Space Based Radar in Europe

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June 14th, 2016

SPACE BASED RADAR: A SECRET START

21/12/1964: Quill (P-40), NRO experimental satellite of Corona Program. 1st SAR in orbit (all weather all time imaging) **Due to the poor quality, images were considered useless and the program was discontinued** (**secret until 9 July 2012**)

RADAR ALTIMETRY: A NEW START IN 1973

14/5/1973 Skylab: mission included **S-193**, NASA & DoD experimental multimode instrument, including technology test of **Radar Altimetry** at 13,9 GHz. Positive results.

9/4/1975 Geodynamics Experimental Ocean Satellite (**GEOS-3**) : First satellite totally dedicated to radar altimetry (13,9 GHz, height accuracy=20 cm). Unexpected result: evaluation of surface wind speed from RA data

27/6/1978:**Seasat**, 3 out of 5 instruments were radar: Radar Altimeter: f.o. of GEOS-3, (Ku-band, accur. 10cm)Scatterometer and the **"first official" Synthetic Aperture Radar (SAR)** (L-band, Res. 25m)

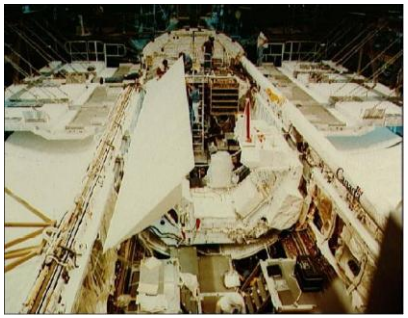
Quil

Seasat

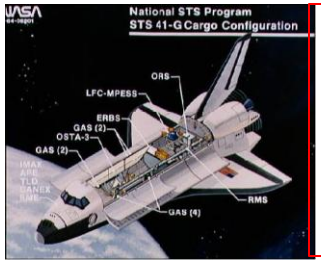
Figure 1: Seasat image of Los Angeles obtained July 21, 1978. Processed by ASF April 2013.

1981, 1984: SPACE SHUTTLE, A NEW OPPORTUNITY FOR EARTH OBSERVATION

Apr. 12, 1981: Inaugural flight of the **Space Shuttle**.
Nov. 12-14, 1981: **OSTA-1**,(***Office of Space and Terrestrial Applications)*** comprised the first ***Shuttle Imaging Radar A*** (**SIR-A**). L band, resolution40x40 m, fixed look angle 47°, swath width 50 km, based on Seasat design, and using its spare parts as well as spare parts of other NASA missions (other 4 instruments were different passive sensors in VIS-IR)



(NASA/JPL)

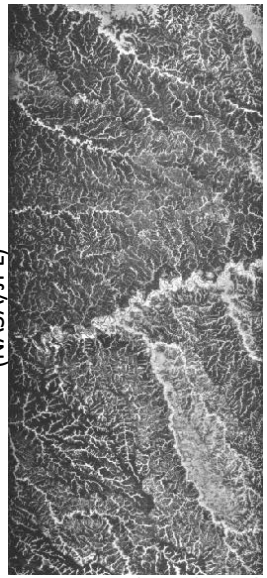


Oct. 5-13, 1984: **OSTA-3**, ***Shuttle Imaging Radar–B*** (**SIR-B**). Upgraded SIR-A, L band, resolution 30-20m (azimuth), 58-16m (range), variable look angle 15°-65°, swath width 50 km.

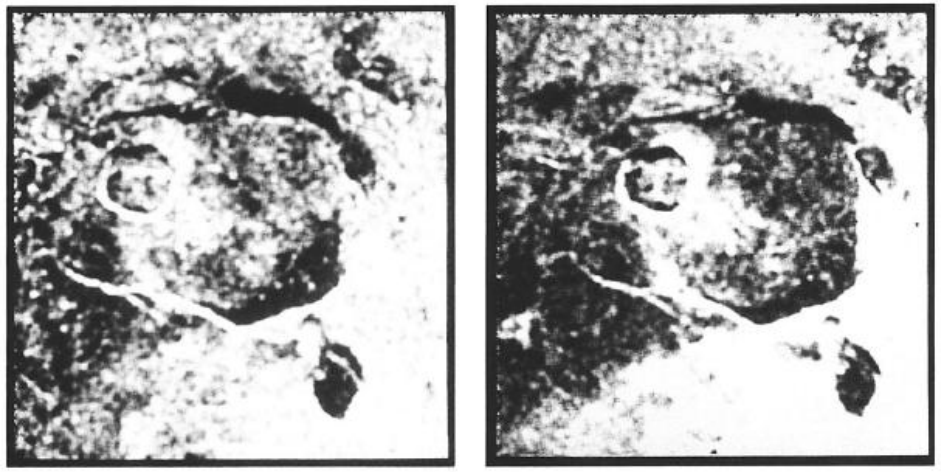
(NASA/JPL)

Landsat vs. SIR-A

(NASA/JPL)



East-central Colombia



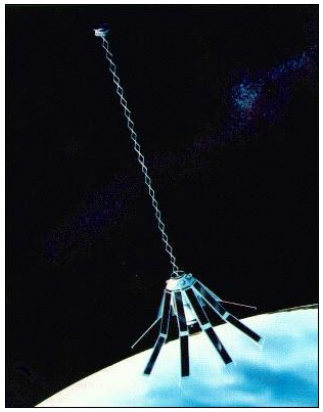
A B

Figure 15. Smoothed SIR-B images of Kilauea Caldera at incidence angles of (A) 28° and (B) 48°. These images were derived using a 7×7–pixel moving window within which the mean pixel value is calculated and substituted for the value of the center pixel.

1983-1991: THE PRIORITY OF DEFENSE

USA policy of national systems for Remote Sensing was focused on Defense needs

Radar Altimetry for Oceanography(US Navy):
• 13/3/1985: **GEOSAT** (GEOdynamic SATellite), classified data passed also to NOAA. Developed by ***JHU/APL***.
• 12/2/1998 **GFO** (Geosat Follow On). Height accuracy <5cm. Developed by ***Raytheon***



GEOSAT (NOAA/JHU/APL)

GFO (Ball Aerospace)

SAR for imaging of Earth surface (NRO):
• **Lacrosse/Onyx**: 5 launches (1988, 1991, 1997, 2000, 2005). No technical or performance information released. 2 orbital inclinations. Developed by Martin Marietta (then ***Lockheed Martin***)
•**NROL-21** (2006): No information or images Developed by ***Lockheed Martin.*** (experimental?)
•**Topaz** (2010, 2012, 2013, 2016) No information or images . Developed by ***Boeing***

Lacrosse/Onix -1 under development (PD - NRO)

For civil application satellites the USA policy was open to collaborations

Space Based Radars in USSR

SLAR

28/9/**1983**: **Okean-OE#1,** first satellite of a series, embarking a low resolution **Side Looking Radar (SLAR)**. Followed by **Okean-OE#2** on 28/9/1984.

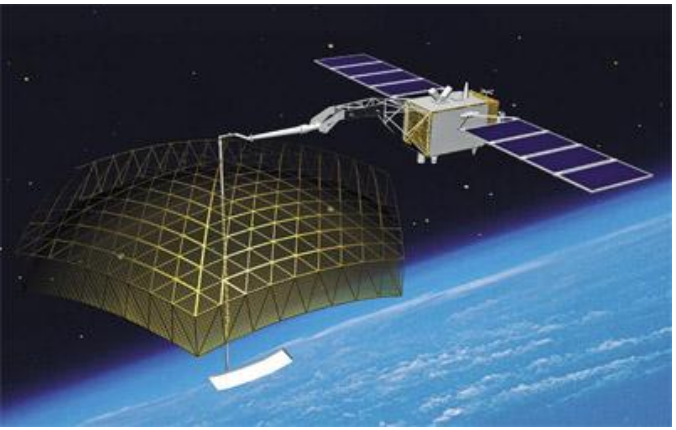
1986-1994: Okean-O1#1-8, initiated as URSS and evolved into a Russia/Ukraine joint program. Res.: 2,1-2,8 km x 1,2-0,7 km

The deployment of Russia/Ukraine SLAR (produced by ***Yuzhnoye***) satellites continued on **24/12/2004** with the launch of **Sich-1M** with the same performances


(Yuzhnoye)

SAR

29/11/1986 Cosmos 1803/*Almaz-T*:1st USSR **SAR** satellite (launch failure) It was followed on **25/7/1987 Cosmos 1870**: 1° successful USSR (resolution 20-25m).
31/3/1991 Almaz-1 (resolution of 10-15 m). Satellites developed by ***NPO Mashinostroyeniya***)



Next series of **SAR satellites** was developed by ***NPO Mashinostroyeniya*** for the **Russia Ministry of Defense.** The **S-band SAR** satellite **Cosmos 2487** (**Kondor #1**) was launched on **27/6/2013** (Resolutioon1-2 m/Spotlight, 1-3m/Stripmap, 5-30m/Scansar) It was followed by **Kondor-E #1** on 18/12/2014, originally developed for South Africa

END OF '70s: SCENARIO FOR SPACE BASED RADARS AND EUROPE START

USA: **Quill**, **Skylab S-193**, **GEOS-3**, **Seasat**

USSR: Possibly first studies or technology dev.

In some **European countries**: preliminary activities at national level to define missions/instruments and to pre-devolep technologies. In particular **France**, **Germany**, **Italy** and **UK**.

ESA: Preparation of ***Spacelab-1*** mission with a Remote Sensing payload
Start of *Remote Sensing Preparatory Program* (***RSPP***)

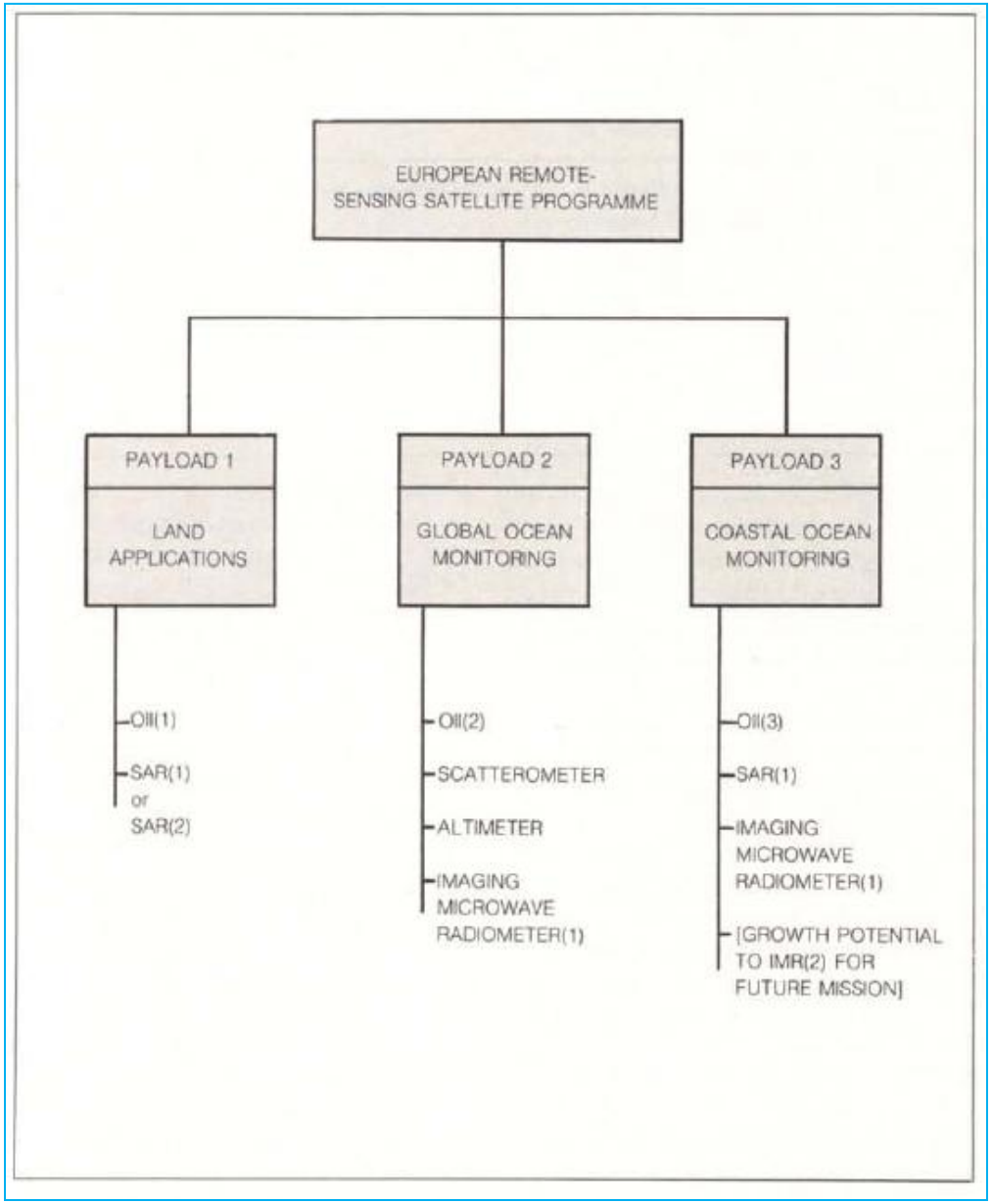
24/9/**1973**, Washington Dept. Of State: Signature of NASA/ESRO MOU on Spacelab as Shuttle lab.
5/**1976**: ESA/Germany Agreement for 1st Spacelab Payload managed and developed by DFVLR

1983: MRSE, THE FIRST EUROPEAN ATTEMP TO EXPERIMENT A RADAR IN SPACE

28/11/**1983**: **Spacelab-1** on board the **STS-9** (Columbia). The German Microwave Remote Sensing Instrument (**MRSE**) was an element of the payload, comprising 1 passive (microwave radiometer) and 2 active (Scatterometer and SAR) instruments.

