The NASA Ice, Cloud and land Elevation Satellite (ICESat) Series: Science, Data Products and Operations

B. E. Schutz and H. Rim
University of Texas at Austin

T. Neumann and S. Luthcke
GSFC
Examples:
- Altimetry is one manifestation of laser ranging
- Early laser altimetry from Shuttle and even earlier from Apollo
- Laser altimetry at Mars (MOLA)
- MESSENGER (Mercury)
- Earth satellite series
  - Ice, Cloud, and land Elevation Satellite (ICESat or ICESat-1)
  - Follow-on mission ICESat-2
- Others
- Focus of this presentation will be ICESat series
ICESat

• **Ice, Cloud and land Elevation Satellite**
  – Launched January 13, 2003 00:45 UTC from Vandenberg (CA) on Delta-2
  – Delta-2 will be used for launch of ICESat-2, expected launch ~October 2017

• **Primary instrument**
  – on ICESat was GLAS (Geoscience Laser Altimeter System)
  – new instrument for ICESat-2 called ATLAS (Advanced Topographic Laser Altimeter System)

• **Purpose:**
  – detect surface change of polar ice sheets and sea ice,
  – map land topography and vegetation canopy with high accuracy
  – profile clouds and aerosol layers

• **Construction:**
  – GLAS and ATLAS are NASA Goddard instruments
  – ICESat-1 spacecraft built by Ball Aerospace (Boulder)
  – ICESat-2 spacecraft built by Orbital Sciences (Phoenix)
Satellite Altimetry Concept: I

- Altimeter (radar or laser) measures the scalar distance from the spaceborne instrument to a point on the planet surface illuminated by the instrument; hence the planet topography is described with respect to the satellite orbit.
- Topography with respect to a fixed planetary reference point and axes is required.
- If the following are known/measured: $R$ and $H$, it follows that the measured point on the surface is given by $R_{\text{spot}} = R + H$, i.e., the geolocated spot; knowledge of POD and PPD are important.
Satellite Altimetry Concept: II

• Determination of surface topography requires POD and PPD
• POD for ICESat-1 and -2 based on GPS (ICESat-1 is JPL BlackJack receiver; ICESat-2 is RUAG receiver)
• SLR provides important validation of orbit determined from GPS (reduces the need for ~ continuous observations, which can be difficult with SLR)
• Experience with ICESat-1 SLR showed that POD accuracy was ~2 cm
SLR Reflector on ICESat-1 and -2

- ICESat-1 SLR array designed and constructed by ITE in Laurel, MD
- ICESat-2 SLR array very similar to ICESat-1 and has been delivered to Orbital Sciences for installation
ICESat POD comparison; GSFC-CSR

Avg. Radial RMS = 1.81 cm
Avg. 3D RMS = 5.03 cm
Avg. Max. Radial = 5.74 cm
Changes in Antarctica from ICESat

Urban and Schutz, 2008
Other Applications: Rio Tapajos (Brazil) ICESat Monitoring

- ICESat measures 5-9 m elevation change
- Very small slope of river consistent with hydrology
- Noise from laser passing through clouds above the river
- Seasonal river stages and temporal phase closely match data from other sources
Status and Future

- ICESat-1 deorbited in 2010 to reduce possible contribution to orbital debris (deorbited at end of instrument life)
- ICESat-2 plans moving forward, with plans to launch in ~October 2017 on Delta-2
  - ICESat-2 under development by Orbital Sciences Corp. (in test)
  - Lower altitude than ICESat-1 (~100 km)
  - ICESat-2 will have much higher repetition rate than ICESat-1; smaller footprint
  - ICESat-2 uses European GPS receiver (RUAG)
- Time series of elevation change important, so several year gap in time series will be partially filled by collection of airborne lidar data (Operation IceBridge)
Status and Future

• Concern about illumination of ICESat-1 detectors by ground-based lasers (SLR) led to development of SLR tracking restrictions
  – Most commonly used restriction for ICESat-1 was an elevation angle restriction of 70 degree cutoff;
  – Other restrictions available, such as a “go/no-go” restriction, which gives a mission control center the ability to enact a global restriction on ranging to its target
  – Specific nature of restrictions for ICESat-2 under investigation by ATLAS developers at GSFC
Other Differences between ICESat-1 and ICESat-2

