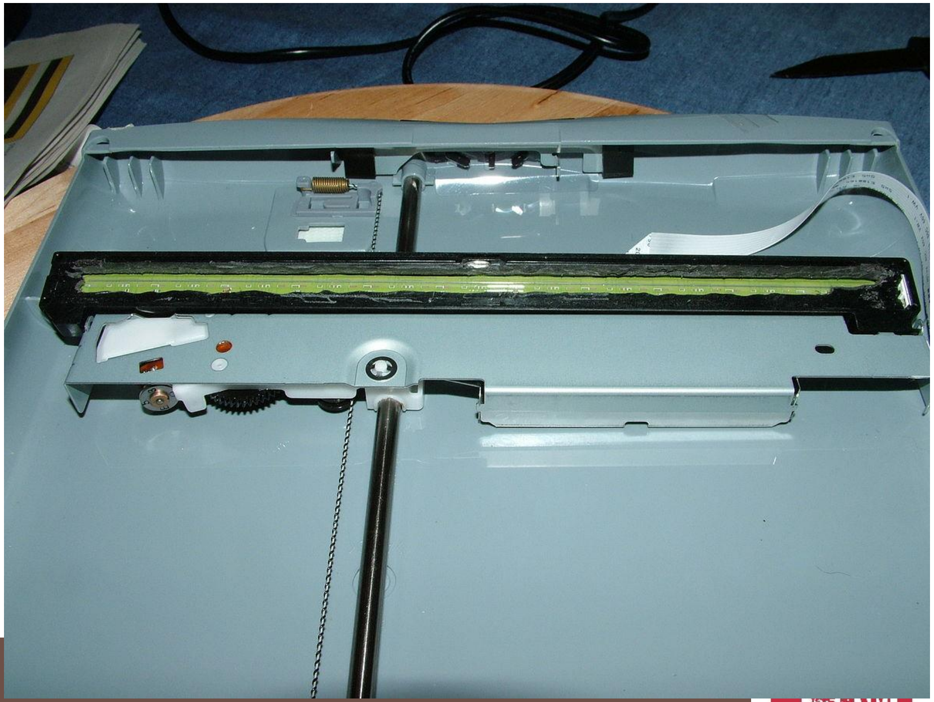
- **Resolution / pixel spacing**
- **For optical systems, resolution depends on distance D, aperture L and wavelength λ**



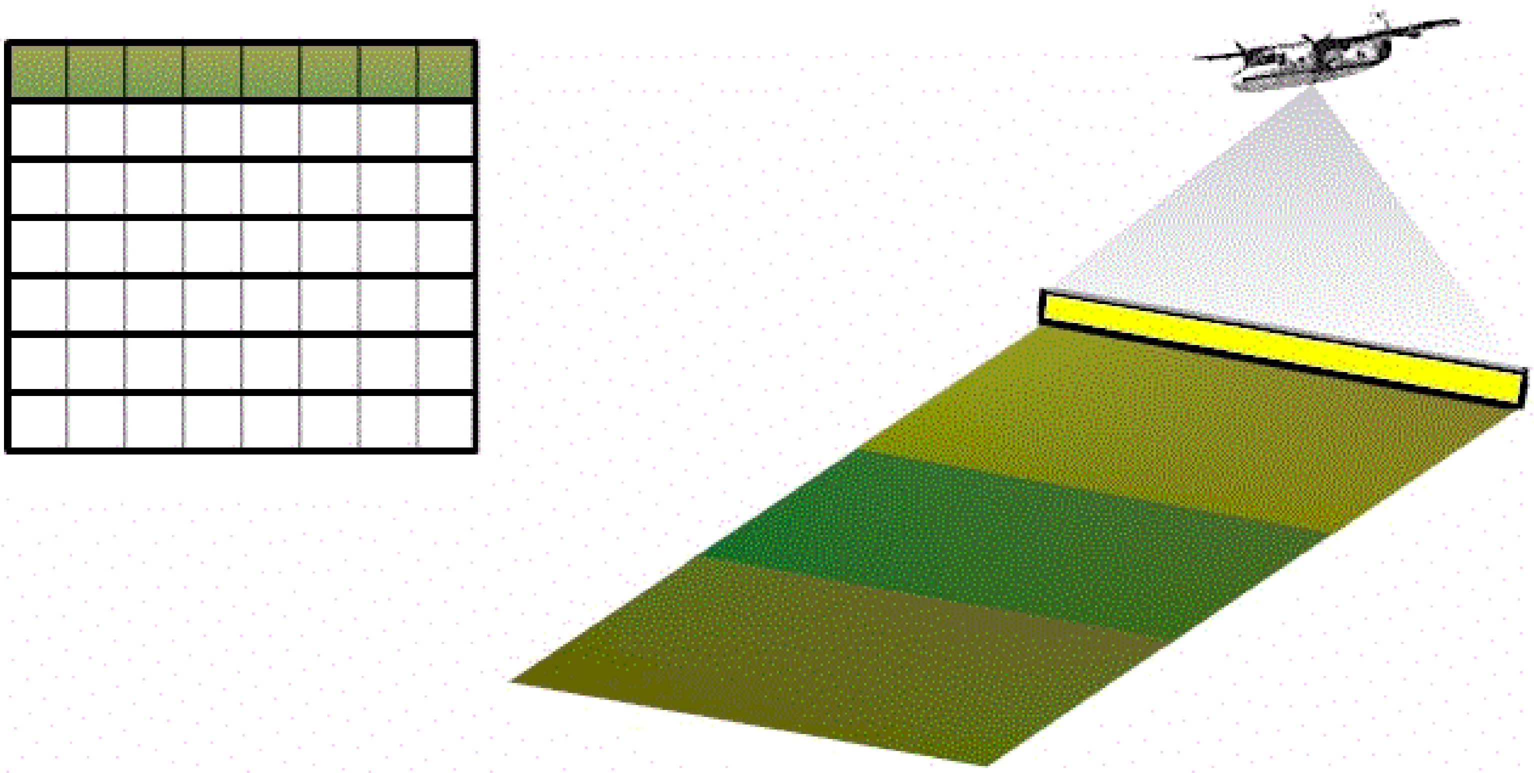
$$\delta y = \frac{\lambda D}{L}$$

Scanning of the earth

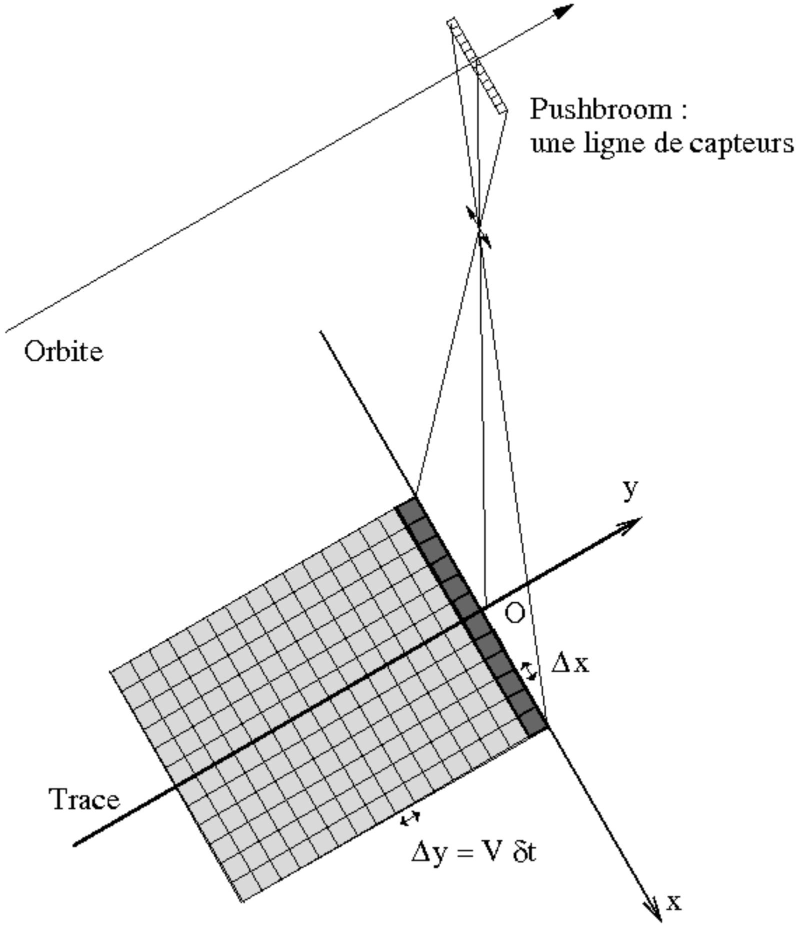
- 1-D sensor (CCD line)
- Building of the image by scanning



Pushbroom:
1 line + sensor movement

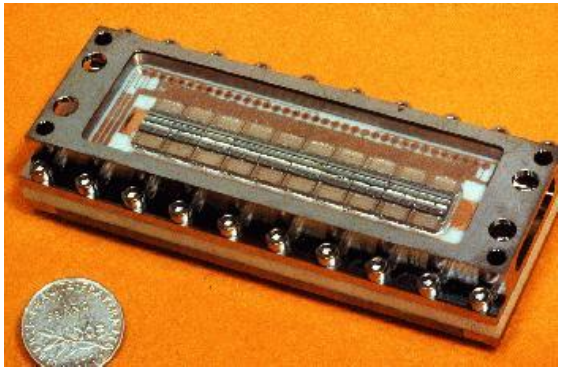


Pushbroom



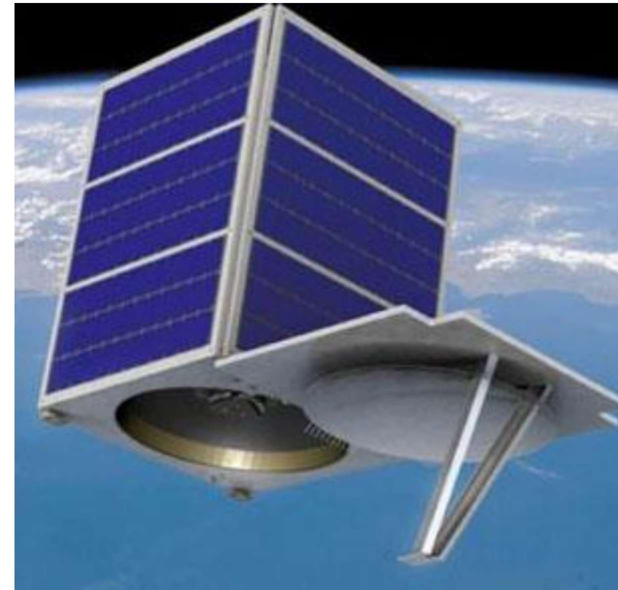
- Line by line acquisition
- 6000 pixels to 24000 pixels
- Resolution in flight direction:

$$\Delta y = V_S \, \delta t$$



- VHR → limited integration time
  - 1 line of CCD → TDI

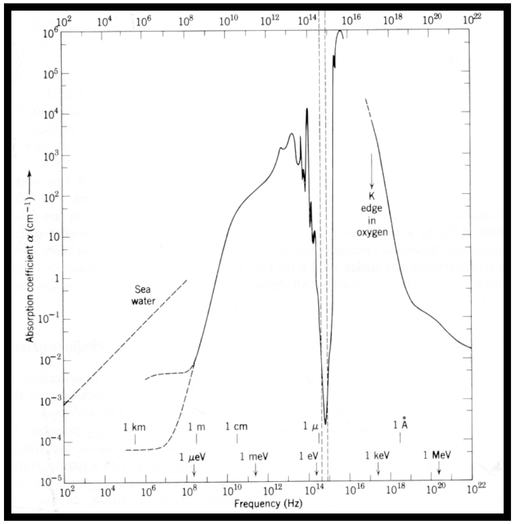
Skysat



- **2D CCD**
  - ~ 2000 x 1000
  - Image swath: 2 km x 1 km
  - 30 images/s

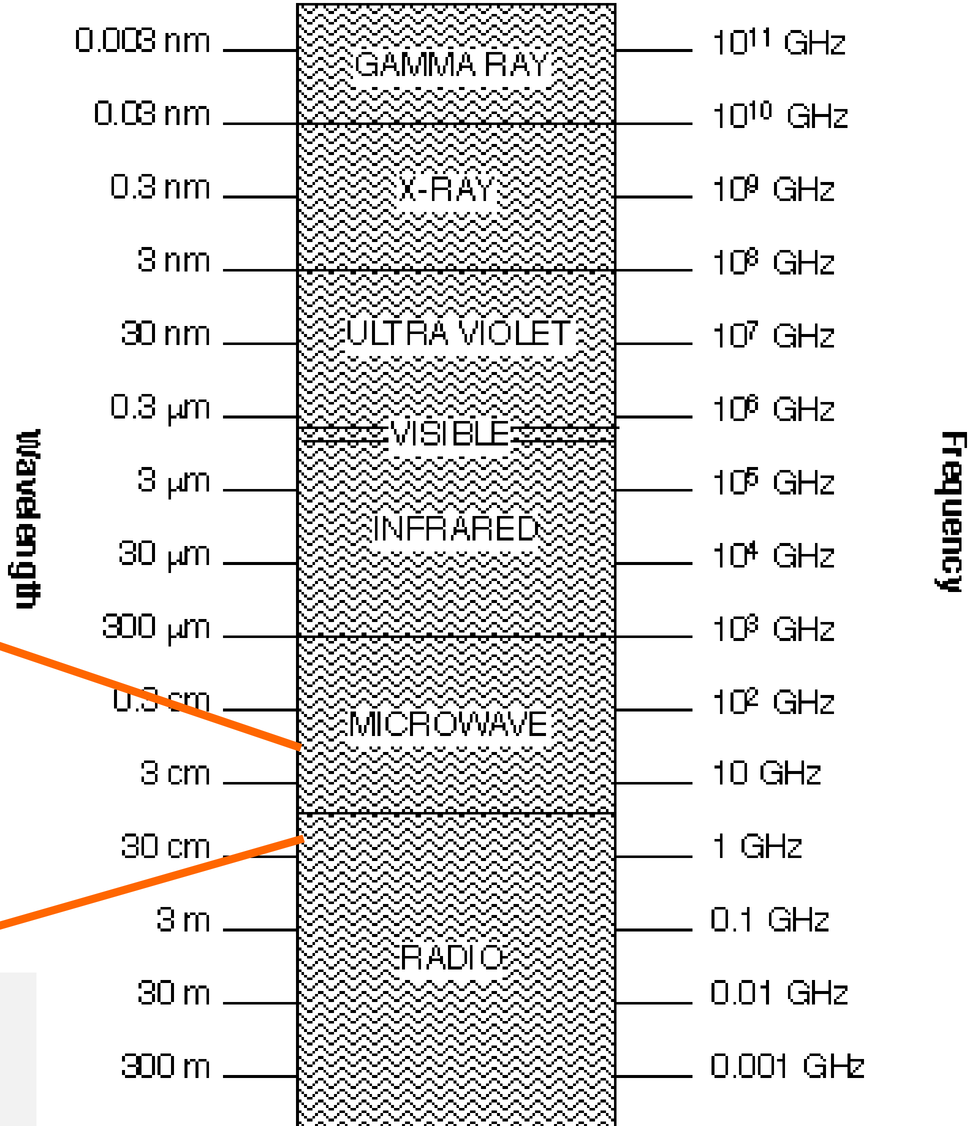
(SkyBox Imaging, then Terra Bella (Google) bought by Planet

SAR sensors - Electro-magnetic waves



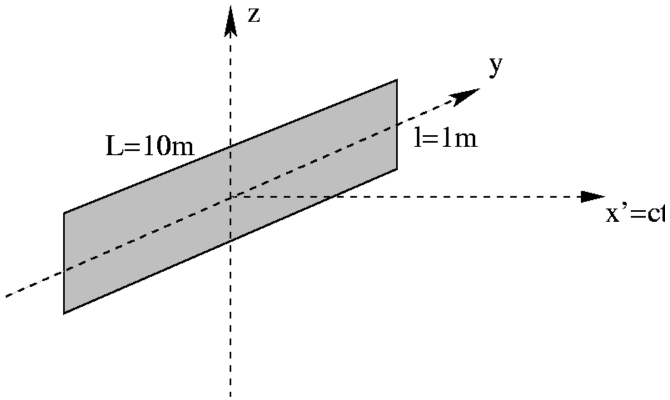
Radar bands:

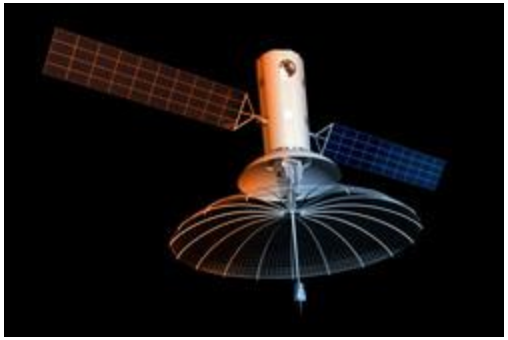
- X ~ 2 cm (~ 9 GHz)
- C ~ 5 cm (~ 5 GHz)
- L ~ 20 cm (~ 1 GHz)

