Clutter and Cross-Track Slopes: Interpreting airborne and orbital radar-sounding data in glacial environments

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1. Clutter

- **Reflections from off-nadir surface features (deterministic)**
  - Issue for both airborne and orbital radar sounding
    - *Anytime you can’t focus the across-track beam (dipole antennas)*
2. Cross-track slopes

- Cause primary echoes to arise from off-nadir locations
  - Mostly a problem for orbital radar sounding, maybe for high-altitude suborbital

Question - how does it impact our ability to produce accurate subsurface layer geometries?
Clutter Analysis - Example from Antarctica

Radar:
UTIG’s VHF radar sounder (HiCARS)

- 60 MHz center frequency (5 m)
- 15 MHz bandwidth
- 8 kW peak power
- 1 µs pulse duration
- 6400 pulses per second
Clutter analysis process

1. Identify potential subsurface echoes in radar data.
2. Simulate surface echoes and compare.
3. If any doubt, migrate echo time delays onto surface, compare with imagery.

*Steps 2 and 3 require a DEM of the surface.*
Flight path for analysis
Radar Data Simulation - DEM input

**DEM:** 2 m postings (airborne lidar - NASA ATM w/ USGS, Univ. of Ohio)

**Simulator:** Geometrical optics scattering model. Faceted surface. Incoherently summed energy. Includes antenna pattern and spreading losses.
Radar data
Radar data

SAR image

Taylor Glacier

Lake Bonney
Identify All Echoes
Simulated Radar Data
Simulated Radar Data – Actual Echoes Superimposed
Cross Track Migration of Echoes to the Surface
Cross Track Migration of Echoes to the Surface
Echoes Migrated onto DEM
Echoes Migrated onto Imagery
Using clutter simulations for flight planning

- Specific flight paths and elevations can be evaluated for clutter.

Bagley Ice Field, AK
180 km flight path
ASTER GDEM
30 m postings

1000 m clearance
Using clutter simulations for flight planning

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Bagley Ice Field, AK
180 km flight path

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500 m clearance
Using clutter simulations for flight planning

- Specific flight paths and elevations can be evaluated for clutter.

Bagley Ice Field, AK
ASTER GDEM
30 m postings

500 m clearance

However, it turns out that the ASTER GDEM is not very accurate in this part of Alaska!
The orbital case

- Two orbital sounders currently at Mars (MARSIS and SHARAD)
- Challenge for Earth due to ionosphere, but has been proposed.
  - Low orbit, short lifetime, night-side observations.
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SHARAD on Mars Reconnaissance Orbiter

- 20 MHz center frequency (15 m)
  - 10 MHz bandwidth
- Orbits at ~ 300 km
- First Fresnel zone is 3 km
  - Along-track resolution ~ 0.3 km (focusing)
- Clutter simulator developed at UTIG
  - Incoherent, facet-based model, includes along-track focusing of antenna pattern
  - Uses surface topography from Mars Orbiter Laser Altimeter (MOLA)
    - ~450 m resolution at equator, ~100 m near poles
Debris-covered glaciers

- found in middle latitudes
- hundreds of meters thick
- remnant of past climate

*(surface ice not stable at this latitude now)*
Deuteronilus Mensae region

MOLA DEM
SHARAD 1232403 - radar data

Echo Power Map (simulation)
SHARAD 1232403 - clutter simulation

100 km

5 µs (422 m in ice)

Echo Power Map (simulation)
SHARAD 1232403 - interpretations

Interpreted Radargram + echosim
Line 1232403000_1

700 m ice

5 µs (422 m in ice)
What about cross-track slopes?

- Primary surface echoes are often assumed to arise from nadir.
- Is this valid?

A slope of only 0.57° should move the first-return point by 3 km.

