convection: the distortion of thermal field was very small.

The presented results show that mean vibrational flows can cause strong heat transport in the fluid. It was found that this transport becomes more intensive with increasing vibrational iinfluence. It opens the possibility of using vibrations as an alternative way of transferring heat and matter in space.

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Coordinated Satellite Observations during the IPY: Towards Achieving a Polar Constellation

[By Mark R. Drinkwater[1], Kenneth C. Jezek[2] & Jeff Key[3]]

Summary

The Global Interagency IPY Polar Snapshot Year (GIIPSY), the World Meteorological Organization (WMO) Space Task Group (STG) for the International Polar Year (IPY), and the Integrated Global Observing Strategy Cryosphere Theme are related projects involved in the implementation of recommendations for spaceborne observations during the IPY. Science requirements are being compiled by GIIPSY and IGOS Cryosphere, which are also seeking to identify ways in which the resources of space-faring countries can be used to achieve the scientific objectives without putting undue burden on any single organization. The STG brings together space agencies from around the world to coordinate their IPY activities. Thus far, the space agencies have worked to develop IPY data 'portfolios' that, in total, aim to satisfy a significant number of scientific requirements. The data legacy and the experience gained in developing scientific consensus and space agency collaborations will provide a strong foundation for the continued observations planned through IGOS Cryosphere. This paper discusses the progress made by GIIPSY, STG and IGOS Cryosphere entities in coordinating international efforts to collect spaceborne 'snapshots' of the polar regions during the IPY, and in establishing a preliminary structure for sustaining observations into the future.

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* IPY 2007-2008 is actually the fourth polar year, following those in 1882-83, 1932-33, and 1957-58. Through-out this article, 'IPY' refers to IPY 2007-2008.

Introduction

The 2007-2008 International Polar Year* (IPY) provides an international framework for understanding high-latitude climate change and predicting world-wide impacts. Recent, well- documented observations of the dramatically changing high-latitude components of the Earth's cryosphere make IPY science investigations particularly timely and relevant to scientists, policy makers and the general public. Effective IPY investigations require a range of commitments of resources, from support for individual field activities to those that require the international coordination of complex systems and their operations. Here we describe the progress being made towards meeting the challenge to obtain spaceborne snapshots of the polar regions during the IPY, and the development of a legacy of satellite observations beyond the IPY, with which to characterize key high-latitude processes.

Currently, there are a number of international activities the goals of which are to define satellite and *in situ* observational requirements and to coordinate observing systems. These include, but are not limited to, the Global Climate (or Ocean or Terrestrial) Observing System (GCOS, GOOS, GTOS), the Integrated Global Observing Strategy Partners (IGOS-P), the work of the Committee on Earth Observation Satellites (CEOS), the Global Earth Observation System of Systems (GEOSS), and the WMO Integrated Global Observing Systems. In this article, we focus on three related activities that are involved in the implementation of the recommendations for spaceborne observations put forth by these international coordinating bodies. While the focus of these activites is on observations of snow and ice, efforts to improve spaceborne measurements of atmospheric properties utilizing the broad spectrum of satellite instrumention (see Figure 1) are also under-way.

The Global Interagency IPY Polar Snapshot Year

The Global Interagency International Polar Year Polar Snapshot Year (GIIPSY) is a WMO/International Council for Science (ICSU) IPY Project the objective of which is to obtain high-resolution, multi-spectral snapshots of the polar regions over the 2007-2008 period (see Figure 2). Our primary purpose is to use these snapshots as gauges for comparing past and future environmental changes in the polar ice, the oceans, and on land. In the spirit of the IGY, we also seek to secure these datasets as our legacy to future generations of polar scientists.

GIIPSY effectively comprises polar scientists from around the world who together have assembled a consolidated list of observing objectives that call upon the collective resources of international space agencies. Our programmatic goal is to identify ways in which the resources of spacefaring countries can be used to achieve these science objectives without making unreasonable demands of any single organization. To that end, we seek cooperation in terms of spaceborne instruments, data relay systems, ground segments, processing, and data archiving capabilities. A general description of the GIIPSY programme and its current status and progress can be found on-line at http://bprc.osu.edu/rsl/GIIPSY. The detailed scientific driving requirements and objectives for the satellite observations were derived from pre-IPY ‘town-hall’ meetings (e.g., AGU’s annual meeting in December 2006), discussions with other science planning groups including IGOS (Goodison *et al.* 2007; anon. 2007), and a wide-ranging debate within the GIIPSY science community. The complete set of requirements has been documented on the GIIPSY web site and in subsequent publications and presentations (Jezek & Drinkwater 2006, 2007, Farness, Jezek & Drinkwater 2007). Together, we have taken the detailed science requirements and distilled them into a set of thematic objectives, which are listed in Table 1. Topics range from permafrost to sea ice and include several acquisition objectives that would be the first of their kind.

