COSMO-SKYMED CONTRIBUTION IN THE POLAR REGIONS

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ABSTRACT

The aim of this paper is to illustrate the contribution provided by ASI to the polar community through COSMO-SkyMed data. In recent years, the CSK datasets acquired, also responding to the needs of the polar community expressed in the context of PSTG, represent relevant data for scientists and users in the study of polar phenomena such as: melting ice, speed of glaciers surface, monitoring of the polynya, mapping of the polar regions.

The Polar Space Task Group (PSTG) has been established under the auspices of the World Metereological Organization (WMO). The group mandate is to provide coordination across Space Agencies to facilitate acquisition and distribution of fundamental satellite datasets, and to support research and applications in the cryosphere. In order to better harmonize the collection and utilization of different Synthetic Aperture Radar (SAR) data sets, the SAR Coordination Working Group was formed as a sub-group of PSTG. ASI (the Italian Space Agency) participates to the PSTG contributing with COSMO-SkyMed (CSK) constellation data generated by four mid-sized satellites equipped with Synthetic Aperture Radar (SAR).

In the north and south polar regions, repeated coverage of ice sheets has been performed using COSMO-SkyMed SAR data since 2010 (also in conjunction with RADARSAT-2, TerraSAR-X, Sentinel-1). In order to support the recent needs, coming from scientific community for Ice Sheet application, ASI has been conceived a new planning of specific background acquisition plan in Antarctica and Greenland. The plans concern CSK high spatial and time resolution interferometric acquisitions of the Glaciers and the Antarctic coast.

In addition ASI has recently issued two open calls dedicated to the scientific utilization of COSMO-SkyMed data (free of charge) for basic and applied Research & Development (R&D).

INTRODUCTION

The Polar Regions are extremely important in terms of their global impacts on weather and climate, and the functioning of the Earth system, in addition to this human presence and activities are increasing in Polar Regions. An integrated approach is needed to understand global impact of changes in Polar Regions so that required services may be provided to users and that governments may be advised on aspects of adaptation and mitigation (1). It is therefore required to identify the satellite observations, in detail the set of satellite measurements, to address key science questions relevant to the assessment of the impacts of climate change in the Polar Regions.

Ice sheet, Reducing Arctic and Antarctic sea ice, has been a widely publicized and visible indicator of climate change. Climate feedback mechanisms involving sea ice and lake ice have important implications for the future progression of climate change. Icebergs present a

significant hazard to marine operations and are an important factor in the transport of freshwater and nutrients, in a changing climate scenario, there is concern that iceberg distribution patterns and iceberg characteristics themselves may be changing. There is a need to monitor all of these changes and to model their behavior in order to develop adaptation responses to deal with the inevitable impacts. There are pressing science questions about all aspects of floating ice and priorities vary greatly depending on the user and the application. However the overall consensus is that, because of their importance in the climate system and the state of current observational limitations, the following areas are most in need of investment to improve our measurement capability: sea ice thickness and thickness distribution, snow cover on sea ice and sea ice deformation (2).

The World Meteorological Organization (WMO) plays a leading role in international efforts to monitor and protect the environment through its scientific and technical programs. WMO facilitates the free and unrestricted exchange of data and information, products and services in real- or near-real time on matters relating to safety and security of society, economic welfare and the protection of the environment. It contributes to policy formulation in these areas at national and international levels (3). Under the auspice of World Meteorological Organization's (WMO) and the Executive Council Panel of Experts on Polar Observations Research and Services (EC-PORS), the Polar Space Task Group (PSTG) has been established in 2011. The group's mandate is to provide coordination across Space Agencies to facilitate acquisition and distribution of fundamental satellite datasets, and to contribute to or support development of specific derived products in support of cryospheric and polar scientific research and applications. In the framework of PSTG the subsidiary PSTG SAR Coordination Working Group was created to address the issue of SAR data acquisitions in the cryosphere (4).

Focusing on SAR capabilities, the general expectation in the ice community is that multiple SAR frequencies, polarizations and incidence angles, along with a higher frequency of repeat observations, will lead to greater understanding of the physical processes involved. The swath width requirement is generally to be as large as possible meeting the requirements in terms of resolution, polarization and interferometry. Scientists are very interested to use HH+HV and HH+VV polarizations (2).

