ESA cci_ice_sheets
Essential Climate Variables for the Greenland Ice Sheet

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Nansen Environmental Remote Sensing Center, Norway (Kirill Khvorotovsky – radar altimetry)
Geological Survey of Denmark and Greenland (Signe Andersen – validation)
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Dr. Ian Joughin, University of Washington, USA
The Greenland ECV ice sheet challenge …

• ECV ice sheet of immediate society interest
  - mass loss from ice sheets contribute to global sea level rise
  - freshwater input may affect ocean currents

• Many different types of satellite measurements:
  - melt area (scatterometer)
  - height changes (radar and laser altimetry)
  - velocity + cross section (SAR interferometry + ice thickness)
  - gravity changes (GRACE)
  - GPS crustal uplift (GNET)

Provide consistent, long-term records across different Satellite missions .. Primarily from ESA EO satellite archives
Prepare for future operational system …


(Johannesson, Khvorostovsky…)
Methods for monitoring the ice sheet..

Satellite radar altimetry (ERS, Envisat, CryoSat)
- Problems in rapidly changing margin zones
- Radar penetration and retracking errors
- CryoSat-2 SARIn altimetry to give margin coverage

Laser altimetry: ICESat 2003-9
- Epoch style measurements, cloud problems
- Common error: Conversion dh/dt to mass change …

GRACE mass changes
- Lack of resolution, GIA errors, ocean leakage..
Methods for monitoring the ice sheet (2).

SAR interferometry
- Estimation of ice velocities
- Combination with "outlet gates" yield mass loss
- Errors due to unknown thickness, accumulation ..
- Grounding line location on tidewater glaciers

Outlet glacier geometry from SAR/optical imagery
- Calving front location

Grounding Line Location from ASAR
Antarctic Peninsula, Larsen-B outlet glaciers (ENVEO)

Calving Front Location from ASAR

East Greenland glacier velocities (Joughin)
**Ice_Sheet_CCI key parameters:**

**Primary:**

<table>
<thead>
<tr>
<th>Variable/Parameter</th>
<th>Application</th>
<th>Horizontal Resolution</th>
<th>Temporal Resolution</th>
<th>Accuracy</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Elevation Change (SEC)</td>
<td>Mass balance</td>
<td>100m</td>
<td>30 days</td>
<td>0.1m/yr</td>
<td>0.1m/yr</td>
</tr>
<tr>
<td></td>
<td><em>Current capability</em></td>
<td>5km</td>
<td>35 days</td>
<td>&lt;0.1m/yr</td>
<td>&lt;0.1m/yr</td>
</tr>
<tr>
<td>Ice Velocity (IV)</td>
<td>Mass balance</td>
<td>1km</td>
<td>30 days</td>
<td>10m/yr</td>
<td>10m/yr</td>
</tr>
<tr>
<td></td>
<td><em>Current capability</em></td>
<td>25m - 500m</td>
<td>3-35 days</td>
<td>3-30m/yr</td>
<td>stable</td>
</tr>
</tbody>
</table>

**Secondary:**

<table>
<thead>
<tr>
<th>Variable/Parameter</th>
<th>Horizontal Resolution</th>
<th>Temporal Resolution</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounding Line Location (GLL)</td>
<td>1 km</td>
<td>1 years</td>
<td>1 km</td>
</tr>
<tr>
<td></td>
<td><em>Current capability</em></td>
<td>20 m</td>
<td>intermittent</td>
</tr>
<tr>
<td>Calving Front Location (CFL)</td>
<td>20m-150m</td>
<td>≤35 days</td>
<td>50m-300m</td>
</tr>
</tbody>
</table>
Special challenges: huge data volumes (SEC: Level-1B reprocessing, IV: Level-0 processing; 20 yrs+)
Output for users in adequate grid / line formats … SARin data only available at irregular intervals
Main tasks in Phase 1 of Ice_Sheet_CCI project 2012-14:

<table>
<thead>
<tr>
<th>Task #1</th>
<th>First 6 months:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• User requirements (questionaire/consultations ..) – URD</td>
<td></td>
</tr>
<tr>
<td>• ECV specifications and data requirements – DARD + PSD</td>
<td></td>
</tr>
<tr>
<td>• Error characterization - CECR</td>
<td></td>
</tr>
</tbody>
</table>

Next 6 months:

• Get data to data bases ..
• Algorithms to be described .. Specify evaluation principles
• Round Robin Excersizes .. open to all interested parties
• Select "best" algorithm

Year 2:

• Prototype development and data bases
• ECV production – R&D context, not industry-standard processing chain
  *Complete coverage of coast-near region 1995/96 and 2008 "golden year”*

Year 3:

• Product validation
• User assessment
• Overall changes compared to other satellite data (e.g., GRACE)

#5
• ECV product usefulness to modellers
• System specification for operational production system

Phase 2: *2015-17: operational system implementation .. + Antarctica??*

Phase 3: *Transfer of operational system to users … (GMES??)*
Short summary of the user survey (67 respondents)

Main user groups:
- Ice sheet flow models
- Volume and mass balance changes/Remote sensing observations
- Outlet glacier changes (dynamic changes, discharge, etc)
- Surface mass balance models

Years of experience:
- >10 years
- 5-10 years
- Other
User recommendations and priorities:

**Generally:**
- The preferred priority is to have high-resolution in margin areas (SEC and IV) and low-resolution in the central parts.

