The IGOS Cryosphere Theme: Background and Summary of Recommendations

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Chair, (former) IGOS Cryosphere Theme

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To monitor the cryosphere we need to measure a broad spectrum of snow and ice properties

**Snow**
- snow water equivalent (SWE), depth, extent, density, snowfall, albedo
- in-situ climate & synoptic (manual, auto), weather radar, remote sensing

**Solid Precipitation**
- in-situ climate & synoptic (manual, auto), remote sensing (challenging)

Unfortunately, responsibility for these measurements was scattered, snow in terrestrial programs, sea ice in oceans, etc.

**Glaciers, Ice Caps, Ice sheets**
- mass balance (accumulation/ablation), thickness, area, length (geometry), firn temperature, snowline/equilibrium line, snow on ice
- ground-based (in-situ), remote sensing

**Frozen Ground/Permafrost**
- soil temperature/thermal state, active layer thickness, borehole temperature, extent, snow cover
- in-situ (manual, auto), remote sensing (new)

Green: mature capability; Blue: moderate/developing capability; Red: little or no capability
* To create a framework for improved coordination of cryospheric observations conducted by research, long-term scientific monitoring, and operational programmes;

* To assess current capabilities and requirements for cryospheric observations;

To achieve better availability and accessibility of data and information needed for both operational services and research;

To strengthen national and international institutional structures responsible for cryospheric observations.
Workshops were held in Canada, Japan, and the Netherlands. Contributions from ~80 people in 17 countries, the basis of an evolving cryosphere community of practice.
## Assessed Capabilities, Requirements, Shortcomings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CTO</th>
<th>Measurement Range</th>
<th>Measurement Accuracy</th>
<th>Resolution</th>
<th>Comment or Principal Driver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow Cover</td>
<td>C</td>
<td>L: 20 H: 100 U: %</td>
<td>V: 15-20 U: %</td>
<td>V: 1 km U: day</td>
<td>e.g. MODIS</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>0: 100 U: %</td>
<td>10: %</td>
<td>0.5 km</td>
<td>Hydromet</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>0: 100 U: %</td>
<td>5: %</td>
<td>0.1 km</td>
<td></td>
</tr>
<tr>
<td>Snow Water Equivalent, satellite (Shallow)</td>
<td>C</td>
<td>0: 0.2 m</td>
<td>2-10 cm</td>
<td>25 km 1 day</td>
<td>e.g. AMSR-E</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>0: 0.3 m</td>
<td>3 cm</td>
<td>0.5 km 6 day</td>
<td>Hydromet</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>0: 0.3 m</td>
<td>2 cm</td>
<td>0.1 km 12 hr</td>
<td></td>
</tr>
<tr>
<td>Snow Water Equivalent, satellite (Deep)</td>
<td>C</td>
<td>none</td>
<td></td>
<td></td>
<td>Need HF SAR</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>0.3: 3 m</td>
<td>10: %</td>
<td>0.5 km 6 day</td>
<td>Hydromet</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>0.3: 3 m</td>
<td>7: %</td>
<td>0.1 km 12 hr</td>
<td></td>
</tr>
<tr>
<td>Snow Water Equivalent, in situ (Shallow)</td>
<td>C</td>
<td>0: 3 m</td>
<td>1 cm</td>
<td>1 m 30 day</td>
<td>Hydromet</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>0: 3 m</td>
<td>1 cm</td>
<td>1 m 7 day</td>
<td>Hydromet</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>0: 3 m</td>
<td>1 cm</td>
<td>1 m 1 day</td>
<td></td>
</tr>
<tr>
<td>Snow Depth, satellite (Shallow)</td>
<td>C</td>
<td>0: ~0.7 m</td>
<td>6-35 cm</td>
<td>25 km 1 day</td>
<td>e.g. AMSR-E</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>0: 1 m</td>
<td>10 cm</td>
<td>0.5 km 6 day</td>
<td>Hydromet</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>0: 1 m</td>
<td>6 cm</td>
<td>0.1 km 1 hr</td>
<td>Transportation</td>
</tr>
</tbody>
</table>
### Proposed Implementation in Three Timeframes

