IPY Legacy of Satellite Radar Data in Polar Regions

Coordination is Key to Success in Acquiring Large Science Data Set

One of the major successes of the International Polar Year (IPY) in 2007-2008 was the unprecedented amount of high-resolution synthetic aperture radar (SAR) satellite imagery collected over the polar regions and the high quality data products that have since been generated. This outstanding accomplishment relied on a well-coordinated effort on the part of several space agencies, satellite operators and the science community. The work continues a tradition of coordinating space-related Earth observation activities, as initially fostered by the Committee of Earth Observation Satellites and practiced, for example, by the International Ocean Colour Coordination Group.

It began with a request in December 2006 from the World Meteorological Organization (WMO) and International Council for Science (ICSU) to provide coordinated synoptic remote sensing data from space-based sensors. In response, the international space agencies convened the IPY Space Task Group to support IPY science requirements, and a SAR Coordination Group was subsequently formed to address the unique challenges of assembling satellite radar data and data products. The following is an account of the overall coordination effort, the unique circumstances that have lead to the provision of processed data and information products, and the lessons that can be learned for future campaigns.

“To our knowledge, this is arguably the first time that civilian space agencies have worked together to create such a huge SAR data set of lasting scientific value. The data set covers both north and south polar regions and has multi-polarization, multi-frequency, multi-temporal and multi-resolution attributes. Over time, it will be used to assess the extent of change and rate of change in polar regions.”

Yves Crevier and Ken Jezek
Co-chairs, IPY SAR Coordination Group
OVERVIEW

Following in the tradition of polar research over the past century, the International Polar Year provides an effective international framework for understanding high-latitude climate change and predicting worldwide impacts. Recent satellite observations of the dynamic components of the Earth’s cryosphere make IPY science investigations particularly timely and relevant to scientists, policy makers and the general public, laying a modern foundation for major scientific advances in knowledge and understanding of polar regions and their functional role on our planet.

The formation of a IPY Space Task Group (STG) goes back to December 2006 when the WMO and ICSU requested the involvement of the space agencies. The STG was tasked to review IPY related space data requirements and, in close consultation with science end-users, draw up data acquisition plans, and recommend data processing, archiving and distribution procedures for potential space agency contributions. There was already a clear understanding among the parties concerned that a well-coordinated effort was required to satisfy IPY satellite data needs and that the space agencies should contribute to the extent possible within their respective resources and capabilities. The Canadian Space Agency (CSA) accepted responsibility to initiate an interagency meeting of mission managers with responsibilities for the operation of satellite-borne synthetic aperture radar (SAR) sensor systems. The intention and declared goal was to collect extensive SAR data over polar regions in order to address top level scientific objectives previously identified in the Science Requirements Document written by the approved IPY project called Global Inter-agency IPY Polar Snapshot Year (GIIPSY). Issued in November 2006, this document states the scientific requirements to be addressed by Earth Observation sensors, based on these criteria:

✦ science goals
✦ science objectives and experiment design
✦ observation objectives (including satellites)
✦ data processing and management.
As an initial and immediate response to the science requirements the space agencies were asked to look at their rich data archives because the satellite SAR data acquired over polar regions over the past two decades have a tremendous scientific and societal value. The Space Task Group has mandated its members to make an inventory of their archival data holdings, assess the thematic content and compile relevant data sets into archive portfolios in order to facilitate access to historical data and add value to new data sets acquired during IPY. Archive portfolios can be accessed through the Internet.

**SAR COORDINATION GROUP APPROACH**

The SAR Coordination Group was convened on three occasions at CSA in Canada (March 2008), at DLR in Germany (September 2008) and at ESA, in Italy (June 2009). The meetings brought together representatives from the space agencies and members of the science community, along with representatives of the STG, WMO, GIIPSY, the Alaska Satellite Facility (ASF), MacDonald Dettwiler & Associates (MDA), and Kongsberg Satellite Services (KSAT). The space agencies included Agenzia Spaziale Italiana (ASI), Italy; the Canadian Space Agency (CSA); the German Aerospace Center (DLR); the European Space Agency (ESA); the Japan Aerospace Exploration Agency (JAXA); and the United States National Aeronautics and Space Administration (NASA).

