THE CONTRIBUTION OF THE COSMO-SKYMED SPACE SYSTEM IN THE INTERNATIONAL CONTEXT

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ABSTRACT

Since 2008 the Italian COSMO-SkyMed constellation is operative and from the beginning of 2011 it became fully operational providing its user community with invaluable information and data in several application domains such as risk and emergency management, multi-temporal acquisitions for agriculture monitoring, ship detection, interferometry, landslides monitoring, maritime surveillance, rapid mapping and security. COSMO-SkyMed adequately supports user needs because of its intrinsic characteristics such as world-wide coverage, high frequency of observations, different resolutions and swath width, varying from mid-resolution images of large geographical areas, up to very high resolution images of smaller areas, fast response time, high geolocation accuracy. These characteristics allowed Italian Space Agency (ASI) to implement very important cooperation with both national and international agencies and to provide support in different emergency situations. In this paper the main international cooperations established by ASI and some examples of the contribution provided by the COSMO-SkyMed mission in the international context are presented.

1. MISSION BACKGROUND AND STATUS

COSMO-SkyMed (*Constellation of Small Satellites for Mediterranean basin Observation*) is a constellation of four identical spacecrafts equipped with Synthetic Aperture Radar (SAR) operating in X-Band (9.6 GHz) and a Payload Data Handling and Transmission (PDHT) for the on-board storage and downlink of the SAR data. The system was conceived and funded by ASI (Agenzia Spaziale Italiana) and MoD (Italian Ministry of Defense), which manage the program in cooperation, and it was entirely developed and produced in Italy by TAS-I (*Thales Alenia Space-Italy*) as *Prime Contractor*, with the support of Telespazio for what concern the Ground Segment and logistic and operations and *Selex Galileo* [1]. A general description of the COSMO-SkyMed system architecture is given in [2, 3, 4, 5].

The constellation was incrementally deployed in the time interval 2007-2010 and its commissioning finished in the first half of 2011, when the constellation became fully operational. Currently, the nominal operational lifetime of the first satellite is concluded (Sept. 2012), but it is still in optimal status.

The COSMO-SkyMed constellation is able to operate in different mission configurations, each characterized by a specific orbital geometry which directly characterizes system capabilities and performances. Currently the full constellation has been deployed having a couple of satellites in one day interferometric configuration through the second and the third satellite whereas the first and the fourth satellite of the constellation are placed with a displacement of 90 deg in true anomaly in order to optimize the time performances of the overall constellation. The orbital cycle is 16 days and the constellation revisit time is lower than 12 hours [5]. The COSMO-SkyMed system can satisfy a User Request in 72 hours for the system working in routine mode, 36 hours for the crisis mode and 18 hours for the very urgent mode. It has to be clarified that these are worst cases values for acquisition in any place of the world while the real life experiences showed that the responsiveness of the system is of the order of 12 hours from the alert.

Civilian (Scientific, Institutional and Commercial) and Military users share system resources under appropriate regulations. ASI manages and coordinates institutional and scientific users allowing the utilization of the service for acquisitions and products ordering by mean of the COSMO-SkyMed web site [2], whereas the commercial users can access at the system through the commercial provider e-Geos, an ASI-Telespazio Company [6]. A summary of the COSMO-SkyMed Data Policy and Data Access is illustrated in [7].

It is well known that SAR data are appropriate for a number of applications: maritime applications including ship and oil spill detection, coastal monitoring, sea ice monitoring and extraction of wind and wave information; land applications including topographic and thematic mapping, agriculture and forestry applications, DEM extraction and subsidence measurements. COSMO-SkyMed can generate image products with various resolutions and sizes, spanning from narrow field/high resolution, up to wide field and mid/low resolution images according to the selected

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operational modes [5, 8]. Details about the operational modes are available in [5, 7].

The COSMO-SkyMed system offers an efficient response to user needs due to its main features:

- World-wide coverage.
- High frequency of observations (revisit time in the order of few hours).
- Night /Daylight /All Weather Observation capability (i.e. SAR technology).
- Various resolutions and swath width, varying from mid-resolution images of large geographical areas, up to very high resolution images of smaller areas.
- Fast response time between submission of Customer's imagery requests (implying new acquisition) to the delivery of the product.
- High geolocation accuracy.
- Interoperability and expandability, toward other Remote Sensing Systems.