In order to support the needs coming from scientific polar community ASI has reorganized and expanded the background mission to monitor the cryosphere, particularly with new acquisition plans in Antarctica to Greenland. In addition, the cost and availability of satellite SAR data remain major obstacles for some researchers ASI has recently issued two open calls allowing the use of a COSMO-SkyMed dataset, free of charge, after receiving positive evaluations of the submitted projects.

POLAR SPACE TASK GROUP ACTIVITY

The PSTG is a successor of the successful International Polar Year Space Task Group (IPY-STG), established for the purpose of Space Agency planning, processing and archiving of the IPY Earth Observation legacy dataset. This new group shall be an independent working group, which reports to the EC Panel of Experts on Polar Observations, Research and Services (EC-PORS) via common membership of its observational task team. A suitable reporting mechanism shall be established to inform CEOS (Committee on Earth Observing Satellites), CGMS (Coordinating Group on Meteorological Satellites) and WMO Consultative Meetings on high-level policy on satellite matters on relevant PSTG progress and issues (4).

The PSTG activity shall enable to assemble disciplinary science requirements for polar and cryospheric research to be addressed with space-borne systems through regular and broad interaction with the science community. Moreover, it shall be to develop a concise, prioritized list of observational objectives based on: efficient use of the international constellation of satellites, operating mandates of each space agency, and satisfying science objectives best served by coordinating agency activities. This task shall be achieved through iteration amongst the planning and processing arms of the participating international space agencies, including their representatives within ET-SAT(Expert Team on Satellite Systems).

In order to assist with the collection and utilization of -borne synthetic aperture radar (SAR) data sets, the members of subsidiary SAR CWG (public space agencies and commercial data providers) are working together to acquire in a coordinated fashion extensive sets of space-borne SAR data to respond to scientific requirements, taking advantage of the specific characteristics of each sensor. The PSTG and the SAR CWG support also data distribution and sharing principles.

SAR-related Science Requirements evaluated

GCW (Global Cryosphere Watch) observational requirements are being formulated, and they are accessible on line through the Observing Systems Capability Analysis and Review Tool (OSCAR), the official source for WMO requirements. In the section of cryosphere theme (5) PSTG requirements are also included, they regard satellite information, particularly with SAR sensor, for the study of ice sheets, permafrost, snow, and floating, ice (4).

SAR-related Science Requirements for Ice Sheets were analysed, consolidated and documented for consideration by the Task Group and SAR CWG, in a document named SAR Science Requirements for Ice Sheets (6). Users emphasized the need for continuous records of low-resolution satellite data in the interior areas of ice sheets and high-resolution data in the margin areas for measuring both ice velocity and grounding lines (where the glacier loses contact with the ground and becomes a floating ice shelf), particularly for modelling major fast-flowing ice streams and glacier systems. The user survey specifically focused on Greenland and antarctica areas. Based on experience general recommendations are given on the use of space-born SAR data, in particular Polarisation HH is preferred as also the stripmap acquisition mode with a incidence angle range between 25 and 45 degrees (even 57 to cover South Pole).

A SAR data acquisition campaigns for Arctic (focus on Greenland) and Antarctic ice sheets monitoring was carried out in 2013. A SAR assets (L, C, and X-bands) of several space agencies was employed us a “virtual constellation” of coordinated satellite SAR missions: RADARSAT (CSA and MDA, Canada), TerraSAR-X (DLR, Germany) and COSMO-SkyMed (ASI, Italy). Moreover area of priority was delineated, on the base of the priority level identified by the scientific community (6) recommending to acquire a set of sites and glaciers (also called supersites) with high-resolution X-band sensors (i.e. TerraSar-X and COSMO-SkyMed) (5,7). There is in Antarctica 6 sites (in Greenland 11) at level 3 (maximum priority), 6 at level 2 (in Greenland 11) and 27 (in Greenland 16) at level 1 (lower priority).

Concerning to the glaciers it is recommended to acquire each cycle (ongoing acquisitions) for level 3; 3-5 pairs per year (i.e. 2 in winter, 1 in summer or 2 in winter, rest evenly spread) for level 2; 1 pair per year (winter acquisition) for level 1; in addition it is recommended to perform the coverage of the Antarctic coast (6). On the base of ice sheet requirements ASI has recently expanded the acquisition plan of background on Polar Regions, as described in next section.