MRSE Power Supply problem caused the mission unsuccess

THE STARTING POINT OF THE ESA REMOTE SENSING PROGRAMME



(ESA Bulletin 17, February 1979)

Three possible payload composition were considered for three possible mission scenarios:

- Land Applications
- Global Ocean Monitoring
- Coastal Ocean Monitoring

Waiting for the programme decisions:

March 1978: two parallel industrial Ph. A studies assigned to **Thomson CSF** (F) and **Marconi Research Laboratory** (UK) for a **C-band SAR**

May 1978: ITT for two Satellite System Ph.A Studies:

- **LASS** (Land Applications Satellite System) (KO August 31)
- **COMSS** (Coastal Ocean Monitoring Satellite System) (KO September 1)

Completed March1979

March 1979: start of **Remote Sensing Preparatory Programme** (**RSPP**) (ESA&Canada)

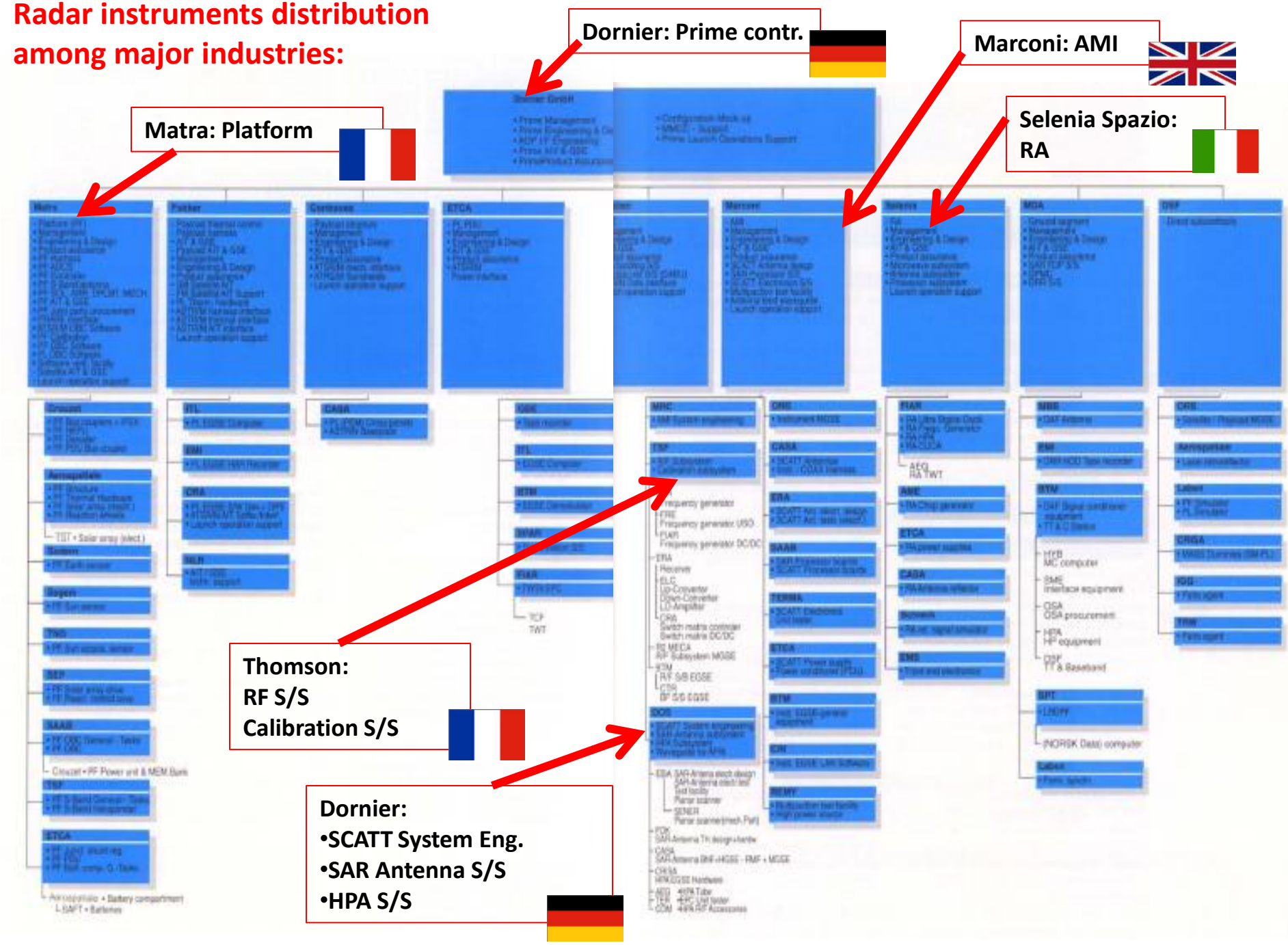
Two Ph. A studies for radar sensors:
• **Scatterometer**: assigned to **Dornier** (D), considering two options, Seasat-like and MRSE-like
•**Radar Altimeter** (Ku band): two parallel industrial Ph.A studies assigned to **Selenia Spazio** (I) and **SPAR** (CND).

•**SAR** Ph.A studies already completed in 1978 by **Thomson CSF** (F) and **Marconi Research Laboratory** (UK)

Program proposal for ERS-1 approved by PB-RS on 17/9/ 1981, enabling resolution agreed on 28/10/1981, dead line for signing the declaration 15/4/1982

1982 Start of the ERS-1 program: Ph. B assigned to Dornier (D) (now *Airbus Defense and Space*) as prime Contractor.

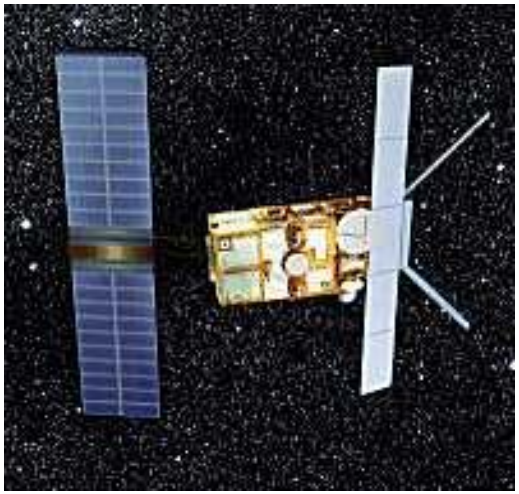
Radar instruments distribution among major industries:



November 1984: signature of ERS-1 Ph. C/D contract

Table 2. Radar Altimeter (RA) characteristics

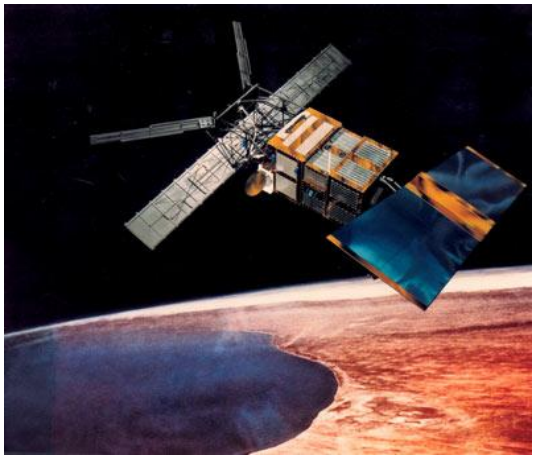
Frequency	13.8 GHz
Pulse length	20 μs
Pulse rept. frequency	1020 Hz
Chirp bandwidth	330 MHz (sea)
	82.5 MHz (ice)
Transmit power	55 W peak
Antenna diameter	1.2 m
Height noise	3 cm at 8 m wave height
Mass	96 kg
DC power	130 W



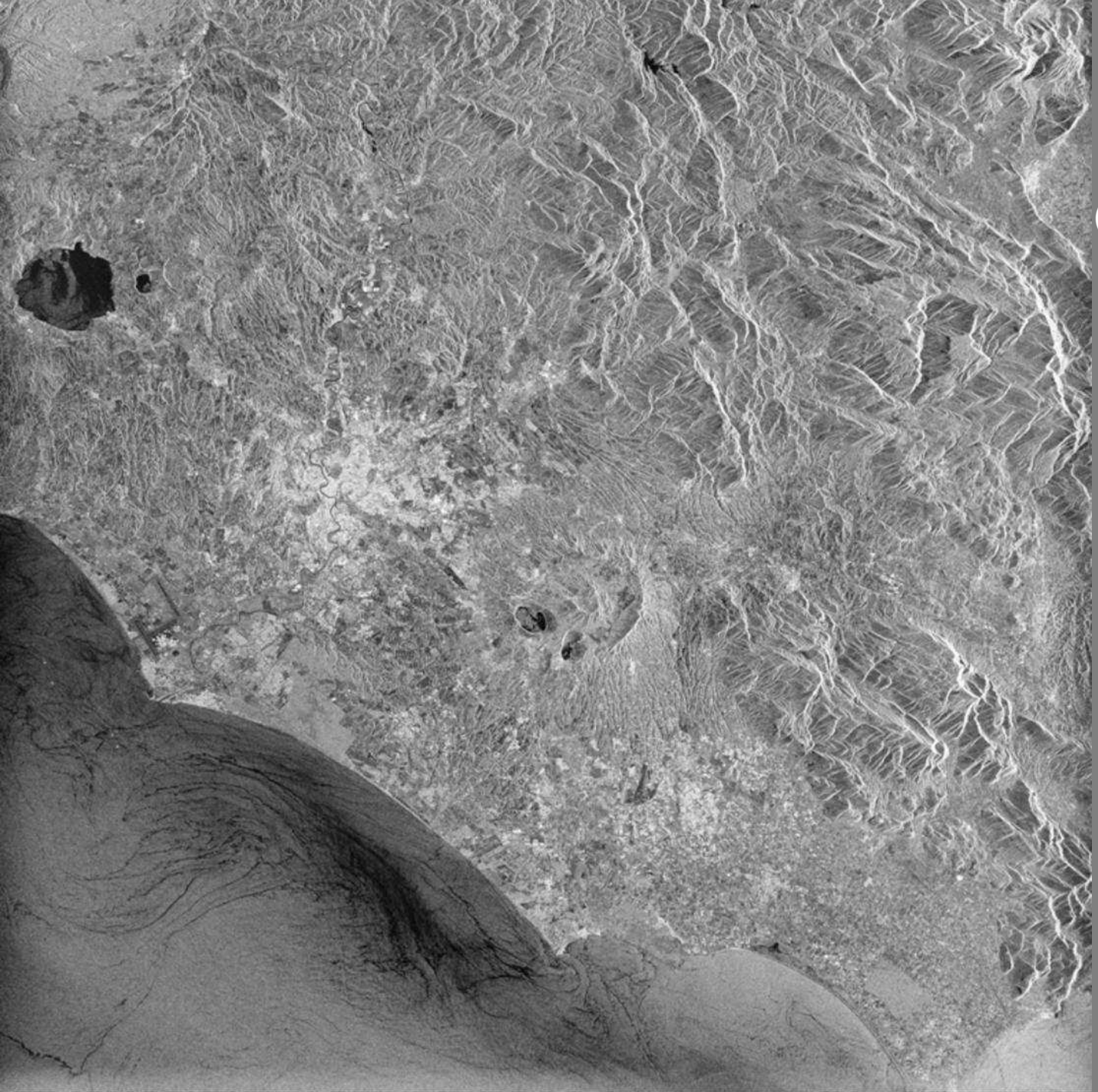
ERS-1: 17.7.1991 / 10.3.2010

AMI Image-Mode (SAR) Characteristics

Spatial resolution	30 m × 30 m
Radiometric resolution	2.5 dB at $\sigma_0 = -18$ dB
Swath stand-off	250 km to the side of the orbital track
Swath width	100 km
Incidence angle	23° at mid-swath
Frequency	5.3 GHz (C-band)
Data rate	<105 Mbit/s



ERS-2: 21.4.1995 / 4.7.2011



July 4th, 2011
(20 years from ERS-1 launch)

ERS-2
Last Image

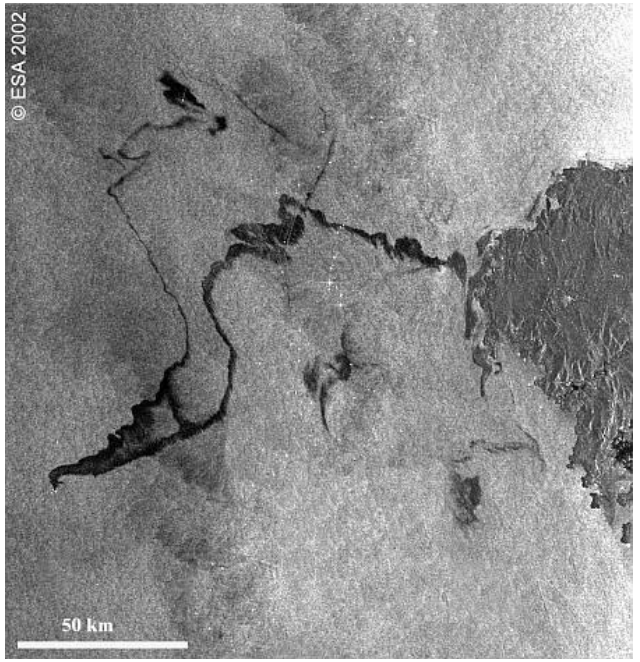
ROME

FROM COLUMBUS TO ENVISAT (launched 1/3/2002)

1985: ESA BoD approval of the Columbus Programme (European participation to the NASA Space Station Freedom). It includes Polar Platform (**PPF**) for Earth Observation (servicedable by the Hermes)., to be firstly used for Polar Orbiting Earth Observation Mission (**POEM-1**). **12/1993** ESA Ministerial Council Meeting: POEM-1 is split into **Envisat** (environment) and **METOP-1** (meteorology). **July 1995: Envisat contract for ph.C/D**

An important set of instruments, among which two 2nd generation radar: **RA-2** (Radar Altimeter 2) and **ASAR** (Advanced Synthetic Aperture Radar).

