→ POLINSAR 2013
The 6th International Workshop on Science and Applications of SAR Polarimetry and Polarimetric Interferometry

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

Fabrizio Lombardini[1,2], Federico Viviani[1,2], Francesco Cai[1]

[1] University of Pisa, Dept. of Information Engineering, Pisa, Italy
[2] CNIT-RaSS National Laboratory, Pisa, Italy

28 January - 1 February 2013 | ESA-ESRIN | Frascati (Rome), Italy
European Space Agency

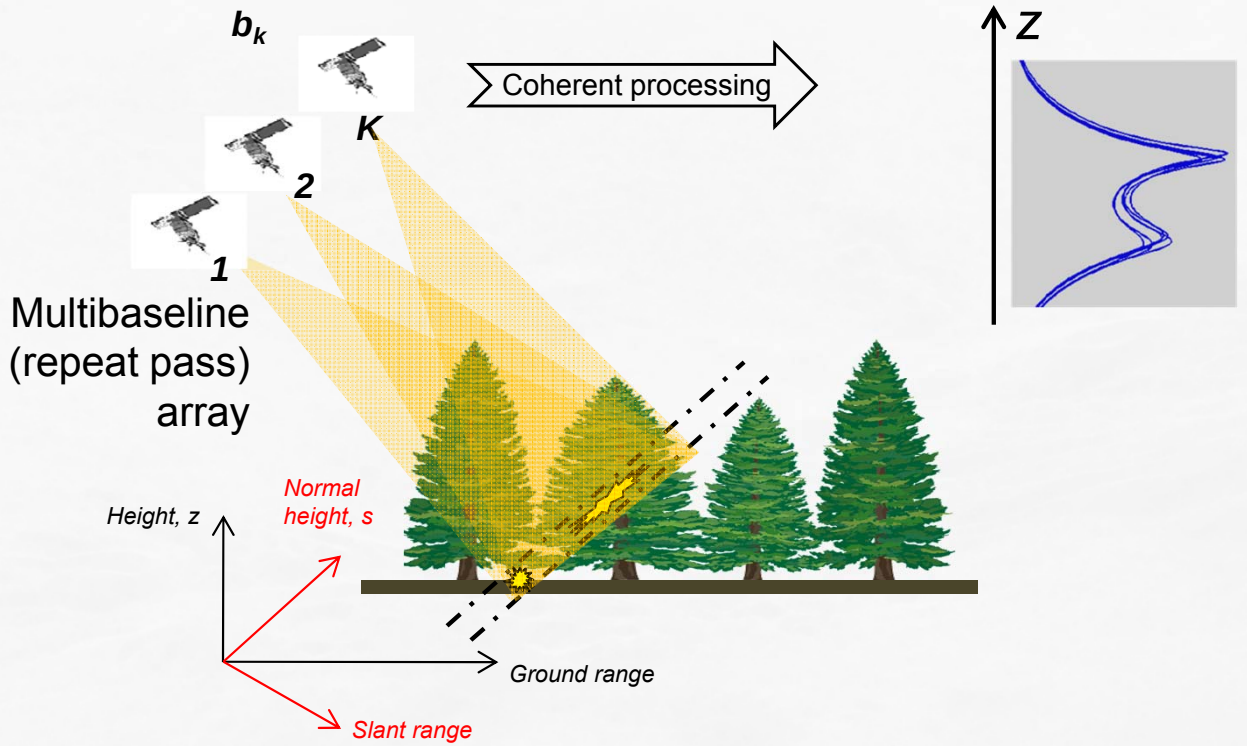
Outline

- **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**

3D SAR Tomography concept

Volumetric forest scenarios

Key importance in the context of the carbon cycle budget control !



Tomo-SAR can localize the multiple scatterers through spatial spectral estimation (i.e. elevation beamforming)

However…

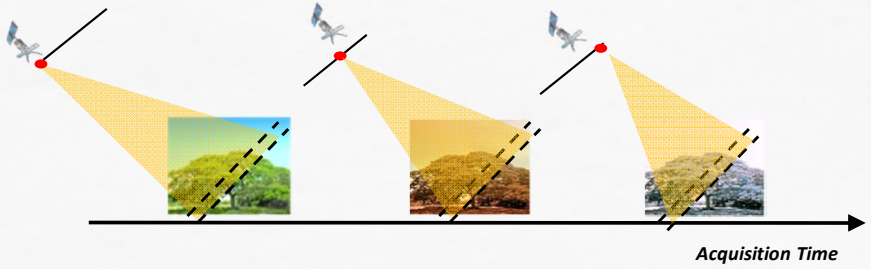
- **Limited and sparse baseline distribution, poor 3D Fourier imaging quality**

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

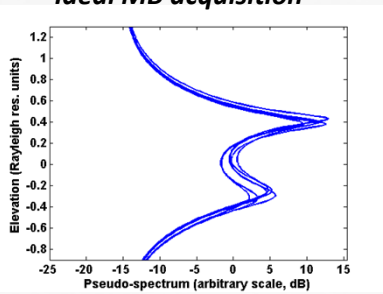
- **Possible limited operativity in non-fully coherent scenarios…**