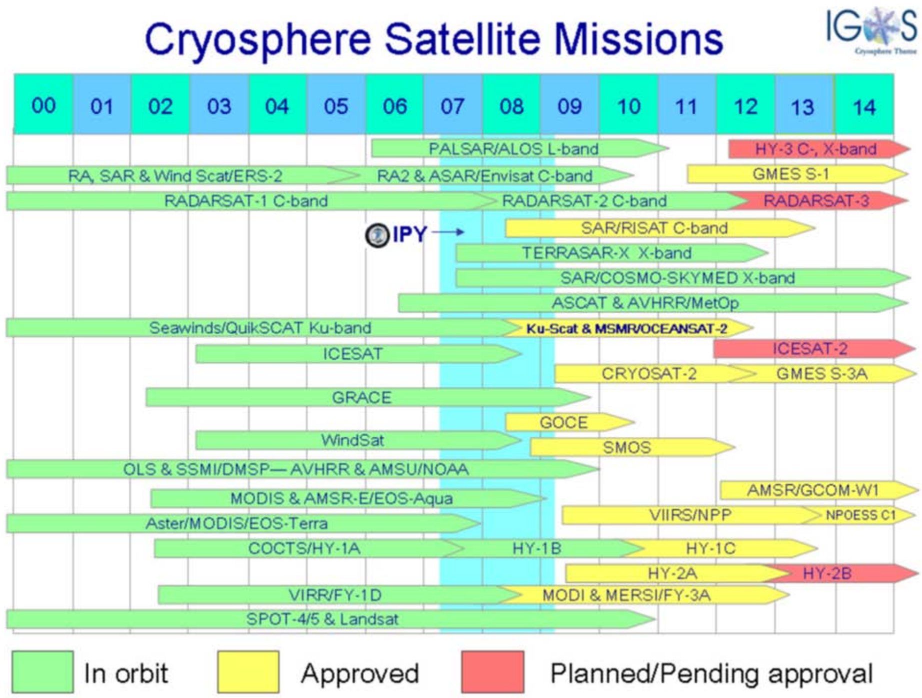

Figure 1. Timeline of current and future satellites. The blue section highlights the interval of the 4th International Polar Year.

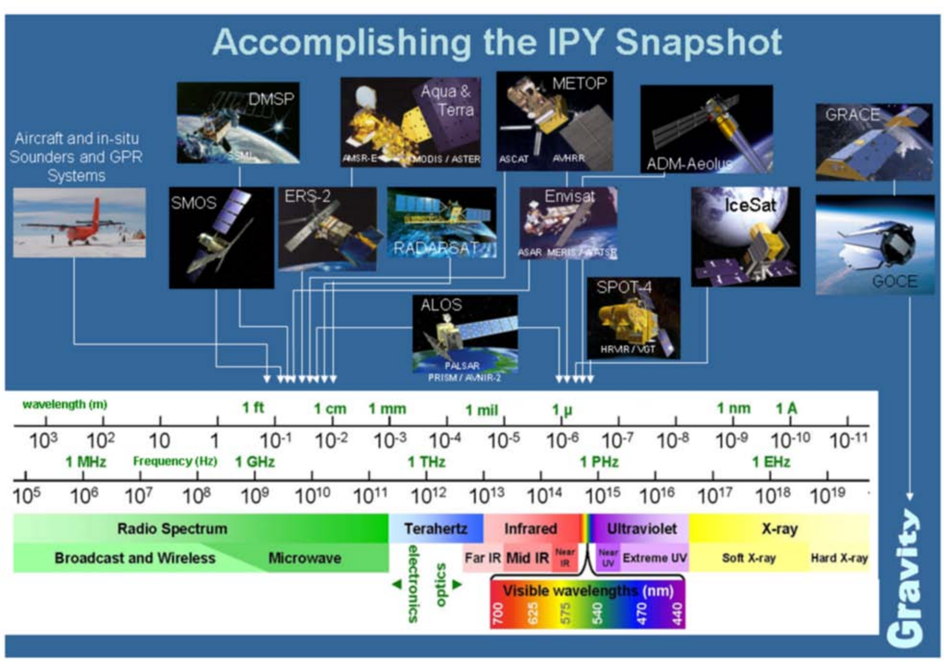

Figure 2. An illustration of the ranges within the electromagnetic spectrum in which optical and microwave airborne and polar orbiting satellite remote sensing observations are being acquired during the IPY.

Table 1. GIIPSY Thematic Objectives Derived from GIIPSY Science Requirements.

