Cosmo SkyMed constellation: state of the art and new perspectives of Remote Sensing

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Abstract
Cosmo SkyMed is the firts national constellation built around a SAR X band. It is a dual system (civil and military). The civilian part is devoted to the environment risk management. Scientific activities for new algorithms and new applications are also planned. Aim of this paper is to decribe the capabilities of Cosmo SkyMed toghether the main features in order to give the state of the art of the system .

Cosmo SkyMed e' la prima constellazione nazionale costruita attorno ad un SAR in banda X. E' un sistema duale (civile e militare). La parte civile e' stata sviluppata in funzione della gestione del rischio ambientale. Sono state anche pianificate delle attivita' scientifiche per nuovi algoritmi e nuove applicazioni. Scopo di questo articolo e' quello di fornire le caratteristiche di Cosmo SkyMed unitamente alle sue capacita' operative, in modo da dare lo stato dell'arte del sistema

Cosmo SkyMed

Italy offers an efficient response to actual needs of environment management with the first Dual-Use (Civil and Defence) constellation of satellites for Earth Observation, the COSMO-SkyMed Programme, a brainchild of the Italian Space Agency (ASI) in the frame of National Space Plan, funded by the Italian Ministry of Research (MUR) and Ministry by the Italian Ministry of Research (MUR) and Ministry of Defence and developed by a team of Italian industries under ASI management and responsibility.

The definition and dimensioning of the COSMO-SkyMed system has been based on a set of Mission Requirements issued by the Italian Space Agency (ASI) together with the Italian Ministry of Defence. Such requirements impose at highest level the following characteristics:

- Capability to serve at the same time both Civilian and Defence Users through a integrated approach (Dual Use System),
- Large amount of daily acquired images,
- Satellites worldwide accessibility,
- All weather and Day/Night acquisition capabilities,
- Very fast interval between the finalization of the user request for the acquisition of a certain geographic area and the release of the remote sensing product (*System Response Time*)
- Very fine image quality (e.g. spatial and radiometric resolution)

Possibility of image spatial resolution trade-off with size, at most possible extent and including

sub-meter resolution

Earth Observations scenario

World-wide civil protection, defence and resource managing users are today under an increasing pressure to take quick and appropriate decisions on a day-by-day basis in fields like monitoring and surveillance, risk management, hydrology, forestry, environmental management, agriculture, urban planning, etc.

In this frame Earth Observation Market indicates that there is a strong request for products and services which have to be reliable and frequently / regularly updated. For these reasons Earth Observation Market is demanding higher resolution, better accuracy (geo-location, radiometry, etc.), better response/revisit time and quicker-and-easier ordering and delivery of data, products and services, as described in next figure. All the above goals can be accomplished by increased density, frequency, duration or extent and bandwidth (resolution) of data acquisitions and new or improved measurement techniques such as a multi-sensor approach and a co-ordinated international co-operation for sharing experiences, technologies and resources