<table>
<thead>
<tr>
<th>Observing System Type</th>
<th>Implementation Action Timeline</th>
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<tbody>
<tr>
<td></td>
<td>Near Term</td>
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<tr>
<td></td>
<td>IPY: 2007-2008</td>
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<tr>
<td>Space Infrastructure</td>
<td>Ensure coordinated interagency planning of the IPY Polar Snapshot (plan for SAR/inSAR; high-resolution Vis/IR; and optimization of coverage in respect to IceSat laser cycles) and continuity in higher-level polar data products for an IPY legacy dataset.</td>
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<td>Mid Term</td>
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<td>Post-IPY: 2009-2015</td>
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<td>Implement a virtual SAR constellation for polar applications – based on uniform, standard, routine data acquisition.</td>
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<td>Long Term</td>
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<tr>
<td></td>
<td>Establish an operational, international SAR satellite constellation for all-weather cryospheric remote sensing, retaining essential modes for large-scale mapping/charting, InSAR terrain mapping, and sea-ice dynamics.</td>
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</tbody>
</table>

#### Observing System Types
- Space Infrastructure
- Near Surface: AUV/UAVs
- In Situ Infrastructure
- Data and Data Management
- Integrative Actions

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**2007-2009, IPY.** CliC IPY project “The State and Fate of the Cryosphere”. *GEO Task CL-06-05; various IPY projects, particularly GIIPSY and WMO Space Task Group.*

**2010-2015.** Preserve the legacy of the IPY observing and information systems; expand to the global cryosphere; realize concepts for space observing systems. *WMO Global Cryosphere Watch; SAON.*

**After 2015.** Implement previously recommended space missions that fill key observational gaps, as well as routine in situ observations of such essential parameters.
Accomplishments

- The IGOS Cryosphere Theme assessment resulted in improved coverage of cryospheric elements in the GCOS Implementation Plan and contributed to the GCOS-CEOS plan for satellite-based products.
- Began efforts to ensure an IPY legacy through the GEO Work Plan.
- Influenced the satellite mission planning process resulting in:
  - Approval of three orbital cycles of coordinated, experimental inter-satellite (ERS-SAR and Envisat ASAR) SAR interferometry.
  - Approval of the GMES Sentinel-3A SAR altimeter mission that will provide sea-ice thickness measurements.
  - Approval of RADARSAT MiniMAMM (Modified Antarctic Mapping Mission) SAR mapping of Antarctica.
  - Approval of CryoSat-2 with a re-launch in 2009.
- Developed new satellite products for real-time applications, e.g., sea ice concentration, thickness, and motion from MODIS. New acquisitions through GIIPSY.
- Contributed to the planning of ongoing SCAR scientific research projects (ISMASS, ASPeCT, PPE, and AGCS).
  - Fed directly into SAON (Sustaining Arctic Observing Networks) and the Arctic Council’s SWIPA project (Snow, Water, Ice, and Permafrost in the Arctic).
  - Inspired the WMO Global Cryosphere Watch.

The community involvement in CryOS gave it the credibility needed for these accomplishments...the first time this has been done internationally for the cryosphere. The community that started with CliC and SCAR expanded through CryOS.
IGOS No More

• IGOS Partnership was dissolved on 28 May 2008 in Paris.

• IGOS Themes and activities “successfully” transitioned into GEO.
IGOS Recommendations

• There are ~90 recommendations in the individual Report chapters.
• There are 40 recommendations in the Executive Summary.
• See Doc4.1 for the complete list. Here are some of them (leaving out those that are either completed or will be completed)…

Phases:

Near term: Now
Mid-term: Now – 2015
Long-term: Beyond 2015
Near-Term Recommendations

- Supplement sparse and sporadic basic in situ observation networks for precipitation, snow water equivalent, permafrost borehole temperatures, ice sheet core properties, met/ocean/ice mass balance tracked buoys, and mountain glaciers, and plan selection and augmentation of at least 15 reference “Supersites” with suites of relevant cryospheric measurements.

- Begin implementing a CEOP-oriented integrated approach for production of integrated cryosphere-related data products.

- Develop satellite concepts for measurements of snow water equivalent and solid precipitation and initiate a comprehensive validation program for in situ and satellite observations of these elements.

- Promote research and development of operational methods to determine sea ice thickness; in particular, by enhancing the Antarctic ice thickness-monitoring project.