Theme/Objective	Activities and Results
Sea level rise and hemispheric climate (glaciers, ice caps, ice sheets)	1) *For the first time*, one summer, one winter SAR snapshot of the polar ice sheets, glaciers and ice caps. Near simultaneous imagery at L, C, and X band, polarimetric quad pole for documenting ice surface physical parameters. 2) *For the first time*, pole-to-coast multi-frequency InSAR measurements of ice surface velocity. 3) *For the first time*, repeated X-band InSAR topography for detecting local changes in ice sheet elevation associated with motion of subglacial water. 4) *For the first time*, one summer, one winter, high resolution visible/near-IR/TIR snapshot of the entirety of the polar ice sheets, glaciers and small ice caps followed with bimonthly coverage of select glaciers for snow-zone mapping. 5) Continued measurements of ice surface elevation from radar and laser altimeters (spaceborne and airborne) for volume change. 6) Continued daily visible and IR medium-resolution imaging of the entirety of the polar ice sheets, glaciers and ice caps: data to be compiled into monthly maps. 7) Continued daily medium-to-coarse resolution active and passive microwave images of the polar ice sheets, ice fields and ice caps for melt extent. 8) Continued measurements of the gravity field for mass balance.
Ocean circulation and polar air-sea interactions (sea ice)	1) *For the first time*, L-band SAR mapping of the sea ice cover of the Arctic Ocean and marginal seas for leads and ridges. 2) *For the first time*, repeat fine resolution SAR mapping of the entire Southern Ocean sea ice cover for ice motion. 3) *For the first time*, SAR and optical fine resolution mappings of the entire Arctic Ocean. 4) Continued 3-day medium resolution SAR mapping of sea ice covered waters for motion, and melt pond coverage. 5) Continued passive microwave observations of sea ice concentration and extent. 6) Continued laser and radar altimeter measurements of ice thickness and sea surface topography. 7) Measurements of IPY Polar Geoid.
Regional climate, precipitation and hydrology (terrestrial snow cover)	1) Daily medium resolution visible/near IR/TIR observations of all snow covered terrain. 2) Daily passive microwave observations of snow covered terrain for determination of snow water equivalent.
Changing permafrost and Arctic climate (permafrost)	1) *For the first time*, one complete high resolution snapshot of all polar permafrost terrain at L, C and X band. 2) *For the first time*, one complete, high resolution visible and thermal IR snapshot of all polar permafrost terrain. 3) Continued medium and coarse active and passive microwave observations of all polar permafrost.
Aquatic ecosystems, transportation and hazards (Lake and river ice)	1) *For the first time*, pan-Arctic high and medium resolution microwave snapshots of fresh water break-up/freeze-up. 2) *For the first time*, pan-Arctic high and medium resolution visible, near IR and TIR snapshots of fresh water break-up/freeze-up. 3) Seasonal, low-frequency (6-10 GHz) passive microwave observations of lake ice thickness.

IPY Space Task Group

Interaction between GIIPSY and the international space agencies is being coordinated through the IPY Space Task Group (STG), which is convened by WMO. To date, two STG meetings have taken place, the first in Geneva, Switzerland in January 2007 and the second in Darmstadt, Germany in November 2007. Space agency members and participating organizations include the China Meteorological Administration (CMA), the Centre National d'Etudes Spatiales (CNES), the Canadian Space Agency (CSA), the German Aerospace Center (DLR), the European Space Agency (ESA), the European Organzation for the Exploitation of Meteorological Satellites (EUMETSAT), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the Russian Federal Service for Hydrometeorology and Environmental Monitoring (ROSHYDROMET), the World Climate Research Programme (WCRP), and WMO. Meanwhile, we have approached several other agencies about joining the federated efforts of the STG, including the Agenzie Spaziale Italiana (ASI), the Instituto Nacional de Pesquisas Espaciais (INPE), the Indian Space Research Organisation (ISRO), the Japan Aerospace Exploration Agency (JAXA), and the US Geological Survey (USGS).

The STG has agreed three important programmatic activities. First it has adopted the GIIPSY science requirements for guiding agency data acquisition planning. Second, the agencies are populating their individual data 'portfolios' for IPY: individual portfolios will represent best efforts within given agency resources and strategic mandates, but in total the goal is to fulfil the requirements for the IPY data portfolio; these include:

- Pre-IPY polar-orbiting satellite benchmark data sets,
- Satellite orbit modification to meet specialized needs (e.g., inter-satellite interferometry demonstration),
- Special data acquisitions and tasking, particularly for synthetic aperture radar (SAR) and high-resolution optical satellites,
- New metadata tags, and
- New polar products, including real-time products at direct broadcast sites.

