Advances in the Science and Applications of SAR Interferometry and Sentinel-1 InSAR Workshop

Advanced Characterization Methods of Height-Varying Short- and Long-Term Forest TomoSAR Temporal Decorrelation

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Tomographic decorrelation issues in forest scenarios

Recall of Differential SAR Tomography (4D imaging)

Multidimensional (4 to 5D) imaging of forest areas: real P-band E-SAR, simulated P-band, and new quick Diff-Tomo analyses and results

- Diff-Tomo space-time signatures of decorrelating forest scatterers
- Vertical separation of long-term temporal decorrelation mechanisms, large scale
- Tomography robust to temporal decorrelation through Diff-Tomo, baseline-time patterns
- First direct radar measurements of short-term height-varying temporal decorrelation

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

Also companion satellites can be impacted for second-long lag time

- Elevation blurring problems from temporal decorrelation in Tomo-SAR and Pol-InSAR
- Studies of Tomo-SAR blurring and investigation of robust processing solutions
- Stratified temporal coherence analysis necessary, blurring origins are local

Phenomenological investigations important of both height-varying long-term and short-term (companion satellites) forest decorrelation for BIOMASS, NISAR, and SAOCOM-CS missions
From 3D Tomo to 4D imaging...

- D-InSAR concept
- Tomo-SAR concept
- Conv. MB/Mpass acquisition
- New processing

\textbf{Diff-Tomo*},

“opens” the SAR pixel extracting joint height and dynamical information of superimposed moving scatterers ("4D imaging", 3D+time)
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This is like a (spaceborne) “dynamic radar scanner” for Earth Observation

4D Differential SAR Tomography

From 3D Tomo to 4D imaging...

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Define an elevation-dependent spatial frequency: \( \omega_S = \frac{4\pi s}{\lambda R} \) (Tomo-SAR)

Define a velocity-dependent temporal frequency: \( \omega_T = \frac{4\pi v}{\lambda} \) (D-InSAR)

2-D Fourier relation
Spatial-Temporal spectral estimation

New output!

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From 3D Tomo to 4D imaging...
4D Differential SAR Tomography

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2-D Fourier relation
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New output!
Multitemporal multibaseline cmplx data
Cmplx amplitude elevation-velocity distribution

- 2D support in 2D baseline-time plane deeply exploited
- 2D elev.-vel. sidelobe handling by advanced spectral estimators
Temporal perturbations of a scattering component can be detected through Diff-Tomo processing. Temporal harmonic distribution of Temp. freq. does not merely code velocity anymore.

New vision in SAR interferometry:
This also allows avoiding misinterpretation of temporal perturbations in the spatial spectral estimation.
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

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

Adaptive 4D Diff-Tomo frame

Normalized adaptive 4D Diff-Tomo frame
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Mild temporal decorrelation
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Non-parametric analysis of a forested cell – Real data
space-time long-term decorrelation signatures
• HV pol.

Canopy scatterer detected with a wider temporal frequency bandwidth w.r.t. ground
Large scale parametric (5D) analysis, long-term
Analysis of stratified temporal decorrelation mechanisms on boreal forest

- Mild decorrelating scenario, weak canopy scattering

**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>
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<td>0.04</td>
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<tr>
<td>Mean coherence times (months)</td>
<td>9.1</td>
<td>16.8</td>
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Boreal forest results

**Estimates for overall coherence down to 0.4**

**Separation of temporal bandwidth maps**

*(LIDAR and overall coherence masking)*

**BIOSAR P-Band data**

[Lombardini-Viviani-Cai-Dini, IGARSS ‘13]

- HV pol.
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BIOSAR P-Band data
[Lombardini-Viviani-Cai-Dini, IGARSS ’13]

• HV pol.

Separated temporal bandwidth maps
(LIDAR and overall coherence masking)

Mean temporal bandwidths (phase-cycles/month)
- Canopy: 0.08
- Ground: 0.04

Mean coherence times (months)
- Canopy: 9.1
- Ground: 16.8

Boreal forest results

Estimates for overall coherence down to 0.4
**P-band temporal decorrelation stratigraphy (2)**

**Large scale parametric (5D) analysis, long-term**
Analysis of stratified temporal decorrelation mechanisms on boreal forest

- Mild decorrelating scenario, weak canopy scattering
  
  Estimates for overall coherence down to 0.4

- Very extensive separations, >500 land hectares analyzed!
  (>> than TropiScat and AfriScat towers ≈≤1 hectares)
  (4700 cells vs 160 cells)

- No special HW required, airborne data
Large scale parametric (5D) analysis, long-term
Analysis of stratified temporal decorrelation mechanisms on boreal forest

