Characterization and Extent of Randomly-Changing Radio Frequency Interference in ALOS PALSAR Data

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Collaborating Organizations:
Outline

- Motivation
- An Uncharacteristic RFI Source in the American Arctic
- Screening AADN’s PALSAR Archive for RFI Issues
- Development of a Modified Notch Filter Approach for Signal Correction
- Performance of Notch Filter Algorithm
- Conclusions
Motivation

• In American Arctic, polarimetric data regularly affected by signal artifacts causing huge variations of polarimetric signature (see examples below)
• Initial survey showed: More than 80% of data over Barrow, AK affected
• **Source:** High power RF interference
An Uncharacteristic RFI Source in the American Arctic

- DEW line and North Warning System:
  - Array of long-range and short-range over-the-horizon surveillance and early warning defense system of US and Canada
  - Originally ~ 90 sites located along American Arctic Coast
  - Migrated to North Warning System in 1985 and reduced to ~50 Sites
The Long Range Radar System FPS-117

- **AN/FPS-117 Long Range Radar (Lockheed-Martin):**
  - Pulsed phased array antenna system, with a PRF of up to 1500Hz
  - **L-band** frequency range of **1215-1400 MHz** (PALSAR $f_c$: 1270 MHz)
  - Low power, long range (up to 450km)
  - Randomly hopping among 18 channels in the 1215-1400 MHz band.

<table>
<thead>
<tr>
<th>Specifications</th>
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<tbody>
<tr>
<td>frequency:</td>
<td>1215 - 1400 MHz</td>
</tr>
<tr>
<td>pulse repetition frequency (PRF):</td>
<td>250 / 1100 Hz</td>
</tr>
<tr>
<td>pulsewidth (PW):</td>
<td>100 / 800 μs</td>
</tr>
<tr>
<td>peak power:</td>
<td>20 kW</td>
</tr>
<tr>
<td>displayed range:</td>
<td>bis 463 km</td>
</tr>
<tr>
<td>beamwidth:</td>
<td>$\beta:3,4^\circ$, $\varepsilon:2,7^\circ$</td>
</tr>
</tbody>
</table>

Source: Lockheed-Martin
Examples of Interference Signatures
PALSAR PLR21.5: Orbit: 17260; Frame: 1440

- Range-frequency azimuth-time representation:
Examples of Interference Signatures
PALSAR PLR21.5: Orbit: 17260; Frame: 1440

• Bandwidth and Power:
  – ~ 1 – 2.5 MHz bandwidth; $f_c$ changing on pulse-by-pulse basis
Effects on SAR Imaging and Polarimetry
PALSAR PLR21.5: Orbit: 17260; Frame: 1440

• Focused SAR image without notch-filtering
PALSAR Operational Notch Filter

- Notch filtering during range compression:
  - Range FFT of block of 256 azimuth lines
  - Average spectrum along azimuth
  - Analyze gain for anomalies & apply notch filter if anomaly is detected
  - Then perform range and azimuth compression

- Problem:
  - Due to the wide bandwidth and changing center frequency, anomalies difficult to detect by PALSAR notch filter

→ *Especially in the cross-pol channels*, PALSAR processor not able to provide sufficiently corrected data
Effects on SAR Imaging and Polarimetry
PALSAR PLR21.5: Orbit: 17260; Frame: 1440

- Focused SAR image with PALSAR operational notch-filtering
A Simple RFI Screening Method

- Per column of range compressed raw data, calculate coherence between odd and even samples:

\[ C_{\text{Line}} = \frac{\frac{1}{N} \sum_{n=1}^{N} f_{\text{even}} f_{\text{odd}}^*}{\sqrt{\frac{1}{N} \sum_{n=1}^{N} f_{\text{even}} f_{\text{even}}^* \frac{1}{N} \sum_{n=1}^{N} f_{\text{odd}} f_{\text{odd}}^*}} \]

- This coherence is composed of SAR signal and RFI components

\[ C_{\text{Line}} = C_{\text{RFI}} + C_{\text{SAR}} \]

- \( C_{\text{SAR}} \) is small and can either be ignored or identified in an averaging process

- The plot to the right shows results where high coherence peaks correspond to RFI affected lines
RFI Affected ALOS PALSAR Frames in the AADN Archive
RFI Affected ALOS PALSAR Frames in the AADN Archive

Test Site Alaska
RFI Affected ALOS PALSAR Frames in the AADN Archive

Test Site Alaska

North Warning System

Severe
Intermediate
Not affected
Notch Filtering based on Azimuth Analysis

• Signatures are high power, narrow in azimuth time, wide bandwidth
  → detection based on azimuth analysis proposed