The third and most recently agreed target is that the agencies will to try to develop a coordinated acquisition strategy for high data rate instruments. The idea is to distribute the image acquisition burden across several agencies. Through collaboration, the combined portfolios will represent a more complete response to the GIIPSY requirements. Procedures for developing and implementing a coordinated acquisition plan will be explored over the coming months and the outcome will be an important lesson for IGOS and GEOSS.

Current progress towards achieving a data legacy is identified on the GIIPSY website in the form of the portfolios already assembled. Some image examples, acquired during 2007, are given here to illustrate the broad range of products that will constitute the IPY data legacy (Figures 3 to7).

Establishing an IPY Data Legacy and Testing the Polar Constellation

To date, significant progress has been made during the IPY in acquiring new scientifically valuable datasets, as well as ensuring access to the more routine datasets required for routine operational meteorological applications and numerical weather prediction (NWP). Figure 3 illustrates the composite, multi-satellite operational meteorological satellite products that are routinely processed and distributed to operational and scientific users. The STG is ensuring that the scientific benefits of these more routine operational meteorological datasets are maximised, in part, by working to tag products to the IPY. Figure 4 gives an example of a near-real time tropospheric polar wind product that is based on cloud-tracking using the Advanced Very High Resolution Radiometer (AVHRR). These data have the combined benefit of being assimilated in the models run at operational NWP centres, such as the European Centre for Medium-range Weather Forecasts (ECMWF) and the National Centers for Environmental Prediction (NCEP); the improved quality forecasts are available to IPY scientists either in support of logistical planning or scientific projects.

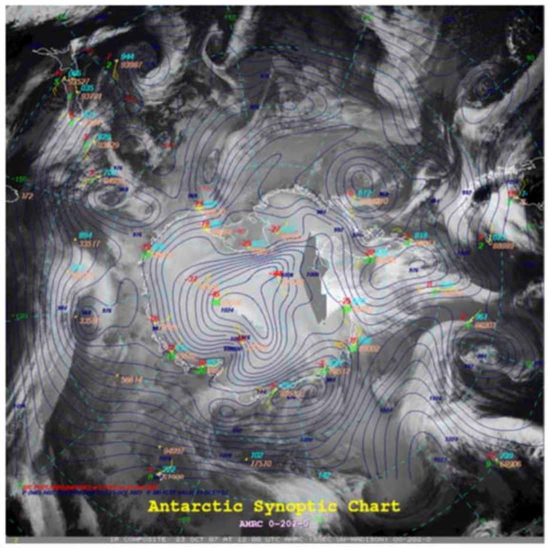

Figure 3. Composite meteorological satellite image products from *GOES*, *Meteosat*, *DMSP*, and AVHRR over Antarctica. Products are available at different spatial resolutions at intervals of 3 hours. [Courtesy: University of Wisconsin-Madison and ESA Polar View Consortium.]

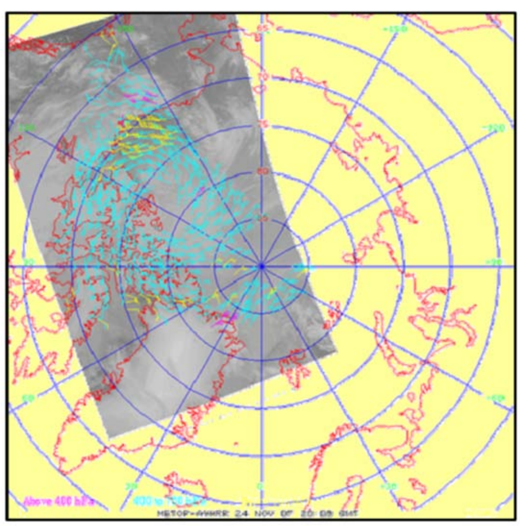

Figure 4. Tropospheric polar winds based on cloud tracking using AVHRR on *MetOP*. Similar products are routinely available from the Moderate Resolution Imaging Spectroradiometer (MODIS) and from AVHRR on NOAA satellites. [AVHRR data courtesy of EUMETSAT.]

