An Overview of Glaciers and Icesheets Mapping Orbiter (GISMO)

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GISMO Technical Challenges

- Obtain Swath Topography and reflectivity data
- Separate basal return from surface clutter
Why is Swath Sounding Hard?

These two returns arrive at the same time and cannot be separated by single antenna timing alone. Need additional information to separate surface and subsurface.

Solution: use interferometry + interferogram filtering

Geometry of the two layer scattering model. H is the spacecraft height above a reference surface; h is the ice surface height above the reference surface; D is the average depth of the basal layer; d is the topographic variations of the basal layer; \( x_b \) is the cross-track coordinate of the basal layer point under observation; and, \( x_s \) is the cross-track coordinate of the surface point whose two-way travel time is the same as the two-way travel time for \( x_b \).
Table 1: Spaceborne System Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of channels</td>
<td>4 (polarimetric)</td>
</tr>
<tr>
<td>Center frequency</td>
<td>430 MHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>6 MHz</td>
</tr>
<tr>
<td>Pulse Length</td>
<td>20 μsec</td>
</tr>
<tr>
<td>Peak Transmit Power</td>
<td>5 kW</td>
</tr>
<tr>
<td>Orbit Repeat</td>
<td>2 weeks</td>
</tr>
<tr>
<td>Orbit Type</td>
<td>Polar</td>
</tr>
<tr>
<td>Platform height</td>
<td>600 km</td>
</tr>
<tr>
<td>1-Look Azimuth Resolution</td>
<td>7 m</td>
</tr>
<tr>
<td>Pulse Repetition Frequency</td>
<td>10 kHz</td>
</tr>
<tr>
<td>Antenna diameter</td>
<td>12.5 m</td>
</tr>
<tr>
<td>Antenna Type</td>
<td>Mesh Reflector</td>
</tr>
<tr>
<td>Boresight Angle</td>
<td>1.5 deg</td>
</tr>
<tr>
<td>Interferometric Baseline</td>
<td>45 m</td>
</tr>
<tr>
<td>Resolution after taking looks</td>
<td>1 km</td>
</tr>
<tr>
<td>Minimum number of looks</td>
<td>500</td>
</tr>
</tbody>
</table>

Interferometric Basal and Surface Signals Have Different Phase Rates

Basal Interferogram

Topography Weighted by Gain

Surface Interferogram

Range

Distance (km)

Range
Interferogram spectra for signal to clutter ratio of 1, radar frequency of 430MHz, bandwidth of 6MHz, for the first 50 km of $x_b$. The basal spectrum is colored orange. The remaining curves show the surface spectra for $D = 1$ km (black), $D = 2$ km (red), $D = 3$ km (green), $D = 4$ km (blue). Notice that the basal fringe spectrum depends very weakly on depth.
Results of Interferogram Filtering Simulation

True basal interferogram

Extracted basal interferogram from band-pass filtering
Background

- Radars
  - Installation in Calgary
  - Measure antenna pattern
  - to measure ice thickness, image ice bed and map layers at depth

- Antennas
  - Twin Otter

2006 Thule02 (GISMO flight)
4.0 hrs at 130 knots groundspeed
10,000' pressure altitude

May ‘06 Flights
First Airborne SAR Images of the Base of the Greenland Ice Sheet
Range and Azimuth Compressed Slant Range Images (log scale)
5200 m along track
First Airborne SAR Interferogram of the Base of the Ice Sheet
Fig. 7 interferograms from combinations of (a) $T_0 R_0 R_0$, (b) $T_0 R_0 R_2$ and (c) $T_0 R_2 R_2$. The equivalent baselines of these combinations are 0.95 m, 6.43 m and 8.35 m, respectively. The azimuth look number is 2 and range look number is one.
Range Offset Sensitivity

Image separation is too small to use traditional image cross correlation techniques, so registration is optimized by manually sliding the images in range.
Tomography

- Combining repeat pass image (Effectively 24 channels)

ground range (3000 m)

base

depth (1250 m)
Filtered Interferogram – Intensity modulated with coherence
First step towards computing swath topography
Technical Objectives for ‘07

1) Acquire data over the May 2006 flight line to compare high and low altitude observations and to compare interferometry acquired with different baselines. Are results consistent with theory?

2) Acquire data at 140 MHz and 440 MHz along every flight line and compare backscatter and interferometric frequency response? Are the results consistent with theory?

3) Acquire data over areas where we expect to find subglacial water. Is water detectable either from backscatter maps or from topography?

4) Acquire data over regions of increasing surface roughness. This may require observations over heavily crevassed shear margins such as those found around Jacobshavn Glacier. Can we successfully implement interferogram phase filtering?

5) Acquire data for tomographic analysis

6) Investigate repeat pass interferometry over repeat periods of days.