RA-2: Nadir looking radar operating in the K_u and S bands to correct the effects of ionosphere propagation
ASAR: full active array antenna (pointing and swath flexibility) and digital "chirp" generation.
Accuracy: Image, Wave and Alternating Polarisation modes: approx 30m x 30m. Wide Swath mode: approx 150m x 150m

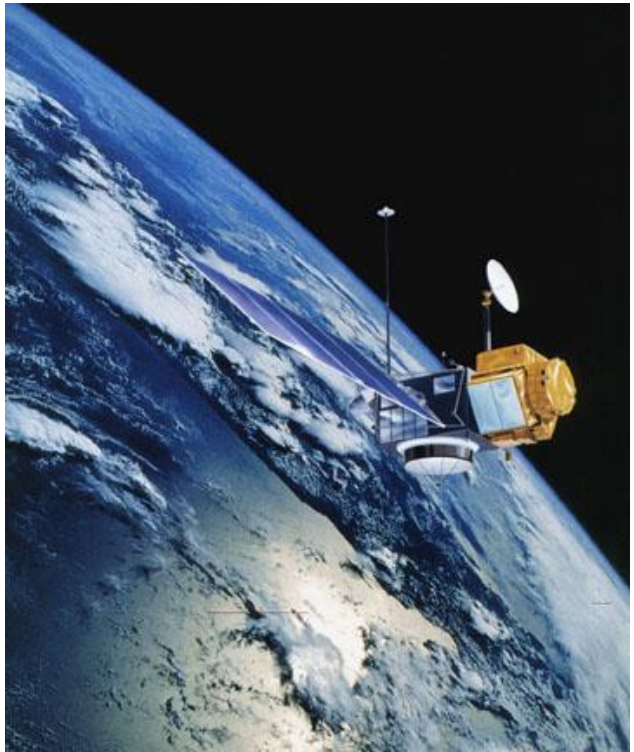


10/8/1992: TOPEX/POSEIDON:TOWARDS THE OPERATIONAL OCEANOGRAPHY

Definion of Radar Altimetry satellites for Oceanography were in progress at national level:

- **NASA/JPL**: **TOPEX** (TOPography EXperiment) by NASA/JPL, to give continuity to Skylab (1973), GEOS-3 (1975), Seasat (1978), Geosat (1985)
- **CNES**: **Poseidon**, to exploit the value of systematic radar satellite observations of oceans (France had already in operation the optical satellite SPOT)

1987: USA/France agreement for **TOPEX-Poseidon**, a mission to study ocean circulation and interaction with the atmosphere. **NASA:** satellite bus, 4 instruments, spacecraft operations **CNES**: 2 instruments, Ariane launch.



– 2 Altimeters were the basic elements of the P/L:

➢ **NRA** ***(NASA Radar Altimeter)***: dual frequency, C band (5.3 GHz) and Ku band (13.6 GHz), altimeter to measure the height of the satellite above the sea (NASA)

➢ **SSALT** ***(Singlefrequency Solid State Altimeter)*** or **Poseidon**: at 13.65 GHz (Ku-band) to measure the height of the satellite above the sea, wind speed, and wave height (CNES)

Both of rhem having a very high accuracy, **better than 5 cm**, for sea-level measurements

JASON: A CORNERSTONE FOR OCEAN OBSERVATION

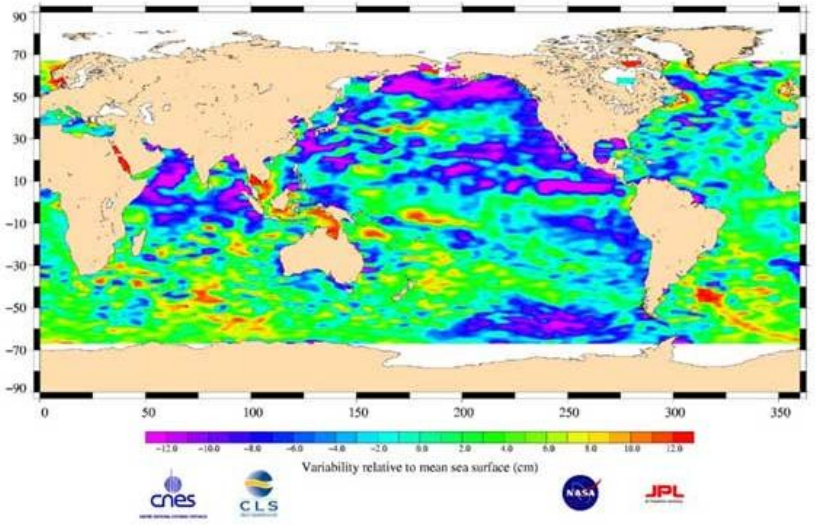
Joint Altimetry Satellite Oceanography Network

The oceanography mission series is considered a cornerstone of **GCOS** (Global Ocean Observing System), advocated (1992) by **WMO** (World Meteorological Organization), **IOC** (Intergovernmental Oceanographic Commission of the UNESCO), **UNEP** (United Nations Environmental Program), and **ICSU** (International Council of Scientific Unions)

December 1996: MOU CNES-NASA for **Jason** to give continuity to TOPEX/Poseidon.

December 7, 2001: Launch of **Jason-1,** produced by ***Alcatel Espace*** *(*now ***Thales Alenia Space France)*** on its bus **Proteus** (developed in cooperation with CNES).

Instruments:
France**: Poseidon-2** Radar Altimeter in C and Ku bands,. **DORIS** (as in T/P)
USA**: Laser Retroreflector Array, GPS Receiver, Microwave Radiometer**




JASON-2/OSTM & JASON-3: Operational Oceanography

June 20, 2008. Launch of **Jason-2** [or, for NASA and NOAA. **OSTM (Ocean Surface Topography Mission)**], in the frame of NASA-CNES cooperation to give continuity to the data acquired by previous satellites. Same industrial organization as *Jason-1*. Program management: NASA and CNES.

Operations passed to ***NOAA*** and ***Eumetsat***, sign of a service mature enough to become operational. *Jason-2 is in operation*

2010, EUMETSAT Member States approved the **Jason3**

Responsibilities/activities distribution:

- **NOAA** and **EUMETSAT** — the operational agencies — take the lead of the program
- **CNES**, significant in kind contribution (Jason3 Proteus platform, its facilities and associated resources to the program). System coordinator at technical level
- **NASA**, in conjunction with the three other partners (NOAA, EUMETSAT, CNES), will support science team activities. The US contribution to Jason3 includes the satellite launch, provision of instruments and support to operations

(SpaceX)

January 17, 2016
Launch of Jason-3 (Falcon-9)

Error Budget for altimetric missions

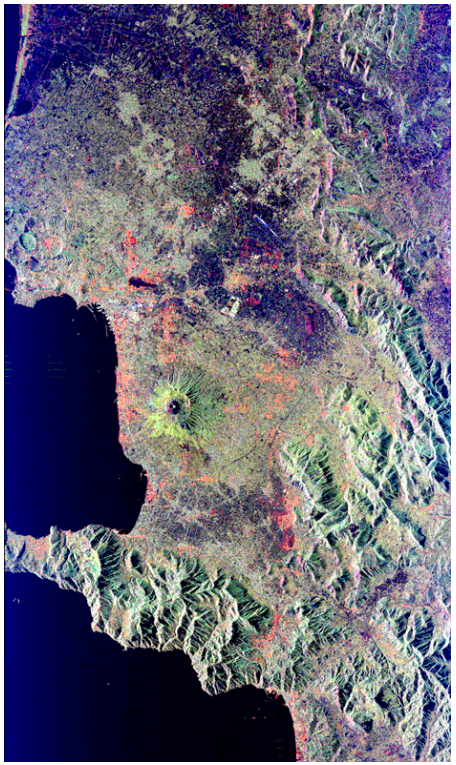
SRL: FROM BLACK&WHITE TO COLOURED RADAR IMAGES

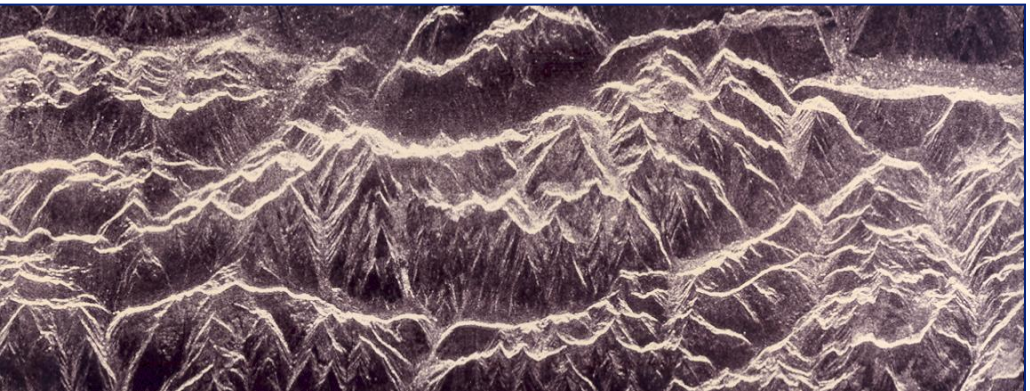
Beginning of '80s: a) CNR/PSN studies and techmology developments for an X-band SAR b) German Industry was working on MRSE for Spacelab-1 c) CNR/PSN - DFVLR discussions on possible X-SAR cooperations d) German and Italian industries cooperation on ERS-1

Space agencies of Italy and Germany agreed on the joint development of an X-band SAR to be flown on Space Shuttle, in the frame of the NASA/DFVLR agreement post-MRSE (1983). On a 50%-50% basis.

9/4/1994: SRL-1
30/9/1994: SRL-2

SRL (Shuttle Radar Laboratory) = SIR-C (L & C bands, USA) & X-SAR (D, I)



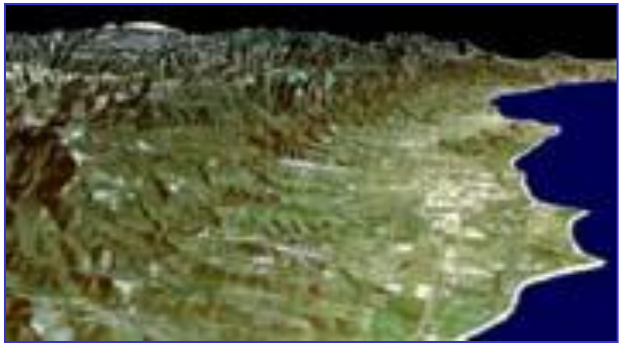


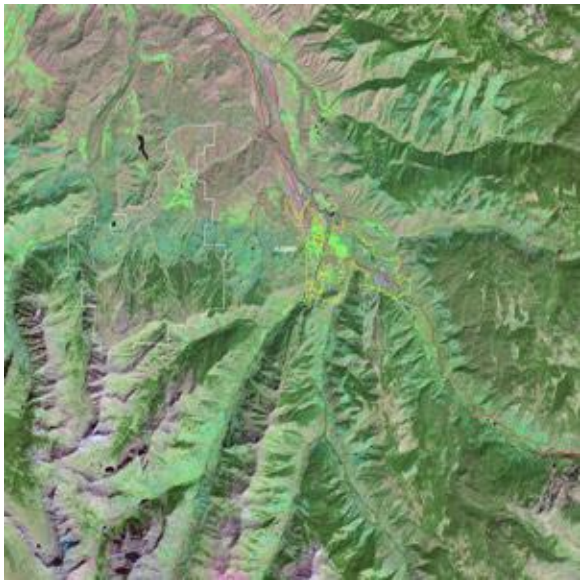
➢**First space based SAR mission with 3 frequencies (colour), to better classify the image elements**

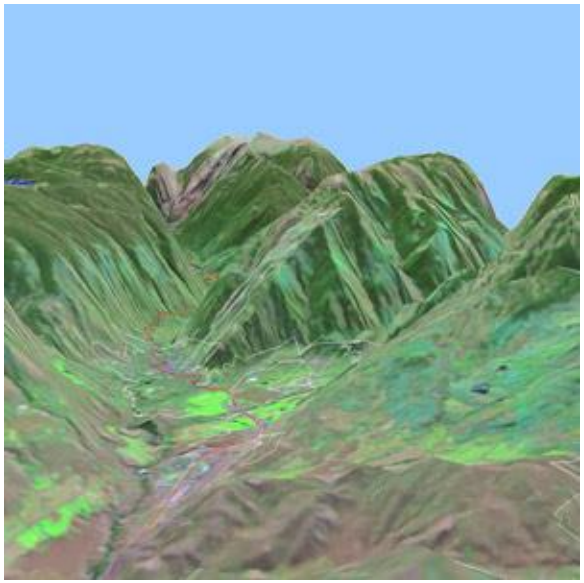
11/2/2000: SRTM (Shuttle Radar Topographic Mission): 3-D RADAR IMAGES

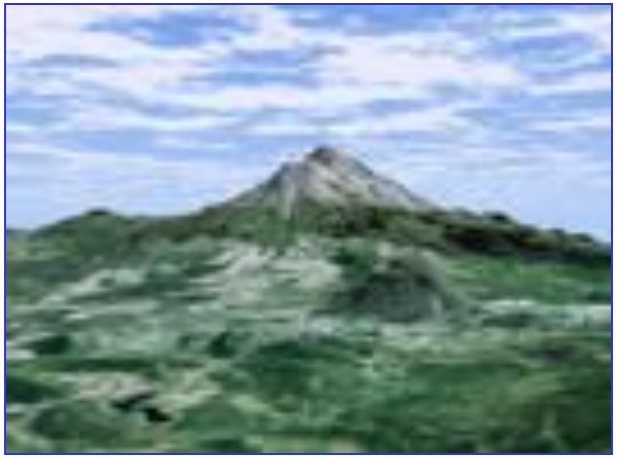
An X-SAR interferometric configuration was obtained by adding a second X-band antenna at then end of a deployable boom (length 60m)