At the outset, scientists were invited to present their research plans and how they would use SAR data to realize their plans, and space agency representatives presented the IPY related science plans for their respective SAR sensor systems. The group began to think about how best to use these assets in a way that would exploit the capabilities of each system, and share the load of SAR data acquisition, processing and dissemination evenly among the space agencies. A coordinated data acquisition approach emerged that focussed a few themes and sought to fill gaps in the planned satellite coverage for IPY, with the goal to solve an important science problem. The participants generally agreed with this approach and defined the following science themes:

1. **C-Band coverage (3-day snapshots) for the Arctic Ocean during the remainder of IPY** (as part of ongoing background missions and operational data acquisitions, etc.).
2. **Pole-to-Coast interferometric SAR (InSAR) coverage of the Antarctic continent during winter in high-resolution imaging mode** (3–4 consecutive data acquisition cycles in ascending and descending orbits).
3. **InSAR acquisition over Greenland and major Canadian icefields during winter in high-resolution imaging mode** (over 3–4 consecutive cycles).

**SUCCESSES**

**ESA / ESRIN:**
C-band INSAR coverage of the northern portion of Antarctica

**JAXA:**
L-band INSAR coverage of the northern portion of Antarctica and repeated L-band PALSAR coverage of Antarctic coastal areas

**DLR:**
X-band SAR coverage of selected areas on Greenland and first Antarctic ‘pole hole’ X-band InSAR coverage

**CSA / MDA:**
First Antarctic pole-to-coast C-band PolSAR campaign and first Antarctic ‘pole hole’ C-band InSAR coverage

**ESA / DLR / ASI:**
Monitoring of Wilkins Ice Shelf break-up at high spatial and temporal detail
Table 1
Coordinated SAR Acquisition Plan with Achievements (bold) and Shortcomings (italics) by Late 2009.
(See text for additional explanation regarding colour coding)

<table>
<thead>
<tr>
<th>Theme &amp; Sensors</th>
<th>3-day Arctic Basin Snapshots</th>
<th>Pole-to-Coast InSAR, Antarctica</th>
<th>Greenland &amp; Icefields</th>
<th>Supersites</th>
</tr>
</thead>
<tbody>
<tr>
<td>PALSAR</td>
<td>New L-band mosaic of sea ice. Following fixed image acquisition plan.</td>
<td>New L-band mosaic Following fixed image acquisition plan South pole hole not covered (see page 2)</td>
<td>Partial InSAR coverage in fine beam and polarimetric mode</td>
<td>Not possible. Robust proposal required for augmentation of the baseline observation plan</td>
</tr>
<tr>
<td>ASAR</td>
<td>Systematic wide swath coverage. Partial acquisition in Chukchi Sea and East Siberian Shelf</td>
<td>Intense InSAR acquisition plan for regions north of about 78 degrees S</td>
<td>Intense acquisition plan with second Tandem campaign ERS and ASAR over large supersites. No coverage over central Greenland; reception hole</td>
<td>Available for supersites. Multi-polarization SAR capabilities not exploited</td>
</tr>
<tr>
<td>RADARSAT-1</td>
<td>No satellite resources are available because of operational requirements.</td>
<td>Receiving station over Antarctica not available. See RADARSAF-2.</td>
<td>Three consecutive cycles of InSAR Fine beam mode</td>
<td>Canadian Arctic Islands covered with Canadian Interferometric Mission-2</td>
</tr>
<tr>
<td>RADARSAT-2</td>
<td>Seasonal coverages acquired, including minimum and maximum ice extent. Three-day snapshot not feasible</td>
<td>Entire continental coverage in Wide dual-co-pol mode. Three consecutive cycles of InSAR in Extended High and Wide Mode</td>
<td>Complete coverage with RADARSAT-1 Not possible with RADARSAT-2 due to large number of imaging conflicts.</td>
<td>Coverage through RADARSAT-2 Background Mission</td>
</tr>
<tr>
<td>TERRASAR-X</td>
<td>N-A</td>
<td>Transantarctic Mts. glaciers and ice streams</td>
<td>Greenland: 22 outlet glaciers.</td>
<td>Greenland: 22 outlet glaciers during 2009. Antarctic Peninsula &amp; Ice Shelves (part of Background Mission)</td>
</tr>
<tr>
<td>COSMO-SKYMED</td>
<td>N-A</td>
<td>Icestreams, Glaciers velocity fields. ‘Pole hole’ gaps (Background Mission)</td>
<td>Ice stream and glacier velocity field (Jaboshavn, Alaska, and Bering)</td>
<td>Both Wilkins Ice Shelf break-up and Perito Moreno glacier covered multiple times</td>
</tr>
<tr>
<td>HIGHLIGHTS</td>
<td>Enhanced coordination required by space agencies to meet intense observation requirements</td>
<td>Multi-frequency and multi-date acquisitions; single- &amp; multi-pol. data; high-resolution supersite and continental coverage</td>
<td>Multi-frequency and multi-date acquisitions; single- &amp; multi-pol. data; high-resolution supersite, complete Greenland coverage</td>
<td>Multi-frequency and multi-date data acquisition at high spatial resolution</td>
</tr>
</tbody>
</table>
4. **SAR coverage** of ‘supersites’ (using existing data where possible), **with selected acquisition parameters** (frequency, resolution, etc.) for multi-polarization and polarimetry data collection.