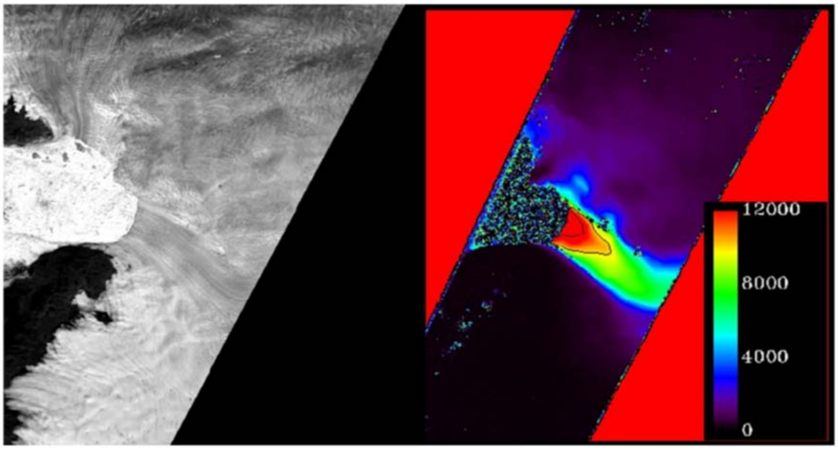

Figure 5. (left) *Spot* HRS image acquired on 24 July 2007 and (right) velocity map (m/year) at the calving front of Jakobshavn Isbræ, Greenland. Velocities were derived from feature tracking over an 11 days interval between 24 July and 4 August 2007. The 10 km/y and 13 km/y contours are shown. The colours indicate high velocities up to a maximum of 15500 m/yr (42.5 m/day). [Images © CNES 2007; Distribution Spot Image.]

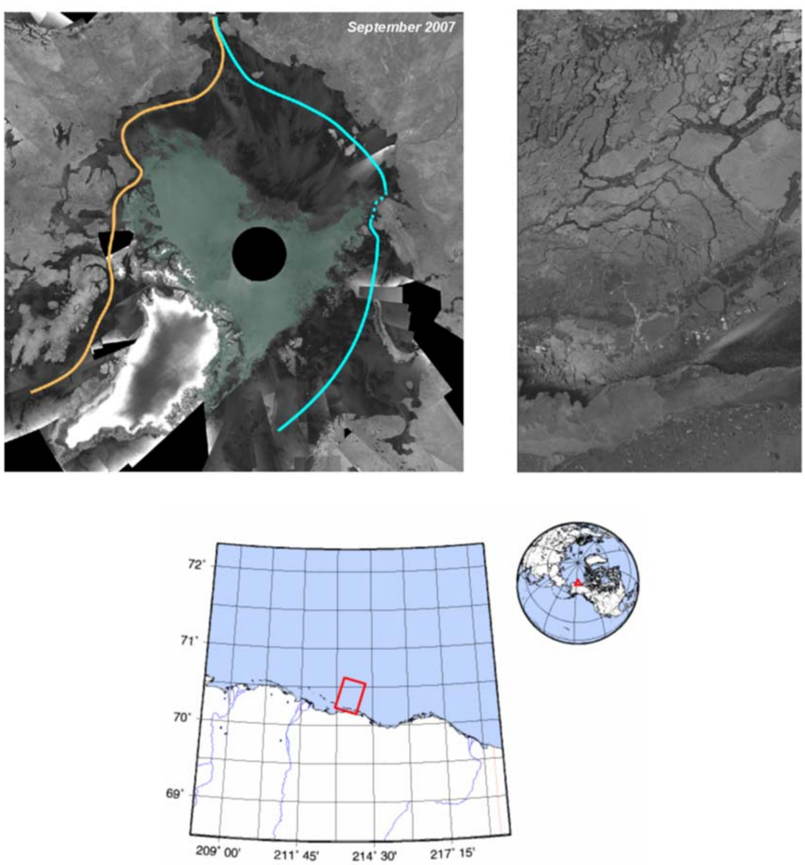

Figure 6. (top left) SAR mosaic illustration of the historical minimum in Arctic ice extent in September 2007, from *Envisat* ASAR [Courtesy: ESA] together with navigable routes through the north-west and north-east passages; and red box (region shown below) inset showing (top right) new ice conditions one month later on 24 October in the Prudhoe Bay region, Alaska from TerraSAR-X. [Courtesy: A. Roth, DLR.]