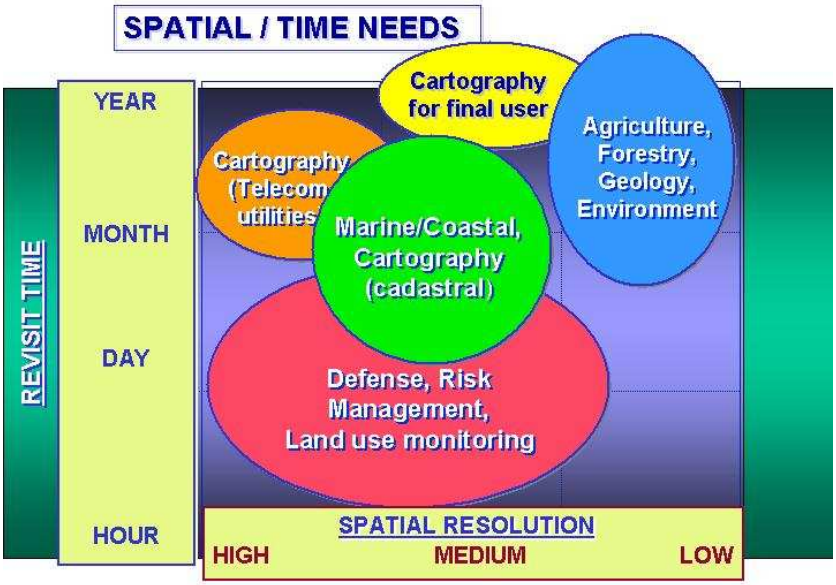

Fig. 1 – Revisit vs Resolution for various EO applications

Cosmo SkyMed features

The system engineering studies lead to a constellation consisting of 4 medium-size satellites, each one equipped with a microwave high-resolution synthetic aperture radar (SAR) operating in X-band (9.6 GHz), having ~600 km access ground area, orbiting in a sun-synchronous orbit at ~620km height over Earth surface, with the capability to change attitude in order to acquire images at both right and left side of the satellite ground track. Next Tables and figures summarizes the system main orbital characteristics and driving performance requirements:

➢ NUMBER OF SAT.	4
➢ ORBIT TYPE	Down Dusk SSO
➢ INCLINATION	97.86°
➢ ECCENTRICITY	0.00118
➢ HEIGHT	619.6 Km
➢ LTAN	06:00 a.m.
➢ SATELLITE PHASING	90°
➢ ORBIT PERIOD	97.2 m
➢ ORBIT CYCLE	16 days
➢ REVOLUTIONS / DAY	14 + 13/16

fig 2 Main orbital elements

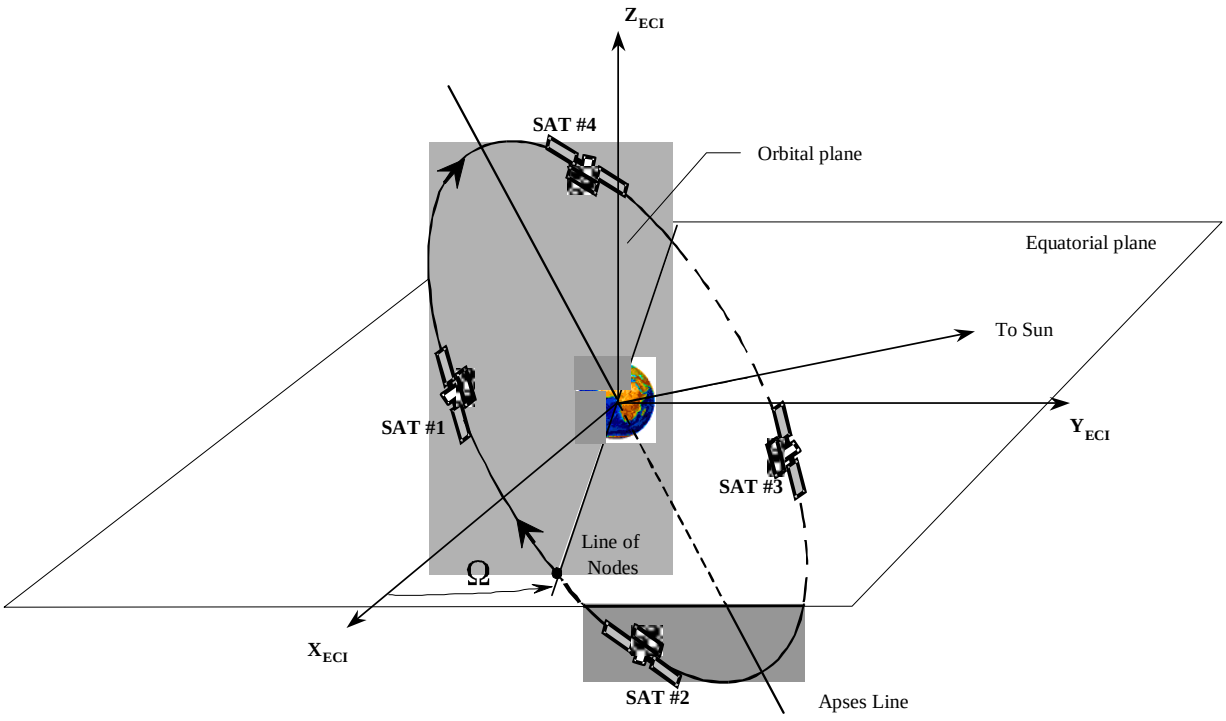

fig 3 Cosmo constellation nominal configuration

Accessibility	+/- 90 latitude
Rivisit Time	12 hours
Response Time	from 18 to 72 hours
Fully image acquisitions	1800 (full constellation)
Image Size	From 10x10 to 200x200 kmq
Spatial resolution	From meter to 100 m
Operational autonomy	24 hours