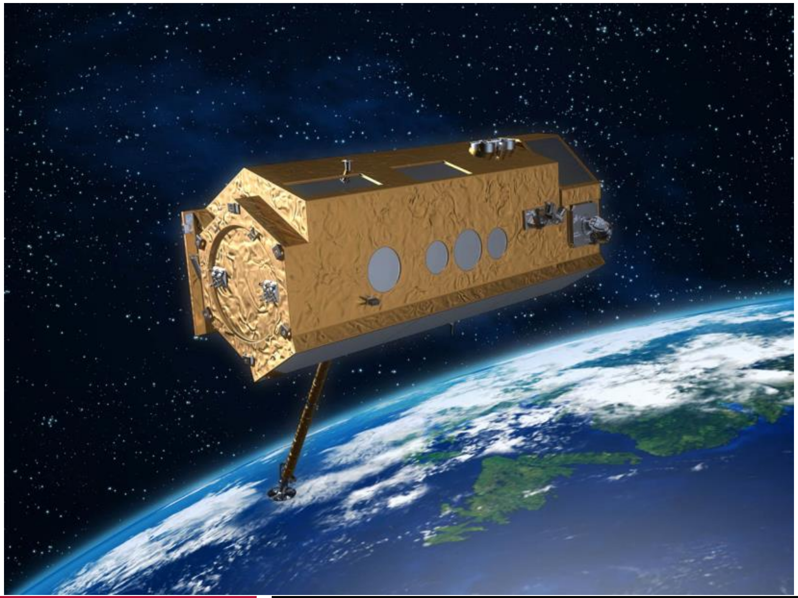


- **X: top of the canopy**
- **L: vegetation penetration**

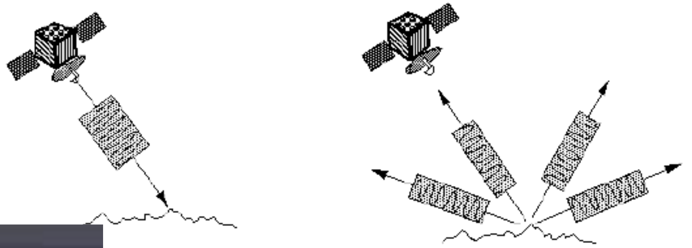
Radar antenna

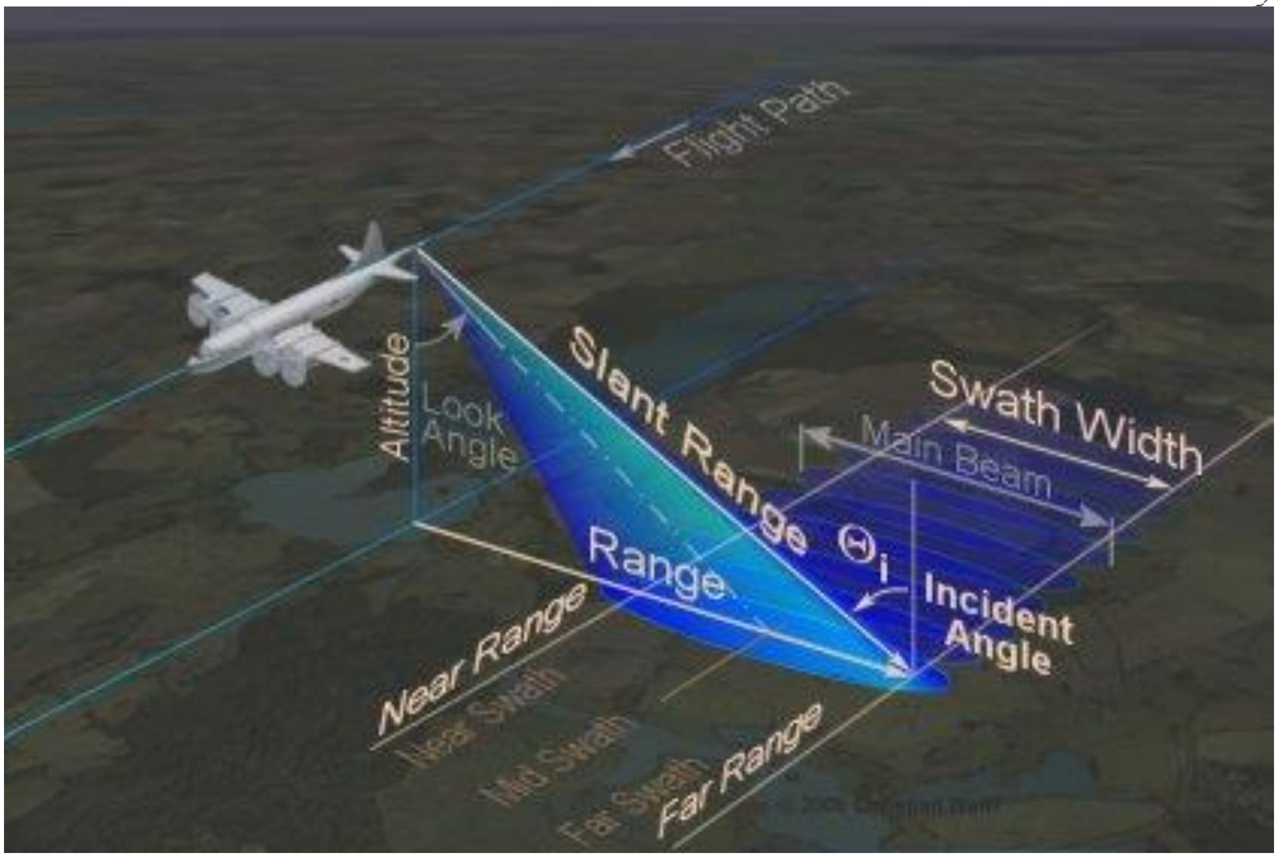






Radar antenna: main lobe

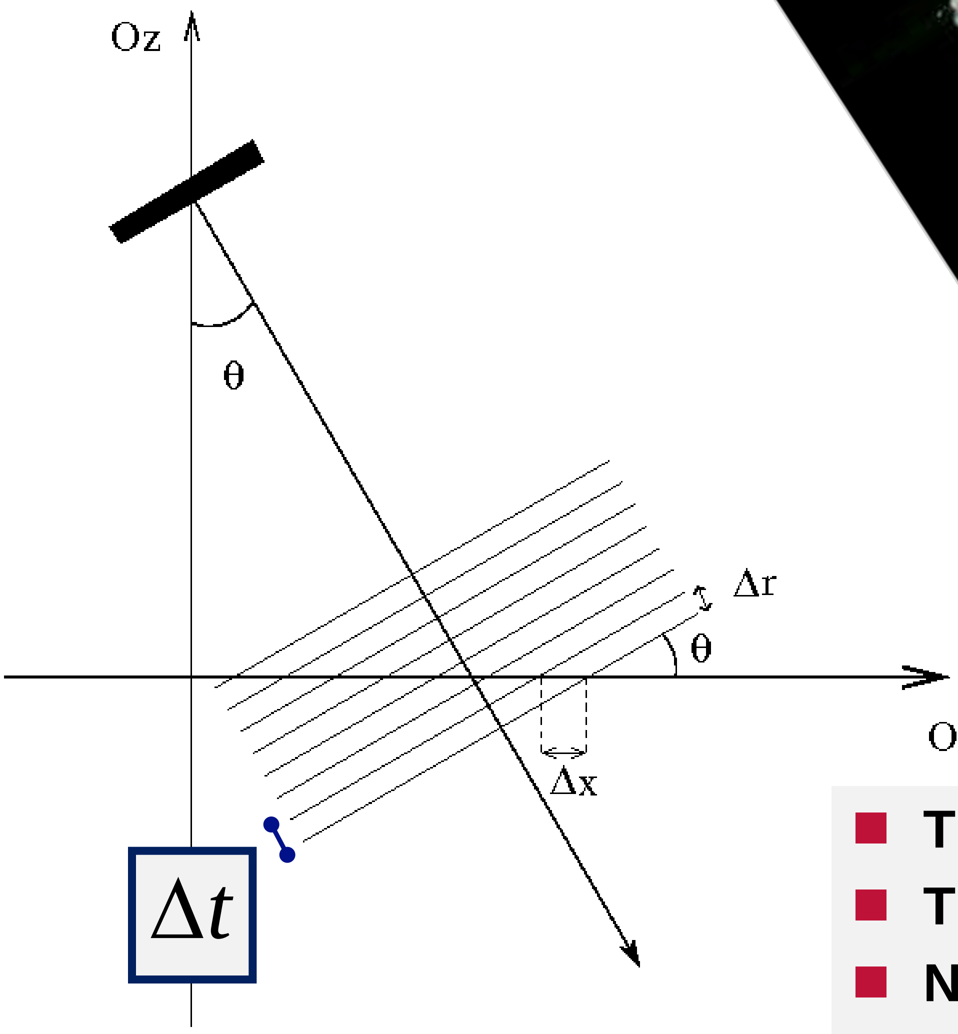




$$\delta y = \frac{\lambda R}{D}$$

©http://www.radartutorial.eu/

Lateral viewing

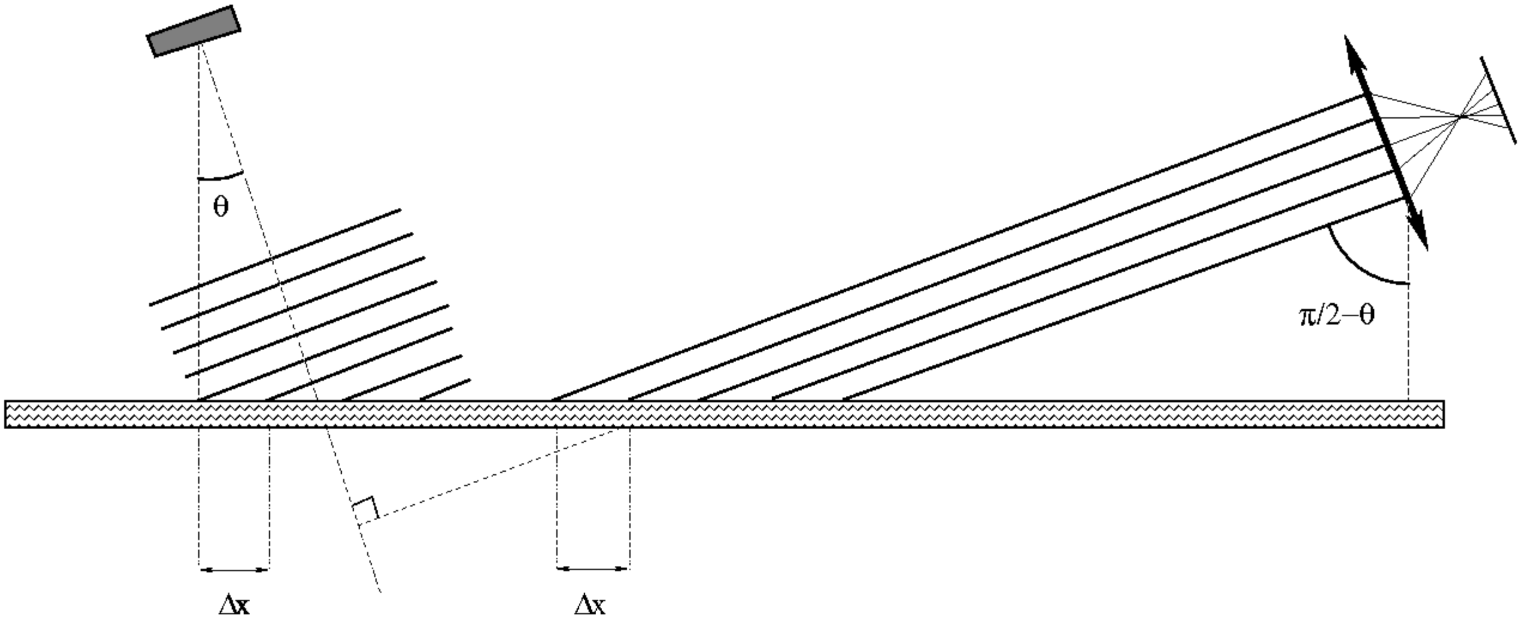


Δt

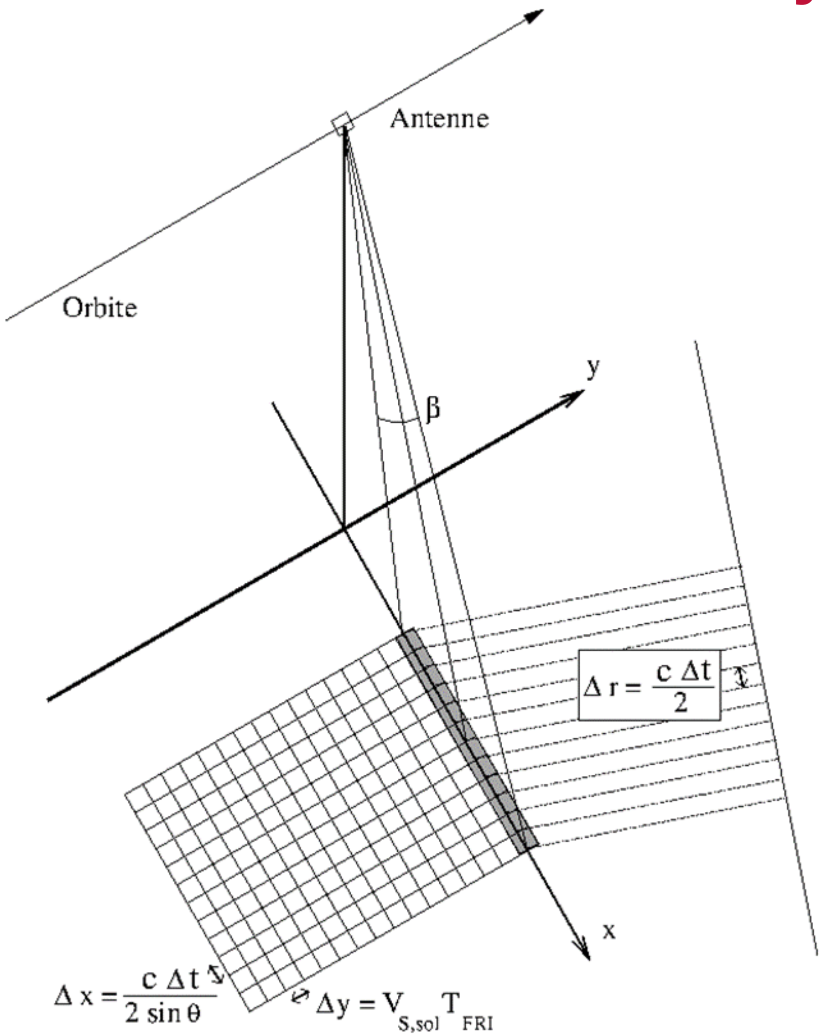
$$\Delta x = \frac{\Delta r}{\sin\theta}$$

- The range cell (Δr) is constant
- The ground cell depends on θ
- No dependency on R !!

Equivalence optic / SAR



« radarbroom » : Movement of the « synthetic » antenna (>5 km)

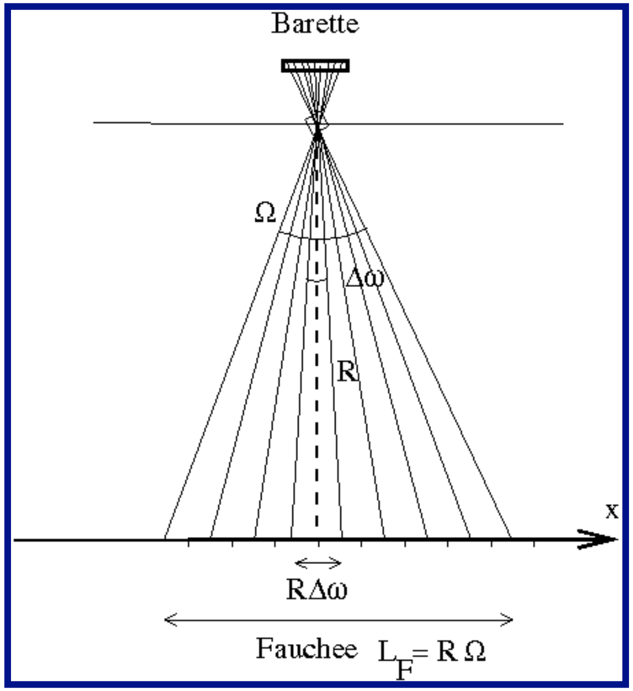


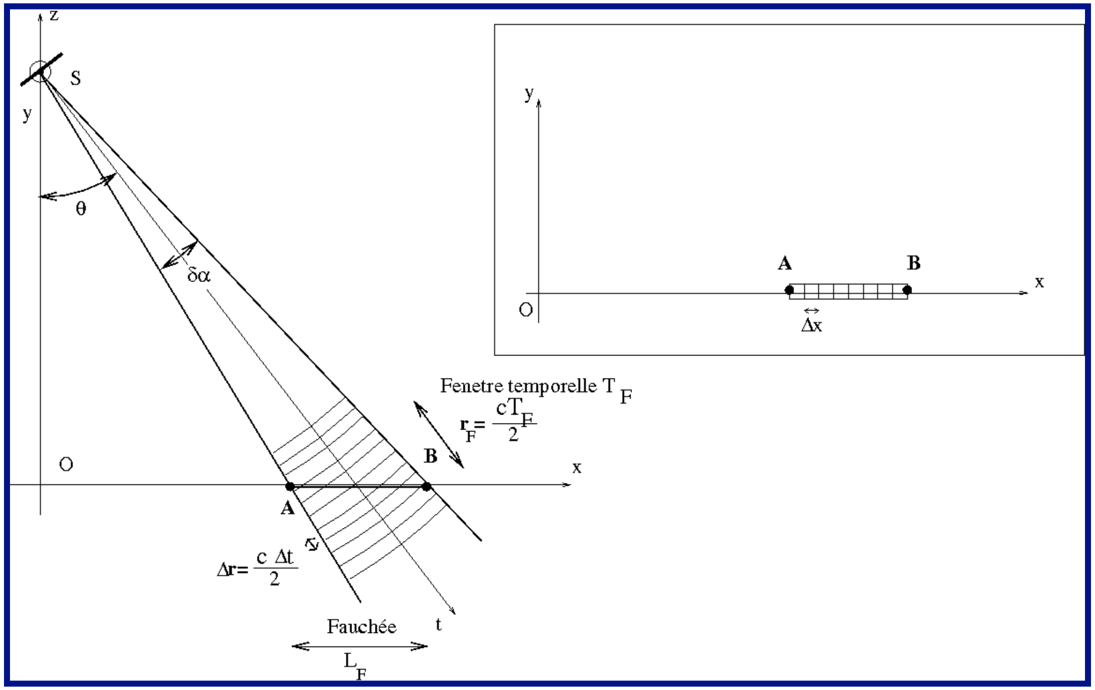
- **SAR: azimuth direction**
  - Real antenna : a few meters
  - Principle of Synthetic Aperture Radar
- **SAR: range direction**
  - Signal duration too long
  - Chirp

Both directions:

matched filters !