First single pass experiment of 3-D radar images



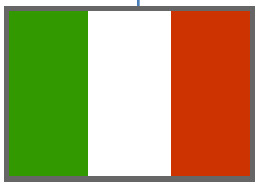






After the successful cooperation on X-SAR missions, Germany and Italy focused their priority on national programs based on X-band SAR

1994: SRL-1 & SRL-2
2000: SRTM



- Defense
- Dual
- Civil

19.12.2006	SAR Lupe-1	
08.06.2007		COSMO-1
15.06.2007	TerraSAR-X	
02.07.2007	SAR Lupe-2	
01.11.2007	SAR Lupe-3	
09.12.2007		COSMO-2
27.03-2008	SAR Lupe-4	
22.07-2008	SAR Lupe-5	
25.10.2008		COSMO-3
21.06.2010	TANDEM-X	
06.11.2010		COSMO-4

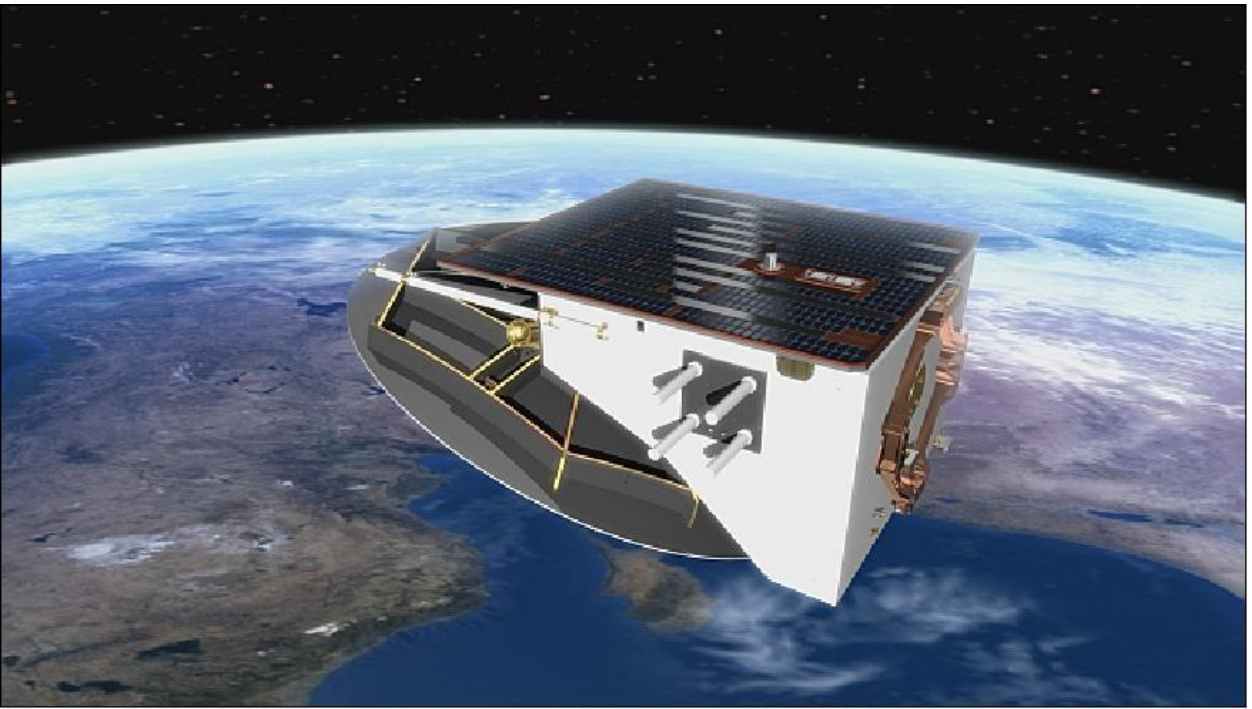
2006-2008: SAR-LUPE, THE FIRST DEFENSE RADAR SPACE SYSTEM IN EUROPE

➢Need to have **independent satellite intelligence high resolution all-weather/all-time** images of direct relevance to the protection and security of forces engaged in NATO operations outside Germany

➢Dec.2001: Contract Signature (5 identical satellites) to ***OHB System AG***, leading a structure of industries (D, F, I, S)

➢Based on study contract (2003) to evaluate the value of a **SAR-Lupe/ Helios-II** tandem operation, a **cooperation agreement** has been signed between **D and F** for data exchange

Launches: 12/12/2006 2/7/2007 1/11/2007 27/3/2008 22/7/2008



Offset refletor antenna, TWT amplification

X-SAR with two Operating Modes:

✓**Strip Map** o StripSAR (fixed antenna ponting Scene 60km x 8 km; Res. 1 m

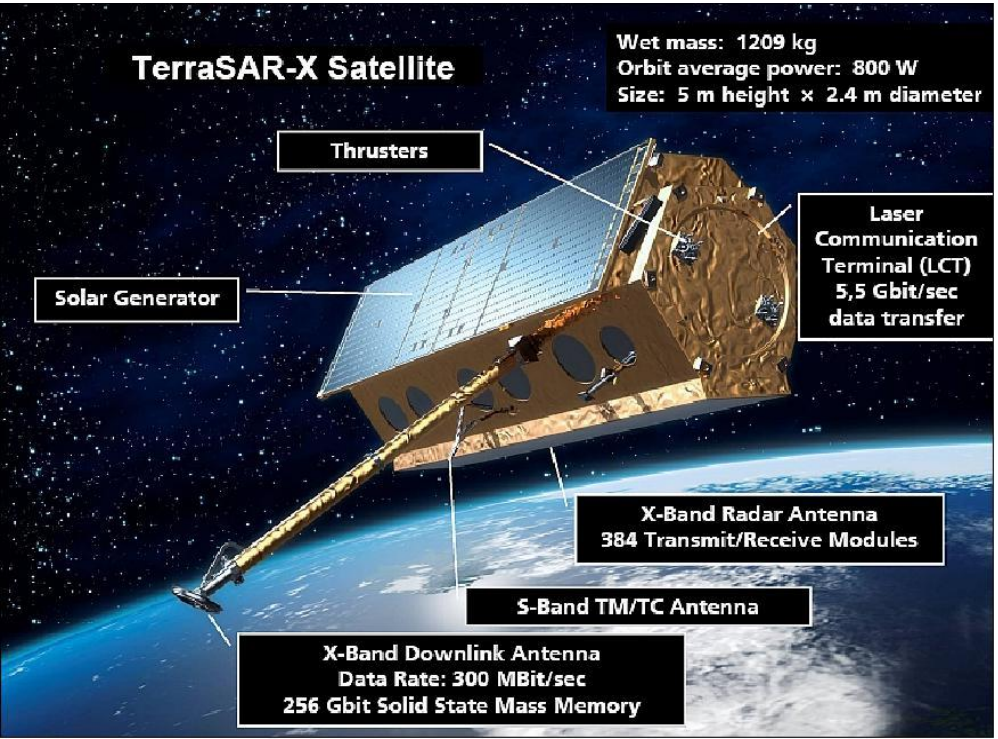
✓**Spotlight** o SlipSAR: Scene 5,5km x 5,5 km, Res. 0,5 m. Pointing by satellite manoeuvre.

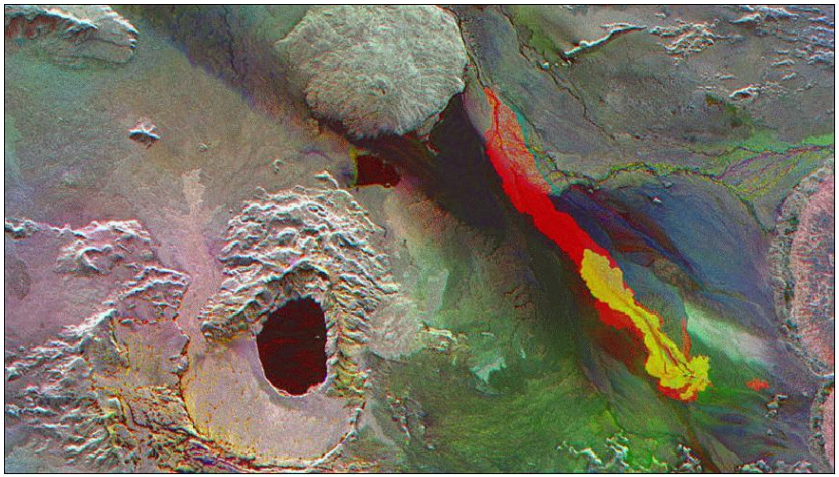
✓**30 images/day**

June 15, 2007 - TerraSAR-X: A P.P.P. FOR SCIENCE AND APPLICATIONS

- X-band SAR satellite system for scientific and commercial applications
- supported by BMBF (Ministry of Education and Science) and managed by DLR
- 2002: PPP for development/production cost share between EADS/Astrium and DLR
  - exclusive commercial exploitation rights for the TerraSAR-X data to EADS Astrium/Infoterra
  - Property of the satellite and scientific data rights to DLR

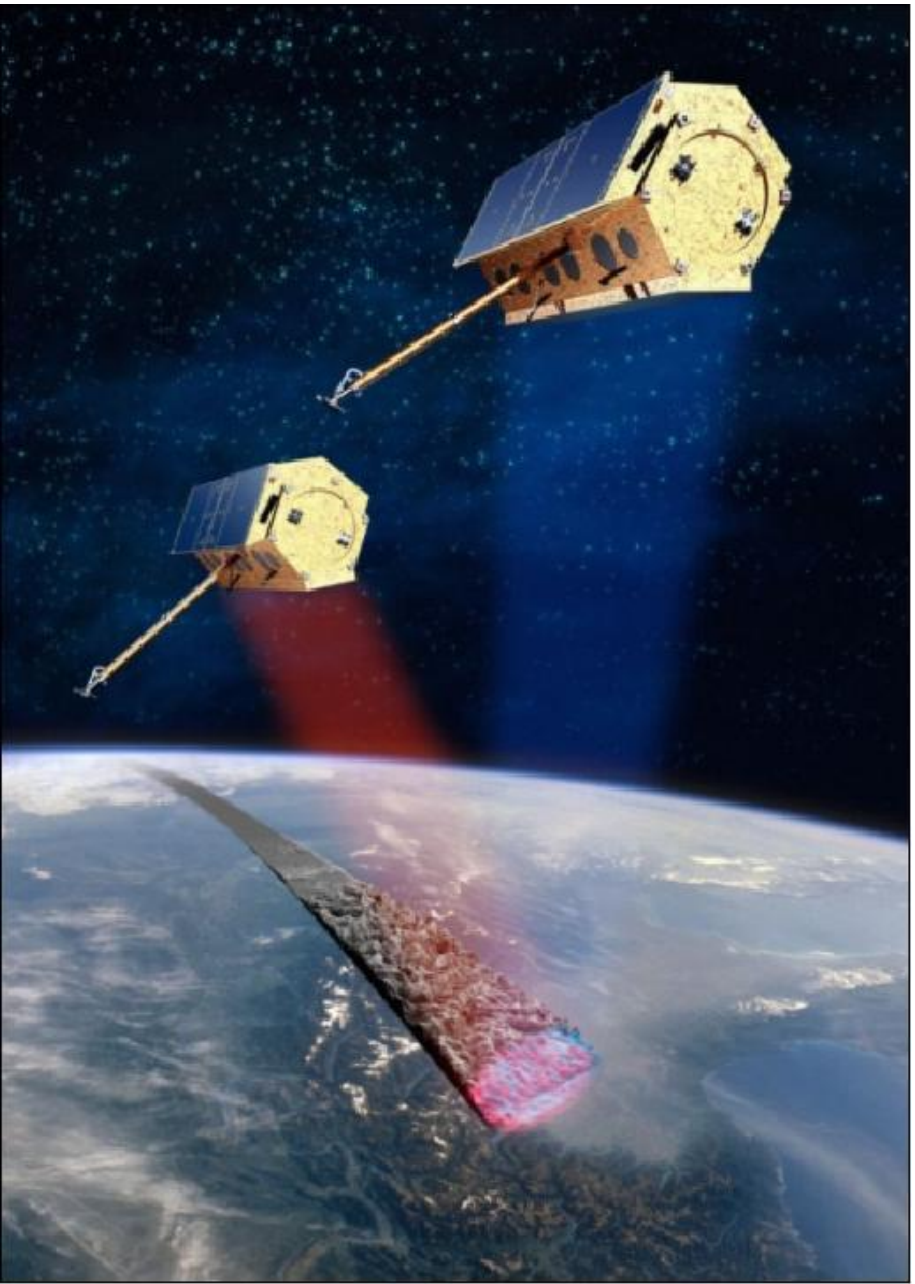
Wide spectrum of applications fields: hydrology, geology, climatology, oceanography, environmental and disaster monitoring, cartography (DEM generation). etc. for both science and commercial purposes.





Superimposed images of 3 TerraSAR-X observations (13 August, 4 September and 15 September 2014) to show the lava flow (Yellow 13.8-4.9; red 4-15.9) of the Bardarbunga Volcano (Iceland), become active mid August (credit:DLR)

June 21, 2010: TanDEM-X: A NEW STEP OF THE GERMAN P.P.P.



