THE COSMO-SKYMED BACKGROUND MISSION: A DATA ARCHIVE OF PRIMARY IMPORTANCE

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ABSTRACT

The experience accrued from the past SAR satellite missions (ERS, ENVISAT, RADARSAT-1) has proved the importance to build-up a data archive devoted both to scientific and commercial users. The availability of such data archive has indeed made possible the development and the fulfilment of new applications an add-value products without the limitation of waiting for the time required for the data acquisition. The access to a "reference" data archive for large areas of the Earth has proved to be of primary importance for Emergency Response applications, as well.
The COSMO-SkyMed constellation represents a really useful instrument able to perform systematic acquisitions in order to guarantee measuring continuity for the population of a substantial data archive. The COSMO-SkyMed Background Mission (BCK Mission) allows to create this archive for future applications, without undermining in any way other acquisition opportunities for users, since it is subordinated to higher priority acquisitions. It means this is a low priority acquisition plan which is kept as simple as possible and which allows to maximize the exploitation of the system. The COSMO-SkyMed BCK mission is intended to guarantee the availability of reference datasets for future mapping projects, emergency mapping and change detection applications. Data collected are stored and made available when required.
Specific aim of this paper is to give an overview about the selection and the development of operational scenarios for the utilization of COSMO–SkyMed system in the definition of the BCK mission, highlighting the proven usefulness and benefits of such kind of archive.

INTRODUCTION

COSMO-SkyMed, COnstellation of small Satellites for the Mediterranean basin Observation, consists of four Low Earth Orbit (LEO) mid-sized satellites, each equipped with a multi-mode, high-resolution and polarimetric X-band Synthetic Aperture Radar (SAR) that allows to acquire images of the Earth surface during night and day and regardless of weather conditions. The COSMO-SkyMed satellites were stepwise deployed from June 2007 to November 2010 and the system is fully operational starting from 2011, building up the largest Italian environmental laboratory in Space Systems for Earth Observation. The system, conceived as a Dual use system (civil and military), was commissioned by the Italian Space Agency (ASI) with the support of the Italian government, and was realized by Thales Alenia Space Italy as the industrial prime contractor for the Space Segment, and Telespazio as prime contractor for the Ground Segment. For what concern the commercial distribution of COSMO-SkyMed products ASI and Telespazio have constituted the e-GEOS company [1].
The availability of a SAR data archive has allowed the fulfilment of several projects based on differential interferometry, among which it is worth of special mention the "Piano Straordinario di Telerilevamento Ambientale". Thanks to this project the whole ESA (European Space Agency) SAR data archive over the Italian territory has been processed by means of Persistent Scatter Interferometry technique in order to update the database of the national cartographic portal based on terrain displacement measurements, providing an historical series from 1992 to 2010.

The COSMO-SkyMed constellation represents an exceptional instrument able to extend this kind of analysis with the necessary condition that a systematic acquisition is provided in order to guarantee the continuity in the population of a substantial data archive.

In the following sections the objectives of the BCK mission, the considerations about the current status and its implementation on a global scale are related.

BACKGROUND MISSION DEFINITION AND OBJECTIVES

The experience accrued from the past radar missions, together with the lessons learnt during the operational activity of COSMO-SkyMed mission, widely demonstrated the importance to collect data over specific areas or sites of interest, in order to build a useful and sizeable archive, considering the overall user community interest and anticipating their future needs. Such archive can be helpful for both developing new applications and providing products in a very short time to satisfy user requests, with the aim to reduce technical times needed for new data acquisitions [2].
Initially, the COSMO-SkyMed exploitation was mostly "on demand", on the basis of specific user requests and signed agreements. Once the constellation was fully-deployed and became fully-operational in 2011, it was decided to exploit the wide imaging and processing capacity offered by the system implementing a well-defined Background Mission [2]. This low priority acquisition plan allowed to maximize the system exploitation during the operational lifetime of the constellation and to build up consistent data sets for the users community, generating a strategic historical data archive. At the first step, it was evaluated that the global coverage could not be the best strategy of coverage, also considering the high degree of complexity of a dual use system, which could limit the system flexibility. For this reason, the areas of interest for the COSMO-SkyMed Background Mission were selected collecting the expression of interest related to specific sites and topics coming from the scientific and institutional community and taking into account possible customers' future needs [2]. The main criteria for the selection of suitable Areas of interest (AOI) are:

- population density (populated areas worldwide, large cities, cities, capital cities);
- economic and strategic relevance (oil and gas sites, UNESCO sites, dams, main railroads, etc);
- sensible areas (active volcanoes worldwide, seismic areas worldwide, areas subject to subsidence phenomena, glaciers).