Recently in 2014 SAR requirements for permafrost, wet snow and floating ice are delineated on PSTG document available online (http://www.wmo.int/pages/prog/sat/pstg_en.php) to address the coordination of SAR data acquisition campaigns among the various member agencies of SAR CWG.

COSMO-SKYMED MISSION OVERVIEW

ASI participates to the PSTG in the SAR Working Group contributing with COSMO-SkyMed (Constellation of Small satellites for Mediterranean basin Observation). It is an Italian Earth Observation Dual-Use (Civilian and Defence) Space System for global environmental monitoring, scientific and commercial purposes and strategic applications (defence and national security). COSMO-SkyMed has been designed to face international partnerships and integration of the system itself into a multi-mission framework of cooperating multi-sensor systems. The CSK constellation is fully operational starting from 2011 and it consists of four mid-sized satellites, each equipped with a microwave high-resolution Synthetic Aperture Radar (SAR) operating in X-band at 9.6 GHz. The four satellites of the COSMO-SkyMed constellation follow a heliosynchronous low orbit (619 km above the Earth surface) around the Earth. The nominal (full sized) constellation configuration is conceived to achieve the best compromise among cost and performance, providing a global Earth access of few hours, with at least two opportunities in one day to access the same target site on the Earth under different observing conditions (incidence angle). In the nominal configuration the four satellites are equi-phased at 90° each other in the same orbital plane. Currently the constellation is deployed in tandem-like configuration, in which the COSMO-2 and COSMO-3 satellites fly in close proximity (67.5°) to achieve a 1-day interferometric configuration as shown below. The orbital cycle is 16 days and the constellation revisit time is less than 12 hours.

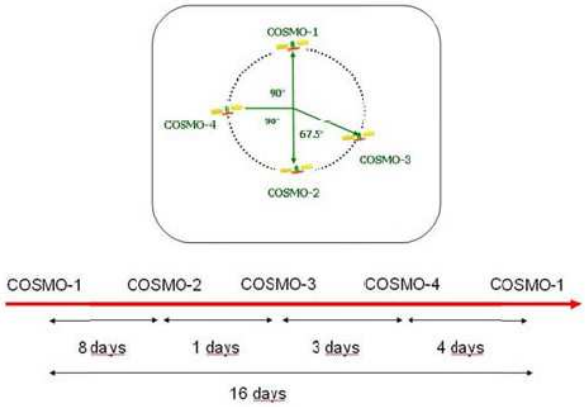

Figure 1: COSMO-SkyMed current orbital configuration

The COSMO-SkyMed ground segment is geographically distributed, the two main ground control stations being located at Fucino and Matera space centers. The Centro Pianificazione e Controllo Missione (CPCM) in Fucino handles and controls the satellites courses, while the Civil User Ground Segment (C-UGS) in Matera, receives satellite data, processes and delivers the SAR products. Additional "support stations" are the receiving stations at Cordoba (Argentina)

and Kiruna (Sweden), in order to augment the satellite visibility, and about 20 GPS stations, part of the so-called GPS “fiduciary network”, distributed worldwide. Moreover a scaled version of user terminals are currently deployed all over the world at civilian customer premises. They are able to acquire and process the satellite data,

The COSMO-SkyMed system is capable to satisfy a user request (ability to deliver the image product required by an end user in a timely manner). it is, which in the worst case is of 72 hours, for the system working in routine mode (acquisition plan uploaded once a day), 36 hours for the crisis mode (acquisition plan uploaded twice a day) and 18 hours for very urgent mode (acquisition plan uploaded asynchronously) (8).