TanDEMX ***(TerraSAR-X add-on for Digital Elevation Measurement)*** is a twin satellite (almost identical) of TerraSAR-X developer by the PublicPrivatePartnership between the German Aerospace centre (DLR), EADS Astrium and Infoterra GmbH.

Missione; produce **WorldDEM™** DEM of the Earth's entire land surface with a vertical accuracy of 2m, within a horizontal raster of approximately 12x12 square meters. Infoterra has the exclusive worldwide commercial rights and is responsible for the developments of commercial products based on the data.

DLR & CSA for projects on Emergency Response and Safety of Operations:

- Airbus Defense and Space/MDA: use of TerraSAR and Radarsat-2 for man.made land changes
- Infoterra/C-CORE for ship arctic routes

COSMO/SkyMed: DUALITY!

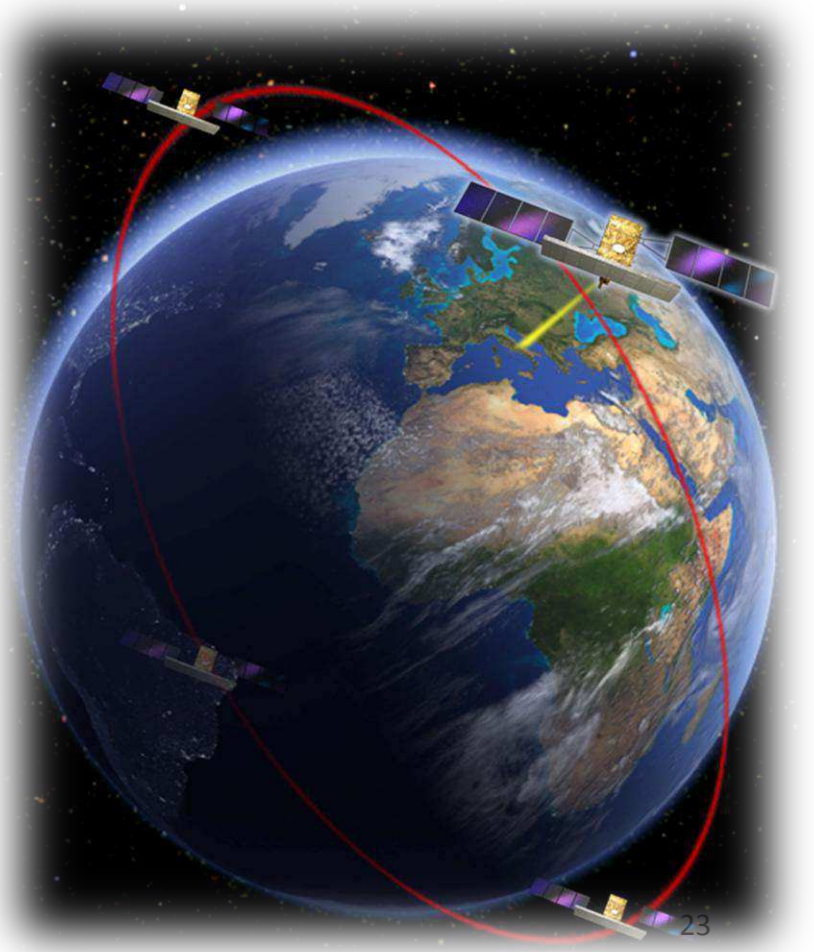
- Prepared through several ASI studies and technology developments since beginning of '90s
- Jointly Specified by ASI and MoD
- Cost shraing among Ministries of Research (ASI), Defense, Economical Development
- Mission mgmt: jointly by ASI and MoD
- Subject of int'l agreements (eg. MoDs of I and F; ASI /CNES, ASI/CONAE, ASI/JAXA, etc.)

8.6.2007: COSMO-1

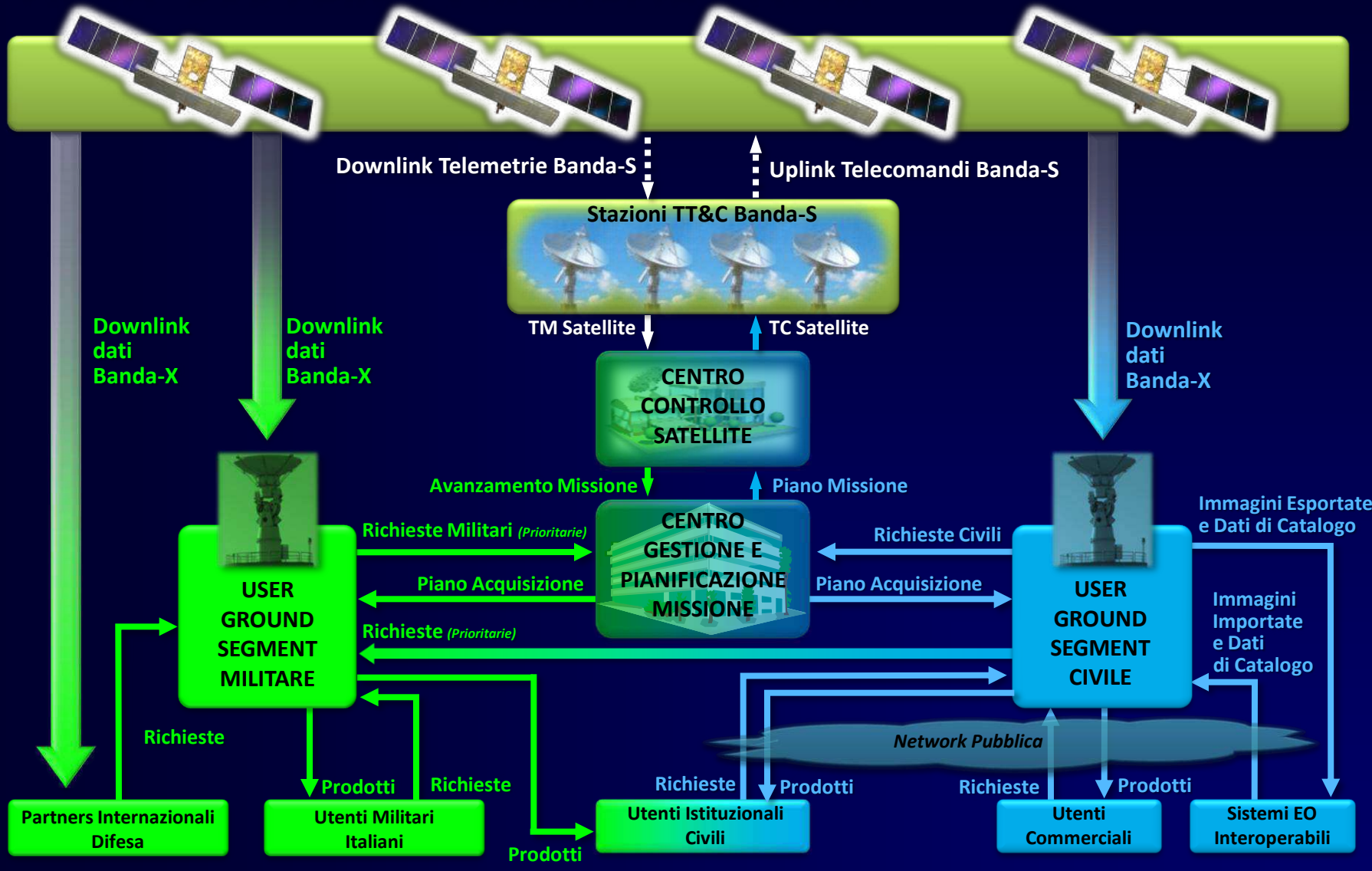
9.12.2007:COSMO-2

25.10.2008 COSMO-3

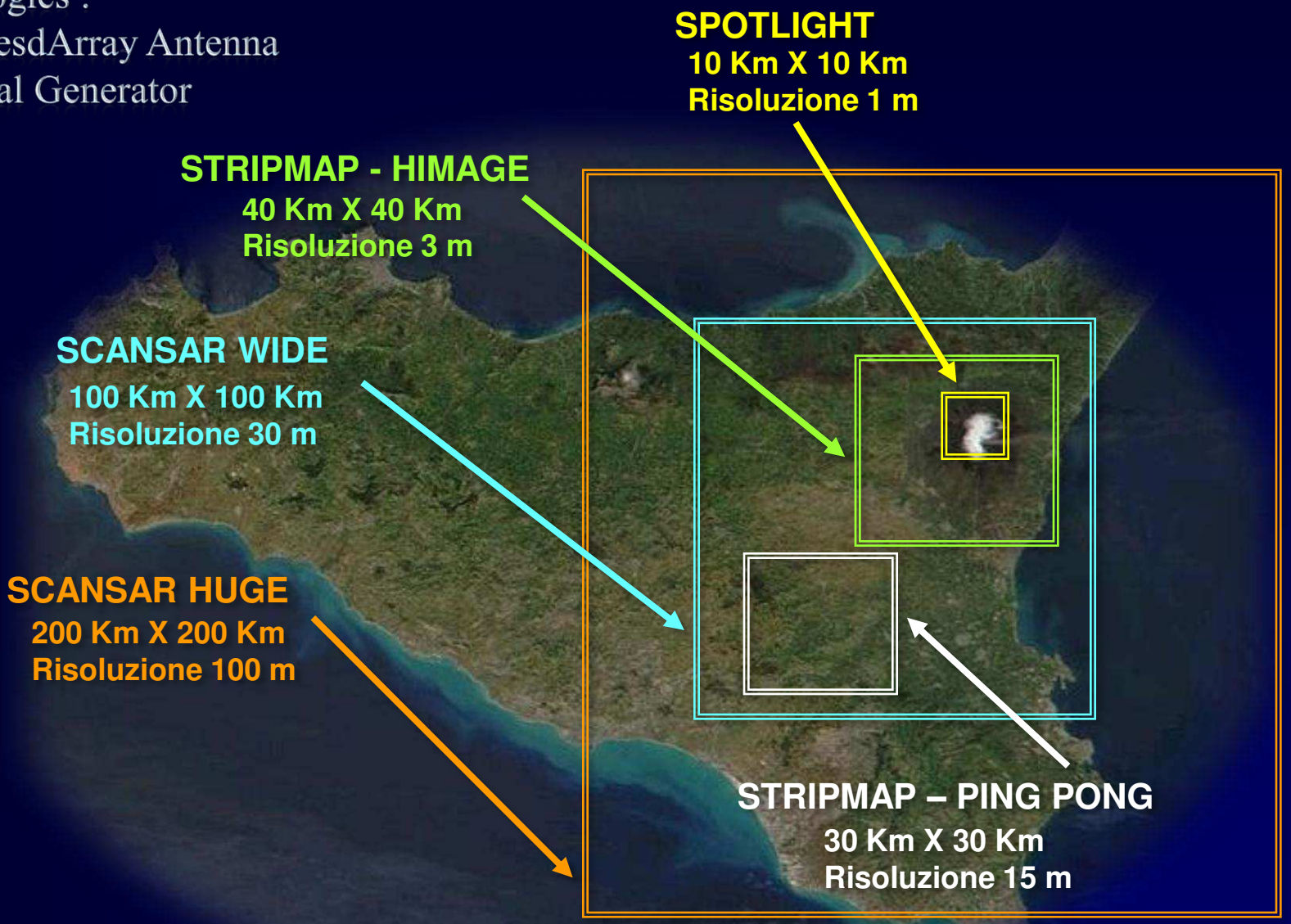
6.11.2010: COSMO-4



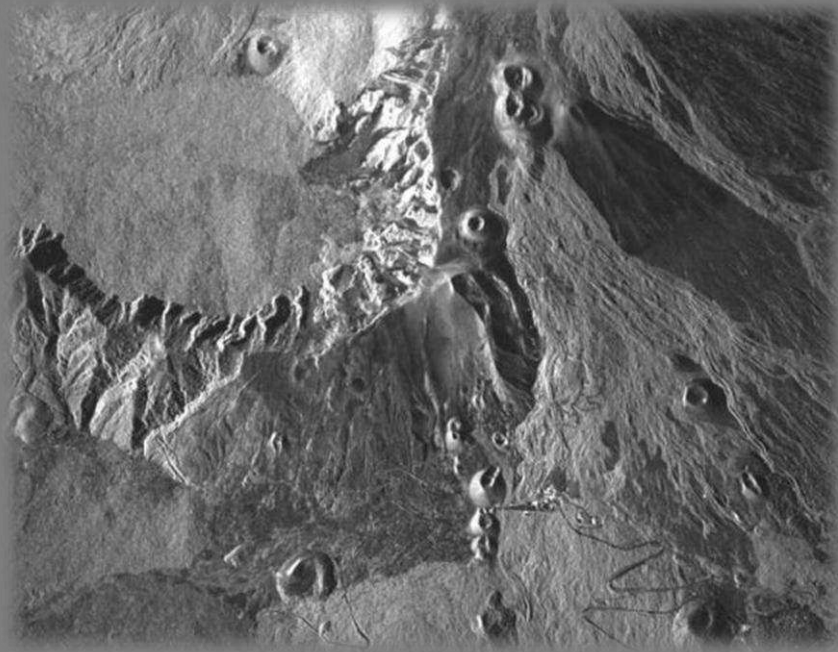
DUAL SYSTEM CONFIGURATION



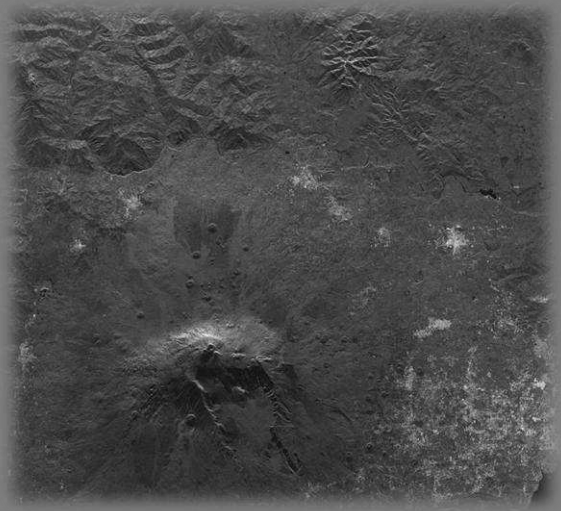
Performances: Different resolution modes
key technologies :
Active PhasesdArray Antenna
Digital Signal Generator