The space agencies subsequently updated the mission plans for their satellite SAR sensors and in a joint effort divided the data acquisition activities as equitably and optimally as possible. The outcome was summarized in a coordinated SAR acquisition plan for the four science theme areas, or requirements. Table 1 shows the acquisition plan, with actual achievements and shortfalls. The green colour coding indicates that the mission is ideal for achieving this particular requirement; yellow means that the mission is not optimal for achieving this particular requirement; and red signifies that the mission is not appropriate for achieving this particular requirement. While mission planning for these acquisitions required significant effort, the ability of the SAR sensors to capture data of scientific significance scored a major success.

The sheer volume and complexity of the acquired satellite SAR data called for the design of a data processing strategy in order to suggest how and where the resources of the committed space agencies could be shared and used to effectively and economically process the voluminous and diverse data set. In fact, this strategy document responded to the science requirements that were first elaborated in the GIIPSY Science Requirements Document, drawing attention on well defined themes specified by the science community and identifying the most important and unique data products that could be created from the IPY data set.

During the fall of 2009, the space agencies presented summaries of the data acquisitions that they had made, prompting discussion about data processing specifications for the envisaged continental mosaics, ice velocity maps and other products, and raising issues concerning data consistency. The SAR coordination group now began to discuss how the various products could be generated in a coordinated way, and how to share the workload of processing the raw data according to the agreed upon specifications. This represented an important juncture, as the space agency representatives had previously committed only to coordinated data collection, not product generation.

**ACHIEVEMENTS**

The coordinated planning activities resulted in the collection of extensive satellite SAR data sets of polar regions, achieving several substantial GIIPSY/STG milestones. The amount and geographic extent of the SAR data acquisition turned out to be extraordinary. It involved extensive coverage of areas of continental scale, *i.e.* Antarctica,
Greenland, at high spatial resolution, as well as frequent repeat coverage over very large marine areas, albeit at relatively low spatial resolution.