Fig 4 Driving performance requirements

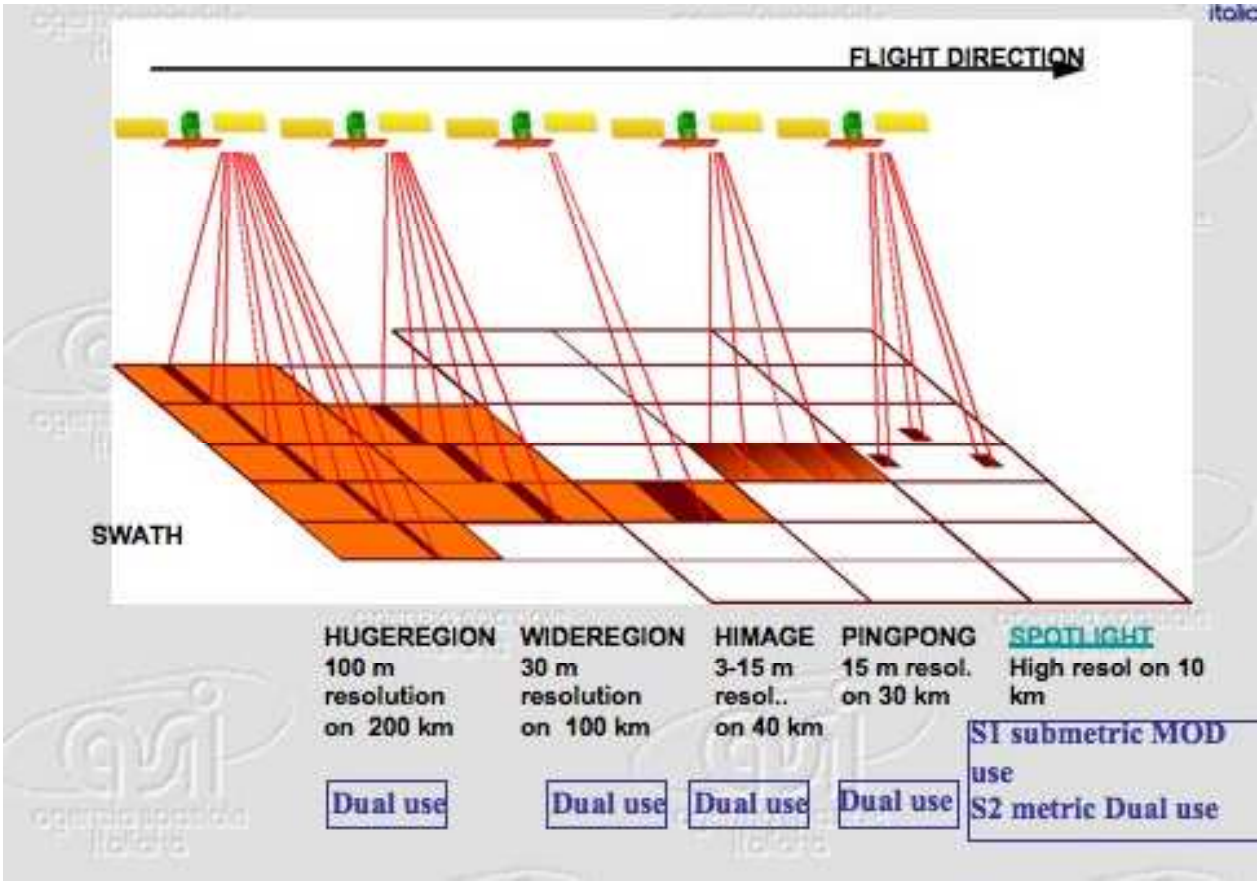

Fig 5 Acquisition modes of Cosmo Sensor

Summary of Cosmo Main Performance

Key performances of the COSMO-SkyMed are:

Worldwide accessible area starting from the first deployed satellite, in order to acquire and furnish data on the entire earth

Capability to acquire, during the orbital cycle, a specific site with at least 2 very different incidence angles, on the same side of the orbital plan

Revisit time of the constellation lower than 12 hours

Constellation average daily acquisition capability of 1800 images acquired in a 24 hours moving window (75 Spotlight plus 375 Strip or ScanSAR for each satellite)

Constellation peak daily acquisition capability of 10 minutes of continuous operation in Stripmap or ScanSAR modes or alternatively 20 spotlight images
Capability to deliver the image product required by the user in a time ranging from 72 hours in routine mode (the normal operating mode) to 18 hours in very urgent mode (the mode to be used e.g. during environmental catastrophe or military crisis)
Capability to acquire interferometric image couples with a time separation of one day or even few minutes (tandem mission in which two SAR satellites fly very closely), allowing the generation of Digital Elevation Model products with a absolute height accuracy ranging from 8m in Spotlight mode to 58 m in ScanSAR mode (horizontal accuracy of 18 m and 52 m, respectively)
SAR Products suite composed by 5 "standard" products levels and 7 types of product "higher" product levels obtained by a postprocessing of the standard products (e.g. coregistration or speckle filtering), with a spatial resolution ranging from 1 m up to 100 m, a radiometric accuracy of 1 dB and a localization error on ground with as low as 15 m
Service Availability better than 95% for the operational lifetime (high resolution – high priority service when 40% of the acquisition requests covers the overall Defence quota)
System Operational Lifetime of 15 years, with a satellite lifetime of 5 year.