Open issues

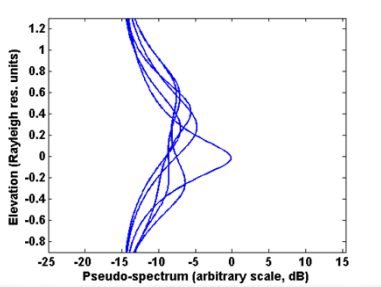
- **Elevation blurring problems from temporal decorrelation and scatterers motion**



Ideal MB acquisition



Temporal decorrelating scenario



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!***

Differential SAR Tomography concept

D-InSAR and Tomo-SAR crossed in a new unified framework: [Lombardini, IEEE-TGARS '05]

Height-dependent spatial frequency: $\omega_S = 4\pi\, z/(\lambda R \sin\theta)$

Line-of-sight velocity-dependent temporal frequency: $\omega_T = 4\pi\, v/\lambda$

$$y(b,t) \rightleftharpoons \gamma(\omega_S, \omega_T)$$

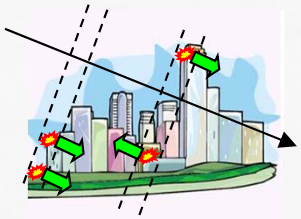
2D Fourier relation

Multitemporal multibaseline cmplx data

Cmplx amplitude elev.-vel. distribution

Joint elevation-velocity resolution of multiple scatterers (by proper sparse-sampling sidelobe cleaning)

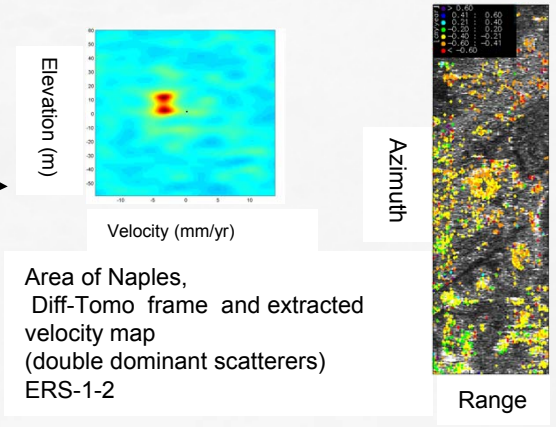
Diff-Tomo "opens" the SAR pixel extracting joint height and dynamical information of superimposed scatterers ("4D imaging", 3D+time) in complex scenarios*



Discrete space-time spectrum

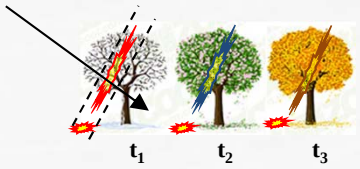
Temporal frequencies code velocities

Example: subsidence in urban layover areas



Area of Naples, Diff-Tomo frame and extracted velocity map (double dominant scatterers) ERS-1-2

[Lombardini-Pardini, IEEE-TGARS '12]



Temporal frequencies are signatures of the temporal decorrelation !

* UniPi Patent

4D space-time signatures of decorrelation

Temporal perturbations of a scattering component
➡ temporal harmonic *distribution*
Temp. freq. does not merely code velocity anymore

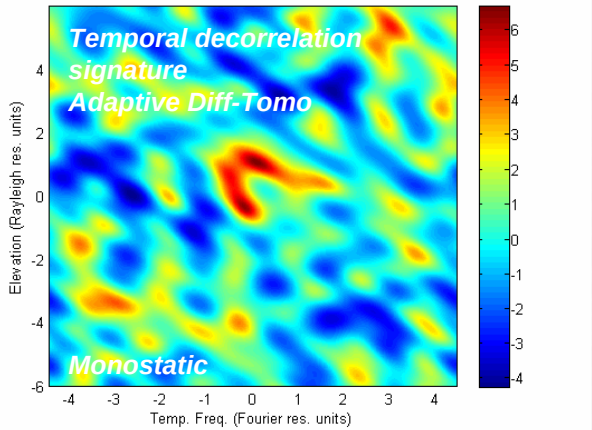
Diff-Tomo processing

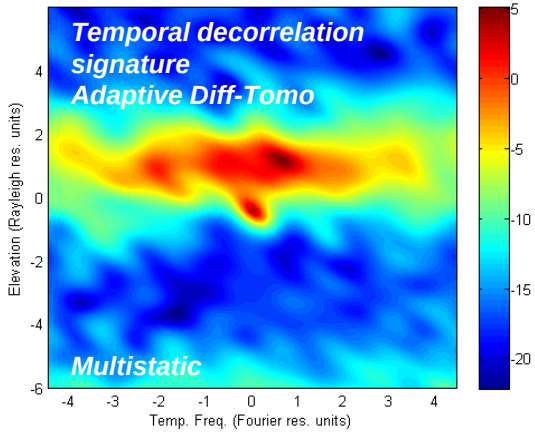
Continuos temporal spectrum signatures of temporal decorrelation can be detected !

