TDS-1 Coherent Returns over Sea Ice and Land Surfaces

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Objective

• Land surface DDMs from TDS-1 and CYGNSS available for analysis by community
• The scattered power at the receiver is composed of a reflected coherent component and a scattered incoherent component [1]
  • Coherent returns mainly from flat young/thin sea ice, small inland waterbodies, and very flat land surfaces (< 10cm rms height)
  • Coherent return offer potential opportunity for enhanced spatial resolution measurements
• Goals for this talk:
  • Report initial work in examining TDS-1 coherent components over ice/land surfaces
  • Examine different detection methods for coherent returns
• Previous methods used for detecting coherent returns:
  • SNR : Reflected power above noise [1,2,5-7]
  • 1-D Correlation between integrated Doppler cut with ambiguity function [3]
  • Using a DDM spreading metric [4]

Overview

• Coherent Reflection: Basic Properties
• Methods for Identifying Coherent Returns
• Applications
  • Sea Ice
  • Land Surfaces
• Conclusion and Further Work
Basic Properties of Coherent Returns

• Physics of coherent reflection from a rough surface:\[8\]:

\[
P_{pq}^c = \frac{P_t G^t G''}{4\pi (R_1 + R_2)^2} \cdot \frac{G'' \lambda^2}{4\pi} \frac{1}{\Gamma_{lr}}
\]

\(\lambda\) : Wavelength
\(P_t\) : Transmit Power
\(G^t, G''\) : TX and RX antenna gain
\(R_1, R_2\) : Ranges from TX and SP, SP and RX

• Removing the constants:

\[
P_{pq}^c \propto \left| R_{lr} \right|^2 e^{-4k^2h^2 \cos^2 \theta} \cdot \frac{G''}{(R_1 + R_2)^2}
\]

\(\Gamma_{lr}\) : Fresnel reflection coefficient

\(R_{lr}\) : Function of soil moisture, soil texture, roughness, and inc. angle

• Resolution: First Fresnel zone ~ a few km or less (flat surface required!)
  • but degraded by motion of satellite during measurement integration time

Example TDS-1 Coherent Return

- Coherent returns should appear as “uncorrupted” ambiguity function in the DDM
- TDS-1 coherent return example from sea ice (RD=33, TD=736, Index=136)

TDS-1 DDM Measurements

2-D Power Ambiguity Function

\[ \chi^2(\delta \tau, \delta f) \approx \Lambda^2(\delta \tau) \cdot |S(\delta f)|^2 \]

\[ |S(\delta f)|^2 = \frac{\sin(\pi \delta f T_c)}{\pi \delta f T_c} = \sin^2(\delta f T_c) \]

\[ \Lambda^2(\delta \tau) = \begin{cases} 
1 - \frac{|\delta \tau|}{\tau_c}^2, & |\delta \tau| \leq \tau_c \\
0, & |\delta \tau| > \tau_c 
\end{cases} \]

Comparison (Doppler cut at SP)

Correlation : 0.9982
Test Statistics for Identifying Coherent Returns

- Conventional SNR method
  \[ SNR = \frac{DDM_{peak} - N_{thermal}}{N_{thermal}} \]
  - \( N_{thermal} \): noise power estimates from averaged early time DDM pixels
  - Declare detection if SNR > threshold

- 1-D correlation between integrated Doppler cut with ambiguity function
  - Calculate the correlation coefficient of normalized \( x \) and \( y \)
  \[ x(\delta f) = \sum_{\delta \tau} DDM(\delta \tau, \delta f) - N_{thermal}, \quad y(\delta f) = \sum_{\delta \tau} \chi^2(\delta \tau, \delta f), \]

- 2-D Correlation between DDM and 2-D power ambiguity function
  \[ x(\delta f) = DDM(\delta \tau, \delta f) - N_{thermal}, \quad y(\delta f) = \chi^2(\delta \tau, \delta f), \]
  \[ \rho^* = \max \{ \rho(k, l) \} = \max \left\{ \frac{\sum_{i,j} (x_{i,j} - \bar{x}) \cdot \sum_{i,j} (y_{i,j} - \bar{y})}{\sqrt{\sum_{i,j} (x_{i,j} - \bar{x})^2} \cdot \sqrt{\sum_{i,j} (y_{i,j} - \bar{y})^2}} \right\} \]
Test Statistics for Identifying Coherent Returns