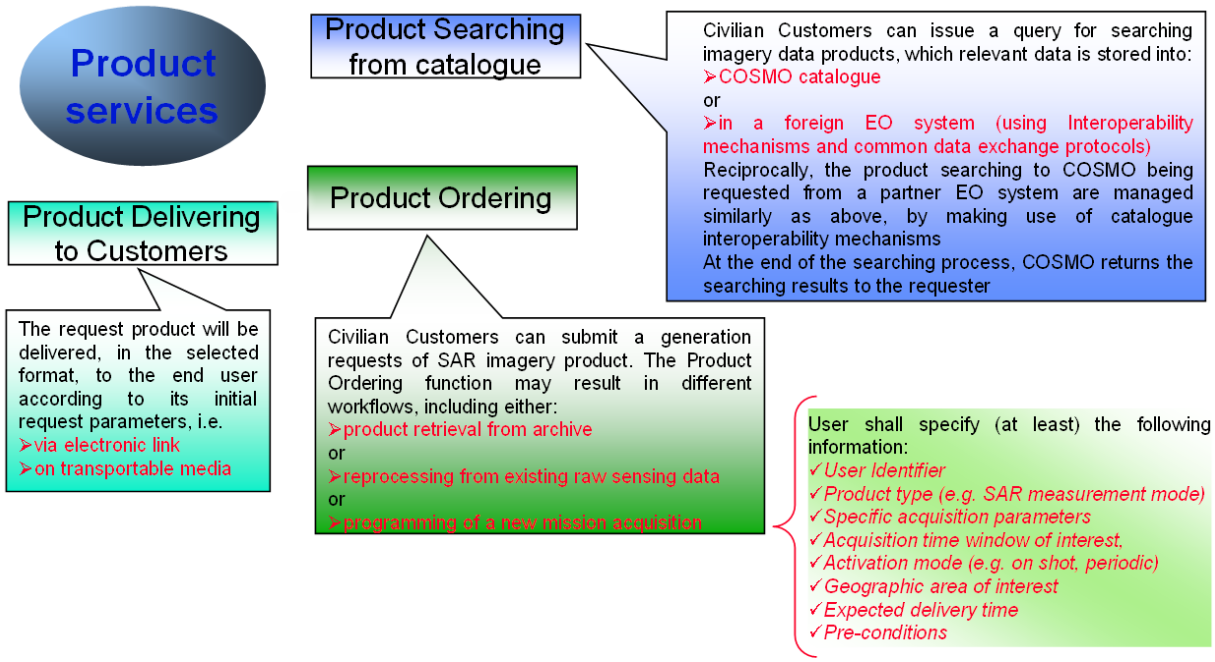

fig 6 Main product services

Civilian Customers

COSMO-SkyMed has built-in functions which allows the following operations to the **civilian customer** (using Internet with the support of a Graphic User Interface or GUI):

Permit to unregistered users a simplified consulting of available services
Perform user registration and user profile creation
Authenticate and restrict the user access to the system on the basis of its own profile
Allow browsing capability to retrieve help and info on the available services
Manage, by means of "easy to use" graphic front-end, all customer service request
Aid the service request composition with tailored data entry forms able to avoid bad

parameters introduction
Permit to customer the status monitoring of its service requests
Manage the final product delivering to customer
Manage commercial aspects (only civilian customers).

There are three ways to fulfill a Civilian Customer Request for a image product:

The system catalogue contains a raw satellite image fulfilling user's constraints (e.g. geographical and temporal coverage, quality level). In this case, the customer submits a Product Elaboration Request composed of one or several imagery products. Such elaboration then starts from input raw satellite images found into the satellite data archive

The system catalogue contains a product (a raw satellite image already processed) fulfilling user's constraints. In this case, the Civilian Customer Request is only composed of a delivery request composed of one or several product copy requests from input products already found into the archive

In the system's archive does not exist a raw satellite image or product satisfying user's constraints, therefore, one or more new acquisitions from satellite are needed

Many types of Civilian Customer Requests exists, in order to satisfy the needs of various kinds of civilian customers:

Routine Request, created by the generic civilian customer and handled within the civilian receiving processing archiving center (civilian User Ground Segment or C-UGS). If any conflict with high priority request (see below) comes out, the planning center (called CPCM) downgrades the civilian request priority in favour of the high priority one

Privileged Priority Requests, created only by authorised Civilian Institutional Customers, and which have an higher priority level (respect routine requests). Such requests are harmonised at international level in order to remove space/temporal conflicts, extracted and sent to the planning center for the next mission horizon

Unrestricted High Priority Request, which can be created only by authorised Civilian Institutional Customers and are sent to Defence UGS in charge of the overall high priority harmonisation activity. Acquisition and production of such requests is managed by the Defence UGS while the final product is sent Civilian UGS

Classified High Priority Request, are the classified version of the previously shown Unrestricted High Priority Request and can be submitted by authorised Civilian Institutional Customers only through the military authority