For example, in the Maritime surveillance domain, the COSMO-SkyMed constellation provides an added value due to its high revisit frequency [6]. The system is able also to monitor large areas for oil spills detection using SCANSAR acquisition mode. Furthermore, thanks to the location of the baseline X-band ground station in Matera (South Italy), COSMO-SkyMed is able to cover the Mediterranean basin with Near Real time (NRT) services (product available within 30 minutes from satellite pass and acquisition) [4, 6].

2. INTERNATIONAL COOPERATIONS AND AGREEMENTS

2.1. ASI-CONAE Agreement

In 2000, ASI signed a cooperative agreement with CONAE (Comisión Nacional de Actividades Espaciales), Argentina's Space Agency. The agreement was referred to as SIASGE (Sistema Italo Argentino di Satelliti per la Gestione delle Emergenze - Italian/Argentinian satellite system for emergency management). SIASGE is a system of systems composed by four Italian COSMO-SkyMed satellites (X-band SAR) and two Argentinian satellites, SAOCOM (L-Band SAR) placed on the same orbital plane. The satellites will be operationally coordinated, using a system based on the interoperability capabilities of COSMO-SkyMed ground segment.

The system will be designed to provide a wide range of civilian applications in the field of emergencies management, being able to perform the temporal correlation of the phenomena of interest and data fusion. Once entered into its operational phase, the system will be available to be used by both ASI and CONAE. The operational integration of the two systems will provide a significant amount of data (in the bands X, X + L and L), thus opening a vast market of data and products relating to Earth Observation. The launch date of the Argentinean component is scheduled for the end of 2015.

According to this cooperation, and according to the system access rules CONAE is receiving COSMO-SkyMed data part of wich is made available to the scientific community in the frame of SAOCOM Announcement of Opportunity.

2.2. ASI-CNES

In 2001, an intergovernmental agreement (Memorandum of Understanding) was signed during the Turin meeting between Italy and France. The objective of this agreement, referred to as ORFEO (Optical and Radar Federated Earth Observation), is the cooperation of France and Italy on a "dual high-resolution Earth observation system" comprising a two-satellite constellation in the optical region under the leadership of France, and a four-satellite constellation equipped with X-band SAR sensors under the Italian leadership. The two-satellites equipped with advanced electro-optical payloads are known as Pleiades, whereas the four-satellites equipped with a synthetic aperture radar (SAR) are the COSMO-SkyMed constellation. The constellation is deployed in two orbital planes, one orbit plane for the SAR satellites and one orbit plane for the optical satellites. The intent of this agreement is to provide a long-term perspective on a number of high-quality data products and services on the commercial market for a wide range of applications in the fields of cartography, agriculture, forestry, hydrology, and geological prospecting.

2.3. ASI-JAXA Cooperation

Among the international cooperation is worth of mention the intergovernmental agreement (Memorandum of Understanding, MoU) signed in 2009 between ASI and JAXA (Japan Aerospace Exploration Agency) concerning the feasibility study and joint research activities for the mutual cooperation in the satellite disaster monitoring. In this framework a cooperative project was implemented for:

- feasibility study and demonstration for the improvement of observation frequency and of coordination during emergencies, using COSMO-SkyMed (X Band), ALOS (L Band), COSMO-SkyMed 2nd generation (X Band) and ALOS-2 (L band) satellites;
- joint SAR research activities related to disaster monitoring.

In particular the activity concerning "Emergency Operational Coordination" allowed to define the procedures to set up a coordinated operational acquisition plan during an emergency, to validate the procedures through simulations (DEMO#1 and

DEMO#2) and to perform a set of demonstrations in a real scenario/real case of emergencies activating the two Systems (DEMO#3-1 and DEMO#3-2 respectively in Japan and in Italy). DEMO#3-1 was regularly performed in the occasion of the earthquake and tsunami which hit Japan on 11 March 2011. In this context, ASI, in order to provide maximum support to the nation affected by the earthquake and tsunami provided about 200 products, an amount bigger than what originally foreseen.

Due to the interest of both Italian and Japanese Agencies, this scientific, operational and strategic cooperation has been extended at least to the end of 2014, with the main goal to use also the ALOS-2 data, whose launch is scheduled by the end of 2013. This cooperation allows the coordination of two radar systems operating in different bands, ensuring a multi-frequency support for the emergency management. Moreover, from a scientific point of view, it makes possible to perform the analysis of radar data in different frequency bands (X and L) with a better characterization of the observed scene and the possibility to use the full potential of the Earth Observation data. In order to obtain this results it is necessary to develop methods and systems that allow the combination of multiple information from different sensors. In this direction some projects have been activated by ASI, such as the ASI-INGV (Istituto Nazionale di Geofisica e Vulcanologia/National Institute of Geophysics and Volcanology) MUSA project (Use of multiband satellite SAR data for the study of crustal deformation related to the seismic cycle) [1]. The COSMO-SkyMed and ALOS data were used to test the processing technique called MAI (Multiple Aperture InSAR) on some test sites.

