Pathfinder Advanced Radar Ice Sounder : PARIS

ESTO-2008

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Agenda

PARIS: Pathfinder Advanced Radar Ice Sounder

2007 Mission to Greenland

The Way Forward
Objective

Develop techniques to enable and/or to enhance the visibility of internal layering and bottom topography of (continental) ice sheets when probed (sounded) by a high-altitude radar (from aircraft or spacecraft)
Perspective

The Major Challenges: Clutter; Weak Signals

Clutter dimensions: Along-track suppression
Across-track suppression

Weak signal mitigation: Innovative radar design
  large dynamic range, very low side-lobes,
  extreme linearity, generous power

NASA-IIP-supported proof-of-concept system: PARIS
  150 MHz (vision: Antarctica; planetary prototype)
  High altitude (first successful demonstration, P-3 aircraft)

Prototype for PARIS: D2P radar altimeter
  (previous NASA IIP project)
Agenda

PARIS: Pathfinder Advanced Radar Ice Sounder
   Along-track clutter suppression
   Delay-Doppler processing
   Radar design: key features

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The Way Forward
Typical B&W radar sounding profile

Dominant features: surface return and its sidelobes, bottom return, internal clutter, triple-bounce from aircraft to surface, etc; along-track and across-track clutter sources

PARIS Quick-look data* (Greenland, 07 May 2007)

*No Doppler processing, range compression with an approximate matched filter

Excellent radar dynamic range

Johns Hopkins University
Applied Physics Laboratory

ESTO-ESTC, June 2008
Along-Track Clutter Suppression: Partially-Coherent Doppler

View of along-track plane

- Transmit “high” PRF (> Nyquist rate) to unambiguously retain Doppler spectrum
- (A) Reflections from nadir will be at zero-Doppler
- (B) Off-nadir clutter reflections will have |larger| Doppler frequencies
- Filter data in the Doppler domain to favor reflections from layers and depth, and to suppress clutter
Along-Track Clutter Suppression: Doppler

Delay-Doppler processing selects along-track (small) footprints, suppressing off-nadir clutter contributions.
Delay-Doppler Technique
Spacecraft altimeter example

In situ sounding: dielectrics of ice differ from air => different velocity of propagation and Doppler scaling in ice.
Benefits of partially-coherent Doppler processing
Radar sounder architecture (minimize RF operations)

- Sampling rate << Nyquist
- Heavily weighted waveform is essential to suppress remote sidelobes
- Dynamic gain control (STC)
- Modulate at carrier freq
Design: isolate aliased (under-sampled) signals
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2007 Mission to Greenland
   Quick-time and initial results

The Way Forward
PARIS on the NASA P-3

- Univ. of Kansas’ CRESIS antennas (shared with PARIS)
PARIS: Inside the P-3

PARIS-I Radar in Operation
Arctic '07 Mission Tracks

- PARIS shared the NASA P-3 w/ Airborne Topographic Mapper (ATM)
- PARIS operated during ATM (low-altitude) flights
- 925 GB of PARIS data collected over 10 days
- High altitude data acquired 04 and 07 May
Raw Data 07 May 2007 14:10:45-14:16:00
(sub-sample – first four seconds)
Delay-Doppler (partially-coherent) Sounding

- Not well focused
- Focused
- Not well focused

- Ice surface
- Bed rock

Processing continues to progress.

- Range focus of top and bottom third of ice
- Along-track “scalloping”
- Extend to more difficult clutter-limited cases
Agenda

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- Background
- Along-track clutter suppression
- Radar design: key features

2007 Mission to Greenland

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The Way Forward

- Refine along-track processing algorithm
- Cross-track clutter suppression
- Conclusions
Cross-Track Clutter Suppression: Polarization (*new concept*)

View of cross-track plane

- Transmit **circularly polarized (CP)** radiation across the beam
- (A) Reflections (specular) from nadir will be single-bounce => reversed sense CP
- (B) Off-nadir clutter reflections usually will be double-bounce => same sense CP
- Different impacts on polarization, coherence, etc. (*potential discriminants*)

\[ E_{x\perp y} \quad S/C \quad E_{x\perp y} \]
Why Transmit Circular Polarization?