Some of the main targets of the COSMO-SkyMed Background Mission (update to 2014) are reported in Table 1. These acquisitions, planned since 2011-2012, are divided by typology. The temporal frequency of observation is reported as well, considering the highest theoretical one, in case of conflict free situation.

Table 1: Some of the main targets of the COSMO-SkyMed Background Mission.

Typology	Number of Sites	Frequency of observation	Number of planned scenes
Small cities	762	4/16d	3048
Large cities	about 150	From 1/16d to 4/16d	954
UNESCO sites	264	4/16d	1056
Volcanoes	163	4/16d	652
Infrastructures	40	4/16d	80
Oil & Gas mining	19	4/16d	76
Ice	2	3/16d	6
Subsidence	20	4/16d	80
TOTAL	-	-	**5952**

The COSMO-SkyMed Background Mission also includes specific handbooks:

- Earthquake risk sites: interferometry acquisitions over areas with high seismic risk (for example, Japan, New Zealand and Iran).
- Monitoring of Volcanoes' craters.
- Mapping of extended areas: for example Kenya, Eritrea, Ethiopia, Djibouti, Somalia, Uganda, South Sudan and the south area of Sudan (starting from 2012).
- Global coverage of the world: this mapping started in 2014 with the coverage of the Alaska territory, selected as test-case to evaluate the operational impact of this handbook, and proceeded with the coverage of Canadian territory (see section *Global coverage*).
- Polar areas monitoring: at the end of 2014 a new ASI acquisition plan started in order to monitor specific elements of interest (e. g. glaciers) in Greenland and Antarctica.

In particular, for what concern the Volcanoes' handbook, 163 volcanoes distributed worldwide are regularly acquired with a frequency of observation of 16 days. Almost 30.000 scenes have been acquired in the framework of this specific Background Mission plan starting form 2011 [3].

The main objectives of the BCK acquisitions can be summarized as follows:

- To fulfil reference coverages over large areas to be used in future applications based on "change detection". In particular, areas with high risk of natural disasters or with events of geopolitical and humanitarian crisis are selected.
- The fulfilment of reference mapping over areas with scientific and, in perspective, commercial interest (e.g. polar regions).
- The performing of acquisitions for technology and innovative applications development (e.g. stereo pair for radargrammetry).
- The fulfilment of temporal series of interferometric acquisitions (interferometric "stack") over areas subject to subsidence phenomena or terrain or building displacements, with the aim both to promote the spread of new application products and anticipate feasible commercial requests.

By definition, the BCK acquisitions internally harmonize the requests coming from the institutional (ASI) and commercial (e-GEOS) users, based on both geographical criteria and type of foreseen applications.

BACKGROUND MISSION ACQUISITIONS' REQUIREMENTS

Specific requirements and guidelines have been identified for the implementation of the BCK acquisition plan. These requirements are described in the following sections.

General requirements (valid for all kind of acquisitions)

- The acquisition geometry over each area must be kept constant over time, irrespective of the number of satellites in orbit: once fixed the incidence angle, and then the beam, for each specific area, this must not be modified any more in order to not interrupt the continuity of the historical series.
- The nominal polarization is HH, this choice recalling the experience gained with ERS, ENVISAT and RADARSAT data.
- Observation direction: Right (nominal).

Further requirements for interferometric applications (PS with long temporal series)

- For the measuring of displacement in the mountainous areas, it deems necessary to have observations taken both in the Ascending and Descending geometry, while in the flat areas just one of the two modalities has been selected.

- The revisit time must be 16-days both on Ascending and Descending orbits: this temporal interval represents the best compromise between the need to acquire as large areas as possible, while guarantee their frequent temporal monitoring, and the acquisition of an interferometric stack in reasonable time.
- The nominal acquisition mode to be used is the Stripmap HIMAGE, since it guarantees a good compromise between resolution and swath (3mx3m Single look, 40kmx40km), and moreover it is the most fully tested modality [4] .
- The selection of the incidence angle is not particularly critical provided that it is kept constant over time. However the acquisition plan must be based on quite small incidence angles (almost between 25° and 37°), similar to those tested with ERS, ENVISAT and RADARSAT, which guarantee a better observation of some potentially interesting phenomena, such as for example slope or urban area landslides.

