The Space Component of an Integrated Arctic Observing System

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Earth Observation Coordination Mechanisms

Past:

- Integrated Global Observing Strategy-Partnership (IGOS-P)

Present:

- Committee on Earth Observation Satellites (CEOS)
- Coordination Group for Meteorological Satellites (CGMS)
- Global Climate Observing System (GCOS)
- World Meteorological Organization (WMO) IPY Space Task Group
- Group on Earth Observations (GEO) Global Earth Observing System of Systems (GEOSS)

Future:

- WMO Global Cryosphere Watch
- WMO Space Task Group?
While CEOS and CGMS address satellite measurements and gaps, the IGOS Cryosphere Theme was the first significant effort to address satellite measurement of the cryosphere.

Workshops were held in Canada, Japan, and the Netherlands. Contributions from 80+ people in 17 countries.

http://igos-cryosphere.org
Multiple Measurement Scales
**Assessed Capabilities, Requirements, Shortcomings**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>C</th>
<th>T</th>
<th>O</th>
<th>Measurement Range</th>
<th>Measurement Accuracy</th>
<th>Resolution</th>
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C = current capability, T = threshold requirement (minimum necessary) O = objective requirement
### Proposed Implementation in Three Timeframes

<table>
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<tr>
<th>Observing System Type</th>
<th>Implementation Action Timeline</th>
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<tbody>
<tr>
<td><strong>Space Infrastructure</strong></td>
<td><strong>Near Term</strong> IPY: 2007-2008</td>
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<tr>
<td><em>Near Surface: AUV/UAVs</em></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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<tr>
<td><em>In Situ Infrastructure</em></td>
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<td><em>Data and Data Management</em></td>
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<td><em>Integrative Actions</em></td>
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**2007-2009, IPY.** CliC IPY project “The State and Fate of the Cryosphere”. GEO Task AR-09-03b; 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.
- 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.
IGOS No More


• IGOS Themes and activities “successfully” transitioned into GEO.
The STG is the body that was tasked with addressing how to meet the space observation requirements of IPY. It is comprised of nominated representatives of 14 space agencies. STG coordinates across CEOS and CGMS Agencies.
Key STG Achievements

- Acquisition of comprehensive multi-satellite, bipolar snapshots;
- Impressive array of new products planned, acquired, developed, and archived, i.e., the space agency „data portfolios“;
- Significant progress achieved in building a space infrastructure element of the IPY data legacy;
- Progress and recent achievements in engaging IGeoLab partners towards:
  - Highly Elliptic Orbit „Arktika“ mission (Russian Federation)
  - Polar Communication and Weather (PCW) mission (Canada)
Examples from STG Efforts
Collecting satellite polar snapshots

- Aircraft and in-situ Sounders and GPR Systems
- SMOS
- ERS-2
- RADARSAT
- ALOS
- SPOT-4
- GOCE
- DMSP
- Aqua & Terra
- METOP
- ADM-Aeolus
- GRACE
- IceSat

wavelength (m)

- 10^3
- 10^2
- 10
- 1
- 10^{-1}
- 10^{-2}
- 10^{-3}
- 10^{-4}
- 10^{-5}
- 10^{-6}
- 10^{-7}
- 10^{-8}
- 10^{-9}
- 10^{-10}
- 10^{-11}

Frequency (Hz)

- 1 MHz
- 1 GHz
- 1 THz
- 1 PHz
- 1 EHz

Radio Spectrum
- Broadcast and Wireless
- Microwave

Terahertz

Infrared
- Far IR
- Mid IR
- Near IR

Ultraviolet
- Near UV
- Extreme UV

X-ray
- Soft X-ray
- Hard X-ray

Visible wavelengths (nm)
- 700
- 625
- 575
- 540
- 470
- 440

Gravity
Visible/IR Image Mosaics of the Poles

e.g. MERIS Data – See live images at http://miravi.eo.esa.int
MODIS MOA see: http://nsidc.org/data/moa/
LANDSAT LIMA Data see: http://lima.usgs.gov/

