CryoSat-2
Sea-Ice Freeboard and Thickness

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CryoSat-2 Sea-Ice Thickness

Satellite mass: 720kg
Size: 4.6m x 2.4m x 2.2m
Orbit altitude: 717km (mean)

Ice floe
Average winter thickness about 2.5m

Freeboard
Draft
Water lead

Not to scale
SOURCE: ESA
Sea-Ice Volume & Uncertainty

Sea-Ice Freeboard & Uncertainty
- Signal Quality
- Radar Penetration
- Sea Surface Height

Freeboard to Thickness Conversion & Uncertainty
- Sea Ice Density
- Snow Depth
- Snow Density
CryoSat-2 sea-ice Cal/Val

Laser – Radar Altimetry
- Radar penetration into snow
- Sea-ice surface roughness
- Direct comparison to CryoSat-2

Airborne EM (AEM) Thickness
- Sea-ice thickness data
- Helicopter and fixed-wing aircrafts
- Direct comparison to CryoSat-2
Freeboard: Airborne vs. CryoSat-2

Airborne (laser & radar) and CryoSat-2 freeboard
- Coincident Data Acquisition (CryoVEx 2011)
- Distribution of airborne radar and CryoSat-2 freeboard comparable
- Difference (22 cm) to laser freeboard smaller than expected snow depth (even for dry & cold snow)
  - Lower wave propagation speed in snow not accounted
CryoSat-2 processing scheme

CryoSat-2 Level 1b

Mean SSH

Mean SSH = Geoid + Mean Dynamic Topography (DTU10)

Actual-SSH (WGS84) = Mean SSH + SSH Anomaly

Radar Freeboard

SSH-Anomaly

Penetration correction

Isostatic Equilibrium

Snow Depth

Snow and Ice Densities

Modified Climatology

Ice Type Mask

Sea Ice Thickness

Uncertainty

25 x 25 km grid
CryoSat-2: First results - Freeboard

Radar Freeboard
- Direct result from CryoSat-2 data
- No physical corrections (snow) applied

Sea Ice Type (OSI-SAF)
- Main classification FYI / MYI
- Similar spatial distribution to radar freeboard

March 2013
Sea-Ice & Snow Parametrization

Snow Depth
- Modified Climatology (Warren et al.)
- 50% over FYI (OIB, Kurtz et al.)

Radar Penetration
- 22 cm (Airborne Validation Data 2011)
- FYI: full penetration to snow
Sea-Ice & Snow Parametrization

- **FYI:** 916.7 kg m\(^{-3}\)
- **MYI:** 882.0 kg m\(^{-3}\)

**Snow Density**
- Climatology (Warren et al.)
- No differences between FYI & MYI
## Contribution to Error Budget

<table>
<thead>
<tr>
<th>Source</th>
<th>Error Source</th>
<th>Error Value</th>
</tr>
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<tbody>
<tr>
<td>CryoSat-2 Level 1b</td>
<td>Speckle Noise</td>
<td>14 cm</td>
</tr>
<tr>
<td>Lead Detection</td>
<td>SSH-Uncertainty</td>
<td>27 cm *</td>
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<tr>
<td>Retracking</td>
<td>Var. Penetration</td>
<td>Not yet quantified</td>
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<tr>
<td>Freeboard</td>
<td>Cumulative Error</td>
<td>30 cm *</td>
</tr>
<tr>
<td>Snow Depth</td>
<td>Depth Variability</td>
<td>7/14 cm</td>
</tr>
<tr>
<td>Snow &amp; Ice</td>
<td>Density Variability</td>
<td>10/100 kg/m³</td>
</tr>
<tr>
<td>Thickness</td>
<td>Cumulative Error</td>
<td>2.5 m *</td>
</tr>
</tbody>
</table>

* : Mean multi-look (point) error

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Error Propagation (Averaging 25 x 25 km)
CryoSat-2 First Results - Thickness

Sea Ice Thickness
- Thick ice in FYI regions
- Artefacts from ice classification

March 2013

Sea Ice Thickness Uncertainty
- Range: 0.5 m – 1 m
- Higher in Archipelago / Ice Edge
CryoSat-2 vs. AEM Thickness

Freeboard to Thickness Conversion
Distribution of AEM thickness and CryoSat-2 thickness
Comparable mean thickness of multi-year sea ice
CryoSat-2 underestimates modal thickness
Validation in first-year ice regimes pending
CryoSat-2 “Trend” 2011 - 2013

Ricker et al., 2013, in preparation

Ice-Type Artifact
Comparison to Seymours & Katharines publication
Comparable volume range for winter season 2011/2011
Data masks might differ slightly (AWI data: ICESat domain for except Baffin Bay)
Data Availability

http://www.meereisportal.de/cryosat

Download Content (Jan. 2011 – ongoing)

Arctic Freeboard + Uncertainty
Arctic Thickness + Uncertainty
Auxiliary Data (Snow Depth, Snow & Ice Density …)

Disclaimer
Not an operational or fully validated data product!

Feedback Welcome!
CryoSat-2 for Antarctic Sea Ice

Polarstern Weddell Sea Winter Experiment (ANTXXIX-6/ANTXXIX-7) (June – October 2013)

CryoSat-2 Validation Experiment for Antarctic Sea Ice
Airborne Sea-Ice Thickness & Snow Freeboard
In-Situ Studies of
  Snow Depth Distribution and Stratigraphy
  Sea-Ice Freeboard / Surface Flooding
  Sea-Ice Density
ANTXXIX/6 Airborne Surveys

Polarstern (ANTXXIX/7) currently in the Weddell Sea (http://expedition.awi.de/)
- Continuation of CryoSat-2 feasibility study -
CryoSat-2 Freeboard & Thickness

Calibration & Validation Results

- radar freeboard ≠ ice freeboard
- unknown spatial pattern of radar penetration
- CryoVEx: good agreement of airborne and satellite freeboard

Remaining Issues

- snow, snow, snow!
- knowledge of spatial & temporal distribution limits thickness accuracy
- remote sensing signature / mass load
- sea ice type
- ice type mask can create thickness artefacts

Future Plans

- Feasibility study Antarctic sea ice
- Impact of surface roughness ◇ Forward model

Download Data: http://www.meereisportal.de/cryosat