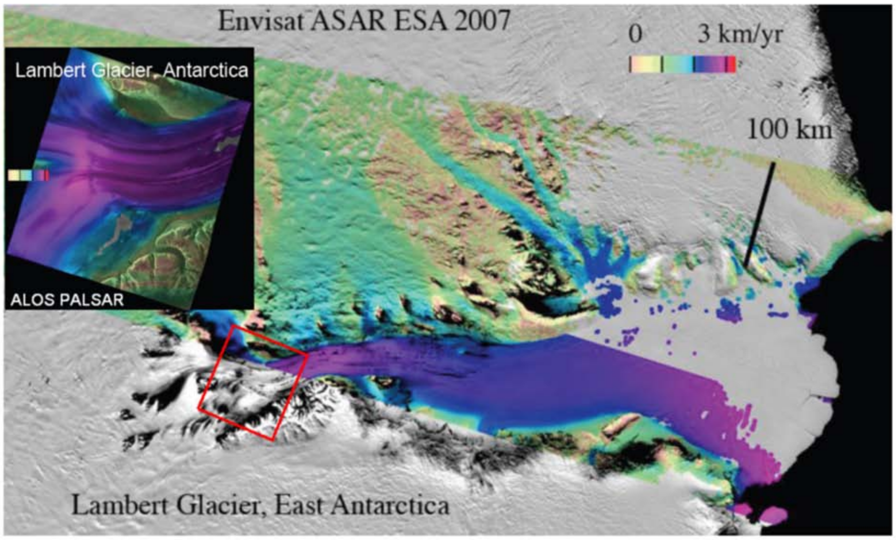

Figure 7. Illustration of mapping the Lambert Glacier streaming ice flow in Antarctica from *Envisat* ASAR and *ALOS* PALSAR (inset) indicating details in the red box of the flow from high resolution imagery. [Courtesy: E. Rignot, JPL.]

Special IPY acquisition planning of the *SPOT* optical satellites has been undertaken by CNES over the Arctic and Antarctic regions. The first Arctic data were acquired during the 2007 Arctic summer. These data are yielding diverse results ranging from 1 km *SPOT-4* VGT sea-ice mosaics spanning the entire Arctic basin, to high resolution stereo image pairs used in the generation of improved digital terrain models over ice sheet margins, ice caps and glaciers. Figure 5 gives a result from the use of *SPOT* HRS images acquired on 24 July 2007 and 4 August 2007. The derived velocity map shows the rate of ice movement at the calving front of Jakobshavn Isbræ, Greenland, together with the 10 km/y and 13 km/y contours. Velocities were derived from feature tracking in pairs of cloud-free images over an interval of several days. Together with improved digital elevation models of these regions, optical velocity maps may be combined with SAR interferometrically-derived ice stream motion to better constrain residual uncertainties in the contribution of ice flux to sea-level rise.

Satellite Synthetic Aperture Radar data routinely acquired during 2007 have delivered spectacular evidence of the historical minimum sea ice extent that occurred during the first Arctic summer season of IPY (see Figure 6a). Time-series of *Envisat* ASAR global mode image mosaics, acquired at daily intervals over both polar regions, are contributing to both GIIPSY scientific goals as well as delivering valuable products for all-weather ice service support to shipping and IPY logistics. Figure 6a indicates the September 2007 sea-ice extent, at which time the Northwest Passage was fully navigable. Importantly, the geopolitical consequences of the reduction of sea-ice in the Arctic magnify the importance of monitoring and management of the Arctic region using all-weather satellite systems. Meanwhile, the successful launch and commissioning of the first two *Cosmo-Skymed* satellites and the German TerraSAR-X (Figure 1) have also led to key additions to the constellation of polar orbiting satellites. Figure 6b shows an image acquired by TerraSAR-X in October 2007, indicating sea-ice growth off the coast of Alaska during the autumn freeze-up period.

Systematic SAR data acquisition is also required to achieve complete bi-polar mapping of the dynamic margins of the large Antarctic and Greenland ice sheets. The additional combinations of different frequency repeat-pass data obtained by the C-band *Radarsat-1* and the *Envisat* ASAR, the L-band PALSAR instrument on *ALOS*, and the X-band of the TerraSAR-X enable intercomparison of the quality of interferometric pairs. These data are helping establish the importance of frequency for achieving temporal coherence between SAR image pairs for the purpose of effective SAR interferometry. Figure 7 shows an intercomparison of L- and C-band results of interferometric tracking of the streaming ice flow of Lambert Glacier in Antarctica. This example highlights the importance and benefits of combinations of multi-mission datasets at different resolutions for the purpose of wide-swath mapping of ice motion from *Envisat* ASAR, together with the high-resolution data acquired by PALSAR.

The IPY has provided a unique opportunity to demonstrate the value of inter-satellite operations between SAR satellites in a polar constellation. Between September 2007 and February 2008, ESA operated *ERS-2* and *Envisat* in a constellation along the same orbit with approximately 30 minute separation. In spite of the differences in C-band SAR centre-frequency and the difference in the way the satellites are piloted, this demonstration has facilitated a first ever test of AMI SAR/ASAR cross interferometry between independent satellite data sets. During this interval of time, a significant number of suited pairs, i.e., pairs with significantly overlapping Doppler spectra and 2-km baselines, have been acquired. Figure 8 shows an example from an area in Franz Joseph Land (81.0°N, 61.0°E). In this location, two separate *ERS-2*/ASAR cross-interferometry pairs were processed to investigate different methodologies and Arctic applcations. The example in Figure 8 shows high coherence achieved over the sea-ice cover of the ocean, and the ability to generate high quality interferograms over these short time intervals. This and other similar such examples from the period of *ERS-2*/*Envisat* inter-satellite operations demonstrate the importance of such data for the mapping of the velocity fields of fast moving polar glaciers, and for the derivation of terrain heights of moving surfaces.