In the framework of the ASI-JAXA cooperation is worth of mention also the SAR4Volcanoes project [9, 10], funded by ASI and involving the joint use of SAR data in X-band and L-band for the measurement of the ground deformation in the volcanic areas, also to support the geophysical modeling of magmatic sources.

2.4. ASI-ESA Agreement

A significant example of the support activity in the international context provided by the COSMO-SkyMed system is represented by the recent agreement between ASI and ESA (European Space Agency).

After the end of life of the ENVISAT satellite, ESA requested ASI to provide COSMO-SkyMed images to a restricted group of Pi's of the Dragon 3 Programme [11]. Dragon is a cooperation between ESA and the Ministry of Science and Technology (MOST) of the P.R. China. The 3rd Dragon Programme formally started in the 2012 and will last four years. It focuses on exploitation of ESA and Chinese EO data for geo-science and applications development in land, ocean and atmospheric applications (climate, ice, geodesy, hazards, oceanography, renewable resources etc) [11]. Due to the end of life of the ENVISAT satellite, some of the projects included in the Dragon 3 Programme are using COSMO-SkyMed data both from archive or from new acquisitions starting from August 2013.

2.5. Other Institutional International Projects

ASI and Canadian (CSA) Space Agencies joint effort to stimulate the scientific utilization of Earth Observation data acquired by their respective national missions, RADARSAT-2 and COSMO-SkyMed, with an announcement of opportunity seeking for basic and applied research, development of algorithms, methods and applications. The call is limited to principal investigators from organizations established in Canada and Italy only and focuses on the synergistic evaluation of both sensors. The announcement of opportunity has been opened in September 2013 for a limited two-month period to submit a proposal (until November 1st, 2013) [1]. Bidders with accepted proposal will have access, free of charge, to ASI and CSA images.

The scientific use of COSMO-SkyMed system has been promoted also thanks to the activity of CIDOT (Centro Interpretazione Dati di Osservazione della Terra) an ASI center of competence in the field of Earth Observation data processing. Among the numerous projects managed by CIDOT is worth of mention the CaliMAP-Poseidon & Hafaestus Pilot (CaliMAP-PHP) project, proposed jointly by ASI/CIDOT and Caltech/JPL (California Institute of Technology -Jet Propulsion Laboratory) with the main objectives:

- to monitor trough systematic COSMO-SkyMed acquisitions the faults system from the northern end of the Gulf of California through western California (CaliMAP acquisition plan),
- to investigate earth surface deformation processes and their temporal evolution by using COSMO-SkyMed data for the earthquake hazard assessment (PHP).

This project is a pilot project in view of a future ASI/CIDOT-Caltech/JPL broader collaboration for designing and building cooperating systems for rapid response to man-made or natural hazards. The project will be developed jointly by ASI/CIDOT and JPL/Caltech and it will be mainly based on an exchanging of know-how, data, products and software.

The secondary objective is to explore the utilization of the CaliMAP (California Mapping) data set for:

- Earth Science studies;
- Applications such as: landslides, ice motion, oceanography/marine studies, vegetation studies, storm damage;
- Requirements for new missions concepts.

The COSMO-SkyMed acquisition plan for the

Califonia Mapping started on May 2013.

3. NATIONAL PROJECTS, COOPERATIONS AND AGREEMENTS

A number of National agreements for the COSMO-SkyMed products exploitation are on-going or are under definition or have been concluded.

A general overview of the current National institutional projects/agreements is provided in the following summary:

ASI PROJECTS

- MAP ITALY
- CIDOT Projects
- Announcement of Opportunity (concluded in 2012)
- Open Call AO-PMI (scheduled for the 4th quarter 2013)
- AO ASI-CSA (see section 2.5)
- Mapping Crater
- MUSA (see section 2.3)
- SAR4Volcanoes (see section 2.3)
- BLUE MASS MED Project
- ASI Pilot Projects
- Institutional National Projects (MATTM - Ministero dell'ambiente e della tutela del territorio e del mare/Ministry of the Land and Sea Environment; DPC- Department of the Civilian Protection; Ministry of Infrastructures and Transports; INGV – Istituto Nazionale di Geofisica e Vulcanologia/National Institute of Geophysics and Volcanology; Institute for Archeological Heritage of Rome; CNR - Consiglio Nazionale delle Ricerche/ National Research Council).
- Institutional request “on-demand”