In order to supply data for a wide variety of application, ranging from cartography to emergency response, the SAR payload has been designed to acquire a scene in three different modes, according to the image area and the resolution that can be obtained. They are SPOTLIGHT (high resolution and medium image area), STRIPMAP (HIMAGE and PING-PONG, medium resolution and large image area) and SCANSAR (WIDE and HUGE REGION, lower resolution and wide image area), more details are given in (8,9). Based on dual-use conception, according to an appropriate and well-defined data policy, the system is conceived in order to allocate 25% of its resource to civilian (scientific, institutional and commercial) users and 75% to defense ones. In the civilian domain, we can have institutional and commercial users. ASI provides technical and operational coordination managing the istitutional use of the system, whereas the commercial exploitation of the system is implemented through the commercial provider e-Geos, an ASI (20%)-Telespazio (80%) Company. Among the institutional users, there are international partners, national and international administrations, agencies, ministries, universities, research Centers, etc. They sign a specific agreement with ASI to access to the system (10, 11).
In polar regions, due to its polar orbit, the COSMO-SkyMed 4-satellites can offer unique opportunities in term of time revisit and high coverage. At 70° latitude up to 8 right-looking and 8 left-looking acquisitions are feasible, then right and left looking modes for each of the 4 satellites allows the coverage of large areas in a short time like in the case of the north-east and north-west pass covered in only 24 hours (12).

PSTG: COSMO-SKYMED POLAR OBSERVATION CONTRIBUTE

COSMO-SkyMed Mission on Polar Region

The experience gained from previous satellite missions, such as ERS, ENVISAT and RADARSAT-1 has shown the importance of building a useful data archive (catalogue of image) for commercial and institutional user community allowing the data exploitation for their advances future needs, so from May 2011, when the COSMO-SkyMed constellation was fully deployed and became fully operational, acquisition plans of background were completed and put in place. The areas of interest were selected collecting the expression of interest related to specific sites and topics coming from a wide scientific and institutional community. The main area selection criteria was: sensible areas (active volcanoes worldwide, seismic areas worldwide, areas subject to subsidence phenomena, glaciers), population density (populated areas worldwide, large cities, cities, capital cities), economic and strategic relevance (oil and gas sites, UNESCO sites, dams, main railroads, etc.). The background mission applies a systematic low priority acquisition strategy, so to obtain regular, repetitive and comparable acquisitions and to minimize possible conflicts with existing user requests more detail on guidelines and general requirements are given in (13,14,15) .

With the aim to meet the objectives of the Polar Space Task Group (PSTG) and assuring the data continuity through space-borne data collection over ice sheets, from September 2014 new background acquisition plans were implemented on polar areas. They regard the acquisitions of interferometric series of glaciers in Greenland and Antarctica, indicated in the SAR Science Requirements for Ice Sheets (6), and the complete and interferometric repeated mapping of the Antarctic coast. Since the end of September 2014 acquisitions on glaciers with higher priority level 3 were planned, they regard 11 glaciers in Greenland end 6 in Antarctica. The glaciers observations are operating in the Stripmap mode (3-5 m res., 40 km swath), polarization HH, , ascending and descending directions, incidence angles between 25° - 45°, same acquisition geometry (InSAR time series) for each glacier. Most of the glaciers are covered with a single standard frame (40 km x 40 km) with time resolution of 4 and 8 days performed using pre-defined acquisition geometry.

Figure 2: COSMO-SkyMed coverage of Antartic (left) and Greenland (right) Glacier.

From January 2015, the InSAR acquisition plan of Antarctic Glaciers of priority level 2 and 1 started with the same requirement characteristics above, but with a time resolution of 16 day.

The acquisition geometries used in all these plans were chosen according to the criteria of minimizing conflicts and acquisition modes considered in background policy (for example only right looking side acquisition mode). For the reason above and the associated low level of priority the glaciers located in the central part of the Antarctica are not currently acquired in fact they would require a left look side acquisition mode and this could be conflicted with the others acquisition plans activated on glaciers with higher priority. Another criterion considered in the definition of these plans in the PSTG context was to continue the time series already in the archive following, as much as possible, the requirements provided under PSTG as it happened to the four glaciers in Greenland Helmen, Jacobshaun, Petermann, and Rink Isbrae.

In addition from January 2015, the InSAR acquisition plan of Antarctic coast of priority level 3 started with a time resolution of 16 days and same characteristics mentioned above. In detail only two beams are used H4_01 for CSK1 and H4_03 for CSK4 (look angle associated to the beams are available at the link http://www.cosmo-skymed.it/docs/ASI-CSM-ENG-RS-092-A-

CSKSARProductsHandbook.pdf), both in right ascending except for a small part of the coast instead acquired in right descending direction.