SPOT VGT 1km daily mosaics (courtesy CNES)
Circumpolar Clear Sky Composites

Spring thaw – Siberian Thermokarst

Winter snow pack

MODIS Mosaic - Courtesy NRCan & NASA

MODIS Mosaic - Courtesy NRCan & NASA
Greenland ice-streams

JERS-1
Oct. 4, 1994

PALSAR
Aug. 3, 2007

TerraSAR-X
June, ‘08

ASAR Browse
Sep. 18, 2008

Jakobshavn Isbreæ

TerraSAR Sites

Fast
Monitoring Antarctic changes

Cycle08:
2006/12/5 ~ 2007/1/19
Cycle14:
2007/9/7 ~ 2007/10/22
Cycle16:
2007/12/8 ~ 2008/1/22

Atka Bay

courtesy ESA

ASAR
Ice-sheet change in Antarctica

Altimeter – Topographic Change

SAR – Ice Flow Dynamics

Rate of change of elevation (mm/yr)

Velocity (m yr⁻¹)

Courtesy Wingham et al

Courtesy Rignot et al
Recovery Glacier – and TerraSAR-X acquisitions (white boxes) – overlaid onto Radarsat-1 Antarctic mosaic (courtesy K. Jezek – OSU)

TerraSAR-X image of Beardmore Glacier – (courtesy D. Floriciou, DLR)
Arctic sea ice changes

A comparison of ice age in September 2007 (left) and September 2008 (right) shows the increase in thin first-year ice (red) and the decline in thick multi-year ice (orange and yellow). White indicates areas of ice concentration below ~50 percent, for which ice age cannot be determined. AVHRR, SMMR SSM/I, and IABP buoy data were used.
Arctic Sea-Ice Thickness Change

ERS-1/2: 1993-2002

Envisat: 2008 ice anomaly


Courtesy S. Laxon
Arctic Sea-Ice Drift

2-day ice drift: April 30, 2008 → May 02, 2008

http://www.seaice.dk/test.N/
New Ice Products from AVHRR, MODIS, SEVERI

Sea Ice Concentration

Sea Ice Thickness

SIC from MODIS/Aqua visible band

03/2003 0400 LST, NOAA

Ice thickness (m)

- >3.00
- 3.00
- 2.85
- 2.70
- 2.55
- 2.40
- 2.25
- 2.10
- 1.95
- 1.80
- 1.65
- 1.50
- 1.35
- 1.20
- 1.05
- 0.90
- 0.75
- 0.60
- 0.45
- 0.30
- 0.15
- 0.00
River Ice &
Ice Jam Monitoring

Alternating polarisation mode ASAR data

January 11, 2008

http://www.polarview.org/services/rim.htm

Courtesy PolarView
Direct Broadcast (Readout) MODIS and AVHRR Winds

- Aqua, Terra, AVHRR winds are generated separately

- Data source is direct readout (broadcast)

- 1 km MODIS and AVHRR remapped to 2 km.

- Cloud-track and water vapor (MODIS) winds

- NCEP’s GFS is used as the background.

- Pros: Low latency; high resolution.

- Cons: Incomplete polar coverage.
Continued atmospheric composition measurements, e.g., ozone (O3) and bromium monoxide (BrO)