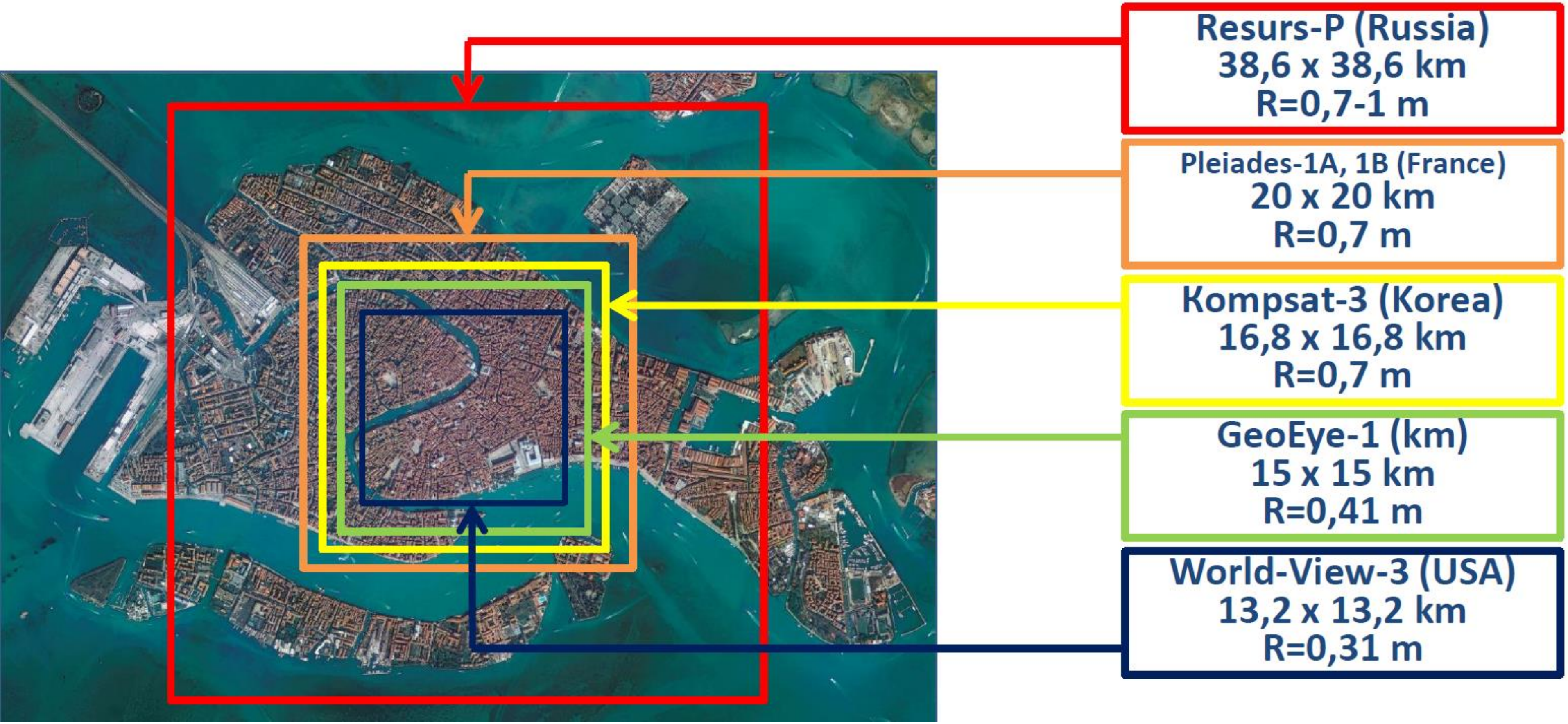
Optic and radar swath



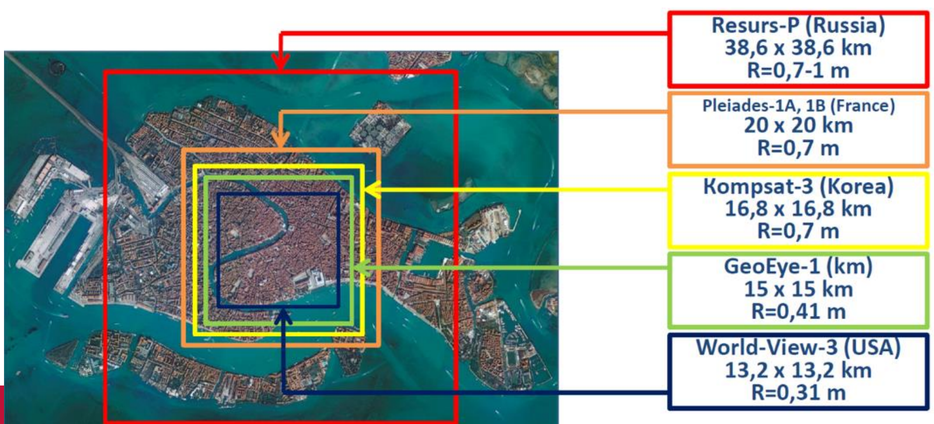


- **HR and VHR sensors:**
  - Swath of 10km to 100 km
  - Ground cell size: 24 cm to 10 m
- **« Large swath » sensors:**
  - Swath of 100km to 2000 km
  - Ground cell size : 100 m to 2 km

VHR sensors


Resurs-P (Russia)
38,6 x 38,6 km
R=0,7-1 m
Pleiades-1A, 1B (France)
20 x 20 km
R=0,7 m
Kompsat-3 (Korea)
16,8 x 16,8 km
R=0,7 m
GeoEye-1 (km)
15 x 15 km
R=0,41 m
World-View-3 (USA)
13,2 x 13,2 km
R=0,31 m

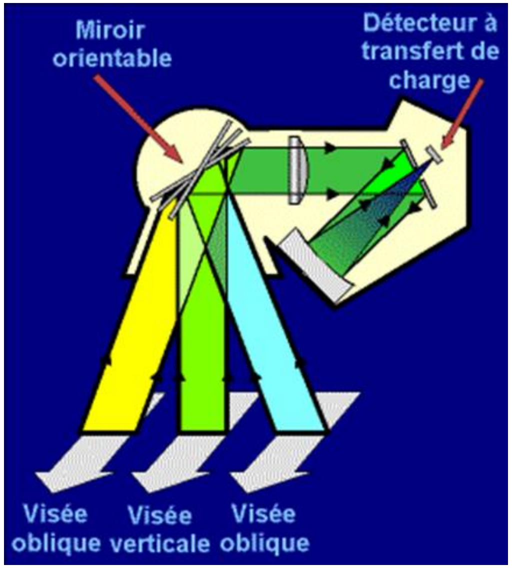
Large / small swath

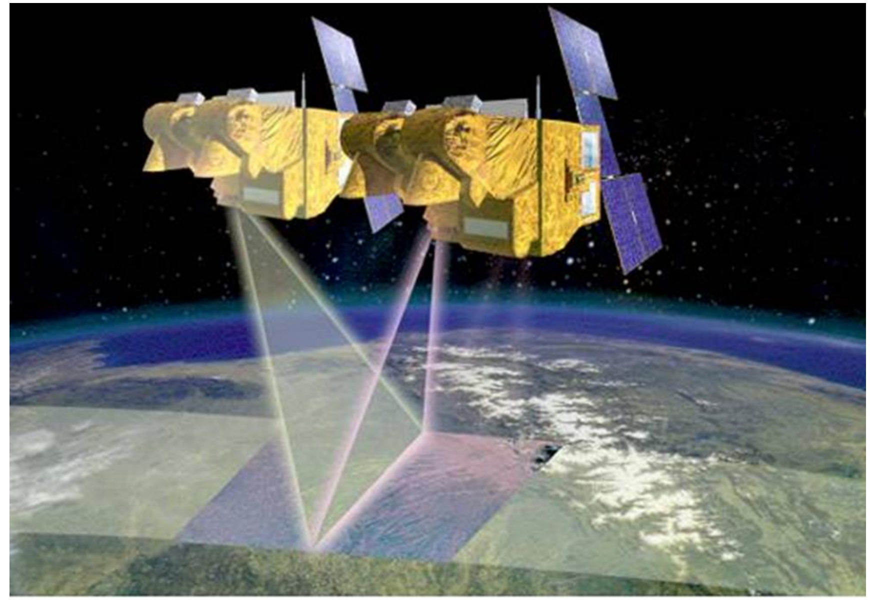


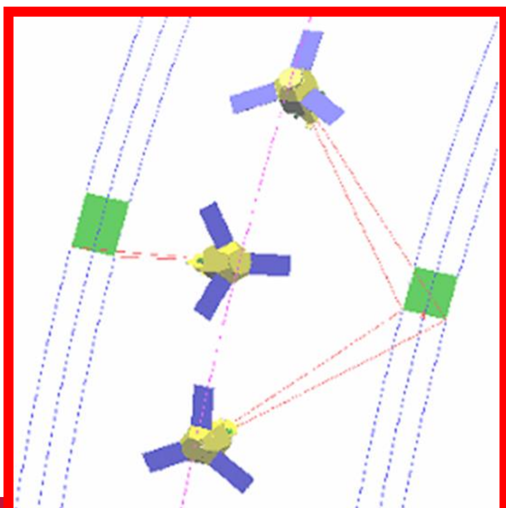
Sensor and satellite

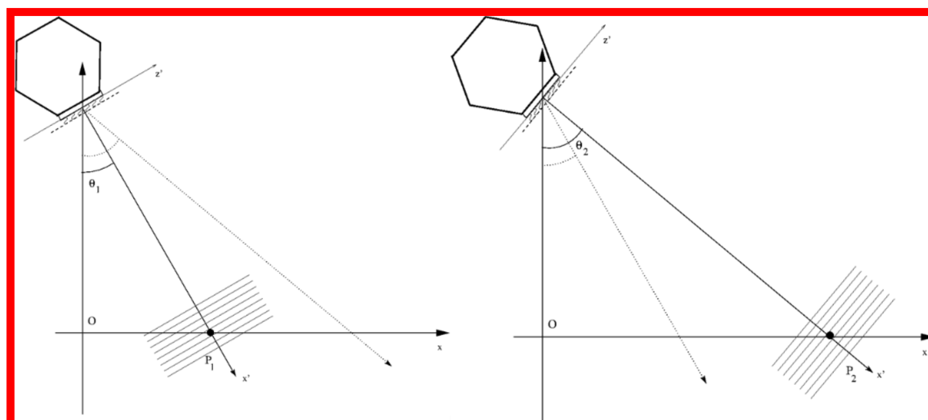
- **Satellite:**
  - $\rightarrow$ Orbital cycle: **time of the cycle**
  - Identical geometry viewing for each cycle
- **Satellite + sensor agility:**
  - $\rightarrow$ **Revisit time**
  - Sensor geometry different for each acquisition
- **Satellite constellations**