- Example: DDM from sea ice (RD 33, TD 421, index=874)

- **Measurements**
  - 1-D Corr. = 0.9862
  - SNR = 15.0769 dB

- **Ambiguity Function**
  - 2-D Corr. = 0.9844

- DDM (thermal noise removed)
  - 1-D Processing
  - Normalizing
  - 2-D Processing
Test Statistics for Identifying Coherent Returns

- Example: DDM from ocean (RD 33, TD 421, index=462)

![Image of DDM (thermal noise removed) with SNR = 1.0319 dB, 1-D Corr. = 0.4325, and 2-D Corr. = 0.2829]
Test Statistics for Identifying Coherent Returns

- DDM measurements with various 2-D correlation values

Corr. = 0.4

Corr. = 0.5

Corr. = 0.7

Corr. = 0.9

Corr. = 0.95

Corr. = 0.98
Test Statistics for Identifying Coherent Returns

- Comparisons of methods for identifying coherent returns
  - 145009 DDMs with antenna gain higher than 10 dB used for this comparison
  - 2-D correlation (mean: 0.4318, standard deviation: 0.2110)
  - 1-D correlation (mean: 0.5810, standard deviation: 0.1394)
  - SNR (mean: 6.3702 dB, standard deviation: 8.9494)

- Continuing to examine performance of these and other detectors of coherency
TDS-1 Correlation Map

- TDS-1 Worldwide Correlation Map (2-D correlation used)
  - TDS-1 Dataset: RD33 to RD71, Fixed gain mode
    - ~35000 Tracks with 5870792 DDMs (Antenna Gain > 5dBi)
    - Data collection period: 06/2015 ~ 04/2016 (11 Months)
  - 0.25 degree grid based worldwide map
    - Correlation range: 0.0710 ~ 0.9902
    - Number of samples averaged in a grid cell: 0~45 samples
TDS-1 Correlation Map

- Seasonal Correlation Map

June ~ August

November ~ March
TDS-1 Correlation Map

- Worldwide Coherent Returns
  - Criteria: 2-D correlation > 0.98 (initial conservative threshold)
  - 25186 coherent DDMs in total 4960996 DDMs (0.51%)
  - Mainly from sea ice and land surfaces
Examining Test Statistics for Sea Ice

- Monthly test statistics compared with sea ice coverage information
- OSI SAF Global Sea Ice Concentration (SIC): Fraction of a given ocean grid point covered by ice (%); model-based daily product (15th day of month used)
Setting Detection Thresholds

- Initial thresholds set to declare sea ice detection:
  - SNR > 5dB
  - Correlation > 0.7 (in general, open ocean < 0.5)

All methods show reasonable performance
- 1-D and 2-D correlations generally similar
- Evidence of reduced performance of SNR detector in some situations
Sea Ice Detector

- Seasonal variation of sea ice coverage in Antarctica
  - Thresholds 5dB for SNR and 0.7 for correlation cases are used
  - Detections show good matchup to SIC model versus time
    - 2-D method generally appears most robust
Example 1: Amazon river (with vegetation and wetlands, March 2016)

Detection with 2-D Corr. >0.98
Example 2: Nile river (Bare soil and no vegetation, March 2016)

Detection with 2-D Corr. > 0.98

1-arc SRTM DEM (m)

DDM
Initial CYGNSS Coherent Returns

- Examples of CYGNSS coherent returns
  - Data information: 05/25/17 (Day 135), CYG4, a00

![CYGNSS Comparison](image1)

RCG=11.75, SNR=18.73 dB, Gain=8.11 dB, Ang.=63.05, 2-D Corr.= 0.9809

![CYGNSS Comparison](image2)

RCG=188.51, SNR=21.24 dB, Gain=14.69 dB, Ang.=31.13, 2-D Corr.= 0.9836
Initial CYGNSS Coherent Returns

- 161 DDMs in total 342768 DDMs (0.047%) have greater than 0.98 2-D corr.
Conclusions

• TDS-1 coherent returns examined using multiple detection approaches
  • Sea ice detection
  • Inland waterbody examples

• Differing detection methods show similar performance
  • 2-D correlation showed somewhat better performance for sea ice cases
  • Examining additional results for inland cases for further assessment

• Future work
  • Examination of coherent returns in CYGNSS data
  • Demonstrations of enhanced resolution from coherent measurements
  • Use of coherent data to provide geophysical information