Moreover in order to maximize the system exploitation during the operational lifetime of the constellation and to generate an historical image archive to be used as necessary in the future, for both institutional and commercial use ASI implemented a background mission. The COSMO-SkyMed Background Mission started in May 2011, when the constellation became fully operational. A more extensive and detailed description of guidelines, general requirements and status of this Background Mission are given in [7]. Currently a the Background Mission is under revision in order to take into account the user needs in terms of area of interests.

Initially, the background mission included also the coverage of the Italy in both, ascending and descending mode, with a frequency of observation of 16 days. The main goal of this project, called Map_Italy and required from the National Civilian Protection, is the analysis of the land instability phenomena (landslides, subsidence...) using interferometry techniques. The number of acquisitions related to this project require to occupies about the 60-70% of the system available resources. In order to realize this mission, due to its strategic importance, it was agreed to increase the priority level of this interferometric mission, which became a "foreground mission" [8].

CIDOT, in addition to the scientific promotion of the research activities, successfully managed the COSMO-SkyMed Announcement of Opportunity (AO). After the success of the first edition of COSMO SkyMed AO that ended in 2012, ASI will issue an “Open Call” for innovative projects based on the exploitation of COSMO-SkyMed data addressing both scientific community and industrial community active in the field of R&D. Through the “Open Call AO-PMI” ASI intended to select and to support the technological projects aimed to strengthening of the competitiveness of the National Small and Medium Enterprises (SMEs).

Mapping Crater is an institutional ASI project which aims to recognize almost 170 craters formed by the hypervelocity impact of a small body with the Earth surface by using the satellites of the COSMO-SkyMed constellation. Due to the high resolution (1 m in the Civilian Domain), the COSMO-SkyMed satellites allow to discriminate between concave and convex circular structures, eliminating a typical disturbing factor in the IR and optical data. Nowadays, a comprehensive crater album based on a coherent instrument does not exist, so the first objective is to generate a catalogue of images of the known impact craters based on the COSMO-SkyMed SAR system. This will help also the knowledge of the crater evolution depending on its age. The second step will be to explore new areas and to try to identify new impact craters. Currently almost the 60-70% of the selected areas of interest were acquired with the COSMO-SkyMed satellites.

The Blue Mass Med (BMM) project [12] is a project with the main goal to define the architecture of the future European wide Maritime Surveillance Network that will allow the interoperability among all Maritime Surveillance Systems, existing or future, basing on an agreed, standard reference model, to optimize the efficiency in the use presently made of the maritime patrolling and surveillance resources. In the BMM pilot project, institutional space assets (COSMO-SkyMed and PLEIADES), commercial assets (Space AIS) and LRIT have been integrated for the first time - in a whole and structured way - within the architecture of the future European maritime surveillance network, together with non-spatial in situ assets, to develop innovative services exploiting in particular SAR technology [8].

ASI Thematic Projects (PILOT PROJECTS) are promoted by ASI in the field of Earth Observation applications, in relation to themes such as the prediction, monitoring, management and mitigation of natural hazards and anthropogenic hazards (floods, landslides, fires, seismic risks, volcanic hazards, air quality, oil pollution on sea, coastal management) [1]. The approach generally followed is the development and demonstration of prototype services, using currently available data from space missions, in particular the COSMO-SkyMed mission [13]. Projects funded by ASI provide the convergence of various national industry expertise, research and institutional reference users [14, 15].

4. CONTRIBUTION OF THE COSMO-SKYMED SYSTEM IN THE RISK AND EMERGENCY MANAGEMENT

In the field of both national and international Emergency Management, ASI provided a strong contribution in a large number of cases. Significant examples are:

- Sichuan earthquakes, China, 2008 [16];
- Cyclone Nargis, Myanmar, 2008;
- L'Aquila earthquake, Italy, 2009 [17];
- Cyclone Aila, North Indian Ocean, 2009;
- Haiti Earthquake January 2010;
- Chile earthquake February 2010;
- Oil Spill of the Deepwater Horizon platform in the Gulf of Mexico August 2011;
- Tohoku Japan earthquake and tsunami, March 2011;
- North Europe Oil Spill, August 2011;
- Cruise ship accident near the Giglio island in Italy-January 2012
- Northern Italy earthquake May 2012 .