By December 2009, ESA succeeded in obtaining C-band interferometric SAR data of the northern portion of Antarctica; JAXA obtained repeated coverage over the northern portion of Antarctica at L-band using ALOS PALSAR, including InSAR coverage. DLR acquired X-band SAR data of Coats Land, Transantarctic Mountains and Greenland outlet glaciers. CSA and MDA conducted the first Antarctic pole-to-coast multi-polarization SAR imaging campaign and conducted the first complete Antarctic ‘pole hole’ InSAR campaign at C-band. DLR performed the first ‘pole hole’ InSAR X-band campaign focused on the ice streams and glaciers of the Recovery glacier system and Ross Ice Shelf. In a joint effort, ESA, DLR and ASI captured the break-up of the Wilkins Ice Shelf in great detail, spatially and temporally. ESA and CSA attempted on a ‘best effort’ basis to fill holes in the Antarctic sea ice coverage.

Work on several SAR data products is progressing well. The CSA is collaborating with NASA to develop an ice velocity map of Greenland. ESA, CSA, NASA, DLR and JAXA have initiated discussions to develop a pole-to-coast ice velocity map of Antarctica. CSA and MDA are collaborating to develop a high-resolution dual polarimetric SAR mosaic of Antarctica. During 2009, DLR surveyed 22 rapidly changing outlet glaciers in Greenland to observe seasonal change of their velocities and mapped detailed structures of ice shelves.
ANTARCTICA
FIRST DUAL-POLARIZATION SAR COVERAGE OF THE ENTIRE CONTINENT

Between 14 October and 3 December, 2008, the Canadian RADARSAT-2 collected dual-polarized SAR data at C-band for a complete pole-to-coast image mosaic of Antarctica. More than 600 passes were acquired using the left-looking ‘Wide’ (C-HH/HV), ‘Extended High 4’ (C-HH) and ‘Standard 5’ (C-HH) SAR imaging modes.

The illustration at left shows the full RADARSAT-2 SAR mosaic in C-HH. The smaller image of the Ronne-Filchner Ice Shelf region (below) is RGB colour composite rendition of HH-HH-HV.

RADARSAT-2 SAR imagery and products © MacDonald Dettwiler and Associates Ltd. 2010 - All rights reserved.
and glaciers in Antarctica. ASI has produced a sequence of the Wilkins Ice Shelf break-up in Antarctica and a glacier velocity map of the Perito Moreno glacier in Argentina. JAXA is conducting browse processing of data collected over Greenland and Antarctica.

Various mission constraints and extremely high cost prevented the production of three day snapshots covering the entire Arctic basin. However, the group achieved partial success as it was able to identify the annual minimum and maximum extents of ice in the Arctic basin. Also, the effort to secure western Arctic basin data during IPY yielded valuable experience in utilizing both public and commercial satellite resources for large scale science observations.

**SAR COORDINATION LESSONS LEARNED**

The successful work of the SAR Coordination Group is testimony that a multi-agency effort can result in multi-frequency, multi-polarization, multi-temporal and multi-resolution coverage of polar regions, in particular Antarctica, Greenland, Canadian icefields and large ocean areas. These accomplishments could not have been done by any single agency acting alone. Mission planning required significant know-how and resources, and the approach of sharing the load and exploiting the characteristics of each SAR sensor culminated in coordinated satellite data acquisition by a host of space agencies in Europe, North America, and Asia. The uniqueness of this experience prompted an informal review among the participants of the SAR Coordination Group in order to capture valuable lessons for similar activities in future.

The active participation of scientists in the SAR Coordination Group was a critical element to the successful outcome, as they provide guidance on high-priority SAR acquisition and processing goals. The well articulated science requirements provided real and meaningful targets which, in turn, allowed the space agencies to prioritize their plans. This joint
The IPY provided a strong raison d’être by offering a policy framework anchor. The requests to create the Space Task Group and subsequently the SAR Coordination Group were made openly and at a high political and administrative level. The establishment of the SAR Coordination Group is an accomplishment in itself, as it enabled the space agencies to move beyond individual project- and mission-specific planning activities and work together toward ambitious goals that no single agency could have accomplished alone. The approach of the IPY SAR Coordination Group has already been copied by other international science-driven projects requiring cooperation between space agencies and scientists.