Spotlight Res. 1m (Civil)



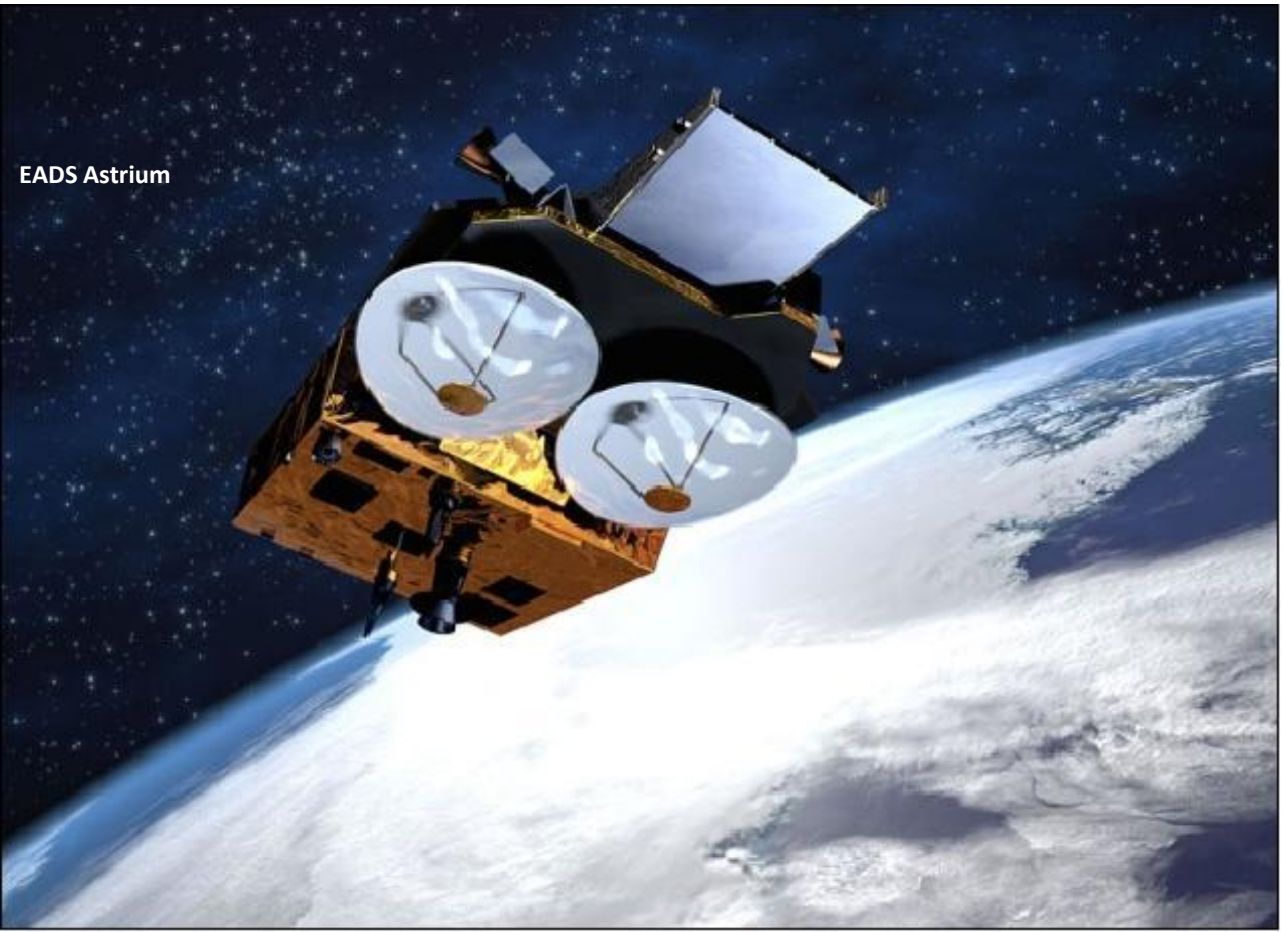
Stripmap
Res. 3m (Himage)
15 m (Ping Pong)



Scansar
Res. 30 (Wide Region)
100 m (Huge Region)

ESA: FROM LARGE MULTIMISSION TO SPECIALIZED EO SATELLITES

Second half of 1990's: start of **Earth Explorer program**, for advancement of earth science and techniques. 1st Earth Explorer GOCE: selected on 10/1999, contract placed on 11/2001. **8/4/2010**: Launch of **Cryosat-2** *(Prime contractor* ***Airbus Defense and Space)***, first Earth Explorer for a radar based mission to monitor the thickness of land ice and sea ice and help explain the connection between the melting of the polar ice and the rise in sea levels and how this is contributing to climate change.



SIRAL-2 ***(Sar/Interferometer Radar Altimeter)*** is a very innovative concept which uses Doppler processing for along-track resolution and interferometry to locate the echo in the across-track direction.

Developed by ***Thales Alenia Space France***, it has different op g modes for the different measurement scenarios (sea-ice, ice-sheet margins, continental ice-sheet, etc.)

A European Policy for Operational Earth Observation

May 1998: **Baveno Manifesto**, EC and ESA committ to set up ***Global Monitoring for Environment and Security*** progamme (2012: **Copernicus**)

Sentinels, which are specialized for specific monitoring needs. The planning of the program is decided according to the priorities of such monitoring needs. 6 **Sentinel** approved. 3 of them embark radar instrument **Sentinel-1** and **Sentinel-3** in orbit

Sentinel-1: radar imaging for land and sea monitoring

Sentinel-1 (Prime contractors ***Thales Alenia Space Italia***), carries an advanced **C-band Synthetic Aperture Radar**, developed :by ***Airbus Defense and Space*** based, to give continuiti to ERS-1, ERS-2, Envisat and Radarsat SAR missions

April 3, 2014 Sentinel-1A **April 25, 2016 Sentinel-1B**

Operational modes:
- **Stripmap** mode (SM): 80 km swath, 5 m x 5 m resolution, singlelook
- **Interferometric Wide Swath** mode (IWS): 240 km swath, 5 m x 20 m resolution, singlelook
- **Extra Wide Swath** mode (EWS): 400 km swath, singlelook
- **Interferometric Wide Swath** mode (IWS): 240 km swath, 25 m x 80 m resolution, 3looks
- **Wave mode** (WM): 20 km x 20 km, 20 m x 5 m resolution, single look

Polarization: Dual polarization for all modes VV+VH or HH+HV

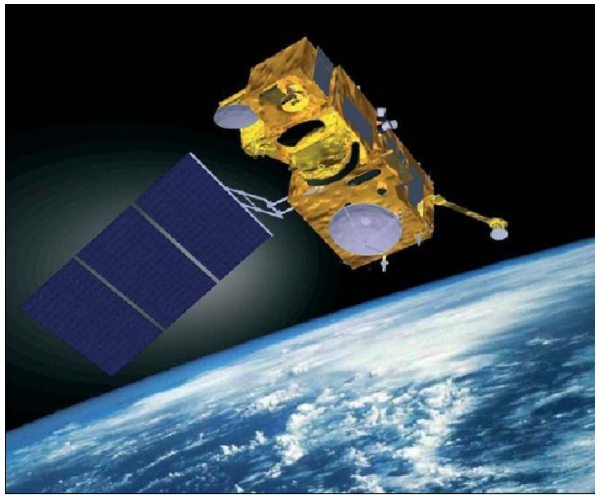
An oil slick detected by Sentinel-1A on May 19, 2016, in the Mediterranean Zone where the EgyptAir aircraft disappeared some hours before

(ESA & Sentinel1 Mission Performance Centre)

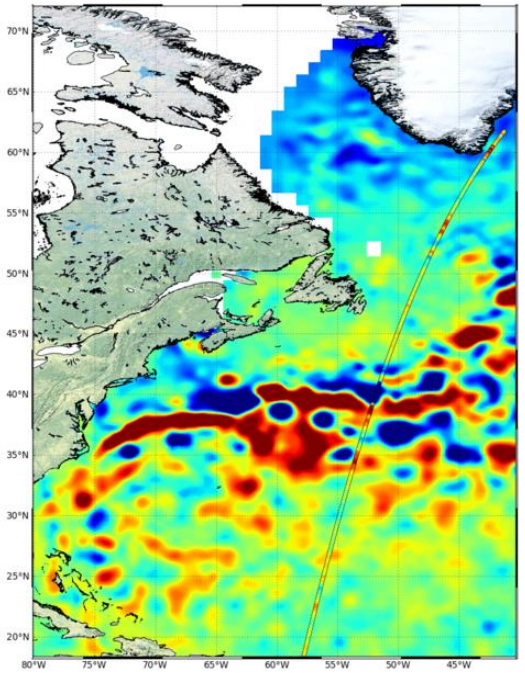
Sentinel-3: Global Sea/Land Monitoring Radar Altimetry Mission

Launch: February 16, 2016

The Surface Topography Mission (***STM***) uses the **Synthetic-Aperture Radar ALtimeter** (**SRAL**) instrument (Heritage: Poseidon, Jason-2) to measure *surface heights*, *sea wave heights* and *sea wind speed*) :
Two frequencies, Ku-Band (13.575 GHz, bandwidth=350 MHz) and C-band (5.41 GHz, bandwidth=320 MHz), to correct for ionospheric errors.
Total range error: 3 cm
STM is also composed of a MWR, a DORIS a GNSS sensor and LRR.

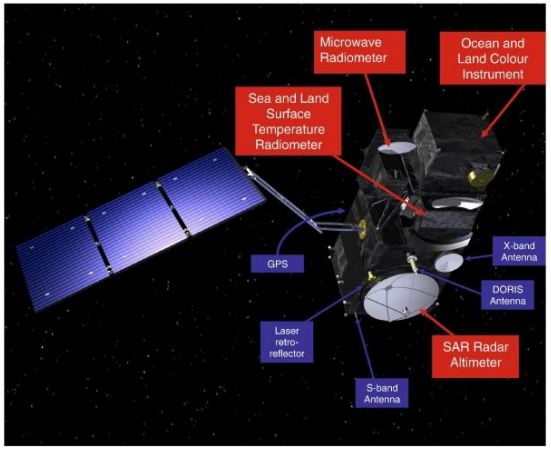


Developed by
Thales Alenia Space France



4/3/2016 - First track measured by SRAL : The Gulf Stream current (Copernicus data (2016)/CMEMS)

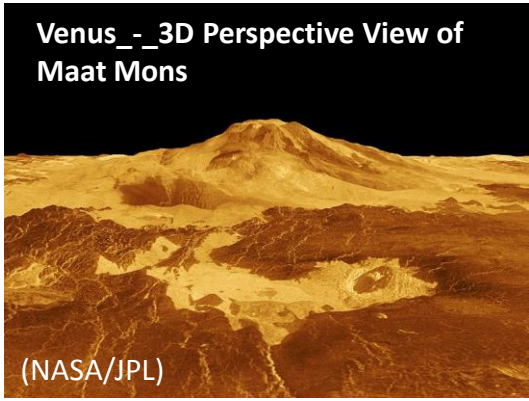
P/L of 4 instruments to measure sea-surface topography, sea- and land-surface temperature, and ocean- and land-surface colour
Operatot: **EUMETSAT**



Solar System Exploration: a further opportunity to develop Space Based Radars

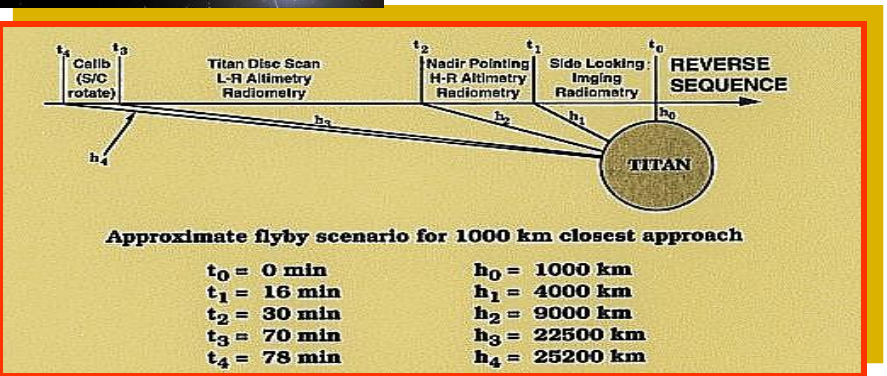
4/5/1989: MAGELLAN: THE FIRST INTERPLANETARY RADAR

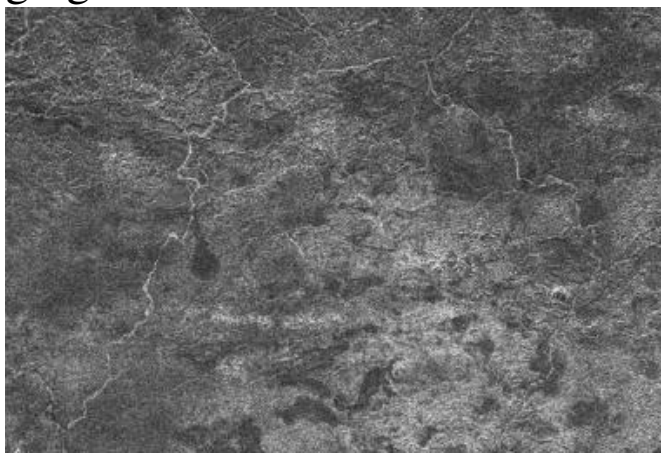
Venus Radar Mapper : 2.385 GHz multimode radar system (SAR, Radar Altimeter, Radiometer) by ***Hughes Aircraft Company*** (now Boeing) to taake images of the surface of Venus through the opaque atmosphere of the planet. ***SAR Resolution***: 150m range/150m azimuth; ***Altimeter Resolution***: 30m; Radiometer Accuracy: 2 degree C.