- Mild decorrelating scenario, weak canopy scattering

**Statistical analysis**
(with LIDAR masking)

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Boreal forest results

- Ground coherence time about two-fold rising in HH pol. with respect to HV pol.
- Phenomenological interpretation consistent with the typical scattering mechanisms
Robust Tomography – P-band simulated analysis

**Robust extraction of forest height in temporal decorrelating scenarios**

*Example of robust Tomography potential capabilities for BIOMASS*

Potential for NISAR already tested

*Parametric 4D+ Diff-Tomo processing vs. model-based 3D*

**Robust 3D via Diff-Tomo**

Misinterpretation avoided of temporal perturbations in the spatial spectral estimation (temporal bandwidths as a nuisance)

\[ \Delta h = 0.6 \text{ Rayleigh r.u.} \]

\[ \tau_c = 3 \frac{1}{2} \text{ months} \]

revisit time = 17 days

\[ \tau_c = 6 \text{ revisit times} \]

P-band forest scenario monostatic monotonic acquisition pattern
(10 passes)

P-band forest scenario monostatic b-t sparse scrambled acquisition pattern
(10 passes)

Robust extraction of forest height in temporal decorrelating scenarios

Example of robust Tomography potential capabilities for BIOMASS

Potential for NISAR already tested

Parametric 4D+ Diff-Tomo processing vs. model-based 3D

Robust 3D via Diff-Tomo

Misinterpretation avoided of temporal perturbations in the spatial spectral estimation (temporal bandwidths as a nuisance)

Orbital design could be reconsidered synergically with 4D decorrelation-robust processing

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revisit time = 17 days

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P-band forest scenario monostatic monotonic acquisition pattern (10 passes)

P-band forest scenario monostatic b-t sparse scrambled acquisition pattern (10 passes)

Robust extraction of forest height in decorrelating scenarios through parametric Diff-Tomo

Model-based 3D Tomo-SAR

Matched model-based 5D Diff-Tomo

• HV pol.

Several canopy layer portions blurred/missed

Height resolution significantly restored, sidelobes better cleaned, both canopy and ground scatterers neatly located

The method could be investigated for BIOMASS

5D processing is here in variable model order form, and “absorbs” also possible trends of collective phase shifts

BIOSAR P-Band data
First set up of a dedicated micro-scale space-time short-term decorrelation signature experiment with a tower mini-sensor (X-band, S-band).

Innovative short-term coherence profiling along the height dimension by a special ground-based miniradar (X-band, HH pol.) also experimented.

1st quick Diff-Tomo characterization of short-term height-varying coherence time

Scenario
- Site in Pisa
- poplar and elm trees
- light breeze
- cross-wind
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\[ \tilde{\tau}_c \approx 60\,ms \quad \tau_c \text{ six-fold decreasing from bottom to top} \]
Short-term temporal decorrelation experiments (2)

First set up of a dedicated micro-scale space-time short-term decorrelation signature experiment with a tower mini-sensor (X-band, S-band)

Innovative short-term coherence profiling along the height dimension by a special ground-based miniradar (X-band, HH pol.) also experimented.

1st quick Diff-Tomo characterization of short-term height-varying coherence time

Important to consider characterizing the (height-varying) short-term decorrelation for SAOCOM-CS

Scenario
- Site in Pisa
- poplar and elm trees
- light breeze
- cross-wind
The **Differential Tomographic (Diff-Tomo) technique** is an advanced methodology for promising 3D sensing and TomoSAR/PolInSAR characterization of **decorrelating forest scatterers**, beyond urban applications.

- **Diff-Tomo separation of different overlayed long-term decorrelation mechanisms:**
  - Coverage exploiting airborne data much larger than **TropiScat** and **AfriScat**
  - No special hardware required
  - Can be considered also to exploit **AfriSAR** extending **AfriScat** analyses

- **Temporal decorrelation-robust Tomography** through **Diff-Tomo**:
  - Sparse (non monotonic) baseline-time sampling can be considered jointly with robust Tomography for monostatic satellite systems;
  - Experimentable with AfriSAR and AfriScat

- **New vertical profiling of short-term temporal decorrelation:**
  - First results from **ground-based quick miniradar** experiment (currently at X-band; possible next extension also at S-band)
  - Phenomenology can be important in designing non-fully simultaneous **SAOCOM-CS** satellites

- Long-wavelength spaceborne missions (BIOMASS, NISAR, SAOCOM-CS, Tandem-L, etc.) and supporting campaigns could benefit from the application of these Diff-Tomo analyses, processing, and measurement concepts
THANKS FOR YOUR ATTENTION!