Sensor agility

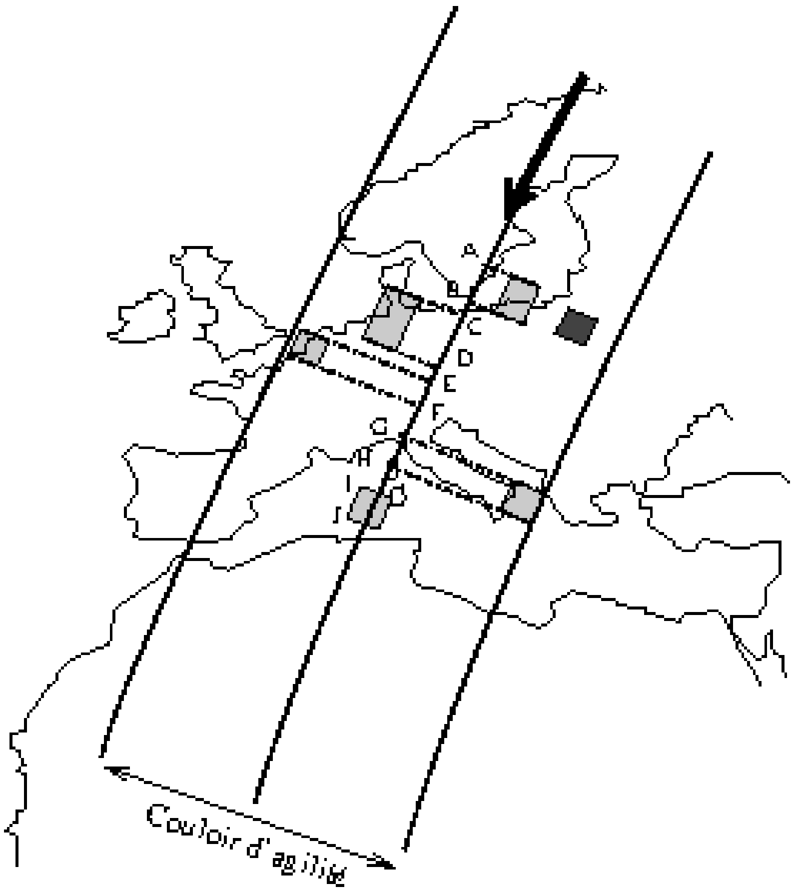


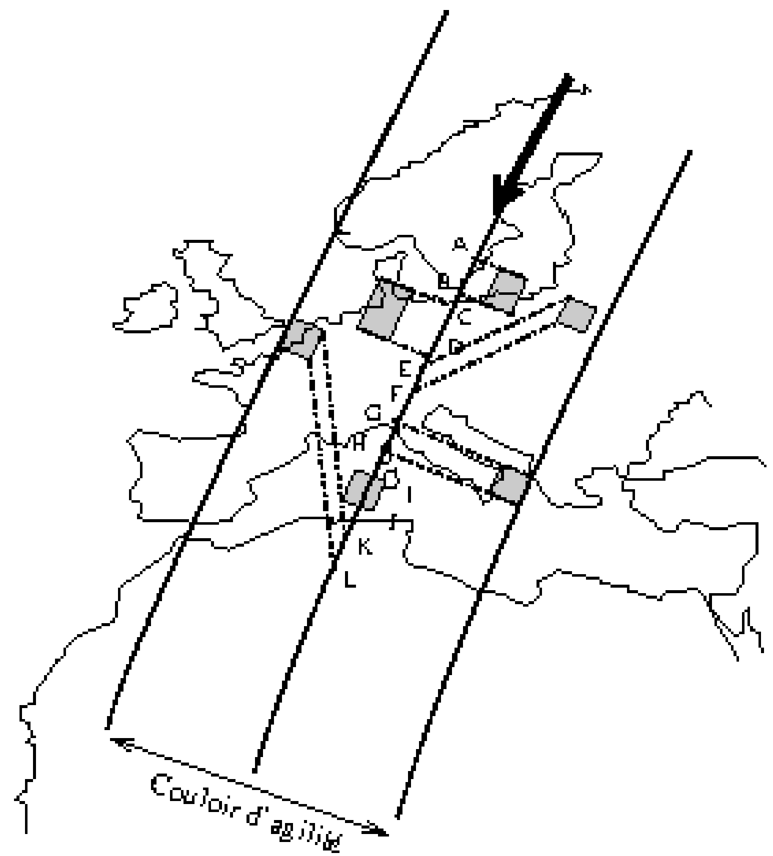






Left / right and forward / backward agility





Pléiades

© CNES

Revisit time: Pleiades

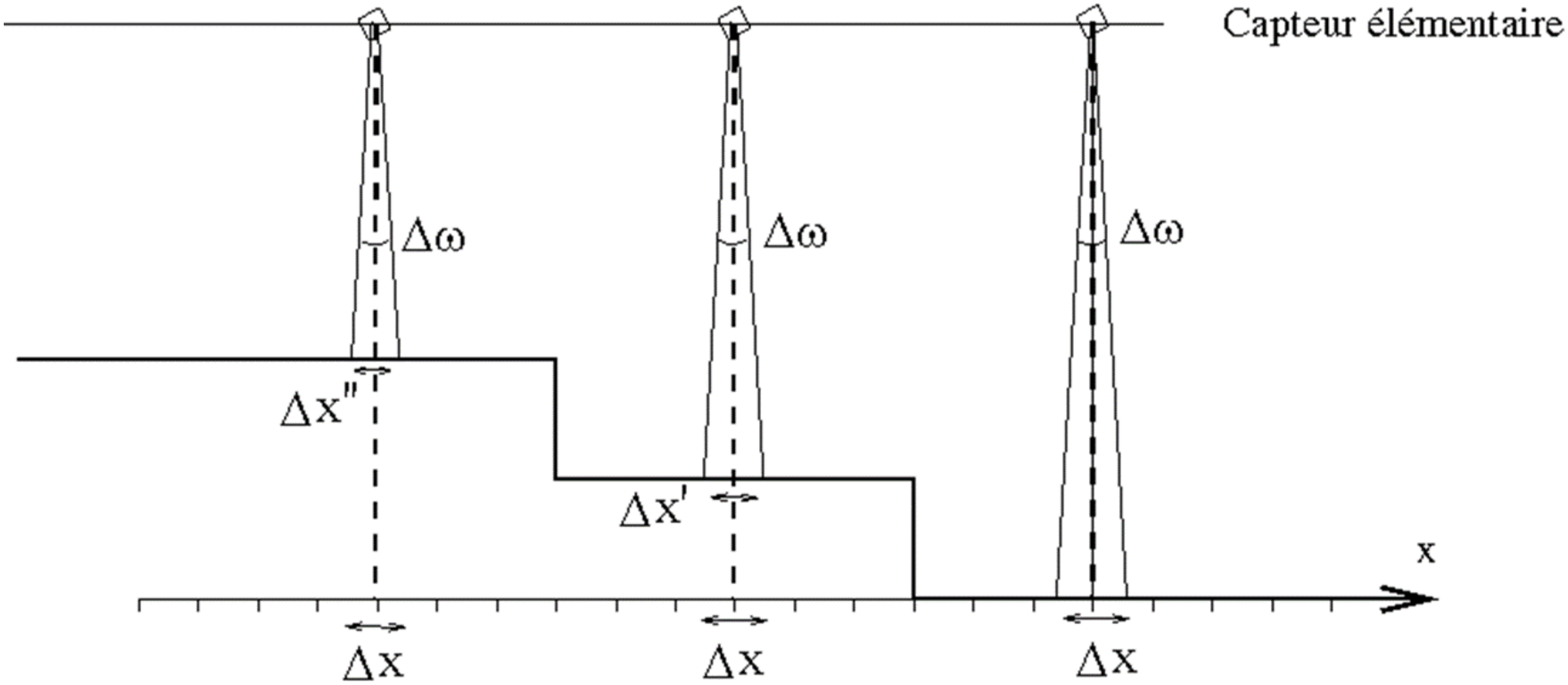
©CNES

- 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

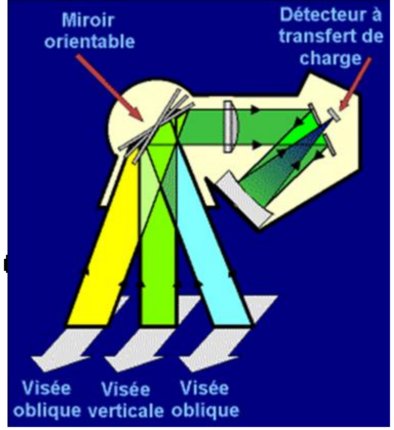
Pleiades

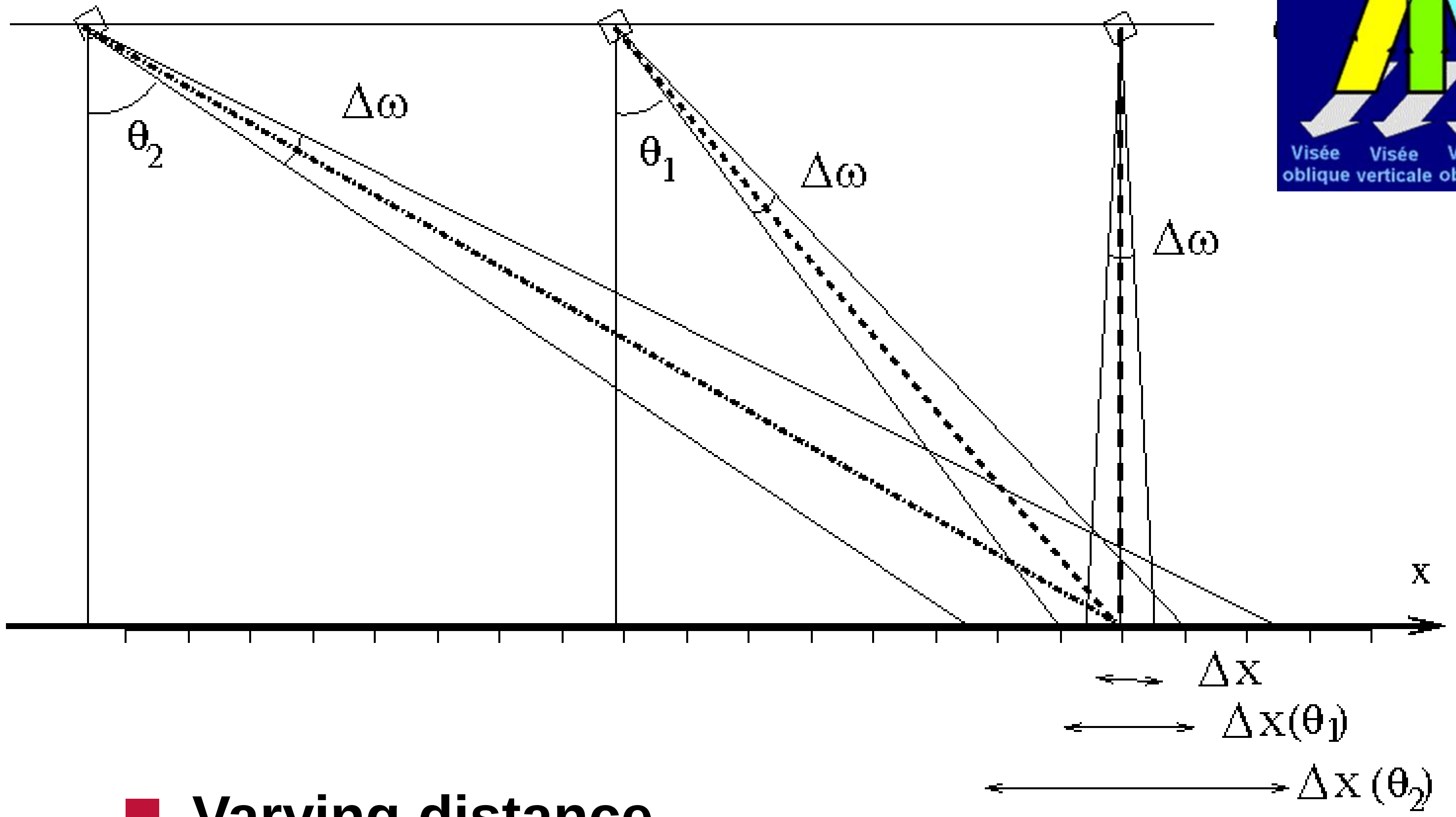
Optic – vertical viewing



$$\Delta x(H') = \frac{H'}{H}\Delta x(H)$$

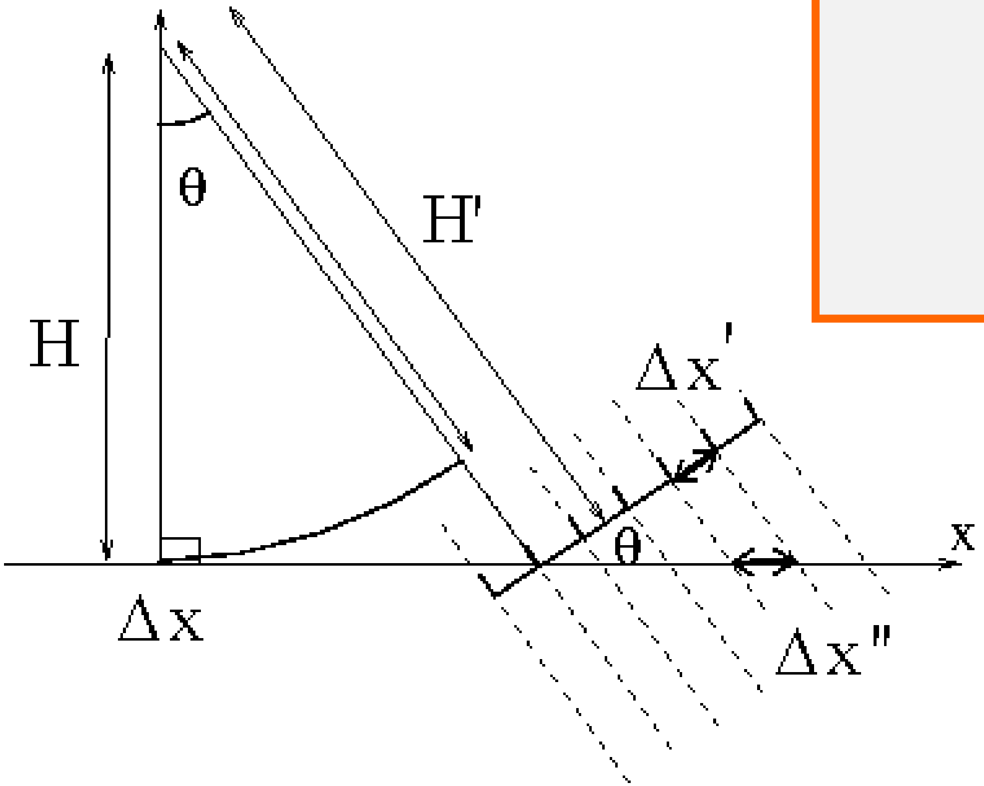
Lateral viewing
Angular step Δω





- Varying distance
- Varying local incidence

Optic – lateral viewing, flat earth



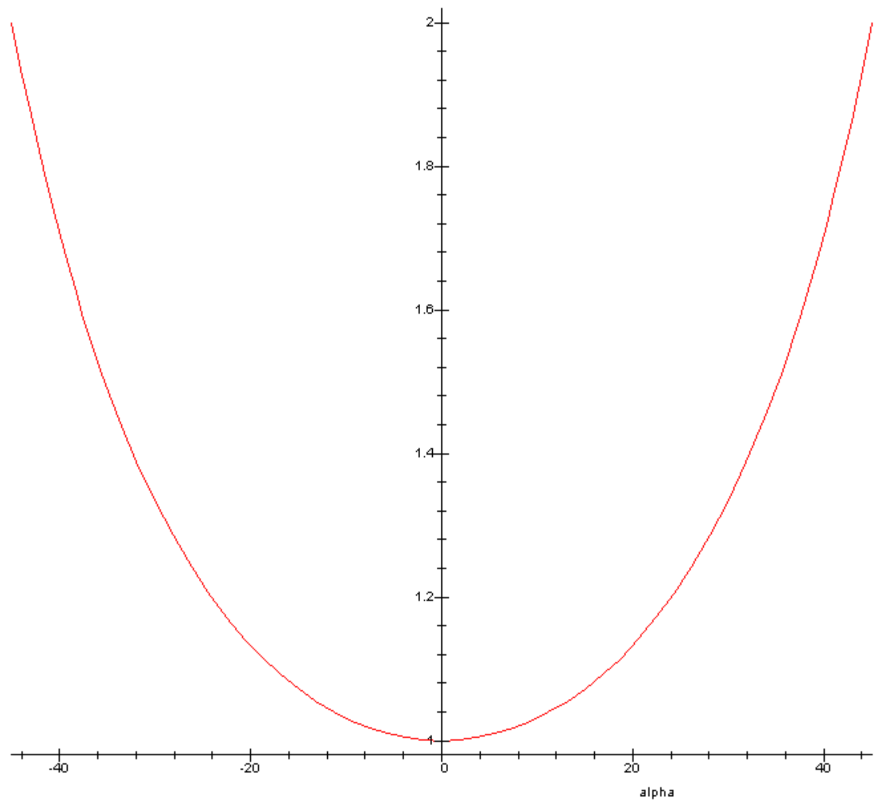
$$\Delta x(H',\theta) = \frac{\Delta x(H',\theta'=0°)}{\cos(\theta)}$$

$$= \Delta x(H,\theta'=0°)\frac{H'}{H}\frac{1}{\cos(\theta)}$$

$$= \Delta x(H,\theta'=0°)\left(\frac{1}{\cos(\theta)}\right)^2$$

Ikonos :
GSI from -45° to 45°

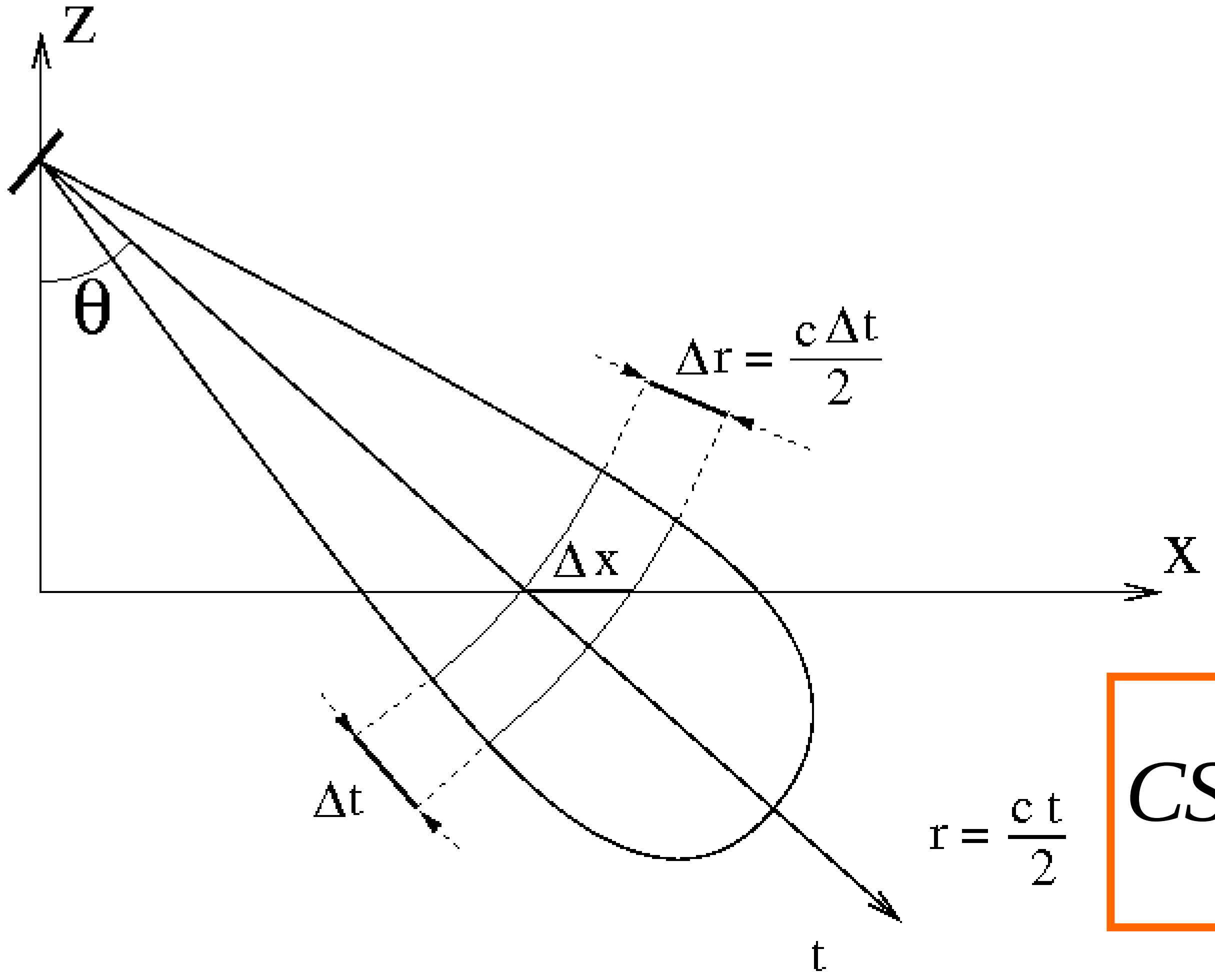
$$GSI(\theta) = GSI(0)\left(\frac{1}{\cos(\theta)}\right)^2$$