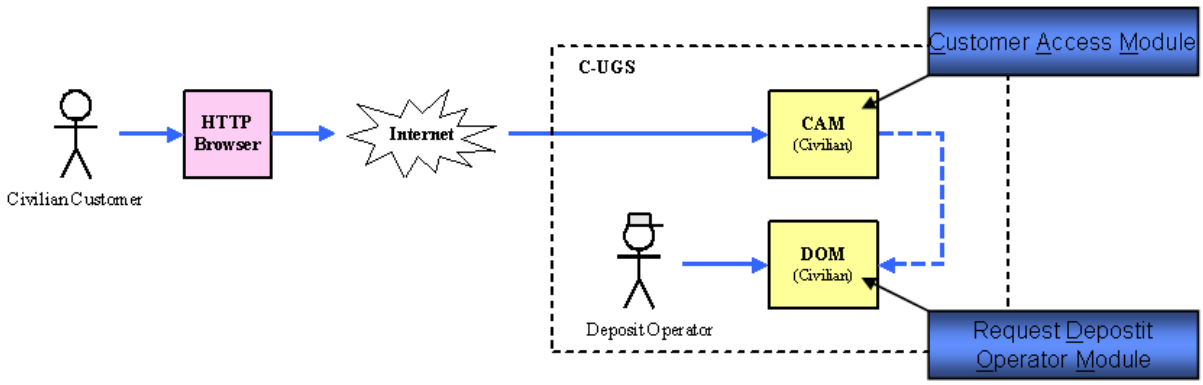

fig 7 Civilian Service Request Composition

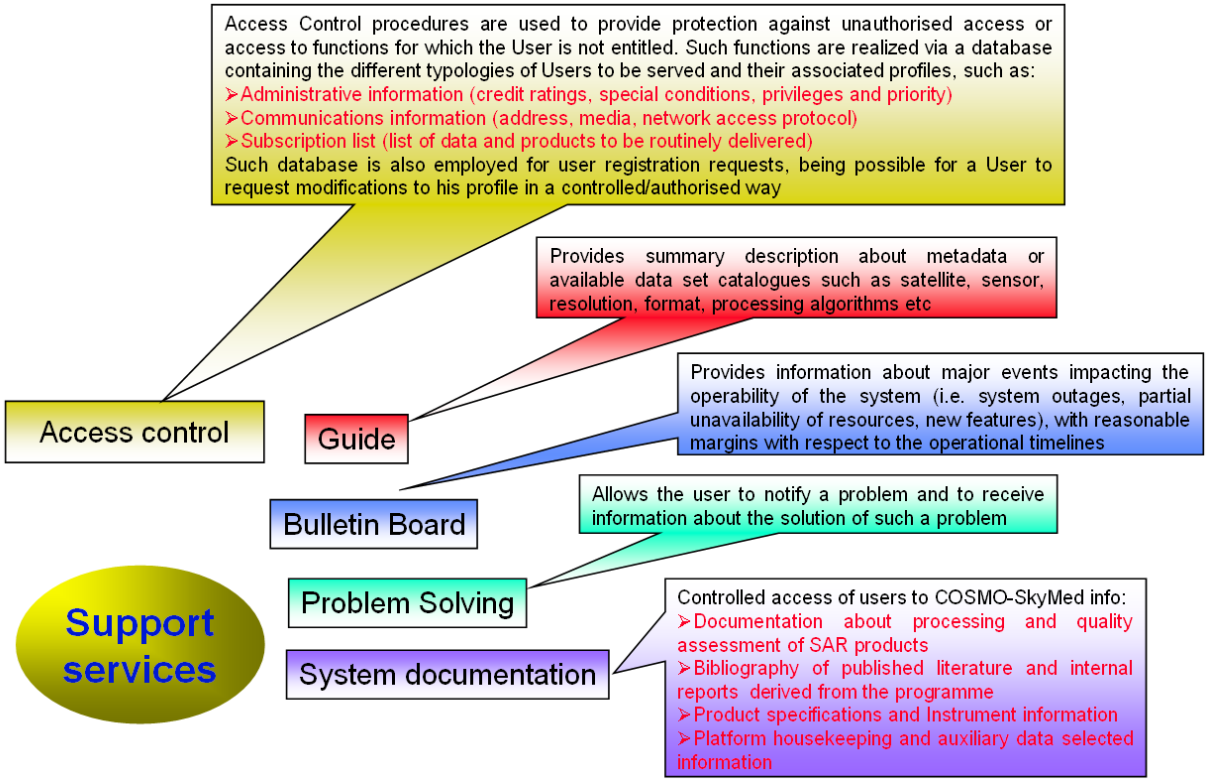

fig 8 Support service of COSMO-SkyMed

Advanced capability: interferometric tandem

One of the potential capability is to put the satellite into a interferometric tandem. Such capability can be performed once a year.

