Diff-Tomo Separation of Temporal Decorrelation Mechanisms in Forest Multi-Pol Airborne Data

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Recall of 3D SAR Tomography concept
  • Open issues: temporal decorrelation

The extended Differential Tomography (4D) framework

Diff-Tomo for multidimensional imaging of forests: results with P-band E-SAR data over a boreal forest
  • Forest 4D space-time signatures of temporal decorrelation
  • Large forest area height-varying temporal coherence separation
    • HV polarization
    • HH polarization
  • Recall of other forest Diff-Tomo functionalities:
    Tomography robust to temporal decorrelation

Conclusions and future work
However...

- Limited and sparse baseline distribution, poor 3D Fourier imaging quality

  Proposed solutions: adaptive BF, SVD, subspace decomposition, spatial interpolators, etc...

- Possible limited operativity in non-fully coherent scenarios...

Tomo-SAR can localize the multiple scatterers through spatial spectral estimation (i.e. elevation beamforming)
• Elevation blurring problems from temporal decorrelation and scatterers motion

NASA-JPL, ESA and DLR recognized this as a possible limiting factor for the operational development of SAR Tomography (forest scatterers and spaceborne acquisitions)

• Studies of Tomo-SAR blurring and investigation of processing solutions

  Experimental phenomenological analysis of forest temporal coherence

• Classical (global) coherence analysis not enough: blurring origins are local

  Stratified temporal coherence analysis necessary!
Discrete space-time spectrum

Temporal frequencies code velocities

Example: subsidence in urban layover areas

Temporal frequencies are signatures of the temporal decorrelation!
Temporal perturbations of a scattering component

**temporal harmonic distribution**

Temp. freq. does not merely code velocity anymore

**Continuos temporal spectrum signatures of temporal decorrelation can be detected!**

New vision in SAR interferometry…

Sample simulated volume:

- \( t_c = 2.8 \) revisit times,
- temporal bandwidth 1 Fourier r.u.,
- \( \rho_0 = 1 \),
- compact electrically stable ground scatterer,
- scatterers separation 1.2 Rayleigh r.u.,
- sparse monostatic/multistatic acquisition pattern

Temporal signal harmonics can be decoupled from baseline signal harmonics

Sample simulated volume:

- \( t_c = \infty \),
- temporal bandwidth 0 Fourier r.u.,
- \( \rho_0 = 0.7 \).
Temporal perturbations of a scattering component

Temporal harmonic distribution

Temporal decorrelation signatures can be detected!

Continuos temporal spectrum processing

Diff-Tomo

New vision in SAR interferometry...

Temp. freq. does not merely code velocity anymore

Sample simulated volume:

- $t_c = 2.8$ revisit times,
- temporal bandwidth $1$ Fourier r.u.,
- $\rho_0 = 1$,
- compact electrically stable ground scatterer,
- scatterers separation $1.2$ Rayleigh r.u.,
- sparse monostatic/multistatic acquisition pattern

...allowing new functionalities for analyzing forest volumetric dynamic scenarios

1 - Coherence separation: the Diff-Tomo framework can recover information about different temporal decorrelation mechanisms of overlayed scatterers, exploiting temp. bandwidth estimates

2 - Decorrelation-robust Tomo-SAR... [Lombardini-Cai-Pardini, EUSAR’10]

3 – Possibly, subcanopy subsidence estimation... (5D parameter extraction)
4D space-time signatures: proof of concept

Remningstorp forest site
Mild temporal decorrelation
- DLR’s E-SAR (ESA project BIOSAR), P-band, 9 tracks
- Baseline span: 80 m, height Rayleigh resolution 28 m
- Time span: 2 months, temp. freq. Fourier resolution 0.5 phase cycles/month
- HV pol.

Non-parametric analysis of a forested cell – Real data investigation of space-time decorrelation signatures

Adaptive Diff-Tomo frame

Normalized adaptive Diff-Tomo frame
**Remningstorp forest site**

Mild temporal decorrelation

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**Non-parametric analysis of a forested cell – Real data investigation of space-time decorrelation signatures**

Canopy-Ground separated normalized temporal spectra

Normalized adaptive Diff-Tomo frame

Canopy scatterer detected with a wider spread along temporal frequency w.r.t. ground!

First verification on real data of the concept of space-time signatures of temporal decorrelation

[Lombardini-Cai, ESA Fringe ‘11]
Temporal coherence separation

Parametric separation of different temporal scattering mechanisms inside the SAR cell

\[ f_{DT}(f_s, f_T, B_{f_T}) \]

(5D parameter extraction)
Temporal coherence separation

Parametric separation of different temporal scattering mechanisms inside the SAR cell

BIOSAR P-band data (HV pol.)
Analysis of a forested cell
- Height-velocity-temporal bandwidth functional (5D)

Semiparametric adaptive Diff-Tomo power frame after bandwidth optimization

Different values of temporal bandwidth are estimated for canopy and ground

First parametric results: [Lombardini-Cai, ESA Fringe '11]

Bandwidth (temporal decorrelation level) profiling is possible, without special HW!
Large scale analysis with HV polarization

Analysis of stratified temporal decorrelation mechanisms on boreal forest
- Mild decorrelating scenario, weak canopy scattering

First area results:
- [Lombardini-Cai, Fringe ’11]
- [Lombardini-Cai-Viviani, IGARSS ‘12]

Statistical analysis

<table>
<thead>
<tr>
<th></th>
<th>Canopy</th>
<th>Ground</th>
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<tbody>
<tr>
<td>Mean temporal bandwidths (phase-cycles/month)</td>
<td>0.08</td>
<td>0.04</td>
</tr>
<tr>
<td>Mean coherence times (months)</td>
<td>9.1</td>
<td>16.8</td>
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Estimates achieved for overall coherence down to about 0.4
Large scale analysis with HH polarization

Analysis of stratified temporal decorrelation mechanisms on boreal forest
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Statistical analysis

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<td>35.5 (eq.)</td>
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Coherence time of ground about two-fold rising in HH pol. w.r.t. HV pol. (trunk-ground dihedral contributions)

Azimuth line separated bandwidths

Separated bandwidth maps

Very extensive separations (500 land hectares processed)!
Robust extraction of forest height in temporal decorrelating scenarios through Diff-Tomo

Resolution can be restored! Higher accuracy than classical methods! The only solution available for (array) Tomo-SAR tailored for robustness to temporal decorrelation!


Sub-canopy subsidence estimation

Reference injected motion pattern

Extensive statistical analysis: Ground / Volume power ratio conditioned RMSE gain

- from 10 to -2 dB 1.1
- from 2 to -2 dB 1.25

(Results w.r.t. the best performing classic method)
Conclusions

- The **Differential Tomographic (Diff-Tomo) technique** is an advanced methodology for description and monitoring of decorrelating volume scatterers, beyond urban applications
  - Concept of *space-time signatures of temporal decorrelation* and proof with P-band airborne data
  - First parametric Diff-Tomo *separation of different overlayed temporal decorrelation mechanisms* extended to *large scale* and *different polarization (HV and HH)*: new phenomenological analyses of temporal decorrelation possible with *no special acquisitions*
  - **Temporal decorrelation-robust tomography** through Diff-Tomo reported, showing its potentials and capabilities
  - Potential of Diff-Tomo for subcanopy ground subsidence monitoring recalled

**Future work and perspectives**

- Extensive investigations on larger timespan dataset and on dataset with stronger temporal decorrelation (e.g. L-band)
- Future spaceborne missions may benefit from the application of these Diff-Tomo analysis and processing concepts.
Thanks for your attention!