1m to 2m

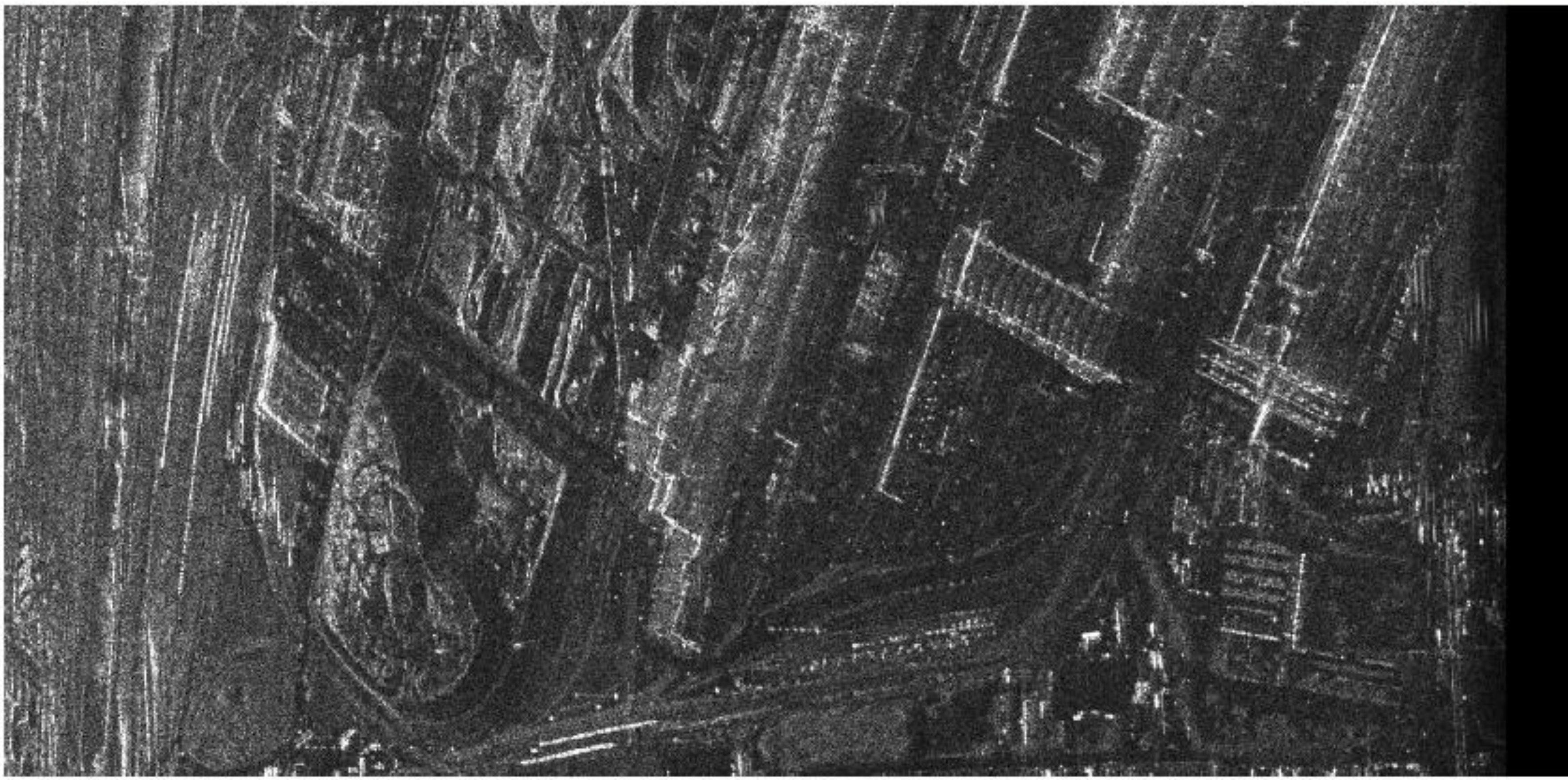
WARNING : flat earth hypothesis

Radar: lateral viewing

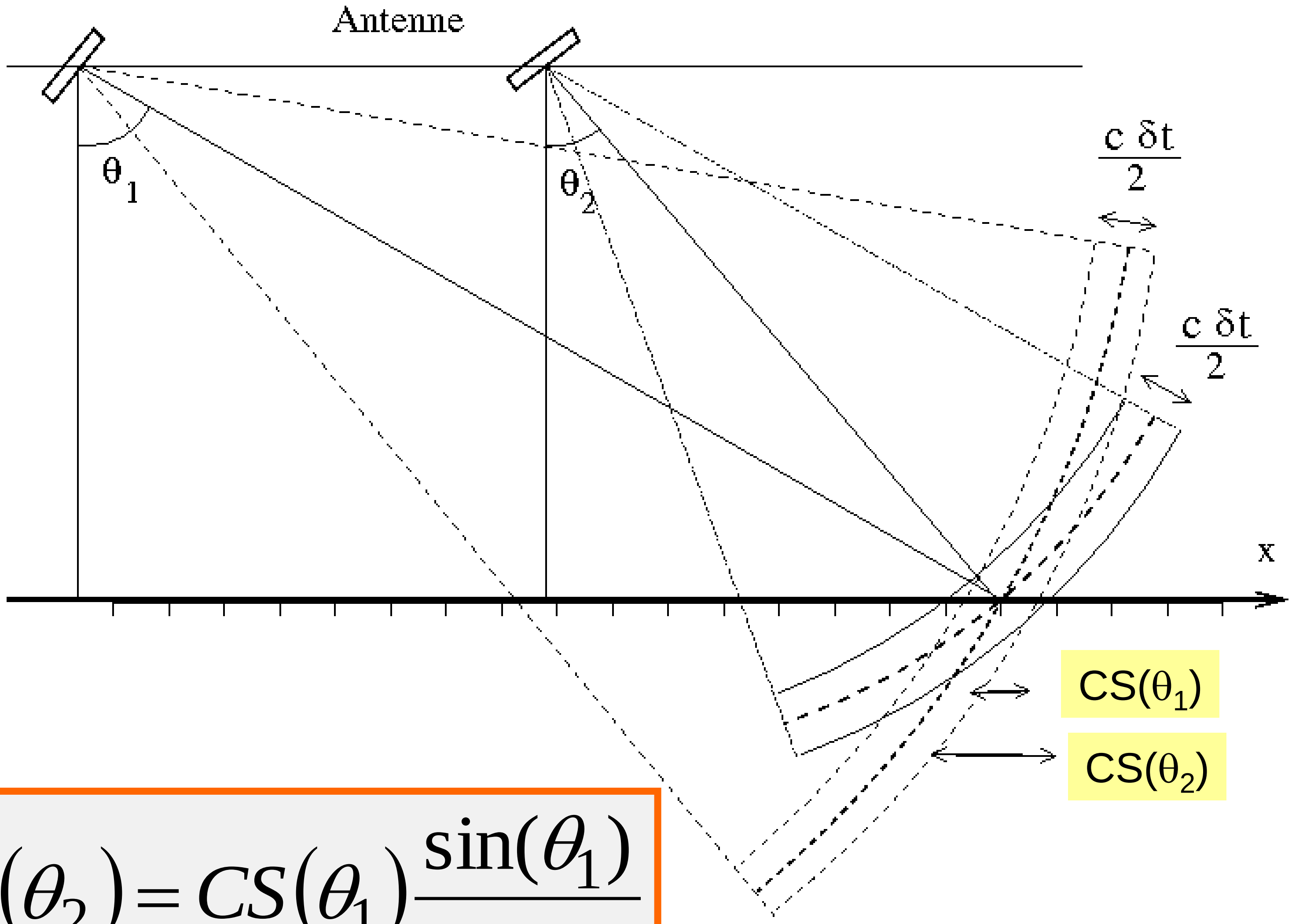


$$CS = \Delta x = \frac{\Delta r}{\sin(\theta)}$$

θ=6°, dx θ=60°, dx/10

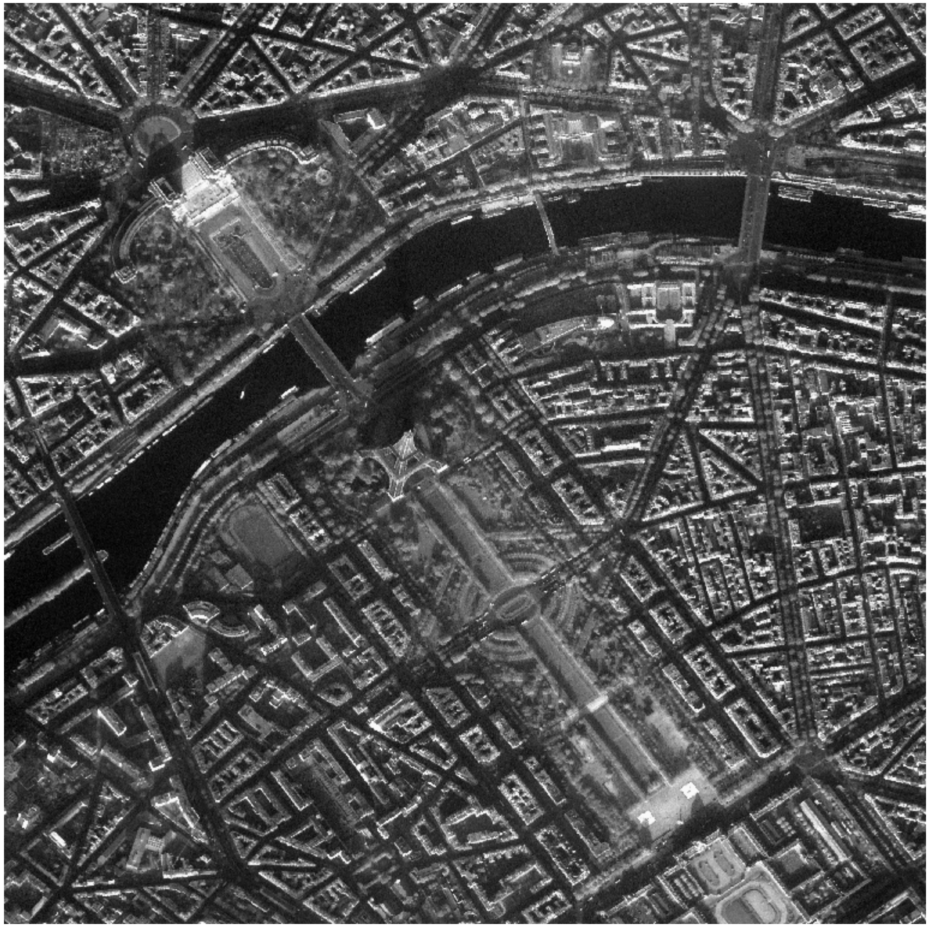


Variation of the ground cell with the local incidence angle



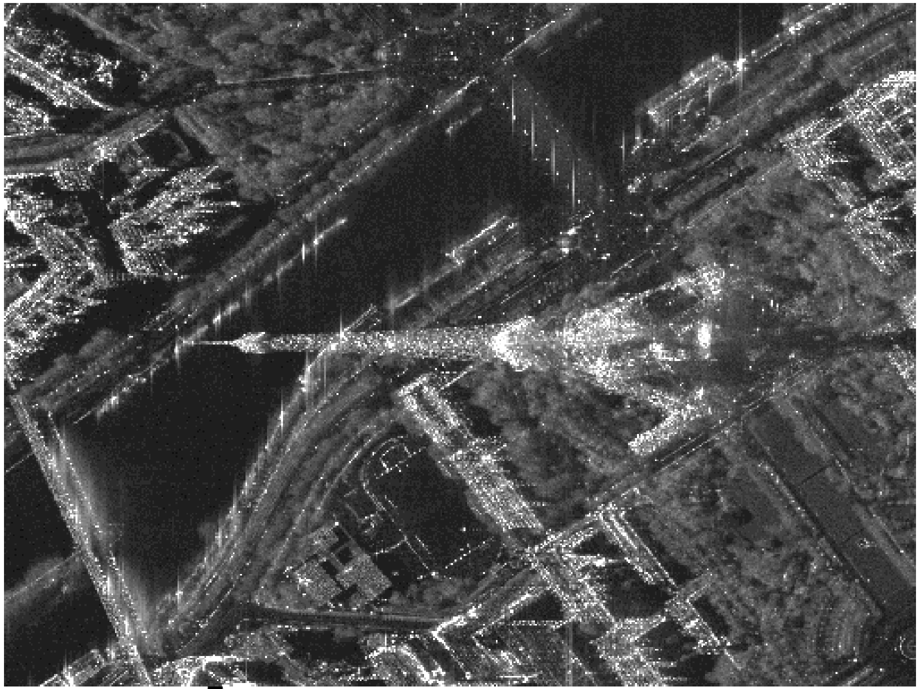
$$CS(\theta_2) = CS(\theta_1)\frac{\sin(\theta_1)}{\sin(\theta_2)}$$