**Useful scenarios:**
- For Surface Elevation Change (SEC):
  - long time records are important. A scenario with low resolution over the entire ice sheet, long time series would be useful for comparing volume changes with estimated mass change from surface mass balance models.
- For Ice Velocity (IV):
  - a snapshot of the surface velocity would be particularly useful for ice sheet modellers and studies of outlet glacier changes.
  - High-resolution velocity at specific fast-flowing glaciers would be particularly useful for process-oriented studies and studies of outlet glacier changes.
User recommendations and priorities, continued:

- **Open access to data is critical.** NSIDC or similar resources are suggested. If not, many users will continue to use publicly available datasets.

- File formats is an important issue for some users, particularly climate modellers. **NetCDF-format** is by far the most preferred format, but there is also a request for simpler file formats. Most users use Matlab or Fortran.

- Request for **high-level data products**.

- **Ensuring long records** is an important issue that must be taken into account when planning future satellite missions.

- Satellite observations are not sufficient to identify key processes controlling ice sheet dynamics. Other data (in situ or radio echo data) are needed.

**A challenge for the future space exploration programs:**

Extend the current radar techniques and initiate development of **new instruments to measure internal ice sheet properties from space**.

(e.g. ice penetrating radar, for example POLARIS proposed by DTU-N)
Computation areas and validation ....

**SEC:** Whole Greenland, 20 yrs

**IV:** Near-coastal regions, 1995/96+2008

**CFL, GLL:** Major outlet glaciers

**Round Robin:**
*Jakobshavn glacier, Upernavik, Petermann glacier & Northern Basin*

**DEM of Greenland**
From IceSat and Photogrammetry (DTU-Space).

Arrows show Round-Robin areas

**Validation data:**
- Optical/SAR imagery feature tracking
- GPS in-situ networks
- IceSat / CryoSat-2 altimetry
- Airborne lidar: IceBridge, CryoVEx ..
ECV product specifications .... based on user requirements

<table>
<thead>
<tr>
<th>ECV parameter</th>
<th>Time sampling</th>
<th>Period</th>
<th>Spatial sampling</th>
<th>Satellite sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice velocity (IV)</td>
<td>1 / year</td>
<td>1991-present</td>
<td>500 m grid</td>
<td>ERS, Envisat, ALOS/Palsar, RadarSat? (2012-)</td>
</tr>
<tr>
<td>Surface elevation change (SEC)</td>
<td>4 / year</td>
<td>1991-present</td>
<td>5 km grid</td>
<td>ERS, Envisat, CryoSat (2012-)</td>
</tr>
<tr>
<td>Calving Front Location (CFL)</td>
<td>4 / year</td>
<td>1991-present</td>
<td>250 m shapefile</td>
<td>ERS, Envisat, optical (Landsat, Modis)</td>
</tr>
<tr>
<td>Grounding Line Location (GLL)</td>
<td>1 / year</td>
<td>1991-present</td>
<td>250 m shapefile</td>
<td>ERS, Envisat, Radarsat?</td>
</tr>
</tbody>
</table>

**Grid format:** NetCDF (with supplementary simple ASCII files)  
**Linefiles:** Shapefiles (+ ASCII supplements)  
**Map projection:** Polar Stereographic (with auxiliary transformation software to geographic/UTM)
Links to other CCI-projects .. www.esa-cci.org

**Sea-ice CCI** (NERSC) - sea-ice thickness (same satellites …)
**Sea-level CCI** (CLS) – some satellite overlap, calibration of cryosphere data over oceans
**Glaciers CCI** (Zurich) - same satellites ..

The other CCI projects:
- Ocean Colour
- Sea Surface Temperature
- Soil Moisture
- Fire
- Land cover
- Greenhouse Gases
- Aerosols
- Ozone
- Cloud Cover

Related project to Ice Sheets:
**IMBIE – International Mass Balance Intercomparison Experiment (ESA-NASA)**
10 US-European teams .. 6 months 2011/12 …
IPCC paper for Greenland and Antarctica changes – GRACE, IceSat, InSAR + GIA comparisons
Lead: Andy Shepard (UL), Erik Ivins (JPL)
Thank you for the attention …