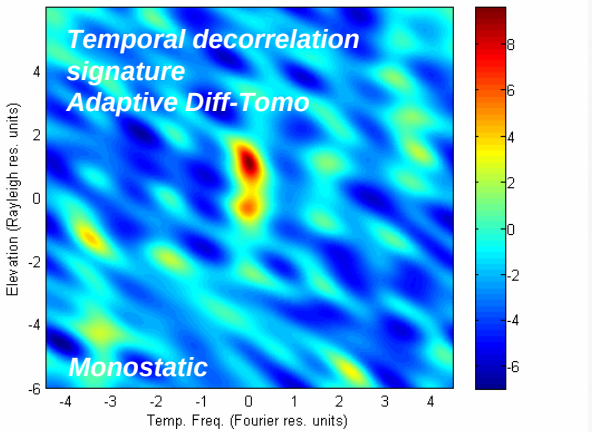
New vision in SAR interferometry…

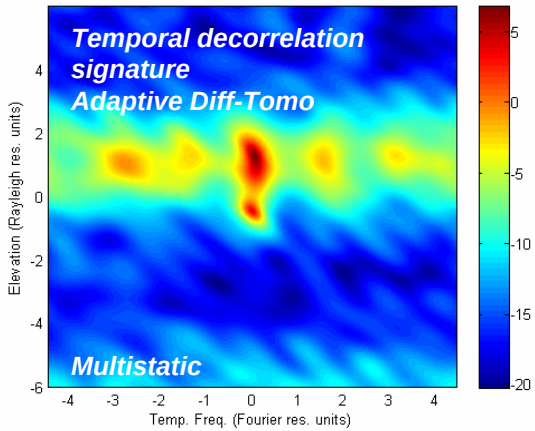
[Lombardini-Cai, IGARSS '08]

baseline-time autocorrelation $r_y[b,t] \Leftrightarrow \overline{|\gamma(\omega_S,\omega_T)|^2}$ space-time p.s.d.









Sample simulated volume:
t_c = 2.8 revisit times,
temporal bandwidth 1 Fourier r.u. ,
ρ_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 = ∞,
temporal bandwidth 0 Fourier r.u. ,
ρ_0= 0.7.

4D space-time signatures of decorrelation

Temporal perturbations of a scattering component
➡ temporal harmonic *distribution*
Temp. freq. does not merely code velocity anymore

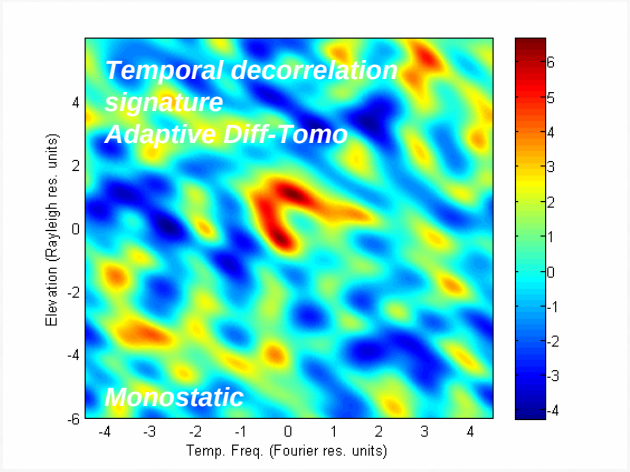
Diff-Tomo processing

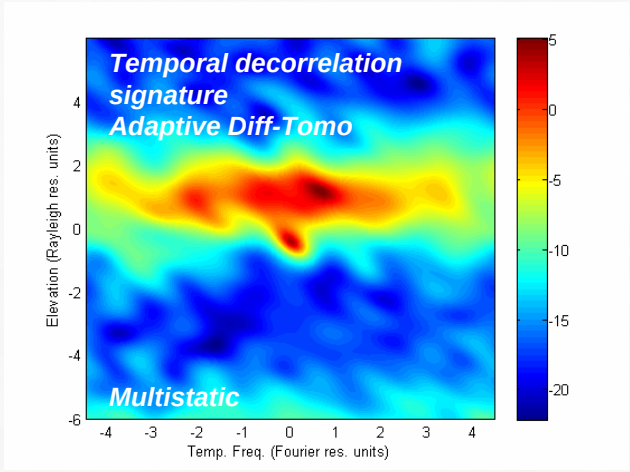
Continuos temporal spectrum signatures of temporal decorrelation can be detected !

New vision in SAR interferometry…

[Lombardini-Cai, IGARSS '08]

baseline-time autocorrelation $r_y[b,t] \Leftrightarrow \overline{|\gamma(\omega_S,\omega_T)|^2}$ space-time p.s.d.