17/101997: Cassini-Huygens – Unveil the surface of Titan

Its payload comprises several scientific instruments, among them the **Titan Radar Mapper , joimtly** developed by **JPL** and **Alenia Spazio,** a13,8 GHz multimode radar (SAR, Altimeter, Scatterometer, Microwave Radiometer) for imaging of the Titan surface.





Radar Sounders – a new family of radars to search underground water of Mars

- **2003: Mars Express**

Agreement for a joint MARSIS development

MARSIS (Mars Advanced Radar for Subsurface and Atmospheric Sounding):

- 4 signals of 1 MHz bandwidth in the range 1.3-5.5 MHz
- vertical resolution: 70m
- resolution: 5-9 km (along track), 15-30 km (across track)
- penetration depth: 0.5-5.0 km

Jontly developed by JPL, Alenia Spazio and University of Roma "Sapienza"

2005: Mars Reconnaissance Orbiter (MRO)

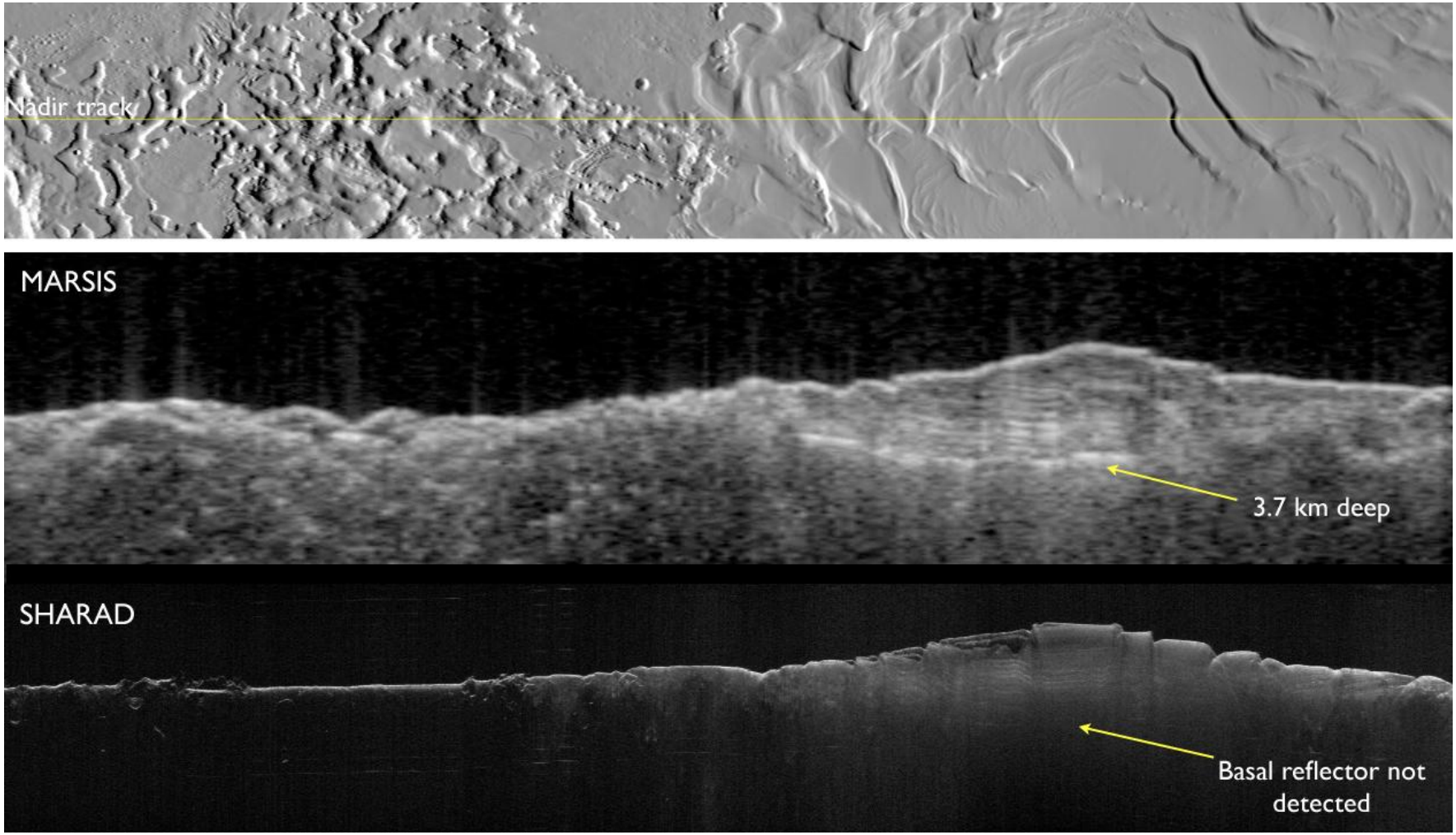
Endorsement of the ShaRad Italian Proposal

ShaRad (Shallow Radar) :

- Frequency 15-25 MHz 1.3-5.5 MHz
- vertical resolution: ~7 m
- resolution: 0,3-1 km (along track), 3-6 km (across track)
- penetration depth: 0.1- 1 km

Jontly developed by Alcatel Alenia Space Italia and University of Roma "Sapienza"

ShaRad vs. MARSIS



European Radars towards Far East: India

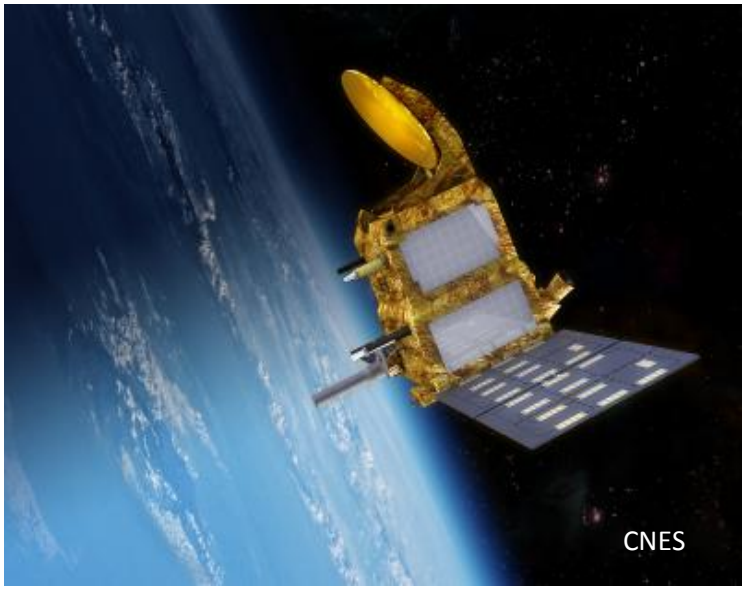
25/2/2013 SARAL: (Satellite with ARgos and AltiKa)

AltiKa, is the **first spaceborne altimeter** to operate at **Ka band** (35,75 GHz, 500MHz BW). Which does not requires a dual frequency for ionospheric correction and gives better performances (range resolution = 1,5 cm) with respect to the Ku band instruments. For the resulting mass reduction, it was Initially proposed in **2002** as a CNES altimetry **minisatellite** mission (150 kg) on the ***Myriade*** platform.

Initially foreseen for the cooperative mission **Oceansat.3** (agreement ISRO - CNES, 2005), AltiKa was redirected , as primary payload to the mission **SARAL** (agreement ISRO - CNES, 2007),

ISRO (platform, launch, operations)

CNES (payload module)



AltiKa has been jointly developed by **CNES** and **Thale Alenia Space France**

European Radars towards Far East: South Korea

2013 KOMPSat-5 (*KOrean Multi Purpose Satellite*) o Arirang-5

First South Korea SAR Satellite.
Primary mission objective: acquire all weather images for geographic information applications and to monitor environmental disasters

The complete radar system, an X band multimode SAR payload, including the instrument data acquisition, storage and transmission to the ground receiving station, has been developed by ***Thales Alenia Space Italia***. Which has provided also the ground SAR image processor and the calibration algorithms and equipments
Resolution from 1m/5km swath (High Res. Mode) to 20m/100km swath (Wide Swarh Mode)

L: 22.08.2013

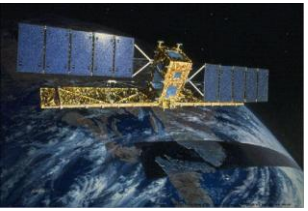
SPACE BASED RADAR IN JAPAN

11/2/1992 JERS-1 ***(Japan Earth Resources Satellite - Fuyo-1):*** Two sensors, one of which a SAR (***Mitsubihi Electronic Co.***) for civil applications: L-band (1,275 GHz); Spatial resolution 18m x 18 m (3 looks)

24/6/2006 ALOS ***(*Advanced Land Observation Satellite *-Daichi):*** Four sensors, one of which (by *JAXA & JAROS*) the civil radar PALSAR *(Phased Array L-band SAR)*: L-band (1,275 GHz); Spatial resolution 1-3m (spotlight) 3-10m (hi-res)

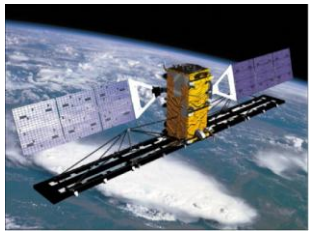
24/5/2014 ALOS-2 ***(*Advanced Land Observation Satellite *-Daichi)-2:*** P/L a multimode L-band radar , PALSAR -2 (***Mitsubihi Electronic Co.***). Resolution 3/6/10m (stripmap), 100m (scansar), 1x3 m (spotlight). Larger access area.

SPACE BASED RADAR IN CANADA



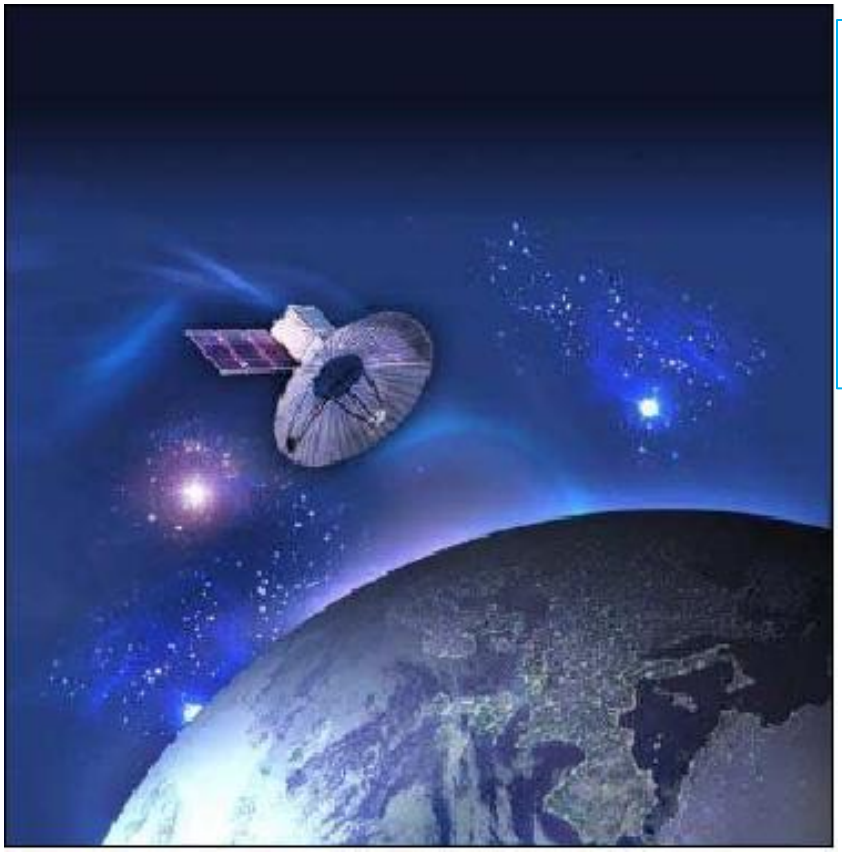
4/11/1995-29/3/2013 Radarsat-1*:* SAR satellite for commercial and civil application. Funded by CSA and MDA, supported by ***NASA*** by an agreement on data access. Bus by ***Ball Aerospace***, SAR by ***SPAR***, operated by ***CSA.***

Multimode instrument, with various Swath/Resolution pair, e.g.: 45km/11-9 x 9m (fine), 100km/25x28m (std), 300km/50x50m (ScanSAR narrow); 500km/100x100m (ScanSAR wide)



14/12/2007 Radarsat-2*:* SAR satellite for commercial and civil application. Funded by CSA and MDA.. Bus by ***Thales Alenia Space Italia***, SAR by ***MDA Satellite Subsystems***, operated by ***CSA.*** C-band ctive Phased Array Antenna. Increased number of modes, with resolution ranging from 3m to 100m

SPACE BASED RADAR IN ISRAEL



Ofeq is a programma of Intelligence satellites (Optical or Radar), developed by ***IAI (Israel Aerospace Industries Ltd.)*** for the Israel Space Agency in the interest of *Ministry of Defense*. Up to now only two **radar** satellistes have been launched.