• Workflow:
  – Range compression
  – Range FFT
  – Cut through azimuth-time range-frequency diagram along azimuth
  – Detection of interference by local outlier analysis along azimuth
  – Notch filtering by removal of detected outliers
  – Azimuth compression
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Effects on SAR Imaging and Polarimetry
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• Focused SAR image without notch-filtering
Effects on SAR Imaging and Polarimetry
PALSAR PLR21.5: Orbit: 17260; Frame: 1440

- Focused SAR image with azimuth analysis-based notch-filtering

<table>
<thead>
<tr>
<th>HH</th>
<th>HV</th>
<th>VV</th>
<th>VH</th>
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<tbody>
<tr>
<td>![HH Image]</td>
<td>![HV Image]</td>
<td>![VV Image]</td>
<td>![VH Image]</td>
</tr>
</tbody>
</table>
Effects on SAR Imaging and Polarimetry
PALSAR PLR21.5: Orbit: 17260; Frame: 1440

No filter applied
Effects on SAR Imaging and Polarimetry
PALSAR PLR21.5: Orbit: 17260; Frame: 1440

PALSAR Operational filter

HV
Azimuth analysis-based filter
Correction Results – Polarimetric Signature

PALSAR PLR21.5: Orbit: 16837; Frame: 1440

Acquisition Date: March 23, 2009

RFI Source: Long Range Radar Station (LRRS) near Point Barrow, AK

Geographic Location

Pauli Decomposition Before Notch Filtering

Pauli Decomposition After Notch Filtering
Correction Results – Polarimetric Signature
PALSAR PLR21.5: Orbit: 17085; Frame: 1440

Acquisition Date:
April 09, 2009

RFI Source:
Long Range Radar Station (LRRS) near Point Barrow, AK

Pauli Decomposition
Before Notch Filtering

Pauli Decomposition
After Notch Filtering
Correction Results – Polarimetric Signature
PALSAR PLR21.5: Orbit: 17260; Frame: 1440

Acquisition Date:
April 21, 2009

RFI Source:
Long Range Radar Station (LRRS) near Point Barrow, AK

Pauli Decomposition
Before Notch Filtering

Pauli Decomposition
After Notch Filtering
Benefit of Developed RFI Filter for Polarimetric Classification of Sea Ice Features

Pauli RGB Level 1.1

Operationally Processed Data

Pauli RGB Level 1.0

Custom RFI-Filtered Data
Benefit of Developed RFI Filter for Polarimetric Classification of Sea Ice Features

Clustered image Level 1.1  
Clustered image Level 1.0

After RFI Filtering → Quality of classification result visually improved
Normalized zero padded bandwidth (%)
RFI monitoring by PALSAR (2010~2011)

Normalized zero padded bandwidth (%)

0  10.0
Conclusions and Recommendations:

- L-band interference from over-the-horizon radars problematic in large parts of the American Arctic
- Pulsed ground based systems cause temporarily narrow, high-power, and wide bandwidth interferences with randomly changing $f_c$
- Standard PALSAR processing scheme insufficient for removing interferences
- A modified azimuth-based filtering algorithm shows good performance in removing RFI signals and restoring original data quality
- Real data examples show successful mitigation of interferences
- Polarimetric signatures after RFI filtering significantly improved
- Growing issues of RFI in Microwave Remote Sensing needs to be addressed
ANNOUNCEMENT:

2011 CEOS SAR Calibration and Validation Workshop
Fairbanks, Alaska

Workshop Dates: November 7 – 9, 2011
Abstract Deadline: September 14, 2011

More information at:
www.asf.alaska.edu/ceos_workshop/
Open Three Year PhD Position
starting fall 2011 / spring 2012 for a radar remote sensing research project at the Geophysical Institute of the University of Alaska Fairbanks on

Theoretical Investigations into the Impact and Mitigation of Ionospheric Effects on Low-Frequency SAR and InSAR Data

Research Focus:

• Investigation of spatial and temporal properties of ionospheric effects in SAR data
• Development of statistical signal models
• Design of optimized methods for ionospheric correction

More information:
Dr. Franz Meyer (fmeyer@gi.alaska.edu) and at: www.insar.alaska.edu
• An average coherence is calculated per image. For example to the right $C=0.010$ (1.0% RFI coherence)

• A kml bounding box is created and color coded according to interference severity (green=low RFI, yellow=moderate RFI, and red=high RFI).