Sample simulated volume:
t_c = 2.8 revisit times,
temporal bandwidth 1 Fourier r.u. ,
ρ_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]

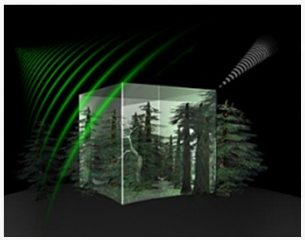
3 – Possibly, subcanopy subsidence estimation… (5D parameter extraction)

4D space-time signatures: proof of concept

Remningstorp forest site

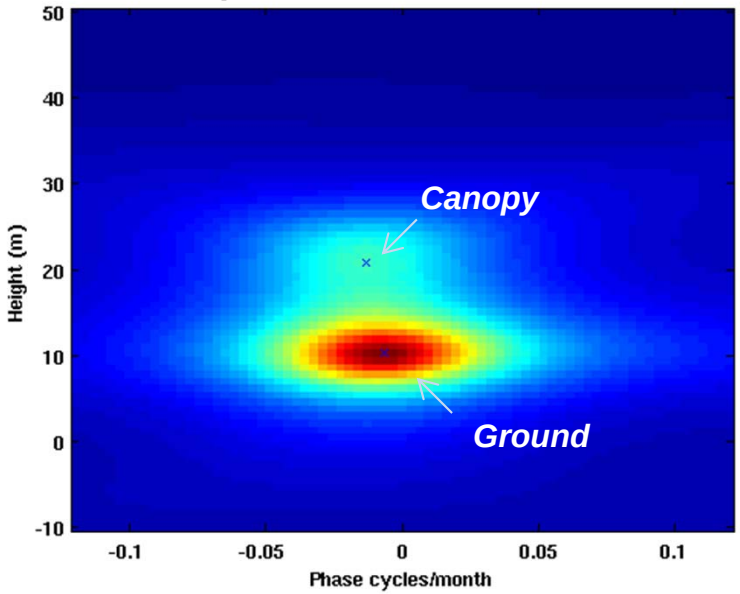
Mild temporal decorrelation

- 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.

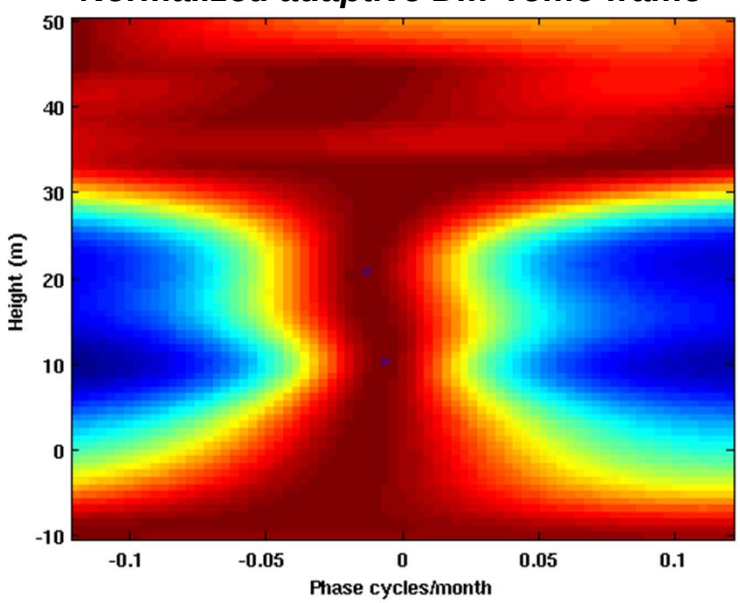


Non-parametric analysis of a forested cell – Real data investigation of space-time decorrelation signatures

Adaptive Diff-Tomo frame



Normalized adaptive Diff-Tomo frame

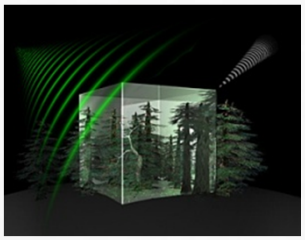


4D space-time signatures: proof of concept

Remningstorp forest site

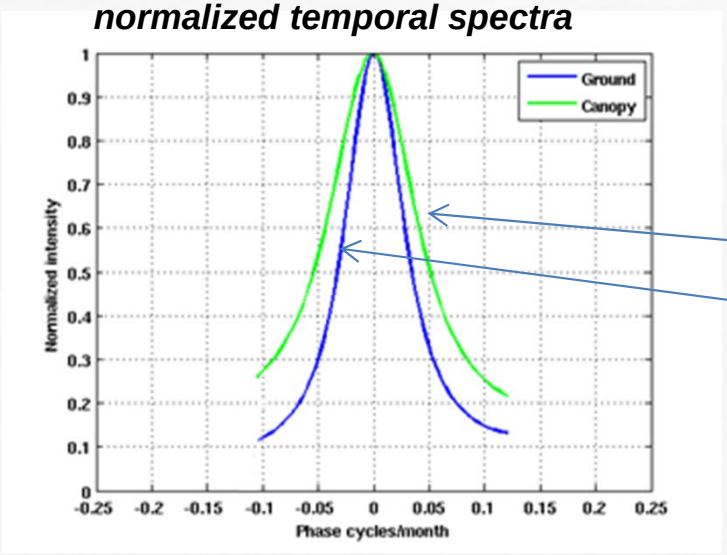
Mild temporal decorrelation

- 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.