Among the information found on the network: radar in X-band, multimode.
Resolution: 3m (stripmap), 8m (scanSAR), <1m (spotlight, with ponting by mechanical steering of the satellite), 1,8m (mosaic)

21/1/2008: Ofeq-8 (or TecSAR-1)
9/4/2014: Ofeq-10 (or TecSAR-2)

Since 2002, **India** and **Israel** have a cooperative agreement for space collaboration:

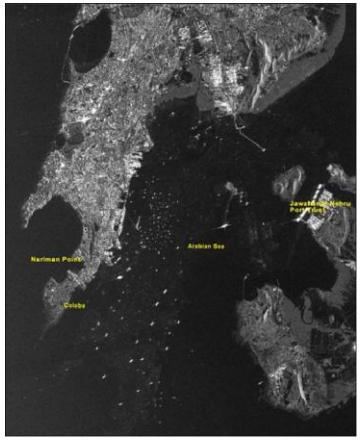
- The Israel ***TecSAR-1*** satellite has been launches by the Indian launcher PSLV
- The X-SAR for the first India Radar Satelllite, ***RISAT-2*** (2009) was built by IAI

SPACE BASED RADAR IN INDIA

22/10/2008: Chandrayaan-1, indian mission to the moon, embarked a **Mini-SAR**, an ***USA (NASA/DoD)*** contributed to the mission, developed by ***JHU/APL*** **,** to analyze polar regions in search of water (Res. 150m)

20/4/2009: The payload of **RISAT-2** ***(Radar Imaging Satellite),*** mainly devoted to defense purposes, embarked an X-band **TecSAR** produced by **IAI**, derived from TecSAR-8

23/9/2009: Oceansat-2 embarks **OSCAT**, a microwave Scatterometer developed at ***ISRO/SAC***, to evaluate ocean surface wind vectors through estimation of radar backscatter



26/4/2012 RISAT-1: the first SAR developed by India: a C-band SAR developed by ***ISRO/SAC*** (ISRO/Space Applications Center), having an Active Phased Array Antenna.

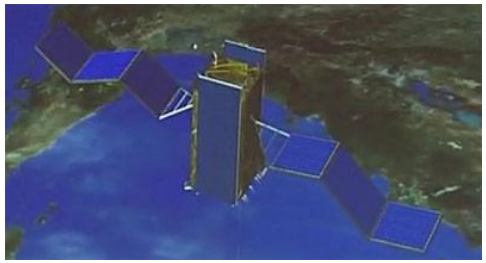
HRS: 1 m (Azimuth) x 0.67 m (Range) resolution, 10 km x 10 km
FRS-1: 3 m(Azimuth) x 2 m (Range) resolution, 25 km swath
FRS-2: 3 m(Azimuth) x 4 m (Range) resolution, 25 km swath
MRS: 21-23 m (Azimuth) x 8 m (Range) resolution, 115 km swath
CRS: 41-55 m (Azimuth) x 8 m (Range) resolution, 223 km swath

25/2/2013 SARAL: (Satellite with ARgos and AtiKa)
AltiKa has been jointly developed by **CNES** and **Thale Alenia Space France**

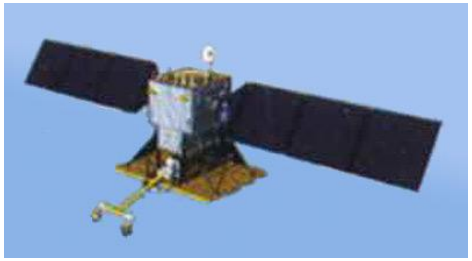
SPACE BASED RADAR IN CHINA: SAR

Second half of 1990's: start of Space Based Radar (SAR) development in China.
The series of Reconnaissance satellites are indicated by Yaogan Weixing (which means *remote sensing satellite),* or simply **Yaogan**, followed by a serial number. The overall series is subdivided in sub-series, **JB-# *(Jian Bing)***, which refers to the type of satellite (optical, radar, ELINT, and model).
Usually China do not disclose information on the ***Yaogan*** satellites, but, according to the expert's published analysis, **SAR** sub-series are: ***JB-5***, ***JB-7***, ***JB-11*** (8 launches out of the 30 Yaogan launches)

JB-5 (Gunter's Space Page)



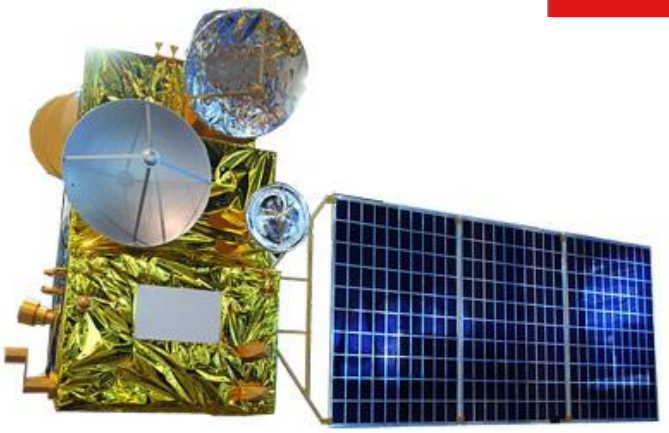
JB-7 (CCTV)



JB-11 (Gunter's Space Page)

24/04/2006 Yaogan-1 (JB-5)
11/11/2007 Yaogan-3 (JB-5)
22/04/2009 Yaogan-6 (JB-7)
09/08/2010 Yaogan-10 (JB-5)
29/11/2011 Yaogan-13 (JB-7)
29/10/2013 Yaogan-18 (JB-7)
14/11/2014 Yaogan-23 (JB-7)
26/11/2015 Yaogan-29 (JB-11)

SPACE BASED RADAR IN CHINA: RA



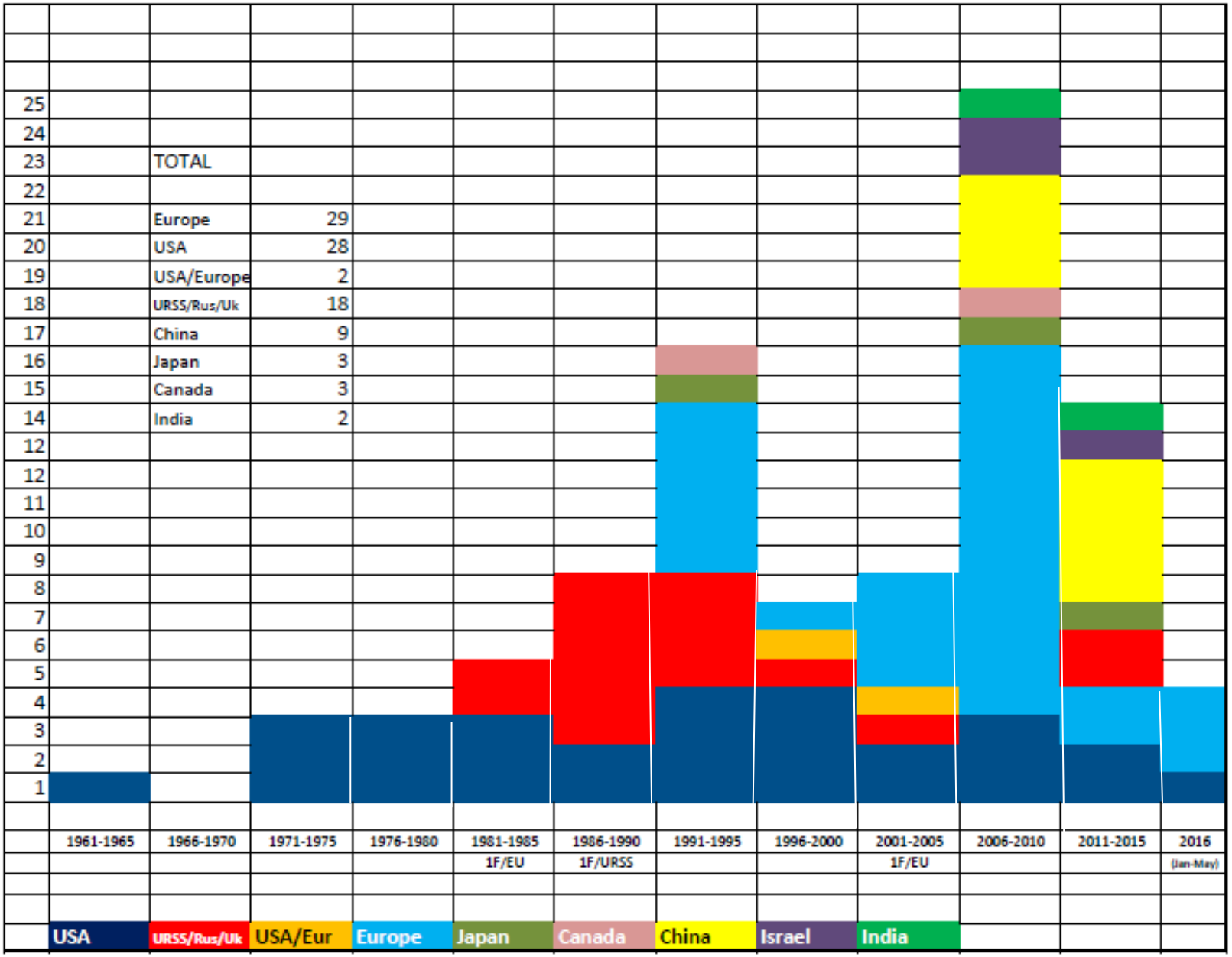
15/8/2011: launch of **HY2A** (**Haiyang2A**) (*Ocean-2A).* First of a series of satellites for oceanography (3 more satellites have been already approved, lanches planned in 2016-2019).

Payload:

• **dual-frequency *(Ku-band and C-band)* Radar Altimeter**: Sea surface height (precision: < 8 cm); SWH (Significant Wave Height) range: 0.5-20 SWH with a precision of < 10 % or 0.5 m (whatever is greater). Another element of the payload, the ***MWRI (Microwave Radiometer Imager)*** measures (among other ocean characteristics) the water vapor content in the atmosphere to correct tropospheric errors if the altimeter

• **KU-RFSCAT (Ku-band Rotational Fan-beam Scatterometer) -**referred to as **SCAT:** to measure the wind speed in the range 2-24 m/s within an accuracy of 2 m/s or 10% of maximum value, and the wind direction with an accuracyaccuracy of ±20º.

	TOTAL	
	Europe	29
	USA	28
	USA/Europe	2
	URSS/Rus/Uk	18
	China	9
	Japan	3
	Canada	3
	India	2



SPACE BASED RADARS PER COUNTRY OF PRODUCTION

PRODUCTION OF SPACE BASED RADAR
WORLDWIDE SCENARIO
1964–2016 (MAY)

Quill
Skylab S-193
Geos-3
Seasat
SIR-A,- B
Geosat
Lacrosse1, ...,-5
Magellan
GFO
NROL-21
Topaz-1,2,3,4

ShaRad/MRO

MRSE
ERS-1, -2
Jason-1, 2, 3
Envisat
Cryosat-1 & 2
SAR Lupe-1,2,3.4,5
COSMO-1,2,3,4
TerraSAR-X
TanDEM-X
Sentinel-1A, -B
Sentinel-3A

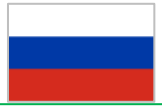
SRL-1 & -2
SRTM
Topex/Poseidon
Cassini TRM
MARSIS/Mars Expr.

Kompsat-5

Yaogan-1,3,6,10,13,18,23.29
HY.2A

mini-SAR
(Chandrayaan-1)

AltiKa (SARAL)



Okean-OE#1, 2
Okean-O1#1,...,6
Almaz
Almaz-T
Sich-1M
Kondot-1
Kondor-E 1

JERS-1
Alos-1, 2

Ofeq-8, 10

TecSAR (RISAT-2)

Oceansat-2
RISAT-1

Radarsat-1, 2

Nearby future of Space Based Radars by European Industries




2016

PAZ
Airbus Defense and Space Espana

2017

Sentinel-3B
Thales Alenia Space France

SAOCOM (tec)
Thales Alenia Space Italia

2018

SARah-1
Airbus Defense and Space

CSG-1
Thales Alenia Space Italia

2019

SARah-2
SARah-3
OHB-System GmbH

CSG-2
Thales Alenia Space Italia

2020

Sentinel-6
Thales Alenia Space France

2021

Biomass
Airbus Defense and Space

Sentinel-3C
Thales Alenia Space France

Sentinel-1C
Thales Alenia Space Italia

Small flags indicate the nationality of the programs

Europe flag stands for European Institutions (ESA, CE, Eumetsat, etc.)

CONCLUSION

the interest of remote sensing systems is threefold: **Defense**, **Social** (e.g. Environment, clima, disaster management, resources, etc.), **Commercial** (e.g. Carthography, agricolture, etc.)

- Radar instruments (SAR, Altimeters, Scatterometers) play an important role in all the above three applications
- Usually **Defense systems** are developed at national levels, but they can lead to cooperations based on exchange of data between complementary systems (optical/radar, different radar frequencies, etc.). This is mainly adopted by western countries (also including japan)
- **Europe** is very active on defense and civil system, has introduced the concept of duality, is leading Radar Altimetry and is among the leaders for high performances SAR
- **USA** deals with defense system at national level, and is very acrive in cooperations for civil (e.g. Jason series) and scientific missions (e.g. cassini, Mars, etc.)
- **Russia** and **Ukraine** are cooperating on civil systems, but since 2013 Russia has started the development of its own defense system based on high perfotmasnce SAR.
- **Canada** and **Japan** have their own national civil systems, and have agreements with other countries (maonly Europe and North America) based on mutual exchange of data.
- **Israel** has an important defense system and has provided a SAR to India on the basis of a specific agreement compliant with its national interest. Other may follow.
- **India** has a mixed policy of development and acquisition in line with their national needs
- **China** had a very late start for their development of space based radars (the first one has been launched in 2006, but they are going on very fast and up to may 2016 there have been 8 SAR and 1 Altimeter satellite launches.