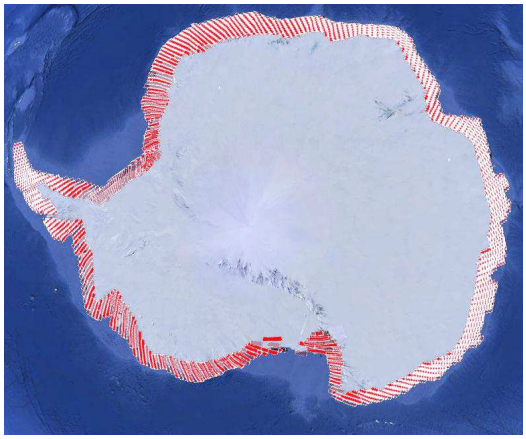

Figure 3: COSMO-SkyMed Antartic Cost Coverage

All acquisition made on polar areas are available on the COSMO-SkyMed archive and they are visible on the online COSMO-SkyMed catalog (http://87.241.31.78/index.php). Among them there are also the acquisitions made on polar areas in the framework of background plans previously activated by a commercial provider (e-geos) to create a useful acquisitions archive for interferometric applications on sites of potential commercial interest. They include the major glaciers as the Petermans, the North-East and North-West passes; in particular the last target requires a temporary monitoring performed during spring and summer. In the same way Periodic interferometric acquisitions are generally performed using a pre-defined acquisition geometry. In addition, from second half of 2013 e-geos has activated new task to demonstrate the ability of COSMO-SkyMed capture with very high frequency data on a specific area or to cover a wide area. In this case, they are not acquired interferometric stack, but series of images with heterogeneous geometry, for example few data are acquired over the same AOI using 4 different geometries for radargrammetric application. This kind of requests has typically a short acquisition window (2-3 Cycles) with respect to nominal BCK having an unlimited validity. In the framework of cryosphere monitoring a task chosen is the Frame Strait. It represents an important area to monitor the phenomenon of ice flows leaving the polar zones; on this area ScanSAR-HR acquisition was planned with a frequency of six acquisitions per day. In addition a sequence of In SAR acquisition both in right descending that right ascending.

The graphic below gives a distribution of data acquired on polar region in the framework of background mission until May 2015. The graphic shows the image percentage, in term of standard frame, acquired on Greenland and Antarctica in new plans is activated from September 2014 in the context of PSTG and the remaining acquired on polar region and available in the COSMO-SkyMed archive.

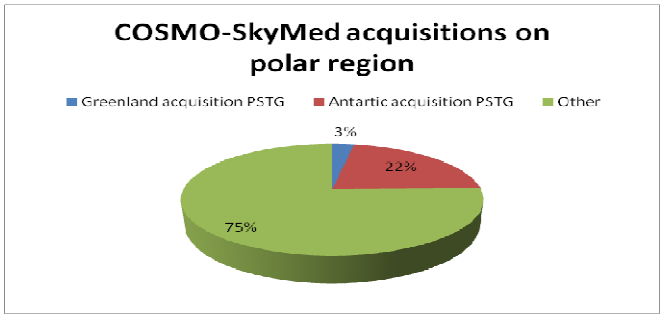

Figure 4: Distribuition of COSMO-Skymed image acquired on polar region by background plans

ASI Open call

ASI periodically issues announcements of opportunities dedicated to COSMO-SkyMed data exploitation in a wide variety of scientific research and application thematic. In May 2010 after the 1st Announcement of opportunity, 172 new projects were activated and concluded in the 2012; in September 2013 the joint call "COSMO-SkyMed-RADARSAT-2 initiative" was issued with the aim to facilitate the synergetic use of COSMO-SkyMed and RADARSAT-2 data. About 50 Project were selected and they are still ongoing. The last open call for national and international scientific community was published on the ASI's website on 25 February 2015 that ASI intends to dedicate to the scientific utilization of COSMO-SkyMed data for basic and applied R&D on new algorithms, products and applications. The main objectives of this call are to improve the existing applications or the development of new technologies and algorithms based on Earth Observation information using products in X band from the COSMO-SkyMed constellation and to facilitate innovative ideas for their synergistic utilization with the ESA and international EO Missions. Proposals shall be submitted in one of the topic between COSMO-SkyMed constellation innovative exploitation, COSMO-SkyMed and synergies with other EO missions and COSMO-SkyMed methods and algorithms. The Proposal shall be submitted in one of the topic between COSMO-SkyMed Constellation Innovative Exploitation, COSMO-SkyMed and Synergies with other EO Missions and COSMO-SkyMed Methods and Algorithms.