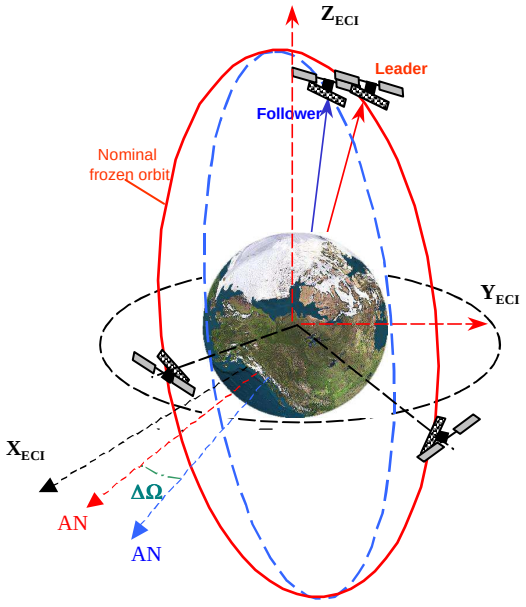

fig 9 Interferometry tandem configuration with different orbit planes

The main performance of the interferometric configuration from the user point of view, is associated with the accuracy of the products which are generated in such acquisition modality i.e. the Digital Elevation Model (DEM). The accuracies of the DEM (shown in next table) are:

Relative accuracies: errors in absence of any calibration, true height not known

Absolute accuracies: true errors within specified Baseline, Incidence angle, terrain slope, availability of Ground Control Points.

Relative accuracies	Spot	Strip	ScanSAR Wideregion	ScanSAR Hugeregion
	B⊥ = 100 ÷ 3500 (extimed with an accuracy better of 20%) Coherence ≥ 0.8			
Relative height accuracy[m]	≤ 5	≤ 12	≤ 24	≤ 53
Relative horizontal accuracy [m]	≤ 5	≤ 12	≤ 22	≤ 45

Absolute accuracies	Spotlight	Stripmap	ScanSAR Wideregion	ScanSAR Hugeregion
Normal Baseline Incidence angle Terrain slope @95% points	B⊥ = 300 ÷ 600 40° < ϑ < 50° α≤30°	B⊥ = 150 ÷ 250 45° < ϑ < 50° α≤25°	B⊥ = 80 ÷ 130 39° < ϑ < 46° α≤20°	B⊥ = 80 ÷ 130 37° < ϑ < 46° α≤15°
Absolute height accuracy[m]	8	17	28	58
Absolute horizontal accuracy [m]	18	22	30	52
Posting [m x m]	3x3	10x10	30x30	100x100

Interferometric DEM performances

Regarding the attitude capabilities of the satellite, four pointing modes are allowed:

The Right Looking Nominal Mode is the standard operation mode of the satellite, in which the SAR instrument has access capability in the incidence angle range 25° ≤ * ≤ 50°, yielding optimum radar imaging performance. It requires the pointing of the SAR antenna mechanical boresight (i.e. normal to the antenna surface plane) on-ground to the right side at 34.065° off-nadir angle

The 'Left Looking Nominal Mode', is obtained by commanding a roll manoeuvre to point the SAR antenna mechanical boresight on-ground to the left side at 34.065° off-nadir angle

System products

fig 10 - Examples of COSMO-SkyMed SAR products

The COSMO-SkyMed products are divided in the following major classes:

Standard products
Higher level products
Service products (for internal use only)

The Standard products are the basic image products of the system, are suitable for many remote sensing applications based on direct usage of low level products and are subdivided into 4 typologies, coded as:

1A, Single-look Complex Slant product, RAW data focused in slant range-azimuth projection, that is the sensor natural acquisition projection; product contains In-Phase and Quadrature of the focused data, weighted and radiometrically equalized

1B, Detected Ground Multi-look product, obtained detecting, multi-looking and projecting the Single-look Complex Slant data onto a grid regular in ground; Note: Spotlight Mode products are not multilooked

1C/1D, Geocoded product GEC (1C level product) and GTC (1D level product), obtained projecting the 1A product onto a regular grid in a chosen cartographic reference system. In case of Lev 1C the surface is the earth ellipsoid while for the Lev 1D a DEM (Digital Elevation Model) is used to approximate the real earth surface. In Lev 1D data is constituted by the Backscattering coefficient of the observed scene, multilooked (except for Spotlight Mode), including the annexed the Incidence Angles Mask

The previous products types shall be considered as product classes rather than products types since each of the four modes in which the SAR instrument operates, namely Stripmap, Polarimetric, ScanSAR, Spotlight, originate the related 1A/B/C/D products.