7) Verify volume clutter is weak (all snow zones)

8) Collect data over thick and thin ice to test for absorption effects
P-band Radar Instrument Concept
(for Veg. 3-D structure)

Instrument Features

- Pointing: 25° cross-track (right) of nadir
- P-band (435 MHz), 6 MHz Bandwidth
- Polarimetric (HH,HV,VH,VV)
- 25° illumination angle
- 62 km swath
- 100 m resolution (20 looks)
- Reflector Diameter: 9 m
- Reflector Width: 7 m
- Geolocation Accuracy: < 10 m
- Calibration: 1 - 1.5 dB absolute, 0.5 - 1.0 relative
- Noise Equivalent σ₀: < -30 dB

Technology

- No technology development required
- Astromesh Antenna technology provides 10-15 year lifetime (TRL 9)
- Phased Array Feed (TRL 6)
- Heritage:
  - MBSat 12-meter reflector
  - INMARSAT 9-meter reflector

Airborne Simulation of P-band Polarimetric Data
Eagle Scout Mission

Mission Characteristics

<table>
<thead>
<tr>
<th>Mission Element</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Primary Mission</td>
<td>21 months</td>
</tr>
<tr>
<td>Launch Vehicle</td>
<td>Delta 2925</td>
</tr>
<tr>
<td>Trajectory Type</td>
<td>Type II</td>
</tr>
<tr>
<td>Launch Period</td>
<td>2011</td>
</tr>
<tr>
<td>Launch C3 (Max.)</td>
<td>17 km/s</td>
</tr>
<tr>
<td>Arrival Period</td>
<td>2011</td>
</tr>
<tr>
<td>Arrival V-infinity (Max.)</td>
<td>2.6 km/s</td>
</tr>
<tr>
<td>Mapping Orbit Altitude</td>
<td>240 x 320 km</td>
</tr>
<tr>
<td>Mapping Orbit Eccentricity</td>
<td>0.011</td>
</tr>
<tr>
<td>Mapping Orbit Period</td>
<td>112.0 min</td>
</tr>
<tr>
<td>Mapping Orbit Inclination</td>
<td>32.8 deg</td>
</tr>
<tr>
<td>Mapping Orbit Node Local Time</td>
<td>3:30-5:00 pm</td>
</tr>
</tbody>
</table>

P-Band SAR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imaging Geometry</td>
<td>a) Look angle 37° (off-nadir)</td>
</tr>
<tr>
<td></td>
<td>b) Nadir-pointing</td>
</tr>
<tr>
<td>Wavelength</td>
<td>63 cm</td>
</tr>
<tr>
<td>Polarizations</td>
<td>Full polarimetric capability</td>
</tr>
<tr>
<td>Number of science modes</td>
<td>4</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>100 m/30 m</td>
</tr>
<tr>
<td>Swath width</td>
<td>8 to 28 km</td>
</tr>
<tr>
<td>Mass (CBE)</td>
<td>76.9 kg</td>
</tr>
<tr>
<td>Slowed antenna dimensions</td>
<td>176 x 33 x 33 cm</td>
</tr>
<tr>
<td>Electronics box dimensions</td>
<td>20 x 30 x 40 cm</td>
</tr>
<tr>
<td>Power needs (average)</td>
<td>33.3 W</td>
</tr>
<tr>
<td>Data rates</td>
<td>0.75 to 2 Mbps</td>
</tr>
<tr>
<td>Pointing accuracy requirement</td>
<td>0.75°</td>
</tr>
</tbody>
</table>

Combines Polarimetry and Repeat-pass Interferometry to characterize Martian subsurface
Latitudinal Variation of the Ionosphere
A Concern at Low and Mid Latitudes

Most of blue areas are not a concern for the Faraday rotation effect at L-band (but may be at P-Band)

Source: http://iono.jpl.nasa.gov/

A year similar to the target launch year - 2014
Faraday rotation estimated from L-Band polarimetric PalSAR data over Washington, DC

Faraday rotation estimated at $\Omega = 2.83 \pm 0.22$

compares well with prior estimate based on GPS-based TEC maps $\Omega = 4.0$

Little range or azimuth dependence in this example

Estimation algorithm for $\Omega$ performs well except in low SNR areas

[caption]
(courtesy Jeremy Nicoll, Alaska SAR Facility)
Ionospheric Storms
A Threat to L- & P-Band InSAR Missions

TEC difference is relative to a quiet-time average using data before the storm day.
L-Band Scintillation at Low Latitudes
Not a Concern for a Dawn-Dusk Orbit
Example of Ionospheric Scintillation Scales at High Latitudes during a Geomagnetic Storm

Scintillations observed @ Fairbanks 20000406

Graphs showing variations in scattering coefficients over time, longitude, and latitude.
Scintillation Effects in the Auroral Zone
A Concern to Dawn Passes

- Occurrence patterns of L-band ionospheric scintillation at Fairbanks, Alaska
- The two-way scintillation statistics is obtained by processing GPS data (50-Hz L1 signal intensity and phase, $f = 1.57542$ GHz) collected during 2000
GISMO

• **Conclusions:**
  1. 1st interferogram from base of Greenland Ice Sheet
  2. P-Band sees base and layering in the ice sheet
  3. Still have to show interferogram filtering works to suppress clutter (main aim of flights later in ‘07)
  4. Faraday rotation can be measured quite effectively using polarimetric data (and corrected) ==> we can live with Faraday rotation
  5. Ionospheric scintillations can cause severe distortions, but we can design the mission orbit/operations to avoid the worst