The acquisition plan offers a coverage of the areas of interest using both in ascending and descending, and as the latitude decreases, 2, 3, 4 or 5 among the following beams:

- H4-1 (incidence angle 24,94° - 28,36°)
- H4-3 (incidence angle 27,73° - 31,0°)
- H4-4 (incidence angle 30,67° - 33,80°)
- H4-5 (incidence angle 32,44° - 35,50°)
- H4-6 (incidence angle 33,95° - 37,13°), to select if the previous beams are not suitable
- H4-0B (incidence angle 22,09° - 25,94°), to be avoided in very mountainous areas

For areas of medium latitude, like Italy, 4 beams are enough (H4-01, H4-03, H4-04, H4-05).

Further requirements for mapping applications

- The acquisition mode varies based on the considered areas (Stripmap or ScanSAR).
- The selection of the incidence angle is defined based on the specific application for which the acquisition is performed (for instance, in case of a mapping devoted to flood risk, great incidence angles are selected).
- Cross acquisitions (ASC/DESC) can be considered for the coverage of areas with marked orography and then subject to layover and shadowing.
- Multiple angle acquisitions can be considered for applications such as the production of digital terrain model (DSM-DTM).
- The revisit time as well is selected based on the identified application (e.g. 1-year for flood mapping, 2/4-year for deforestation mapping, up to one coverage every 2/3-days for polar regions mapping).

BACKGROUND MISSION STATUS AND ACQUISITION PLAN

Overall, the Background Mission consists of more than 400 tasks a day, that become real acquisitions only if there are no conflicts with higher priority tasks. Data acquired by the BCK Mission are archived into the system with RAW level [4], without implementing any kind of processing for the generation of products. Nevertheless, the CSK catalogue allows the browsing of these data. The tasks included in the acquisition plan are very heterogeneous and can be listed as follows:

- ASI routine requests in the framework of Earth Observation projects or international cooperation
- e-GEOS requests over targets of potential interest for the customers

- e-GEOS requests for the development of new applications and the promotion of the system.

Figure 1 shows the geographic distribution of the BCK tasks during 2015.

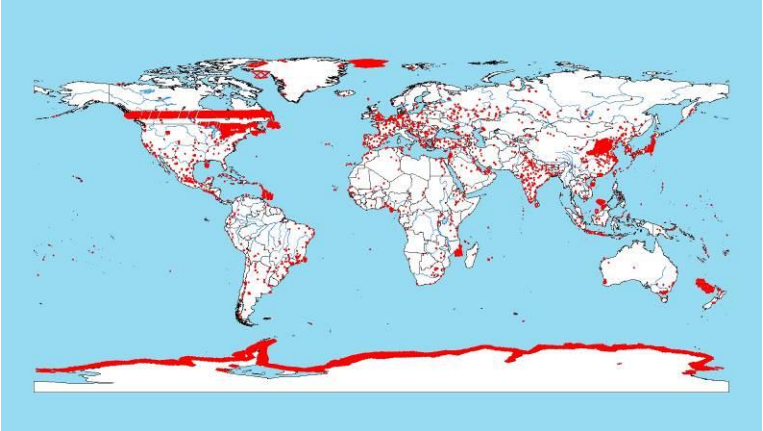

Figure 1: Targets distribution of one of the handbook of the COSMO-SkyMed Background Mission (courtesy of e-GEOS)

Background Mission acquisition requests have a mean planning percentage of about 75% (evaluated during the last four months).

Interferometric Stacks

Since May 2011 multiple acquisition planning (interferometric multi-temporal series) have been activated over well-defined areas, in compliance with one of the objectives of Background Mission (see section *Background Mission definition and objectives*). In the vast majority of cases, the selected acquisition mode is Stripmap, HH the polarization and the beams are those ranging between H4_0B and H4_06 [4] (in order to have the best sensitivity on the vertical movements). The planned revisit frequency is the highest possible, that is 4 data every 16 days for punctual areas (i.e. areas that can be covered by one frame only) and among 4 and 1 datum every 16 days for large areas (depending on the number of beams to be needed for the coverage). These acquisitions are foreseen to be continued during the entire 2015.

Polar region monitoring

Starting from 2013, an acquisition plan devoted to the cryosphere monitoring (Artic/Antarctic and Himalaya) has been implemented in order to study glacier dynamics and understand the ice sheets' response to the climate change. Since September 2014, this BCK plan has been reorganized and extended, in particular for what concern the acquisitions in Antarctica and Greenland in accordance to the objectives of the Polar Space Task Group (PSTG), an international research group in which ASI has a strong participation [5].
These acquisitions represent the contribution provided by ASI in the framework of the international cooperation with other space agencies. Figure 2 shows the glacier monitoring tasks, a part of which foreseen interferometric acquisitions with 4 satellites (4 acquisitions in 16 days):