This is equivalent to the diameter of the first Fresnel zone for SHARAD.
North polar cap of Mars

Water ice composition (a bit less than volume of Greenland ice sheet)
Overall very smooth, but take note of the spiral troughs!
SHARAD observation across north pole

~ 1000 km across

~ 2 km
SHARAD observation across north pole

~ 2 km

~ 1000 km across
Echo Power Map (simulation) with first return locations calculated (in blue)

SHARAD data

No Data Zone

45 km

FPA data
Echo Power Map (simulation) with first return locations calculated (in blue)

Clutter simulation, with nadir elevation profile (in yellow)

Yellow profile = MOLA height (delay) along nadir track
What is the impact on subsurface reflector geometry?

Test case: Multiple SHARAD observations crossing a trough in the NPLD, slightly oblique angle. Compare radar reflectors with outcrop, using both assumptions.

Christian et al., *Icarus*, in press
Radar reflector interpretation example

Christian et al., *Icarus*, in press
Gridded subsurface reflectors ("layers") using positions from both assumptions

Nadir assumption

First-return assumption

Christian et al., *Icarus*, in press
How do we know which is correct?

We can co-register and compare radar reflectors with DEM and imagery of nearby outcrop.

First-return echo locations are correct for BOTH surface and subsurface echoes!

Christian et al., *Icarus*, in press
Do we need higher resolution simulations?

- Maybe for really small features (few-km-scale)
- Gale Crater (Curiosity landing site) example:
Using higher-resolution topography

- High Resolution Stereo Camera (HRSC) on Mars Express (50 m)
EchoPower map comparison

- MOLA (~ 300 m postings)
  - Note some problems in the gridded data result in problems
EchoPower map comparison

- HRSC (~ 50 m postings)
  - Shows much more detail, potential clutter sources
In Conclusion
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- Deterministic clutter can be mostly predicted with DEMs having resolution 10 - 20x the resolution of the radar wavelength.
  - More a question of scale of features being investigated than wavelength of radar.
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• Visualization of potential clutter sources can be very useful.
  • Cross-track migration of echoes onto imagery can be useful for identifying specific clutter sources.
  • Simulated surface echo maps can help visualize clutter sources.
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  • More a question of scale of features being investigated than wavelength of radar.
• Visualization of potential clutter sources can be very useful.
  • Cross-track migration of echoes onto imagery can be useful for identifying specific clutter sources.
  • Simulated surface echo maps can help visualize clutter sources.
• Even minor surface slopes can significantly shift the location of echoes from the nadir point for orbital sounding.
  • Needs to be accounted for when reconstructing subsurface layer geometry.
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- SHARAD instrument team, MRO Project (JPL)
Byrd Glacier sounding with UTIG HiCARS

Valley walls are far enough away to not interfere with basal reflections.

Not always the case!
Slope map of surface with ground track and first-return locations

Each black point is 3 km wide (first Fresnel zone)
Converting Time to Depth

Plaut et al., GRL, 2009
Converting Time to Depth

Plaut et al., GRL, 2009
Can be a factor for smaller features (glaciers)
SHARAD Profile Crossing This Feature
SHARAD Profile Crossing This Feature

Holt et al., Science, 2008
SHARAD Profile Crossing This Feature

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Holt et al., *Science*, 2008
Check against surface clutter simulation

- Clutter predicted based on MOLA surface DEM, s/c positions
  - Subsurface interfaces are detected unambiguously in most cases
  - Apparent internal reflections are shown to be clutter

- No layering within LDA
  - Homogeneous material
  - Contrasts with PLD where layering is pervasive.

- Low volume scattering
  - Indicates lack of large debris component

Holt et al., Science 2008
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Holt et al., Science 2008

Simulated surface clutter (shows surface echoes ONLY)

Focused data

IT’S MASSIVE ICE!
Additional crossing

6830

6705

6830

6705

4.28 µs one-way
730 m in ice

30 km
Additional crossing

4.28 µs one-way
730 m in ice

30 km
Starting echoes
Remaining echoes
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