The opportunity to submit a proposal for this call will be open permanently and proposals can be submitted anytime via online submission. Selected projects will be supported until a maximum of two years, through a provision of a maximum of 100 COSMO-SkyMed scenes free of charge, exceptionally a request of a greater number of images could be possible, after right valuation of justification. Normally for each project the majority (at least 80%) of the products must be ordered from COSMO-SkyMed archive, a number of new acquisitions can be requested too, for a maximum of 20% out of the total number of the products16.

COSMO-SKYMED APPLICATIONS IN POLAR REGIONS

A COSMO-SkyMed Greenland 2008-2010 campaign managed in cooperation with e-geos and focused on the Petermann was implemented to acquire until two images per day in specific periods. In the picture below the short time interval of 18 minutes between two acquisitions has allowed a perfect identification of the current pattern around the big iceberg not moving since blocked by the rocks.

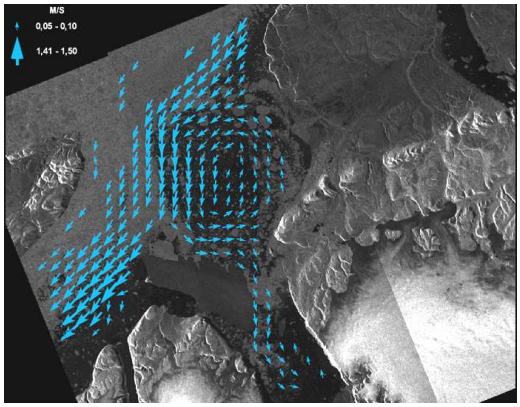

Figure 5: Peterman Glacier: a current pattern around a big iceberg is carried out using two scansar wide images, the former acquired on 3 September at 8:50 UTC, the latter 18 minutes later at 9:50.

The COSMO-SkyMed Greenland 2011-2012 campaign provided the possibility to monitor polar routes in one day (using the ScanSAR huge region mode). In the picture below the area covered is shown with a sequence of Scansar huge acquisition (e-geos property image, kindly provided).

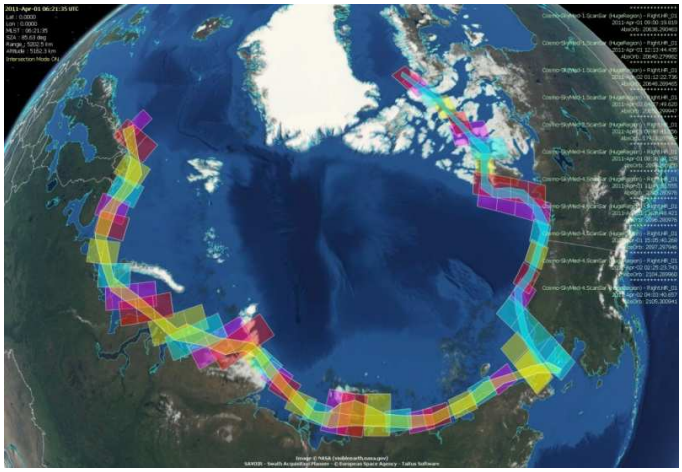

Fig 6: COSMO-SkyMed Coverage of polar route, full scenario in one day (e-geos property image, kindly provided).

The COSMO-SkyMed Greenland 2013-2016 campaign is ongoing on Fraim strait to provide information on the east Greenland current and sea ice drift using ScanSAR, and stripmap acquisition. A one / eight day revisit time could be used for specific cases if needed.

Over Antarctica, the COSMO-SkyMed Antarctica 2008-2012 mission aimed to monitor main glaciers (e.g. Drygalsky) and ice sheets, the French-Italian Concordia Station (Dome-C), the M. Zucchelli Station, the polynya in Ross Bay and to survey the Antarctic Peninsula (breaking of the Wilkins ice shelf). The whole Antarctic Coast and the Glaciers of different priority level in Greenland and Antarctica are monitoring (15).