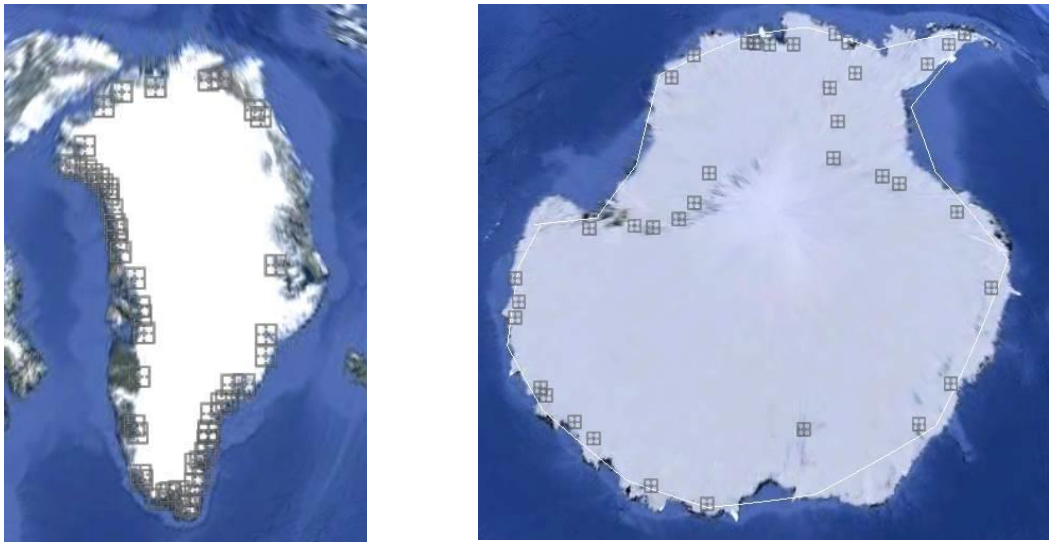

Figure 2: Greenland (left) and Antarctic (right) glaciers

The tasking plan includes 53 glaciers in Greenland and 12 glaciers in Antarctica, for a total of 247 scenes over the glaciers in Greenland and 465 scenes for the Antarctic border. In addition the complete and repeated mapping (interferometric series) of the Antarctic coast has been planned, as showed in Figure 3:

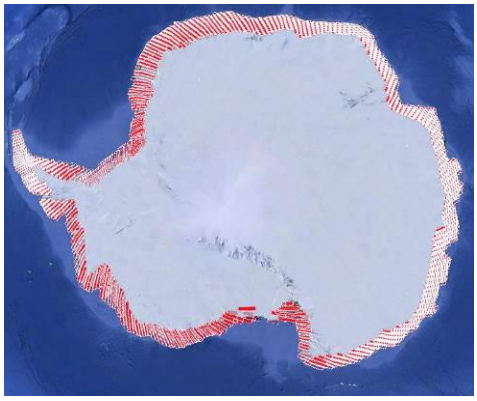

Figure 3: Antarctic Coastal mapping

Global coverage

Starting from the beginning of 2014, ASI requested a preliminary study for a new Background Mission in Stripmap HIMAGE mode with the aim to guarantee a global coverage the most complete as possible.
This Background Mission plan aims to the coverage of all the land area of the globe, having the challenging goal to acquire about 150,000,000 Km2 in Stripmap HIMAGE mode. A rough estimate of the extension of this activity shows that it requires to acquire more than 100,000 standard scenes (corresponding to the nominal Stripmap scene 40kmx40km).
Due to the huge amount of data to be acquired it has been decided to implement these coverages starting with some specific areas, the criteria used for planning this coverage being:

- Area coverage in both Ascending and Descending orbit direction

- Only right look view (nominal mode)
- Low incidence angle Beams have been used : H4_0A up to H4_05 [4]
- Definition of sub areas (sections) in latitude direction not greater than 400-450km, in order to avoid too long strip lines (operational constrains due to, for instance, the necessity not to overload the Acquisition Subsystem)

The first AOI to be selected as test-case in order to evaluate the operational impact of this Global coverage handbook, was Alaska. The whole Alaska territory has been split in several sections (along the latitude direction) in order not to schedule satellite acquisitions longer than 450 Km which would have risked to overload the processing chain and increase the cancellation rate (see Figure 4) . Consecutives sections have been programmed with different orbit direction (Section 1 Ascending + Section 2 Descending + Section 3 Ascending, etc.) with the aim to speed up full coverage. The coverage of Alaska foresaw about 800 strip line acquisitions in Ascending and Descending mode, corresponding to over 4200 standard acquisitions. The coverage of the Alaska territory, started in May 2014, was completed at the end of September 2014.
In Figure 4 the planned coverages of Alaska both in Ascending and Descending orbit direction are showed.