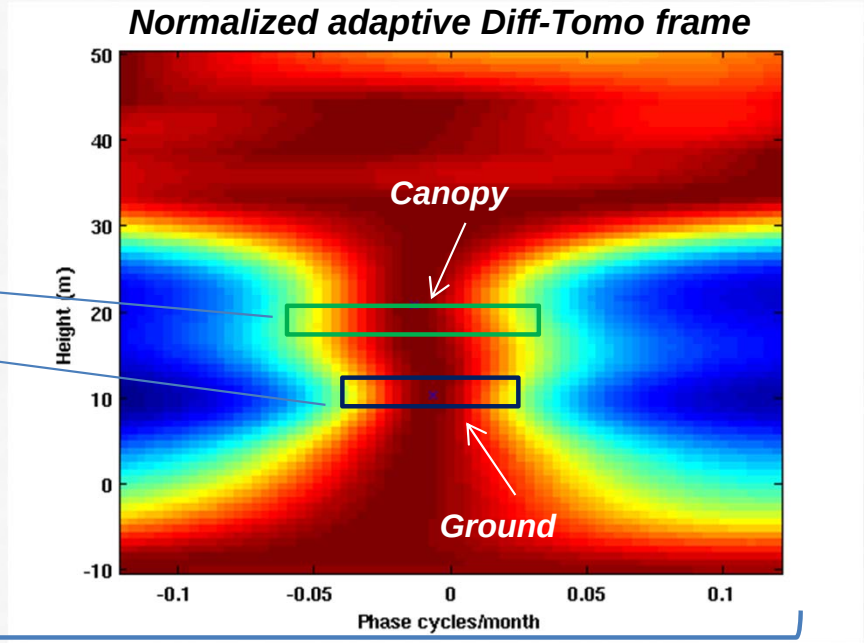


Non-parametric analysis of a forested cell – Real data investigation of space-time decorrelation signatures

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

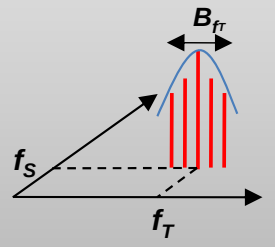
[Lombardini-Cai, ESA Fringe '11]

Temporal coherence separation

Parametric separation of different temporal scattering mechanisms inside the SAR cell

$$f_{DT}\left(f_S, f_T, B_{f_T}\right)$$

(5D parameter extraction)



Temporal coherence separation

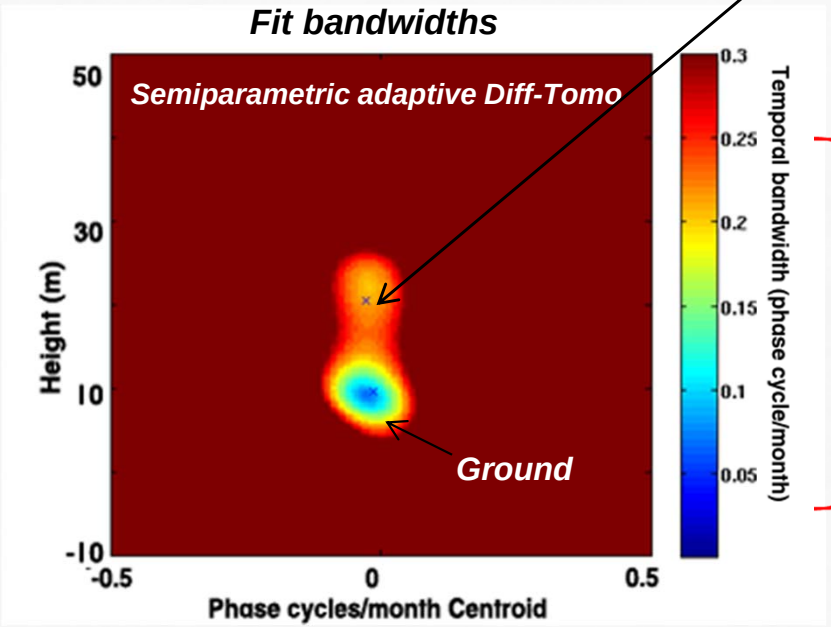
Parametric separation of different temporal scattering mechanisms inside the SAR cell

BIOSAR P-band data (HV pol.)