The Cryosphere Component of GEOSS

Leading up to the IPY, one of the key near-term goals of the WCRP Climate and Cryosphere (CliC) project has been to develop an Integrated Global Observing Strategy Theme on the Cryosphere (http://IGOS-Cryosphere.org/) (anon. 2007). IGOS Cryosphere is intended to:

- Improve coordination of cryospheric observations conducted by research, by long-term scientific monitoring and by operational programmes,
- Facilitate the generation and exchange of data and information for operational services and research,
- Strengthen national and international institutional structures responsible for cryospheric observations, and
- Increase resources for ensuring the transition of research-based cryosphere observing projects to sustained observations.

The IGOS Cryosphere Theme Report provides detailed recommendations for improving the observing system for snow and ice now and well into the future. The ongoing IPY provides a unique opportunity to illustrate the benefits of coordinated observations by a range of polar observing systems, be they *in situ*, airborne, or satellite-borne measurement capabilities. Through the Cryosphere Theme, CliC and the Scientific Committee on Antarctic Research (SCAR) are developing a conceptual framework and vision for a sustained Cryosphere Observing System, known as CryOS. The initial phase of development of CryOS coincides with IPY. GIIPSY is providing the mechanism for the implementation of many near-term IGOS Cryosphere recommendations.

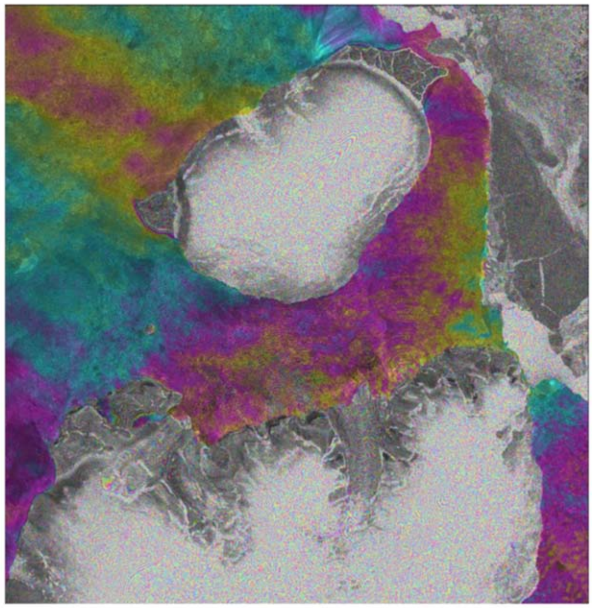

Figure 8. Geocoded *ERS-2*/ASAR cross interferogram acquired on 7 December 2007 over Franz-Joseph-Land (size 53 km x 56 km, baseline=2066 m) demonstrating the feasibility of inter-satellite interferometry. [Courtesy: U. Wegmüller, M. Santoro& T. Strozzi, Gamma Remote Sensing.]

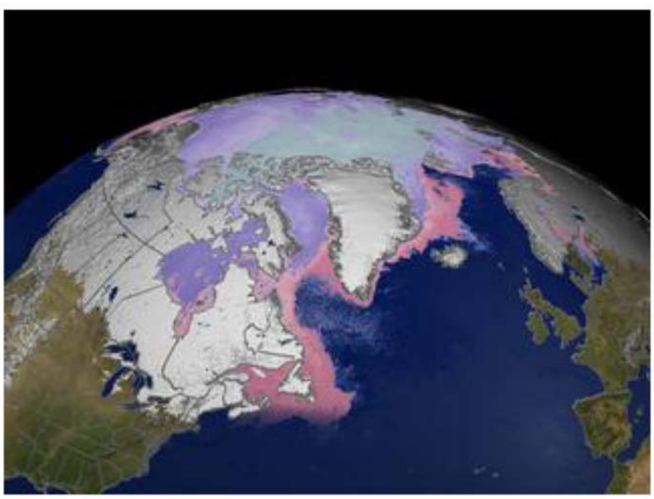

Figure 9. GIIPSY efforts during IPY offer the potential to illustrate the benefits that may accrue from the establishment of sustained, routine coordinated observations of the polar regions. This MODIS satellite picture of snow cover, sea-ice temperature, glaciers and ice sheets illustrates the diversity of the terrestrial and ocean elements of the cryosphere which need to be captured by the CryOS enterprise. [Courtesy: NASA/Goddard Space Flight Center Scientific Visualization Studio.]

In essence, the IPY has facilitated the establishment of the cryospheric system of systems as described in the IGOS Cryosphere Theme Report and elsewhere; this is the system that embodies the vision of the Global Earth Observing System of Systems

(GEOSS)[2]. In many ways, this concept comprising space infrastructure may also be regarded as the initial vision for a CEOS Polar Constellation. In this context, GIIPSY is making a tangible contribution to establishing CryOS and the Polar Constellation, by addressing the challenge of inter-agency planning and coordination of observing infrastructure such as to deliver a critical functional high-latitude element of the observing system (Figure 9).