- Single-bounce (specular) reflection always reverses the sense of the illuminating (circular) polarity

- *(Linear polarization sense-reversal is not observable)*

- Most reflections from nadir (and from depth) will be specular => opposite sense circularly polarized

- Specular reflections => high coherence (~ degree of polarization)

- Reflections from clutter almost always will have different polarization properties
Dual Hybrid-Polarity Radar Sounder

Transmit Circular Polarization
Receive (coherently) linear (H & V)

Primary data product:
2x2 covariance (or coherency) matrix of the observed field, or (equivalently) the 4-element Stokes vector

New degree-of-freedom to realize cross-track clutter suppression
On Polarimetric Parameters

- Stokes parameters fully characterize the received EM field => *innovation for radar sounder data*
- Stokes parameters support parametric discrimination
  e.g.:  
  > Measurement of relative ($E_X :: E_Y$) phase $\delta$
  > Degree of polarization $m$

**Hybrid Polarity**

\[
S_1 = < |E_X|^2 + |E_Y|^2 > + 2N_0
\]

\[
S_2 = < |E_X|^2 - |E_Y|^2 >
\]

\[
S_3 = 2 \text{ Re} < E_X E_Y^* >
\]

\[
S_4 = - 2 \text{ Im} < E_X E_Y^* >
\]

\[
m = \frac{(S_2^2 + S_3^2 + S_4^2)^{\frac{1}{2}}}{S_1}
\]

\[
\delta = \arctan \left( \frac{S_4}{S_3} \right)
\]
Clutter vs Signal in \textit{m-delta} Feature Space

Transmit left-circular polarization (Example: Real non-ice data)

Hypothesis: Desired depth signals will differ from clutter in a decomposition feature space.

Selective filtering in a polarimetric feature space can enhance depth returns, and suppress clutter.

Off-nadir discrete clutter and volumetric scattering

Low coherence \textit{in situ} clutter

Desired depth signals

Surface return (main and sidelobes)

Relative H-V phase $\delta$ (degrees)
Clutter Suppression Issues (Recap)

A good sounder => a “clean” radar: dynamic range, linearity, extreme side-lobe control, etc

Doppler (along-track): Well established
  Proven technique (PARIS, Marsis, etc.)
  Ground processing
  Optimal performance => must match ice index of refraction

Polarization (across-track): New strategy
  Developmental technique: requires proof-of-concept
  Ground processing
  Optimal performance may imply adaptive selectivity in response to clutter and depth polarization signatures
Conceptual Flow of Clutter Suppression

Notional radar sounder → Presum (on-board) → Range-Doppler (FFTs) → Doppler selectivity → Enhanced profile

Along-track (Doppler)

Stokes vector values → Feature space → Selectivity decomposition

Across-track (Polarity) → Ground processing
Comments on hybrid-polarity

• Hybrid-polarity is a proven methodology for (compact) polarimetric SAR (classification by matrix decomposition)

• The cross-track polarimetric method is fully compatible with along-track enhancement techniques (Doppler and/or polarimetric) for a radar sounder

• Sidelobes from the surface return can be suppressed if their polarimetric signature differs from depth signals

• The same technique could help to suppress the triple-bounce reflection of the aircraft (ideal for a UAV or airborne radar sounder application)
Conclusions

- Delay-Doppler is successful for suppressing along-track clutter, enhancing radar sounding signals
- High-altitude radar sounding proven to be feasible
- PARIS design successfully demonstrates robust (and generalizable) radar sounder principles
- Cross-track clutter suppression by polarimetric selectivity is a promising (but as yet untested) technique
- In practical situations for which clutter vs. signal polarimetric phase distributions are significantly different, then large SCR gain is likely
- Recommend continued development of these themes