In the framework of Sea ice monitoring, sea ice information is required by a wide spectrum of users (Authorities and privately held companies) operating at high latitudes, including navigation (rivers, lakes and sea) and offshore operations. Satellite Earth Observation and in particular SAR instruments represent a reliable tool for ice monitoring, providing a synoptic view that complements the accurate but low coverage reports from ships and airborne sources (17). SAR data provide information on the ice coverage, the size and shape of ice floes. In particular, SAR images provide the crucial advantage of a weather-independent, day–night imaging system, in the ice-sheet and glacier environments where persistent clouds continue to hamper data acquisitions by visible imagers and where the polar night imposes a prolonged period of darkness.

Ice monitoring is also of great significance for studies of climate history and ice-climate interactions and ice velocity is one of the fundamental parameters in the study of glacier's dynamics. Vectors can be extracted by tracking glacier's surface features from the sequence of visible and Synthetic Aperture Radar (SAR) satellite data, and the proven ability to extract ice velocity vectors from time-sequential imagery significantly expanded the amount and density of such data available to glaciologists. The study illustrated in (18) uses the monitoring capability offered by COSMO SkyMed to acquire a high resolution SAR images sequence with a time lag of few days, to extract ice velocity fields and to reveal (using the sequence) the variability of the ice flow in the study period. Vectors are extracted from pairs of sequential images by an automated processing based on the maximum cross-correlation (MCC), often referred to as amplitude correlation when applied to radar data.

Timely and variable information on sea ice conditions are essential for all operations in ice-covered areas. The safety and efficiency of sea transportation, offshore operations, fisheries and other activities in regions covered by sea ice have been the motive for establishing operational sea ice monitoring and forecasting services in many countries. There is a need for high-resolution ice information and ice forecasts. One of the service required is the Ice Charting, more details about service in Baltic Sea are reported (19,17). Finnish Meteorological Institute (FMI) produces information in the sea sciences for the benefit of decision-makers and to meet operational needs, it offers services to the authorities, industry, commerce and private citizens. It actively participates in pertinent national and international collaboration (20, 21).

Finally Several projects on polar areas, using COSMO-SkyMed data, were activated in the framework of a joint call “COSMO-SkyMed-RADARSAT-2 initiative” regarding topics such as sea ice snow cover, sea ice mapping, displacement and velocity of West Antarctica glacier ice sheet derived from X- and C-band InSAR pairs in combination with other sensors too.

CONCLUSIONS AND FUTURE INTENT

Next step will be to optimize and calibrate the COSMO-SkyMed background acquisition plans on polar regions on the base of the requirements collected also in the framework of PSTG. Feedbacks from scientist community are considered essential to improve the exploitation of COSMO-SkyMed data allowing the realization of new innovative projects aiming at increasing the measurements accuracy of the climate change indicators.

In the framework of the PSTG the assets of participating space agencies will continue to monitor ice sheets and contribute to the legacy of archived Earth observation satellite products of the Arctic and Antarctica. Repeated coverage of ice sheets in the north and south polar regions are just planned in the period from 2014 to 2016 through RADARSAT-2, TerraSAR-X, COSMO-

SkyMed, ALOS-2, and Sentinel-1 SAR data acquisitions plan. In particular The German and Italian X-band mission plans will include timed series of fast flowing glaciers in both Greenland and Antarctica. In order to meet the requirements indicated in the PSTG context ASI has reorganized and expanded the background mission to monitor the cryosphere, particularly with new acquisition plans in Antarctica to Greenland. The large dataset available in the CSK archive encompasses various glaciers and ice sheets located in polar regions also using InSAR coverage with different time resolutions (i.e.: 1, 4, 8, 16 days) (22).

Finally a last consideration can be worthwhile to underline: satellite SAR missions are rapidly progressing from the purely scientific domain to the commercial realm. A significant concern of the scientific community is that the need to acquire data for commercial activities will reduce the quantity and variety of data available for research. The cost and availability of satellite SAR data remain major obstacles for some researchers while the operational centres have access to large quantities of data. ASI are supporting in and promoting the use of SAR data by scientific community through periodic calls allowing the use of COSMO-SkyMed datasets free of charge.

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