Conclusion

It is exactly 50 years since the technical triumph of *Sputnik* and the International Geophysical Year (IGY = IPY-3). Combined developments since the dawn of the space age and the IGY place us in a unique situation today. The confluence of international science programmes, technical capabilities in satellite remote sensing, and the IPY present a once-in-a-lifetime opportunity for gathering data essential to understanding the changing polar climate and its global impact.

The IPY uniquely federates scientific activities across 63 nations. The IGOS Cryosphere Theme provided a detailed implementation plan for improving the cryosphere observing system during the IPY and beyond, while the IPY Space Task Group and the GIIPSY IPY Project are actively harnessing the technical capabilities of the world's space agencies and the specialist knowledge of their science communities to obtain a 'polar snapshot' and unique legacy data suite. Through these efforts, we hope to leave a legacy dataset compiled from multiple space agency satellite data portfolios comprising a broad range of snapshot products. This data legacy will provide the opportunity to engage a new generation of researchers, experts, educators, policy makers, and polar residents in improving our understanding the polar regions and changes in its environment, as well as the global consequences of these changes.

[2] In fact, at the time of this writing, IGOS Cryosphere and other IGOS themes are being incorporated into the GEOSS framework. The CEOS Polar Constellation represents the space infrastructure element of a comprehensive cryospheric observing system.

Acknowledgements

This article has been prepared on behalf of the IPY Space Task Group, whose fundamental contributions are acknowledged in this endeavour. Without the contributions of the participating space agencies and other supporting organizations, this effort would not have been possible. Further details about agency portfolios and access to data products may be obtained at the Global Interagency IPY Polar Snapshot Year website (http://bprc.osu.edu/rsl/GIIPSY). The views, opinions, and findings contained in this article are those of the authors and should not be construed as an official position, policy or decision of any government or government agency.

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Research Notes

Surprises from Mercury

[From NASA release, 30 January 2008]

The recent flyby of Mercury by NASA's *Messenger* spacecraft has given scientists an entirely new look at a planet once thought to have characteristics similar to those of Earth's moon. Researchers are amazed by the wealth of images and data that show a unique world with a diversity of geological processes and a very different magnetosphere from the one discovered and sampled more than 30 years ago.

After a journey of more than 2 billion miles lasting three and a half years, NASA's MErcury Surface, Space ENvironment, GEochemistry and Ranging (*Messenger*) spacecraft made its first flyby on Jan. 14. The mission is the first sent to orbit the planet closest to our Sun. The spacecraft's cameras and other sophisticated, high-technology instruments have collected more than 1200 images and acquired a variety of other scientific data. These included the first up-close measurements of Mercury since the *Mariner 10* spacecraft's third and final flyby on 16 March 1975.

"This flyby allowed us to see a part of the planet never before viewed by spacecraft, and our little craft has returned a gold mine of exciting data" said Sean Solomon, *Messenger*'s principal investigator at the Carnegie Institution of Washington. "From the perspectives of spacecraft performance and manoeuvre accuracy, this encounter was near-perfect, and we are delighted that all of the science data are now on the ground".

Unlike the Moon, the spacecraft showed that Mercury has huge cliffs with structures snaking hundreds of miles across the planet's face. These cliffs preserve a record of patterns of fault activity from early in the planet's history. The spacecraft also revealed impact craters that appear very different from lunar craters.

The instruments on board *Messenger* provided a topographic profile of craters and other geological features on the night side of Mercury. The spacecraft also discovered a unique feature that has been dubbed 'The Spider'. Nothing like this formation has been seen before on Mercury and nor has anything like it been observed on the Moon. It lies in the middle of a large impact crater called the Caloris basin and consists of more than 100 narrow, flat-floored troughs radiating from a complex central region.

"The Spider has a crater near its centre, but whether that crater is related to the original formation or came later is not clear" said James Head, science team co-investigator at Brown University, Providence, R.I.

Now that the spacecraft has revealed the full extent of the Caloris basin, its diameter has been revised upward from the *Mariner 10* estimate of 800 miles to perhaps as large as 960 miles from rim to rim. The plains inside the Caloris basin are distinctive and more reflective than the exterior plains. Impact basins on the Moon have opposite characteristics.

The magnetosphere and magnetic field of Mercury during the flyby appeared to be different from their characteristics as judged by the *Mariner 10* observations. *Messenger* found the planet's magnetic field was generally quiet, but showed several signatures indicating significant pressure within the magnetosphere.