Analysis of a forested cell

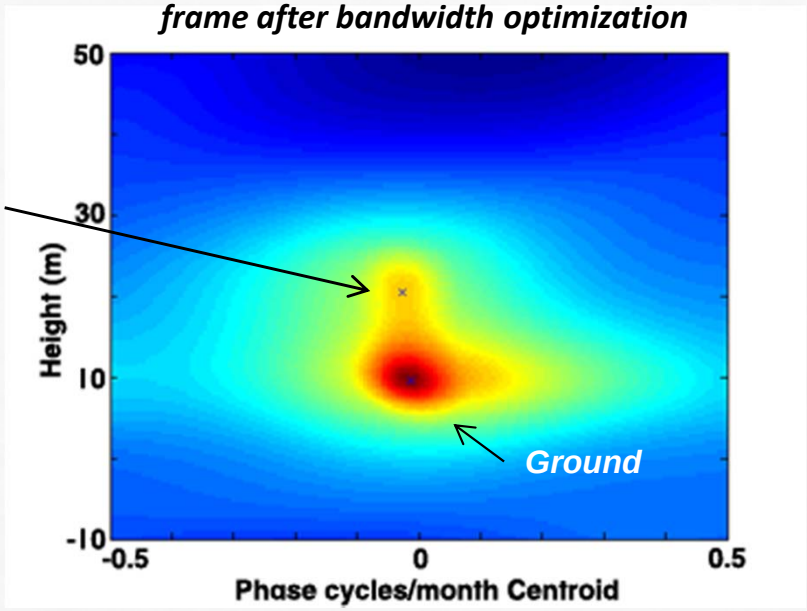
- Height-velocity-temporal bandwidth functional (*5D*)

Fit bandwidths



Canopy

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 !

Temporal coherence separation (2)

Large scale analysis with HV polarization

Analysis of stratified temporal decorrelation mechanisms on boreal forest

- Mild decorrelating scenario, weak canopy scattering

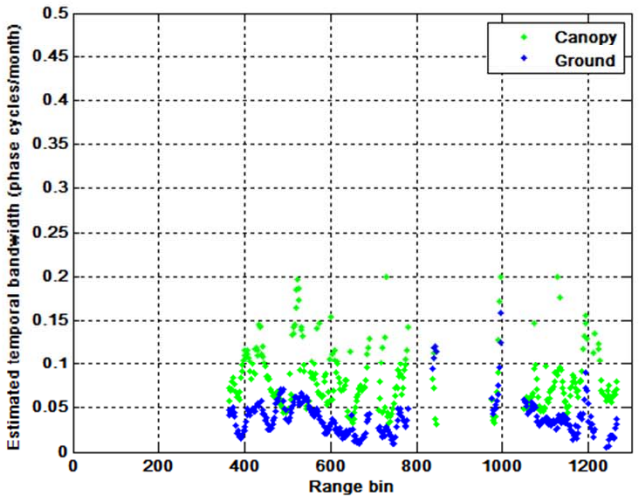
First area results : [Lombardini-Cai, Fringe '11]
[Lombardini-Cai-Viviani, IGARSS '12]

Statistical analysis

	Canopy	Ground
Mean temporal bandwidths (phase-cycles/month)	0.08	0.04
Mean coherence times (months)	9.1	16.8

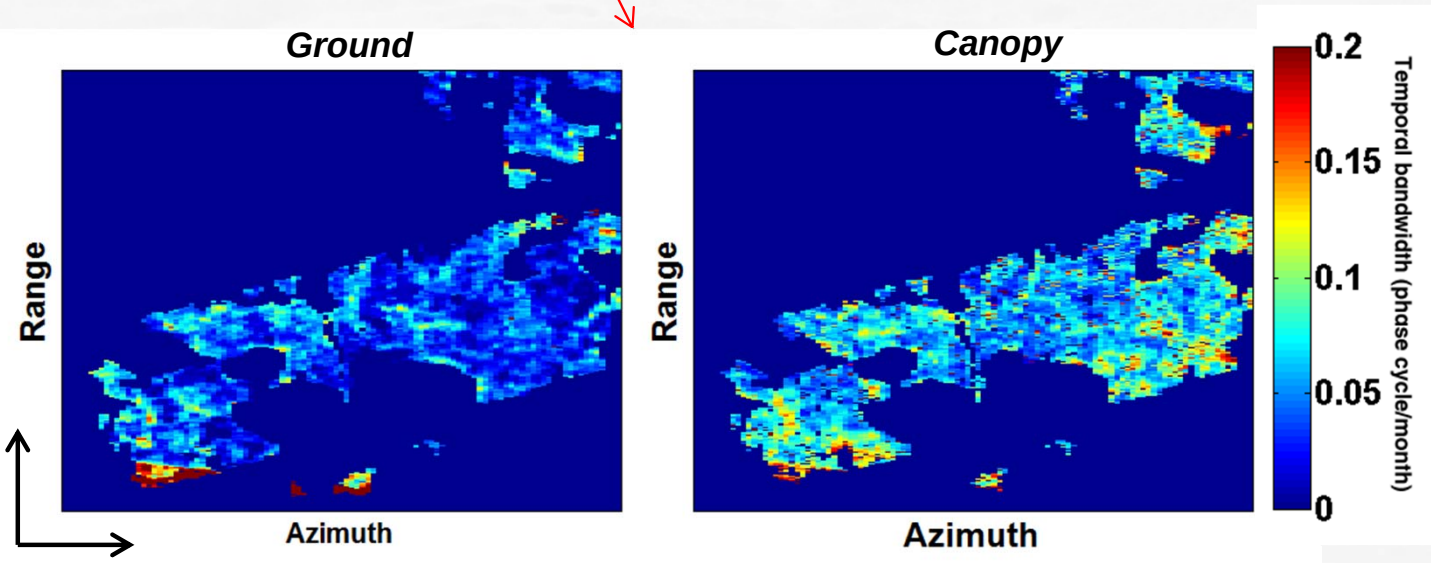
Estimates achieved for overall coherence down to about 0.4