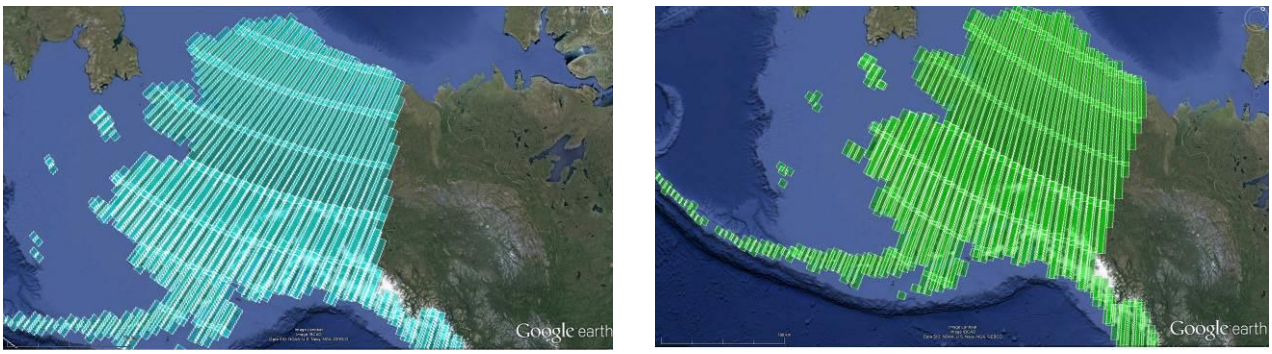

Figure 4: Coverage of Alaska in descending (left) and ascending (right) mode

Second Mapping to be inserted into the system, in June 2014, was the complete coverage of Canada using the same criteria defined above. The coverage of Canada is on-going and foresees about 3000 strip line acquisitions in Ascending and Descending mode, corresponding to about 10000 standard frames in Ascending and about 10000 in Descending direction.
Each coverage can be satisfied in a time frame that will vary depending on AOI extent, number of adjacent beams used, number of section and number of satellites used.
In order to increase the planning percentage of the World coverage requests, these orders can be managed as Privileged, giving them a higher priority than the other background requests that have routine priority.

Next AOIs to be acquired will be:

- Europe (except for Italy)
- United States
- Central America
- South America
- Africa
- Japan
- Australia (one coverage already performed in 2010)
- Middle East (Seismic areas)

Over the Italian territory a full interferometric mapping service has been activated and is still on-going, based on every-16 days Stripmap HIMAGE acquisitions, This project, called *Map Italy*, was expressly requested by the Italian Civil Protection. It started as Background Mission but, due to its strategic importance, it was agreed to increase it to a "Foreground Mission" priority level.

Other mapping coverages have been implemented that must be in addition to the above described Background Mission plans. They include:

- MapCalifornia (over the entire California territory, similar to Map Italy)
- MapChile (over the area between Chile and Bolivia, following the earthquake occurred in 2014, similar to Map Italy)
- Antarctic platform section

New Background Handbooks definition

As part of a complex and in-depth re-engineering process, aimed to exploit the full space capability for Civilian Users (which represents an upper limit for the constellation operational profiles), the Ground Segment has been modified. A series of upgrades dealing with programming, planning, acquiring, raw data processing and archiving activities, have been planned
Thanks to these improvements it will be possible, among the other things, to download the whole data volume of the constellation giving new start in the creation of a consistent data archive based on the mapping of large areas worldwide.
The dimensioning of this new Background Mission is foreseen to be performed in order to acquire the full constellation capability, namely more than 1000 standard images/day, compared with the current 475 standard images/day (due to the past sizing of the Ground Segment).

CONCLUSIONS

The COSMO-SkyMed constellation represents a very suitable instrument able to perform systematic acquisitions in order to guarantee measuring continuity of the past SAR satellite missions (ERS, ENVISAT, RADARSAT-1) for what concern the population of a substantial data archive.
The COSMO-SkyMed Background Mission is a low priority acquisition plan that allows to maximize the system exploitation while building up consistent data sets both for institutional and commercial user community, generating a strategic historical data archive.
In this paper an overview about the definition of the COSMO-SkyMed Background Mission and its current status has been provided. The applied requirements and objectives, the selected AOIs for the various handbooks and the specific acquisition plans for the implementation of the BCK Mission on a global scale have been described, as well, highlighting the proven usefulness and benefits of such kind of archive.

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