SCIAMACHY Bromoxid 04.2004

Assimilated total ozone
7 Oct 2006
12 UTC

150 175 200 225 250 275 300 325 350 375 400 425 450 475 500

Courtesy S. Kern
### Planning: Cryosphere Satellite Missions

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<th>Year</th>
<th>Mission</th>
<th>Status</th>
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<td>PALSAR/ALOS L-band</td>
<td>In Orbit</td>
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<tr>
<td>2003</td>
<td>RA, SAR &amp; Wind Scat/ERS-2</td>
<td>Approved</td>
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<td>2004</td>
<td>RADARSAT-1 C-band</td>
<td>Planned/Pending approval</td>
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<tr>
<td>2005</td>
<td>RADARSAT-2 C-band</td>
<td>Scheduled for launch</td>
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<tr>
<td>2006</td>
<td>SAR/RISAT C-band</td>
<td>Planned/Pending approval</td>
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<tr>
<td>2007</td>
<td>TerraSAR/Tandem-X X-band</td>
<td>Planned/Pending approval</td>
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<tr>
<td>2008</td>
<td>SAR/COSMO-SKYMED X-band</td>
<td>Planned/Pending approval</td>
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<td>2009</td>
<td>ASCAT &amp; AVHRR/MetOp -1, -2, -3</td>
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<td>2010</td>
<td>Seawinds/QuikSCAT Ku-band</td>
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<td>2016</td>
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*In Orbit = R&D mission; hatched = operational mission*
Planning: A CEOS “Thread”

Societal Benefit

Decision Topic

How will changes in the cryosphere impact sea level?

Information Products and Services

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CEOS measurements

- Ice sheet/cap topography and rate of change
- Ice stream velocity
- Glacier extent
- Glacier and ice sheet mass balance
- Ice sheet calving rate
- Snow cover
- Ice surface energy budget
- Geoid measurements
- Continental rebound

Contributions from N CEOS instruments and M missions.

Science Knowledge and Models

- Societal impact reports
- Sea level trends
- Glacier and ice sheet state
- Glacier and ice sheet elevation change, surface melt, gravity, etc.
- Cryosphere monitoring and assessments

- Fully coupled ice sheet models (currently inadequate)
- Regional models that represent glacier variability
- Climate Models (accumulation, ablation currently inadequate)

Measurements

Instruments and Missions

EPA impact reports
IPCC Scenario Impact Assessments
Research products (e.g., GRACE mass change, passive microwave melt, ice velocity)
WMO Global Cryosphere Watch
World Glacier Monitoring Service

Research models, e.g.,
Community Ice Sheet Model

Climate models & reanalyses:
- ECMWF, NCEP, JMA reanalyses
- Hadley Centre
- NOAA GFDL (Princeton) Global Coupled Climate Model
- NASA GISS Global Climate Model
Status of satellite systems for monitoring ice sheets, ice caps, and glaciers

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Mission/sensor categories indicated in the table:

A) **Med-res vis/IR** - 1: AVHRR, 2: MODIS, 3: HY-1, 4: FY-3, 5: VIIRS
G) **Gravity** - 60: GRACE, 61: GOCE

Colors: Green: sufficient satellite capabilities; Orange: suboptimal mission/sensor or sensor characteristics/availability is uncertain; Red: no sensor will be available

Notes:
1. Assumes that GMES Sentinel-3 will continue the Jason-series measurements.
2. No gravity mission planned after GOCE.
3. Gap between ICESat-1 and both ICESat-2 and CryoSat-2
4. Uncertainty in the characteristics of the NPOESS microwave sensor
5. While there are a number of SAR instruments, current and planned missions are generally not optimized for interferometric SAR (InSAR) measurements over ice sheets.
6. Ice sheet thickness measurements can be done with VHF and UHF radars (~5 MHz to ~500 MHz).
The 15th WMO Congress (May 2007) welcomed the proposal of Canada that WMO will create a Global Cryosphere Watch which would be an important component of the IPY legacy. Congress requested the WMO Inter-commission Task Group on IPY to establish an ad-hoc expert group to explore the possibility of creation of such global system and prepare recommendations for its development.

What Next? The Global Cryosphere Watch

A legacy of IPY

A component of WIGOS

A legacy of WCRP/CliC in the area of observations

A contribution to GEOSS
Summary

- IPY polar snapshot dataset provides a critical 21st century climate benchmark dataset.
- IPY satellite Legacy dataset is multi-dimensional and spans data from 14 space agencies.
- While we have not yet achieved the ideal, integrated satellite observing system for the polar regions, we have made progress and we are on the right path.
- The WMO Space Task Group, GCW, and GEO/GEOSS will continue to help coordinate the satellite observing system.