Azimuth line separated bandwidths



Very extensive separations (500 land hectares processed) !

Separated bandwidth maps



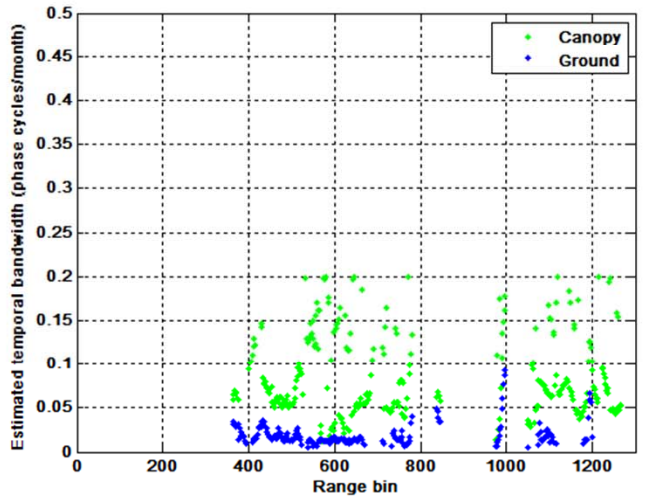
Temporal coherence separation (3)

Large scale analysis with HH polarization

Analysis of stratified temporal decorrelation mechanisms on boreal forest

- Mild decorrelating scenario, weak canopy scattering

Azimuth line separated bandwidths

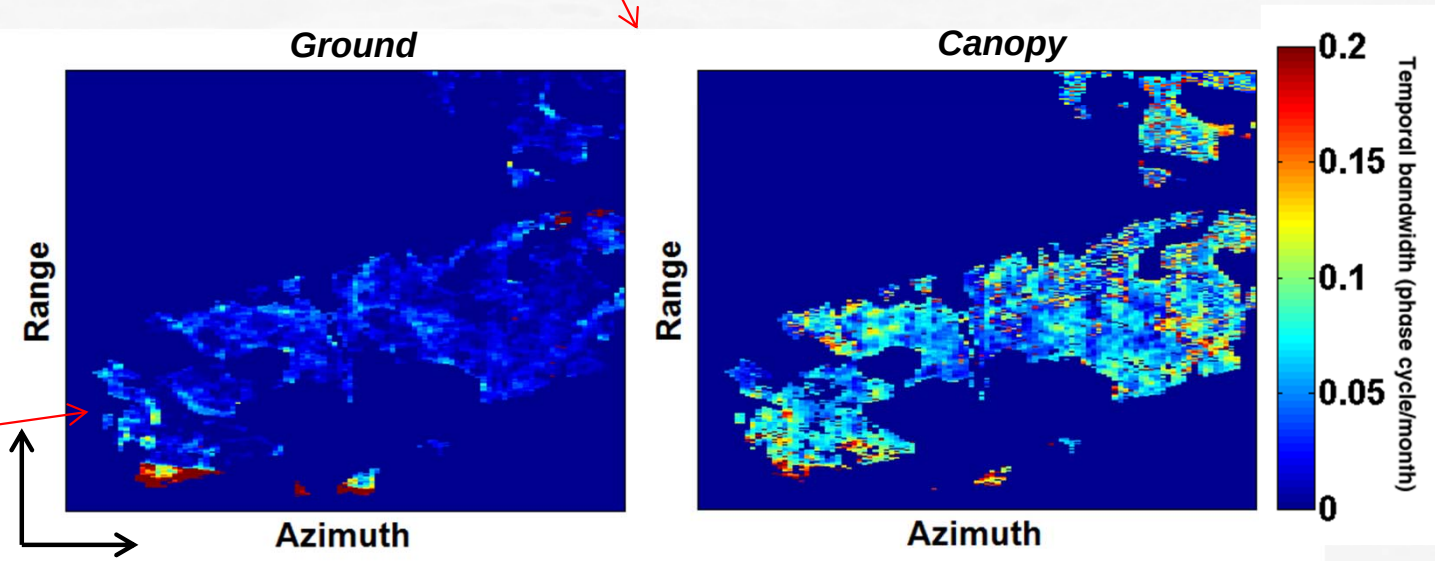


Statistical analysis

	Canopy	Ground
Mean temporal bandwidths (phase-cycles/month)	0.08	0.03
Mean coherence times (months)	9.1	35.5 (eq.)