<table>
<thead>
<tr>
<th></th>
<th>ICESat-1</th>
<th>ICESat-2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orbit</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inclination</td>
<td>94 degrees</td>
<td>92 degrees</td>
</tr>
<tr>
<td>Altitude</td>
<td>~600 km</td>
<td>~500 km</td>
</tr>
<tr>
<td><strong>Repeat</strong></td>
<td>91d with 33d sub-cycles</td>
<td></td>
</tr>
<tr>
<td><strong>Laser</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>IR and green</td>
<td>Green only</td>
</tr>
<tr>
<td>Beams</td>
<td>1 beam</td>
<td>6 beams</td>
</tr>
<tr>
<td>Rate</td>
<td>40 Hz</td>
<td>10,000 Hz</td>
</tr>
<tr>
<td>Measurement</td>
<td>Echo digitization (waveform)</td>
<td>Photon counting</td>
</tr>
</tbody>
</table>
## Other Differences between ICESat-1 and ICESat-2

### Data Products

<table>
<thead>
<tr>
<th>ICESat-1</th>
<th>ICESat-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLA01 Waveform</td>
<td>ATL01 Level 1A product</td>
</tr>
<tr>
<td>GLA02 Global Atmosphere</td>
<td>ATL02 Instrument corrected data</td>
</tr>
<tr>
<td>GLA03 Engineering</td>
<td>ATL03 Global geolocated photons</td>
</tr>
<tr>
<td>GLA04 Pointing</td>
<td>ATL04,09 Atmosphere products</td>
</tr>
<tr>
<td>GLA05 Corrected Range</td>
<td>ATL06,11,14,15 Land ice H and dH</td>
</tr>
<tr>
<td>GLA06 Global Elevation</td>
<td>ATL07,10 Sea ice SSH, freeboard</td>
</tr>
<tr>
<td>GLA07-11 Atm products</td>
<td>ATL08 Land and vegetation</td>
</tr>
<tr>
<td>GLA12 Ice sheets</td>
<td>ATL12 Ocean</td>
</tr>
<tr>
<td>GLA13 Sea ice</td>
<td>ATL13 Inland water</td>
</tr>
<tr>
<td>GLA14 Land</td>
<td></td>
</tr>
<tr>
<td>GLA15 Ocean</td>
<td></td>
</tr>
</tbody>
</table>
### ICESat-derived ice loss as a function of slope

<table>
<thead>
<tr>
<th>Slope</th>
<th>Fraction of area</th>
<th>Estimated Mass Loss</th>
<th>Total Ice Sheet Loss</th>
<th>Fraction of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;0.5°</td>
<td>33%</td>
<td>175 GT</td>
<td>145 GT</td>
<td>&gt;100%*</td>
</tr>
<tr>
<td>&gt;1°</td>
<td>18%</td>
<td>132 GT</td>
<td>145 GT</td>
<td>83%</td>
</tr>
<tr>
<td>&gt;2°</td>
<td>8.5%</td>
<td>68 GT</td>
<td>145 GT</td>
<td>43%</td>
</tr>
<tr>
<td>&gt;3°</td>
<td>5.1%</td>
<td>40 GT</td>
<td>145 GT</td>
<td>26%</td>
</tr>
</tbody>
</table>

*there is a net gain of ice in areas with slopes <0.5°

**ICESat-derived ice sheet elevation change**

- **Slope < 3°**
  - Total \(-117.5\) GT/yr
- **Slope > 3°**
  - Total \(-40.4\) GT/yr

Zwally and Saba (2009)
ICESat measured canopy height

• ICESat’s accurate ranging capability has provided large-scale global biomass estimates from canopy height measurements.

• 50-70 meter footprint provides about 5 m average height accuracy.

Lefsky et al., 2010
What will the ICESat-2 data look like?

Ice sheets:

Sea ice

Vegetation