5. STATUS of the SYSTEM EXPLOITATION

Nominally, the constellation average daily acquisition capability is 1800 images in a 24 hours window (75 Spotlight plus 375 Stripmap or 150 ScanSAR for each satellite). This capability is independent from the number of UGS implemented in the Ground Segment that will process the data and it represent an upper limit for the satellite constellation operational profiles.

Currently the data volume is 475 new acquisitions per day at the C-UGS (Civilian User Ground Segment) with the limitation of 560 products downloadable at the Civilian Ground Segment.

In 2012 the percentage of system exploitation in the civilian domain was permanently greater than 80% of its current capability. In the last year this percentage is permanently greater than 90% reaching the 102% of its current capability (*Figure 1*): it means more than 14250 standard frames were acquired in 1 month.

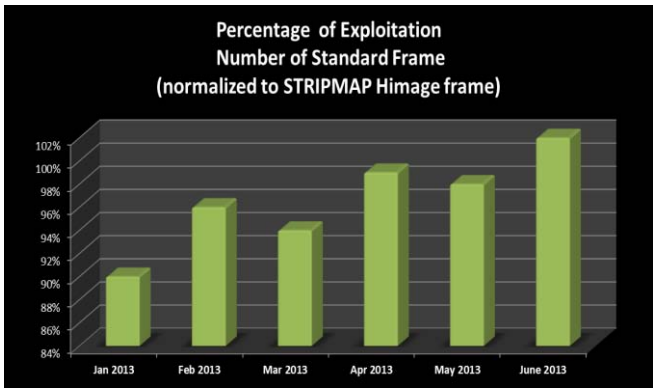

Figure 1- COSMO-SkyMed global statistics 2013 in the Civilian Users Domain (Percentage of exploitation in the civilian user domain).

6. FUTURE PERSPECTIVES

With the aim to guarantee continuity in the SAR data exploitation, ASI together with MoD is developing COSMO-SkyMed Seconda Generazione (CSG) [18]. The new constellation of two satellites aims at improving the quality of the imaging service, providing the end users with enhanced capabilities in terms of higher number of images and image quality (larger swath and finer spatial and radiometric resolution) with respect to the current COSMO-SkyMed. Moreover it will provide additional capabilities (e.g. full polarimetric SAR acquisition modes) granting a greater operative versatility both in terms of programming capability and the effective sharing of the system resources among different typologies of users requesting images of different characteristics.

CSG mission has been conceived, according to the requirements stated by ASI and Italian Ministry of Defence, at the twofold need of ensuring operational continuity to the currently operating "first generation" constellation, while achieving a generational step ahead in terms of functionality and performances. In doing so, CSG inherits the operative modes of the former CSK sensor improving their performances. In addition, CSG will also support new sensor modes and functionalities, not provided by the current CSK.

Hence CSG is not a mere recurring copy of COSMO-SkyMed first generation, constituting a jump ahead in terms of functionality and performances. CSG is based on a top level, state-of-the-art technology that interests:

- a brand-new design of the synthetic aperture radar (SAR) instrument, capable to make the space resolution of the "narrow field images" finer than CSK, while providing multi-polarization.
- a renewed payload data handling and transmission (PDHT) design that significantly improves the performances of the PDHT currently in use in CSK, in terms of on-board data storage capacity (doubled), space-to-ground data transmission throughput (doubled), data reception rate from SAR.
- a satellite platform enhanced from CSK, in terms of augmented electrical power (i.e. more than 40% of increasing, necessary to sustain the imaging performances), an avionics subsystem (AVS) new state-of-the-art design for a very high satellite agility, and an increased propulsion fuel tank capacity for a prolonged operative lifetime;
- the ground segment (GS) upgraded from the CSK to complement the CSG space segment innovations necessary to manage, control, and utilise a system with such an increased performance, while ensuring the full architectural integration between the 'old' CSK and the new CSG ground architectures and capabilities, necessary for a smoother transition first, and an optimal conduction of both the systems during the nominal operative phase. Moreover, the CSG ground segment will implement increased interoperability and expandability capabilities;
- the integrated logistic support and operations (ILS&OPS) segment that also provides an unique (CSK and CSG) operative perspective, unified tool suite and procedures for managing, operating, and maintaining the integrated "COSMO system" that will govern both constellations.

In order to ensure operational continuity, the new CSG satellites will be ready for operations timely to replace the previous generation satellites whenever they are being progressively phased out at the end of their lifetime, starting from 2015 onward.

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