- Develop appropriate best practices via establishment of ‘observer’ protocols and standard suites of instrumentation for in situ sampling.
Near-Term Recommendations, cont.

- Continue to develop and improve methods for estimating the spectral properties of snow and ice from optical satellite sensors.
- Forge relationships for developing a virtual multi-frequency, multi-polarisation SAR constellation for meeting cryospheric requirements.
  - Foster development of Arctic and Southern Ocean–Antarctic observing systems, including their ocean and terrestrial and atmospheric components such as Arctic-HYCOS.
- Coordinate near-surface, high-resolution remote sensing activities from aircraft, UAV and AUVs with satellite and in situ experiments during IPY.
  - Develop observer networks for river ice, lake ice, and snow, via schools and native communities.
  - Create a global 2-dimensional glacier inventory as a reference for assessing glacier change.
  - Identify and initiate data rescue and reprocessing of historical benchmark datasets.
  - Establish an IPY data management structure and standardize metadata principles.
Mid-Term Recommendations

- Develop integrated, operational analysis products based on cryospheric data assimilation, models, satellite, and in situ data, and develop an operational cryospheric forecasting capability.
- Implement a dual and high frequency radar mission for Snow-Water Equivalent (SWE) and an extension to the Global Precipitation Mission (GPM) for solid precipitation.
- Develop an integrated data processing capability for cryospheric products from a SAR virtual constellation.
  - Augment selected supersites, and extend essential geographic networks to obtain appropriate measurement density and distribution, for representative data. (hydrology emphasis)
  - Adopt GCOS climate monitoring principles (GCMP) for all operational satellites and in situ sites.
  - Train local community observers and recruit schools for observations of freshwater ice and snow.
  - Implement standard data formats for distributed web/Earth data visualization services.
Mid-Term Recommendations, cont.

- Recover and reprocess long time series archived data relevant to the development and construction of cryospheric fundamental climate data records (FCDRs).
  - Assure that there is adequate temporal overlap to inter-calibrate satellite sensors for consistent time series.
  - Collate, digitize and analyze the long-term ice record contained in historic regional ice charts produced by various Northern Hemisphere countries in order to document historic variability and trends in the sea ice state and the climate over the past 1000 years.
- Undertake extensive reprocessing of all cryospheric variables based on an IPY legacy dataset and better calibrated and validated retrieval algorithms.
  - Initiate an Antarctic reanalysis project.
  - Implement an Antarctic Radarsat Geophysical Processing System.
Long-Term Recommendations

- Develop seamless integration and distribution of cryospheric data products, including data fusion products.
  - Establish operational, international SAR satellite constellation for all-weather cryospheric remote sensing.
  - Operationalise satellite SWE and gravity measurements.
  - Implement the P-band microwave concept for ice-sheet sounding, taiga biomass estimation, and potential permafrost applications.

- Evaluate in situ cryospheric reference network (CryoNet) and supplement it with new sites, and retire others, as needed. Ensure that CryoNet is an acknowledged and supported component of WIGOS.
  - Develop a large network of autonomous robots, equipped to measure surface energy and mass flux.

- Assimilate cryospheric products in next-generation GCMs, medium range and seasonal-interannual forecasting models and climate models.
  - Develop interannual forecasting capability for ice sheet dynamics, mass-balance changes, and sea level rise rate estimates.
Conclusions

Some CryOS (IGOS Cryosphere Theme) recommendations have been completed. Some are being pursued by other groups (e.g., the Polar Space Task Group). Most fit the GCW mission perfectly.

Although the implementation of IGOS Cryosphere recommendations is a GCW task, we should develop GCW based on what we now feel are the priorities. We can and should, of course, use the CryoOS recommendations to help guide GCW development.
GCOS Climate Monitoring Principles

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Operation of historically-uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.
Furthermore, operators of satellite systems for monitoring climate need to:
(a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and (b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term inter-annual) changes can be resolved. Thus satellite systems for climate monitoring should adhere to the following specific principles:
1. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.
2. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.
3. Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.
4. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.
5. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.
6. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.
7. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained.
8. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on decommissioned satellites.
9. Complementary in situ baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.
10. Random errors and time-dependent biases in satellite observations and derived products should be identified.