Eiffel Tower – effect of lateral viewing



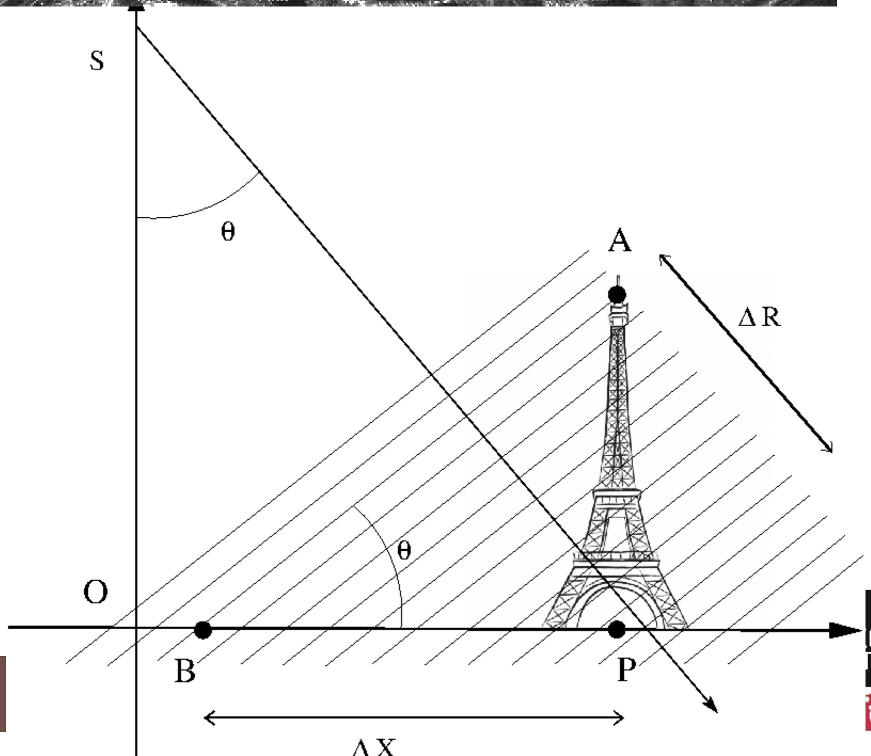
Visée latérale

- **Terrasar-X, θ~34°**

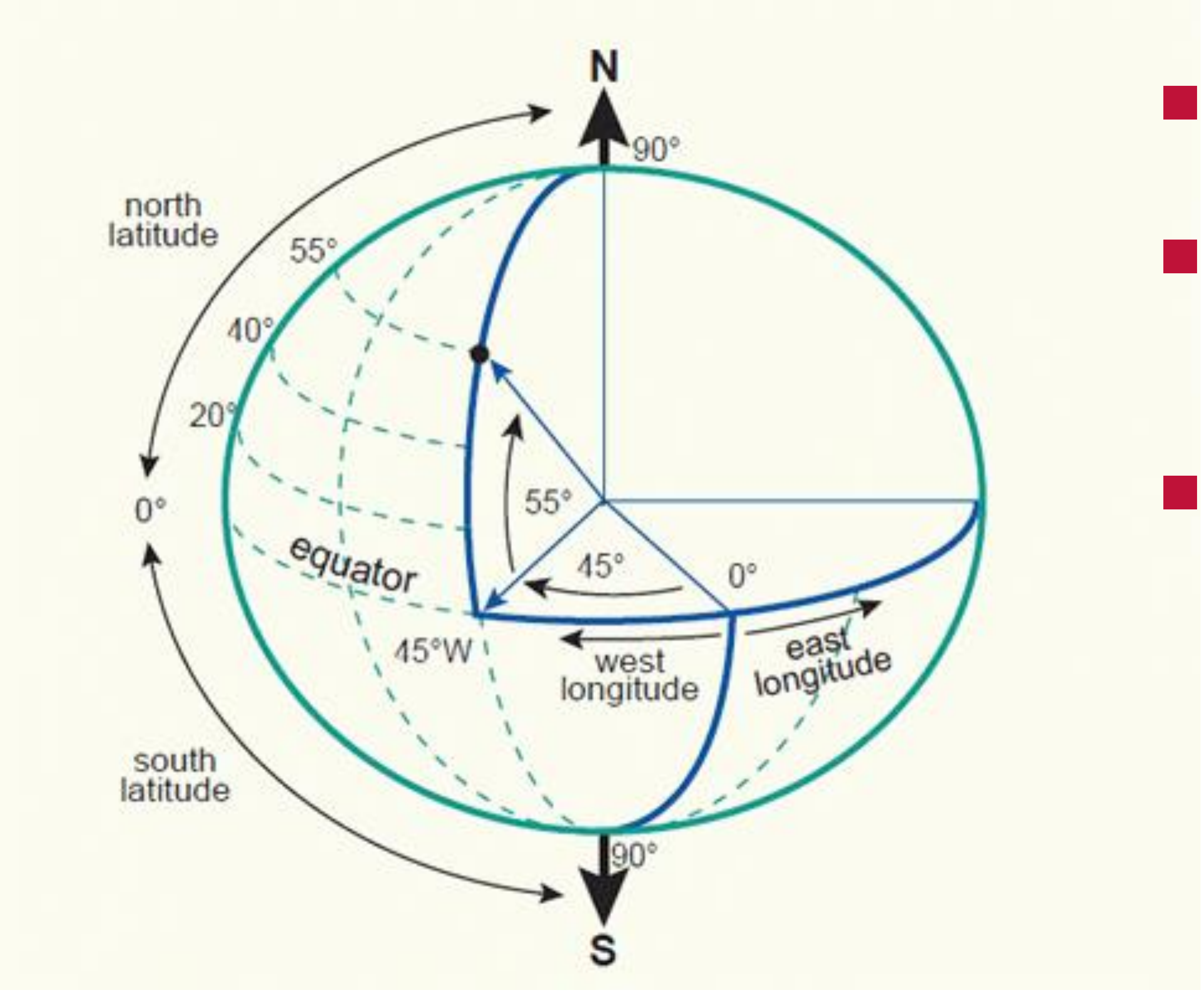


$$H = \frac{\Delta X}{\tan\theta}$$

$$H = \frac{\Delta R}{\cos\theta}$$

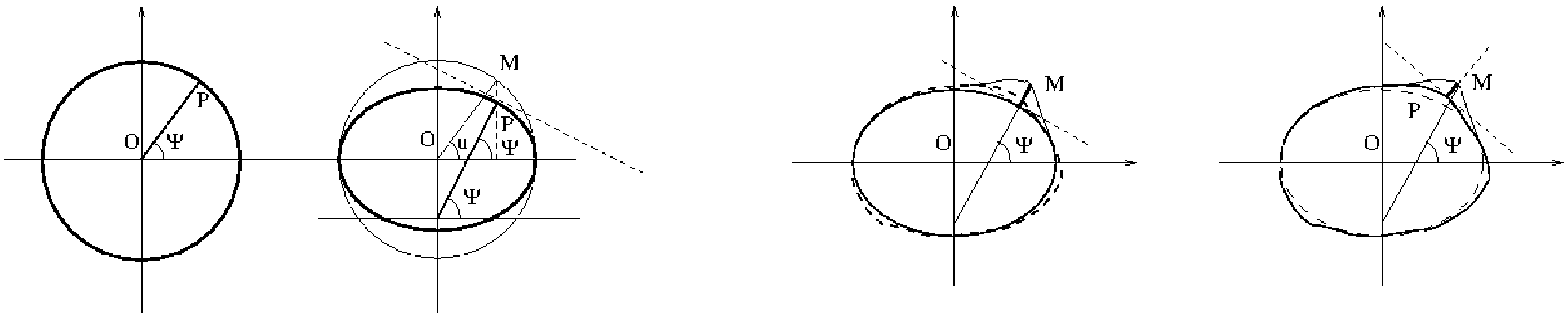


Geographic coordinate system

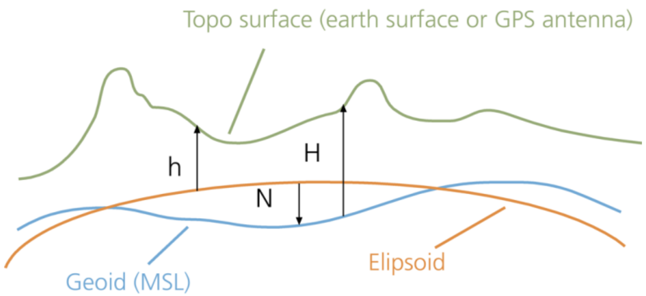


- **Choice of an eliposoid**
- **A point is defined by**
  - Longitude
  - Latitude
- **Altitude: h ?**

Coordinate of a point on earth (X,Y,Z) : Longitude, latitude, altitude



h=H+N



h=elipsoid height
H=orthometric height
N=geoid height

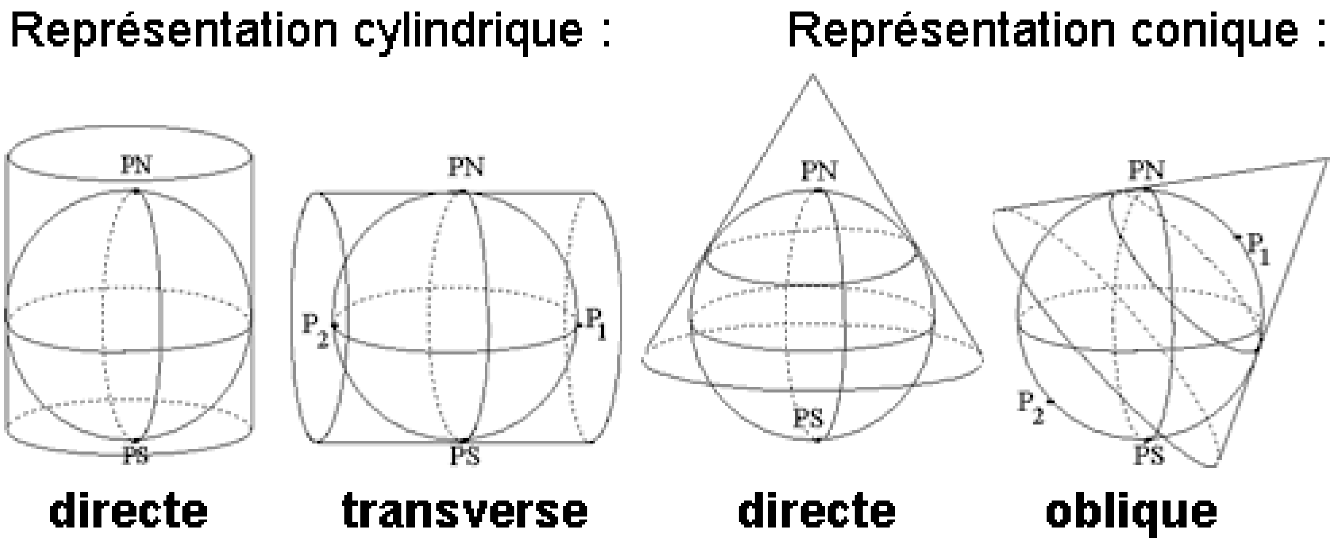
Ellipsoid / geoid

Different altitude definitions :

- orthometric height (H) = the height above an imaginary surface called the geoid, which is determined by the earth's gravity and approximated by MSL (Mean Sea Level)
- GPS = height (h) above the reference ellipsoid that approximates the earth's surface.

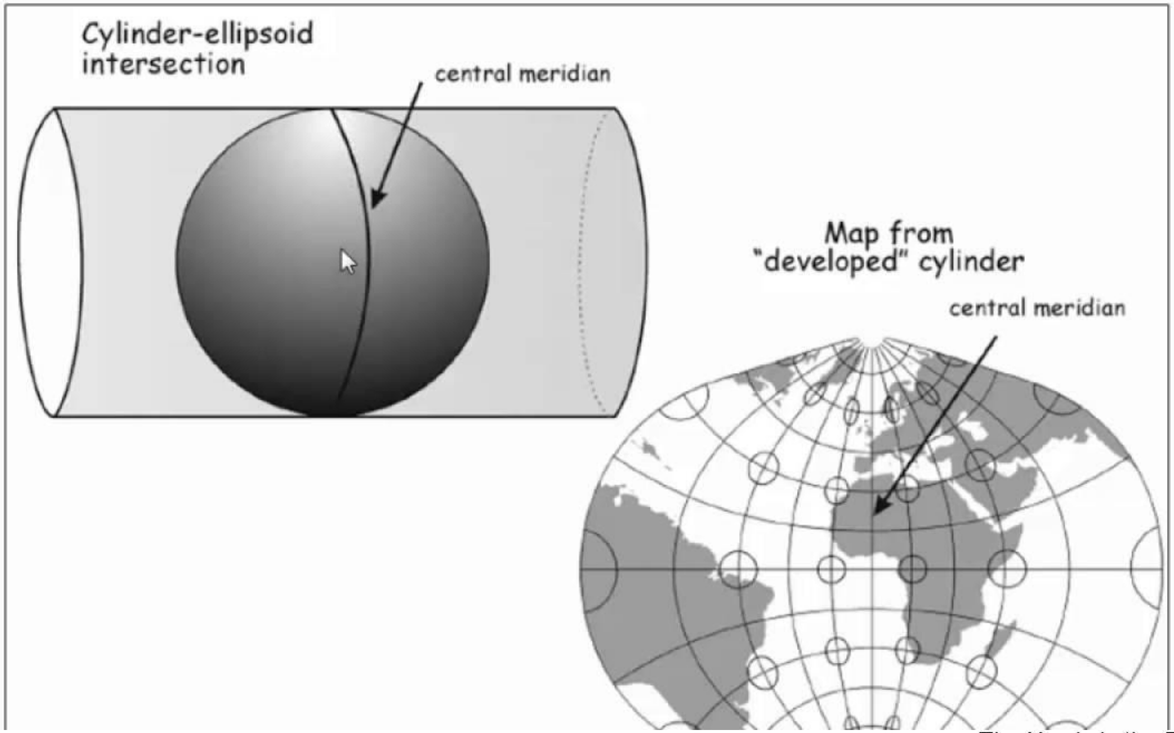
From earth to map

- « modeling of the earth surface »

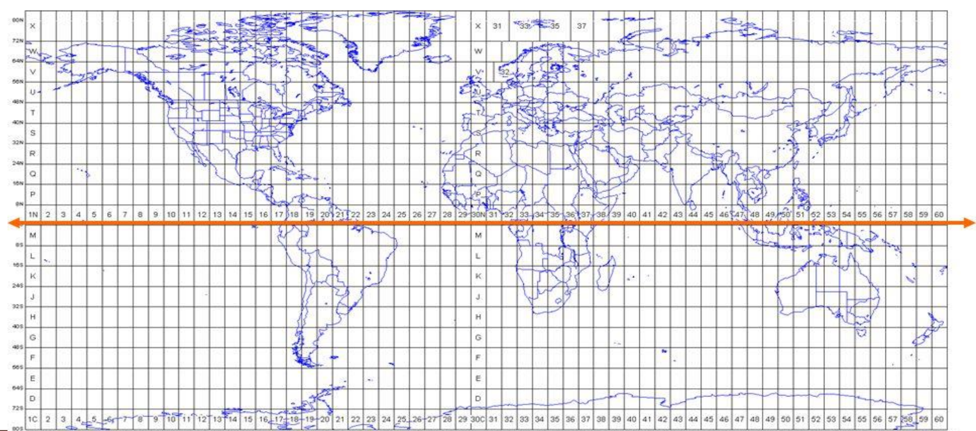


- Two main projection families:
  - UTM : Universal Traverse Mercator Projection
  - Lambert : Conformal Conic Projection

-Unroll cylinder to make flat map



ses a "flat earth," model and is
own below.
The X axis is the Equator, and there is a different Y axis for each zone.



Converting image positions to cartographic coordinates

- **Product levels**
  - Level 1 or 2 (depend on the data provider) for georeferenced data
- **Softwares for data conversion**
  - GDAL, NEST (ESA)
  - May need a Digital Terrain Model
  - Chosen geoid is often IAG GRS 80 with terrestrial reference system WGS84

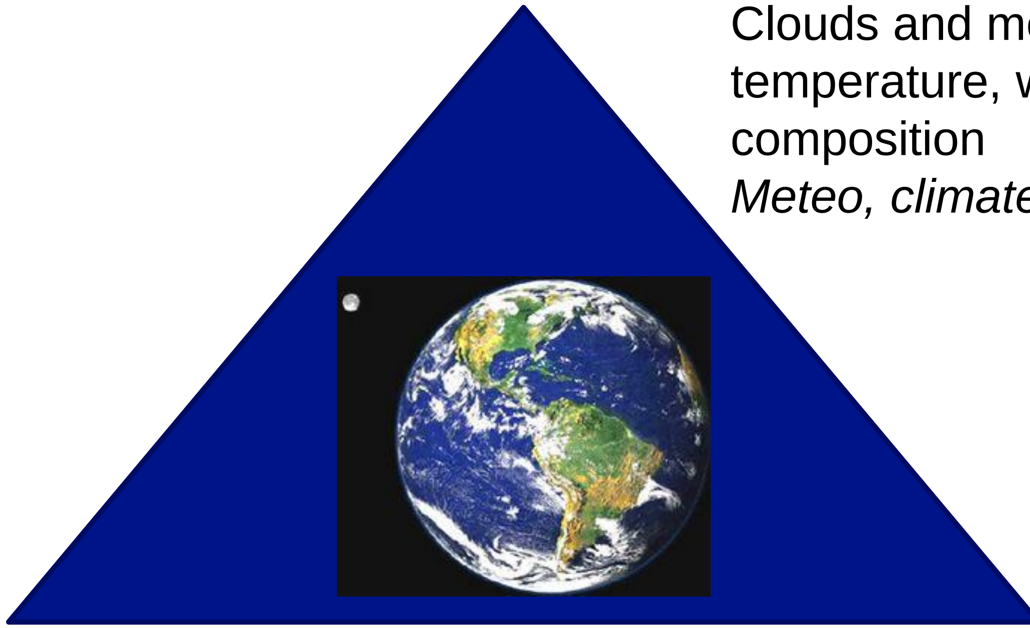
Overview of the course

- Short history of remote sensing
- Satellites and orbites
- Imaging systems
- Applications

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

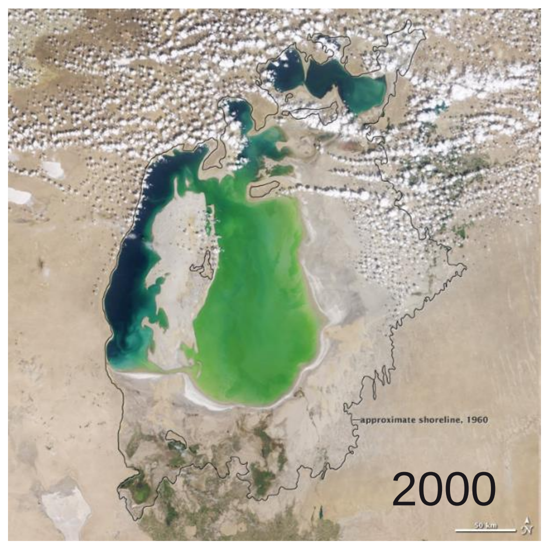
Urban and land use, topography
Emergency reponse, land or urban mapping and monitoring

LAND applications

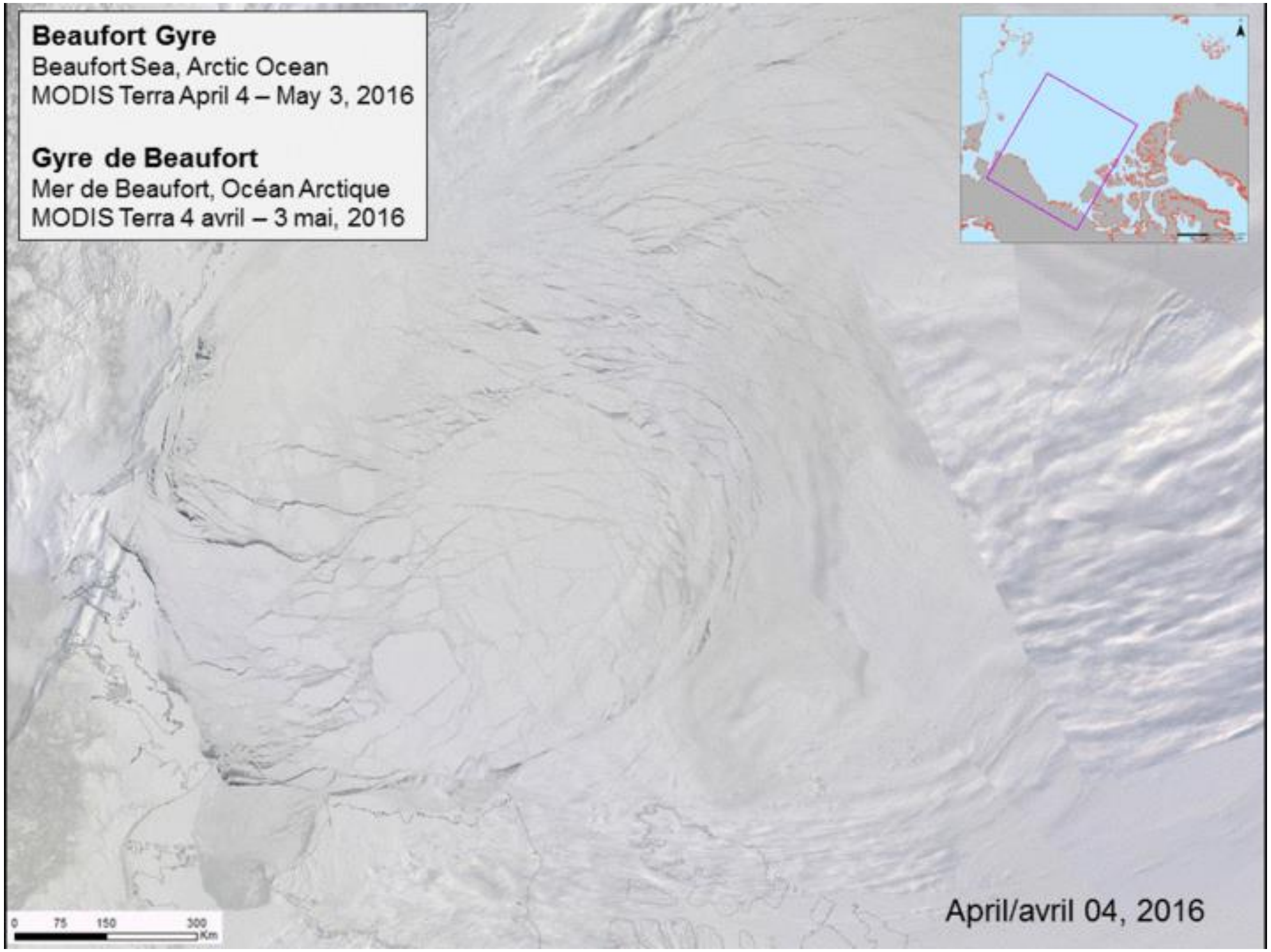
- **Environmental applications**
  - Vegetation and hydrology survey
  - Agriculture monitoring
  - Urban monitoring
  - Snow / glacier monitoring
  - DTM / DSM
- **Security applications**
  - Ground movement monitoring
  - Disaster management
- **Defense applications**
  - Land survey
  - Activity area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