The hybrid nature of several of the SAR missions posed challenges, since commercial and a science or ‘public good’ components had to be reconciled during the data acquisition planning and coordination stages. Yet, despite operational constraints, the SAR Coordination Group managed in most cases to maneuver within existing policy frameworks and concepts of operation. Members of the SAR Coordination Group were able to effectively utilize available ground segment and communications satellite resources. This allowed more polar data sets to be acquired.

The two-year time frame for the coordination exercise under the IPY raised some concern, as it took considerable time initially to plan, coordinate and acquire data, and the IPY period was almost over! There are good reasons for a longer period,
perhaps several years, as achievements could be maximized. On the other hand, commitments for resources tend to be more forthcoming if the duration is limited.

Closely related to the issue of resource allocation and SAR data acquisition planning is the quest for new funds for product generation. Scientists often perform the product generation with funds from separate science budgets, as they can not rely on the operational budgets of the space agencies for extensive product generation. The suggestion was made that participating space agencies should allocate funds toward coordinated product creation so as to ensure more tangible results. However, this may not be possible in light of the mandate of some space agencies.

Another concern related to the distribution of SAR data products derived by scientists from the working group activities. The issue revolved around products, such as ice sheet velocity maps, that will either have limited availability or will require that each investigator reprocess the raw data to obtain the necessary geophysical product. It appears difficult to reach a consensus regarding standard product specifications.

Communication and awareness are important at several levels. There is concern that not enough scientists are aware of the datasets produced or their significance. Some space agency representatives felt that their own management may not have sufficient knowledge about the good work of the SAR Coordination Group. Many people thought that more and better outreach activities should inform the public about the significant contributions of satellite SAR data collection and analysis to assess impacts of climate change in polar regions.

**CONCLUSIONS**

The STG SAR Coordination Group was formed in response to a request by the WMO and ICSU, the coordinating agencies for IPY 2007-2008. This paper has described the processes that were developed by the civilian space agencies operating civilian SAR sensors and related assets. Along with members of the science community, the agencies responded to science requirements to acquire SAR data in a coordinated manner, sharing the load between the agencies and exploiting the characteristics of each SAR sensor. Major achievements to date were presented. Lessons learned with recommendations for future similar efforts were described.
The approach pioneered by this group is already being emulated by other science-driven projects where multiple space agencies are cooperating to create a huge data set that no single agency could produce alone. This is the first time that so many of the world’s civilian space agencies have worked together to create such a large SAR data set of lasting scientific value. The data set covers the world’s most significant polar regions and has multi-polarization, multi-frequency, multi-temporal and multi-resolution attributes. This data set will have the potential of being compared with data sets from the past and future to assess the extent of change and rate of change in polar regions.

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RELATED WEB LINKS

Byrd Polar Research Center/GIIPSY: http://bprc.osu.edu/rsl/giipsy
European Space Agency, ESA: www.esa.int
MacDonald Dettwiler & Associates, MDA: www.mdacorporation.com
Japan Aerospace Exploration Agency, JAXA: http://www.eorc.jaxa.jp
German Aerospace Center, DLR: www.dlr.de/terrasar-x
Italian Space Agency, ASI: www.asi.it
Canadian Space Agency, CSA: www.asc-csa.gc.ca
Alaska Satellite Facility, ASF: http://asf.alaska.edu
International Polar Year, IPY: www.ipy.org

RECOMMENDATIONS

1. Find a policy framework with visibility and higher level support; stimulate scientists to state clearly articulated requirements; include the commercial stakeholders who make decisions regarding the missions; coordinate SAR data acquisition planning activities and exploit the characteristics of each sensor.

2. Participating space agencies should consider allocating funds to the product creation to show more tangible results at the end.

3. Consider a longer duration than two years for data collection and processing.

4. Improve the communications to scientists, governments, the media and through the media to the public.

5. Strive for consensus on product specifications and availability of products resulting from the acquisitions.