Very extensive separations (500 land hectares processed) !

Separated bandwidth maps

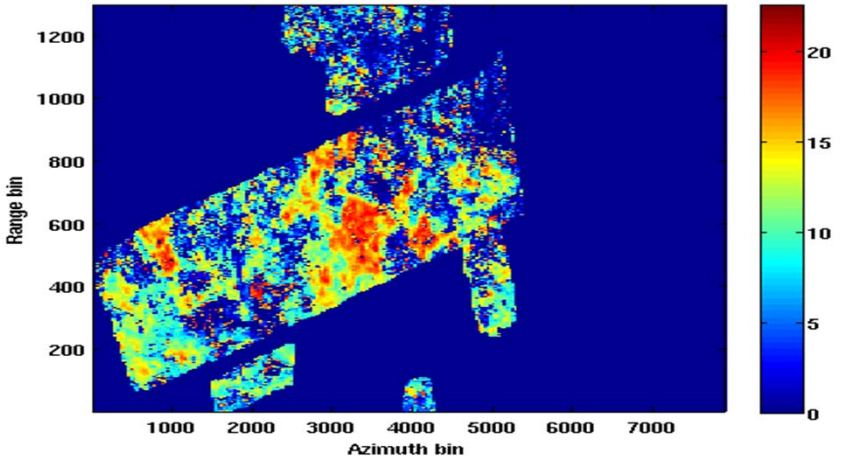


Coherence time of ground about two-fold rising in HH pol. w.r.t. HV pol. (trunk-ground dihedral contributions)

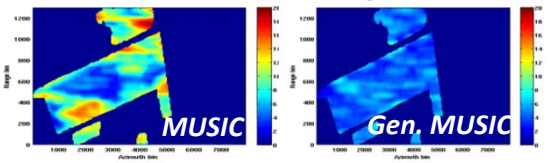
Other Diff-Tomo functionalities

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

Estimated Canopy-Ground height difference



Accuracy map (from reference LIDAR data)



Extensive statistical analysis:

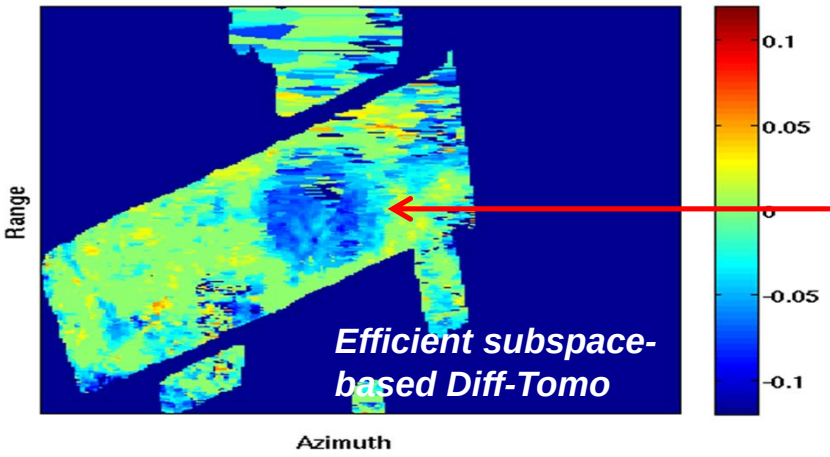
Method	Resolution
Gen. MUSIC	90 %
MUSIC	45 %

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

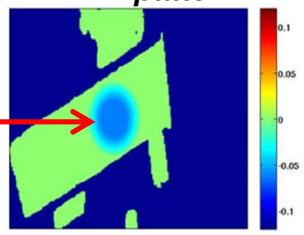
[Lombardini-Cai-Pardini, EUSAR'10] [Lombardini-Cai, Fringe '11]

Sub-canopy subsidence estimation

Estimated ground subsidence



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

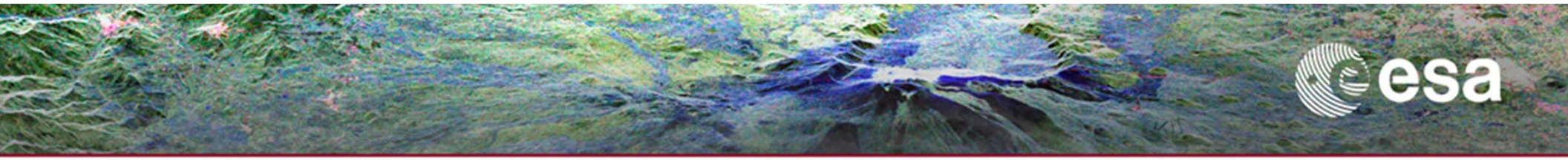
(Results w.r.t. the best perfoming classic method)

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!