Environment monitoring

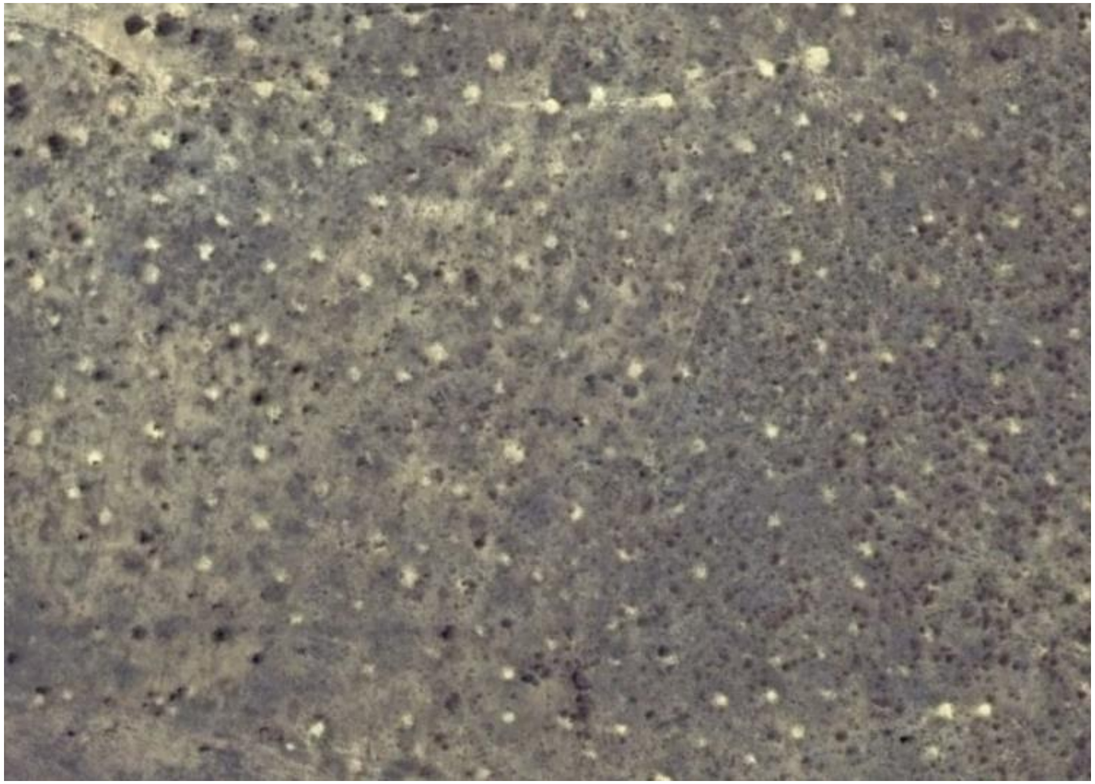
50 km



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



Regional analysis, metric optic images
Termite's mount in Brazil

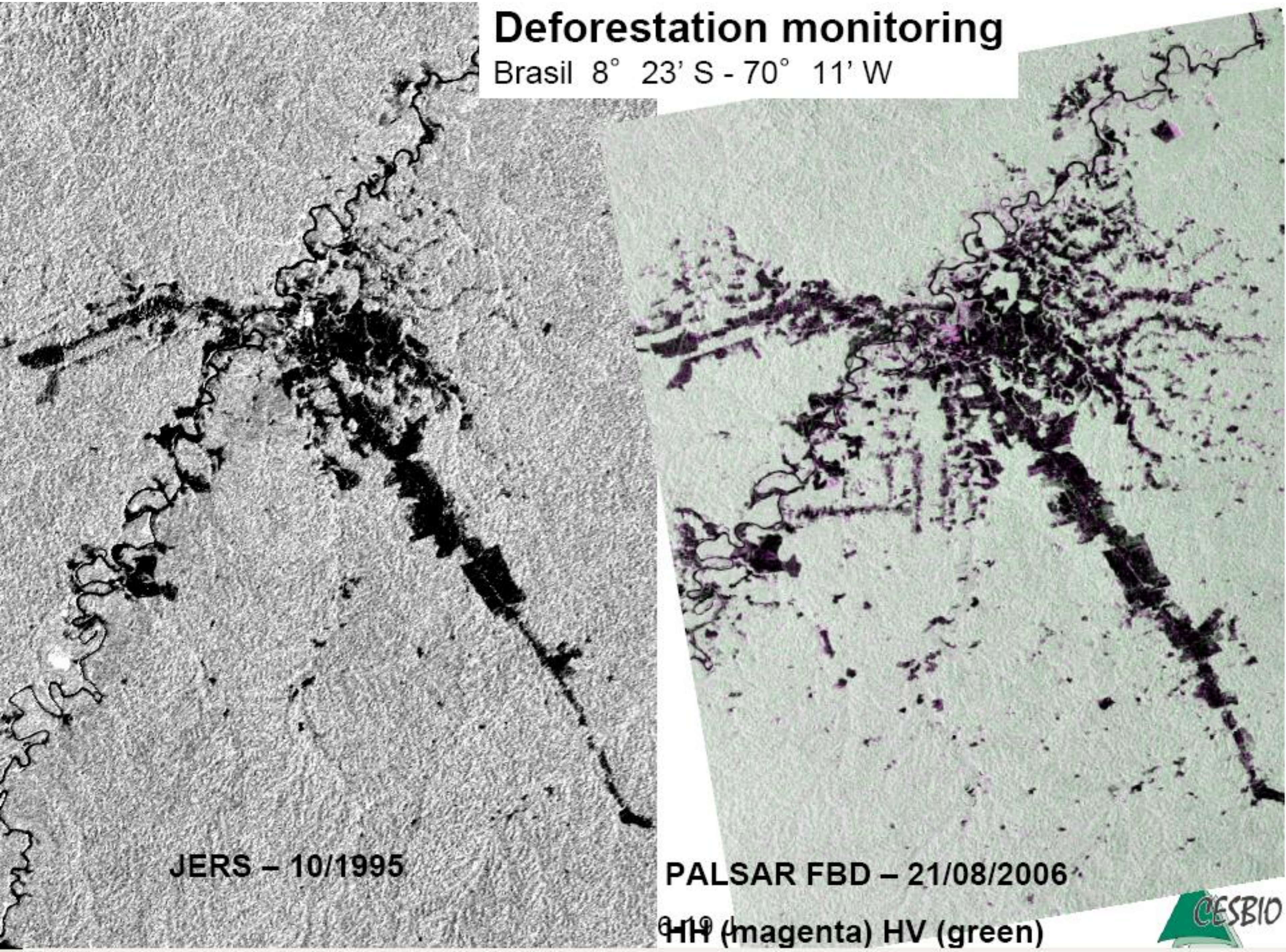


~1 km^2

- **Total area: 230 000 km^2 (~Great Britain)**

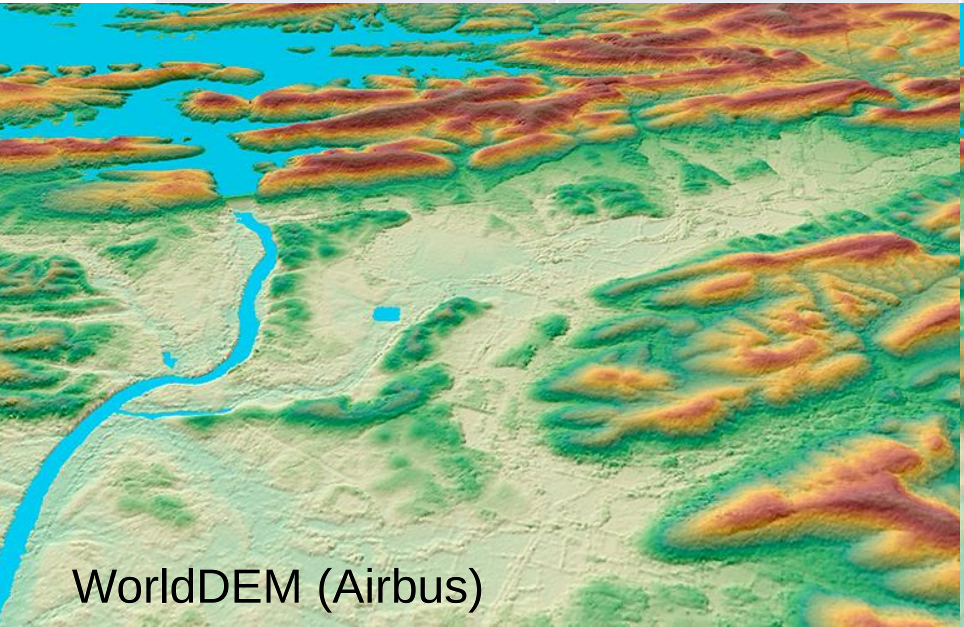
Deforestation monitoring

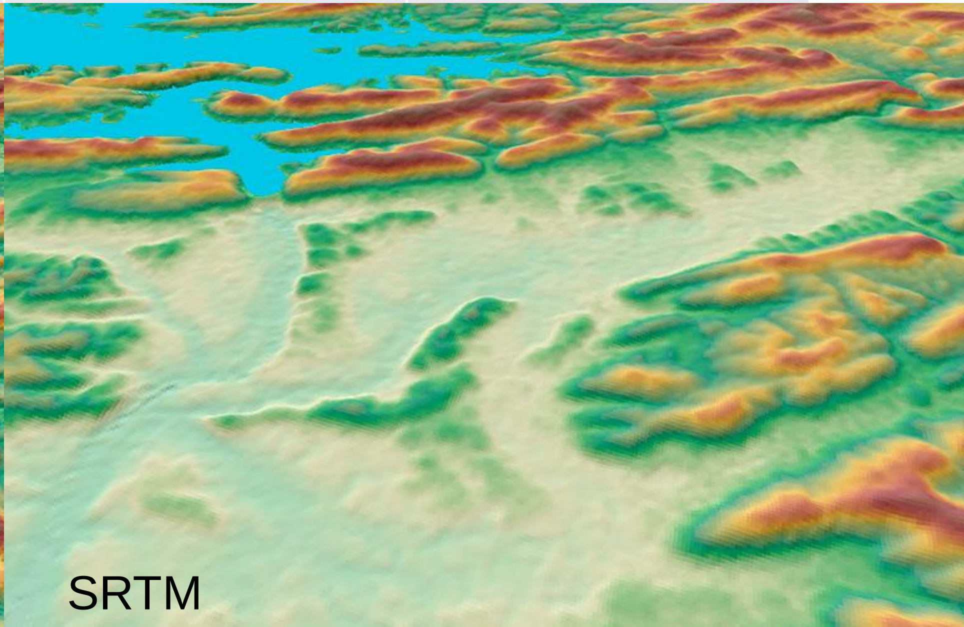
Brasil 8° 23' S - 70° 11' W



Reconstruction 3D - MNT

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.





Subsidences by radar interferometry: ERS-1

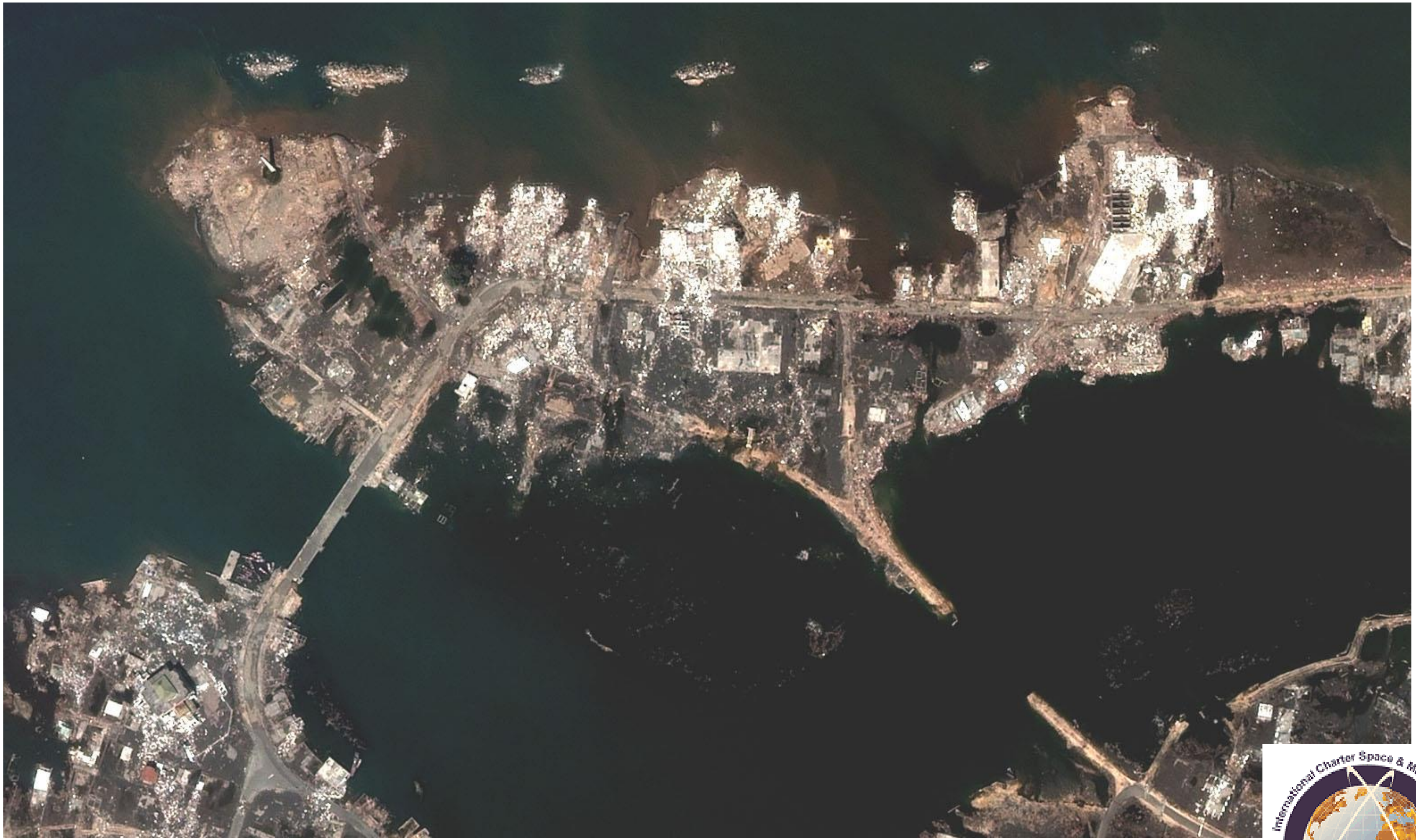
Pomona subsidence: animation of Politechnico di Milano