The Higher Level products, suited for mid or even high level remote sensing applications, are composed by the following products:

Quicklook, reduced spatial resolution image for browsing purposes

Co-registered products, a set of image layers coregistered together (i.e. merged in vertical direction), for interferometry, change detection and so on

Mosaiked products, a set of image joined together (i.e. merged in horizontal direction), for large spatial coverage representation

Speckle filtered image, an image with an increased equivalent number of looks (ENL)

Interferometric products (interferometric coherence and phase), in support of the interferometric applications

DEM, Digital elevation data and related height error map obtained with interferometric techniques

The common quality parameters of all the SAR products are:

PSLR ≤ -22 dB
ISLR ≤ -12 dB
Azimuth Point Target Ambiguity ≤ -40 dB
Radiom. Accuracy ≤ -1 dB (single look)
Radiom. Linearity ≤ -1.5 dB
Radiom. Stability ≤ -1 dB
Total NE°σ ≤ -19 dBm2/m2

SAR products are distributed in:

Format: HDF5

Media: DVD, CDROM, Magnetic cassette

Conclusions. System concept :*IEM* Interoperability, Expandability and Multi-Sensoriality

Current EO International initiatives, such as GMES (Global Monitoring for Environment and Security), GEOSS (Global Environment Outlook Support System) aim at finding a viable way to provide cost-effective solutions for future EO systems, granting Users with simple access to Multi-Mission/ Multi-Sensor (MM/MS) capabilities, and streamlined operations.

The COSMO-SkyMed system architecture strongly pursues these MM/MS goals, making feasible today the key capabilities of the future EO systems. Even if it is natively conceived as a spaceborne SAR observation system, provides at the same time a highly versatile architecture capable to support dual-use operations (Defence and Civilian), and further expansion to other sensors (SAR, optical, ..) such to effectively provide MM/MS observation capabilities.

In fulfilling this charter, highly innovative design solutions have been conceived for sustaining the whole MM/MS cycle, from the deposit of multi-sensor request throughout the delivery of multi-sensor products to End Users. In this sense the MM/MS design choices and actual capabilities of COSMO-SkyMed, can be explained through the basic concepts of IEM (i.e. *Interoperability*, *Expandability*, *Multi-Sensoriality*) :

- *Interoperability*; capability of exchanging data and information with external heterogeneous systems according to pre-defined agreed modalities and standards, and irrespective of internal design of the cooperating parts. The COSMO-SkyMed architecture implements standard Catalogue Interoperability Protocol based on CEOS guidelines, through which it provides access to a variety of EO systems worldwide;
- *Expandability*, ability of COSMO-SkyMEd architecture to embody mission-specific components "imported" from Partner's EO System, i.e. the capability to "expand" COSMO Capabilities to new Sensors/Systems by embedding into COSMO-SkyMed architectural elements **(**called *PFI= Partner Furnished Items***)** from Partner's systems (Foreign PFI) or "exporting" COSMO's PFI to be integrated into the partner's system.
  "Expandability" extends the concept of *Scalability*, that is the COSMO-SkyMed capacity to vary its configuration to satisfy new needs, adding (or deleting) 'copies' of blocks already part of the system, and configuring it properly (e.g. adding other archiving or processing units). COSMO-SkyMed is also capable to grow adding up to 5 more International Defence Partners, and up to more 5 Civilian Partners, by adding new entire UGS.
- *Multi-sensoriality*; ability to request, process and manage mission data related to different observation sensors. This is carried out by satisfying User requests, from depositing to product delivering, integrating COSMO-SkyMed with other relevant sensors, such as Optical, other Band SAR , Bistatic Radar, etc.
  Multisensoriality feature finds its architectural and procedural foundation on the Interoperability and Expandability.

In the last three years the Italian Space Agency started with 10 new application projects based on Cosmo SkyMed. These projects are: floods, fires, nowcasting, landslides, oil spill, earthquake risk, volcanic risk, coastal risk, air quality. Beyond air quality, the natural risk are matter of Cosmo SkyMed constellation. The great capability of short rivisit time together the high spatial resolution and all weather give at the user an excellent instrument whose features will be for the future the state of the art.

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