Image Orbview3
©DigitalGlobe

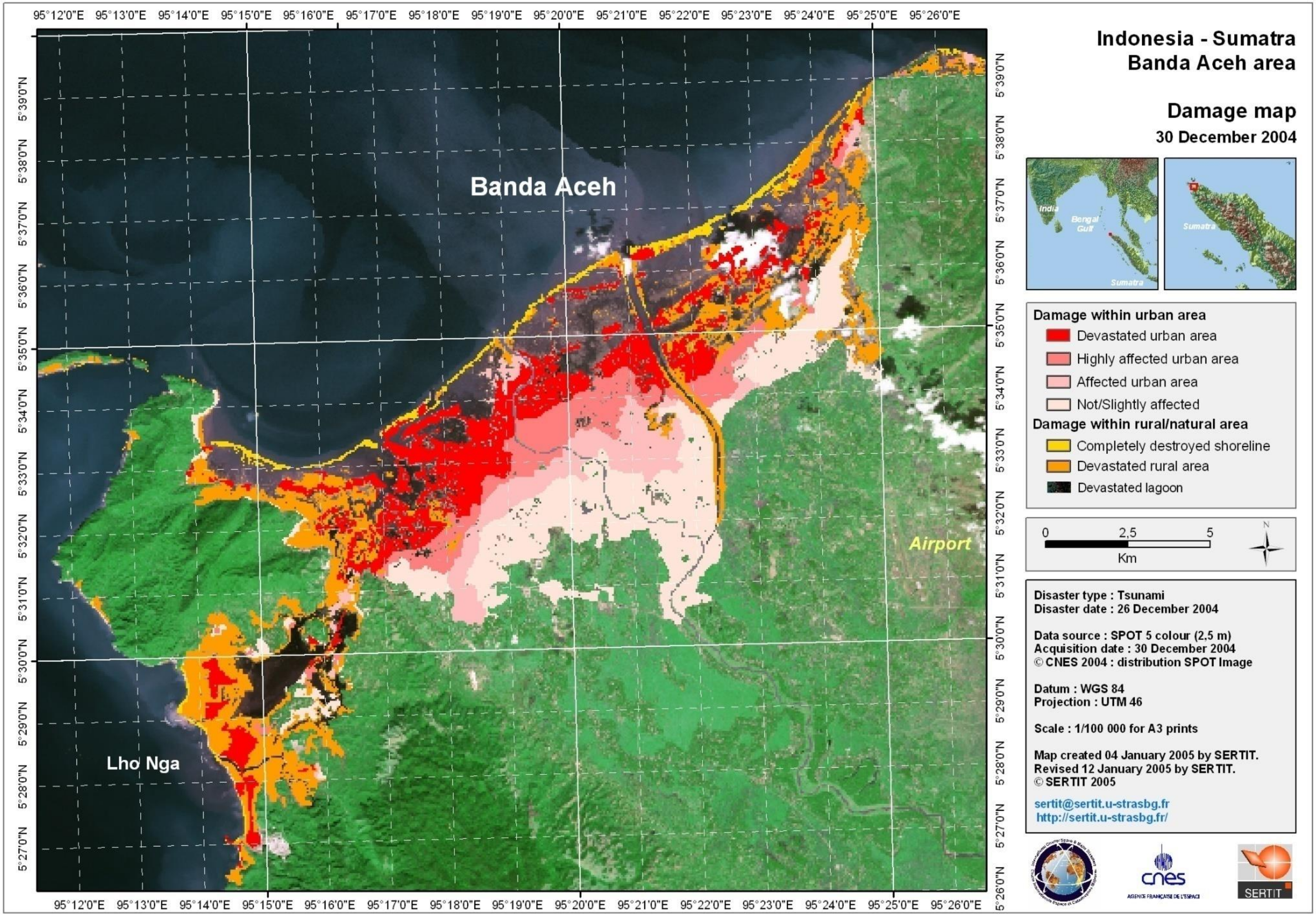
Banda Aceh, summer 2004

Image Orbview3
©DigitalGlobe

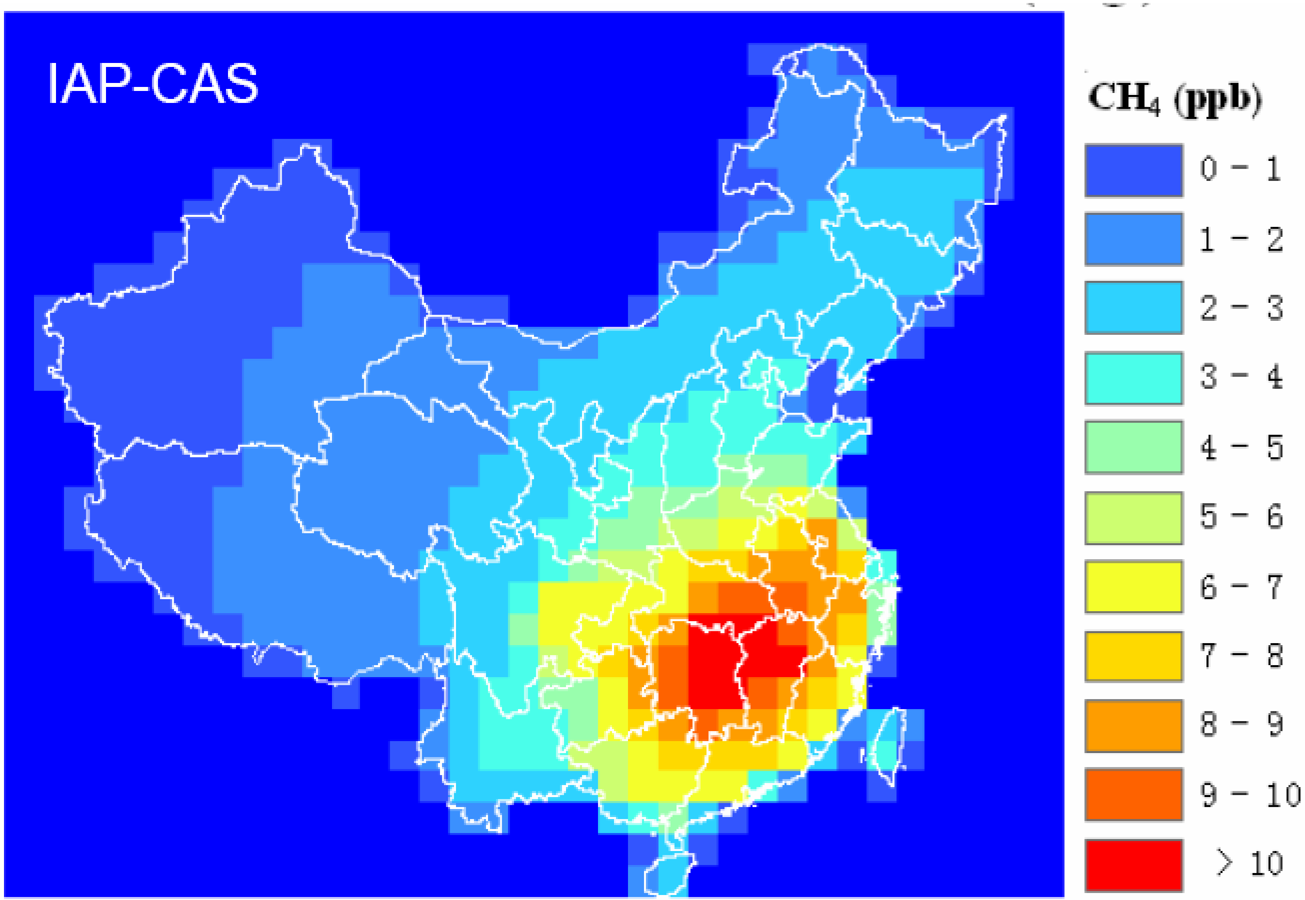
Banda Aceh le 28 décembre 2004



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


Indonesia - Sumatra
Banda Aceh area
Damage map
30 December 2004
Banda Aceh
Airport
Lho Nga
India
Bengal Gulf
Sumatra
Sumatra
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
N
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/
cnes
SERTIT

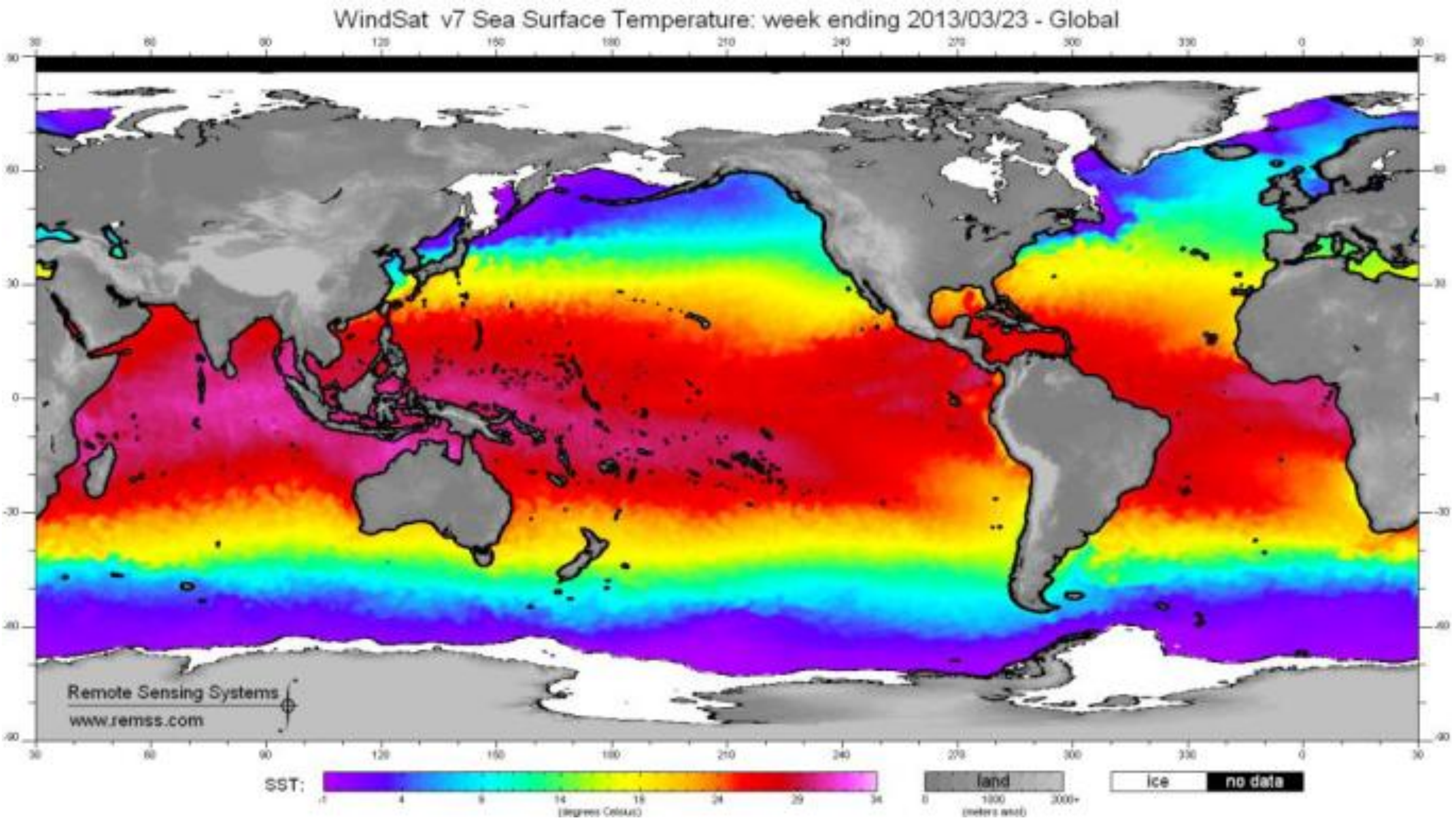
Methane map on China
Linked to rice production

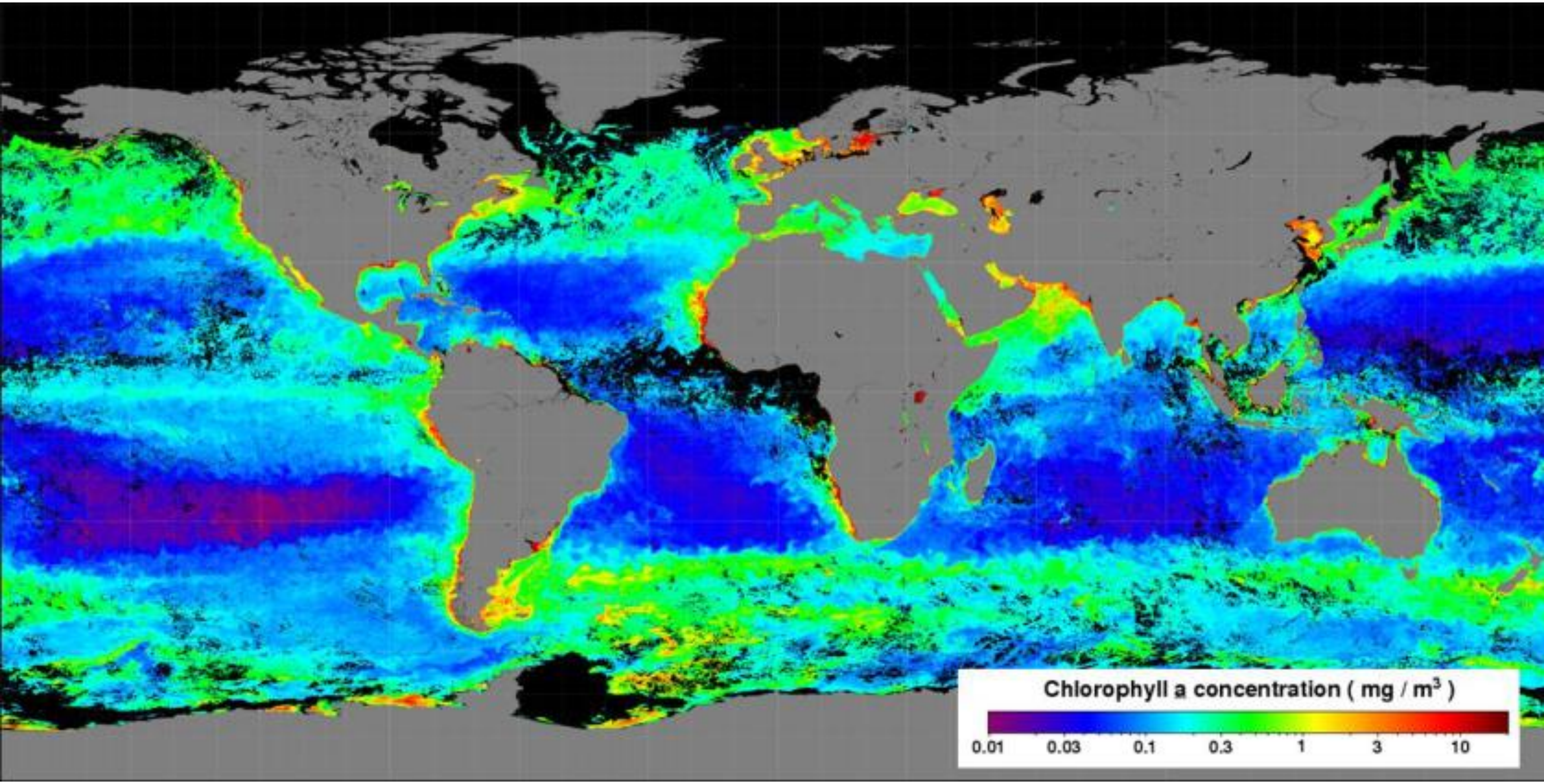


OCEAN applications

- **Oean survey**
  - temperature
  - color
  - tides,
  - sea levels

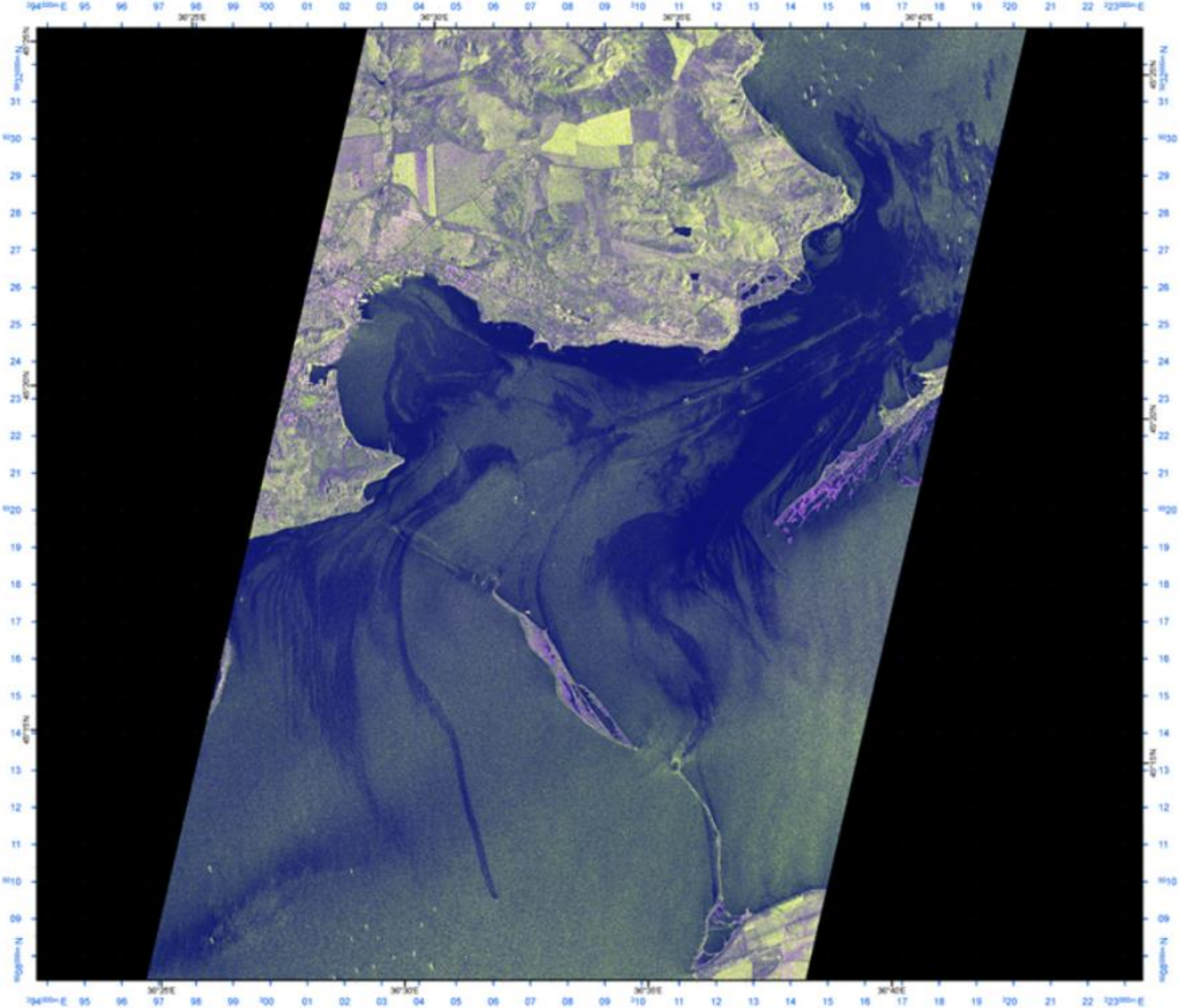
Ocean survey, climate change, pollution


WindSat v7 Sea Surface Temperature: week ending 2013/03/23 - Global
Remote Sensing Systems
www.remss.com
SST:
land
ice
no data


Chlorophyll a concentration (mg / m³)
0.01
0.03
0.1
0.3
1
3
10

Eastern Crimea (Ukraine) - Oil Spills

infoterra
an EADS Astrium company



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

TerraSAR-X SERVICES

TELECOM ParisTech