ADVANCED TECHNIQUES AND NEW HIGH RESOLUTION SAR SENSORS FOR MONITORING URBAN AREAS

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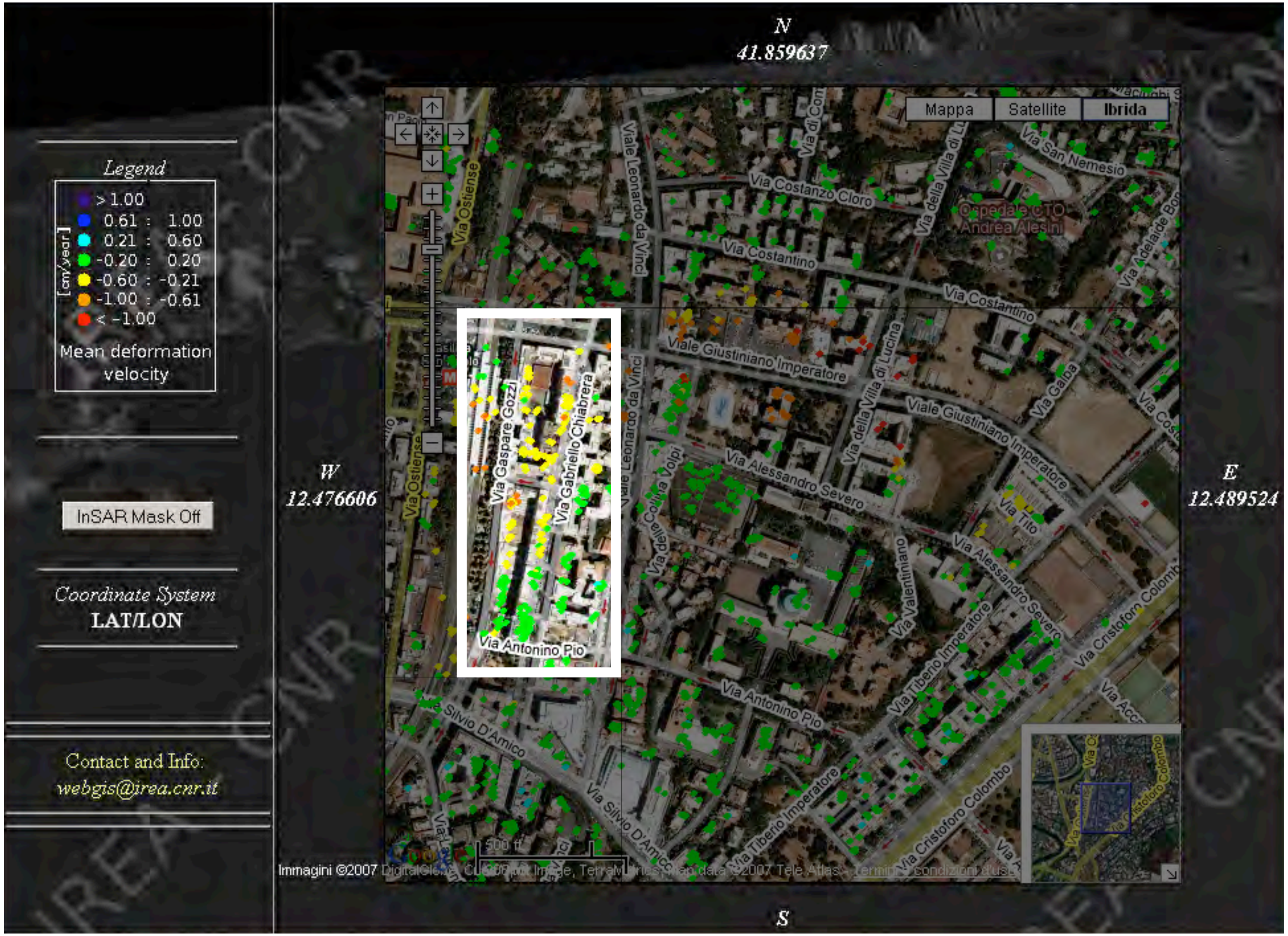
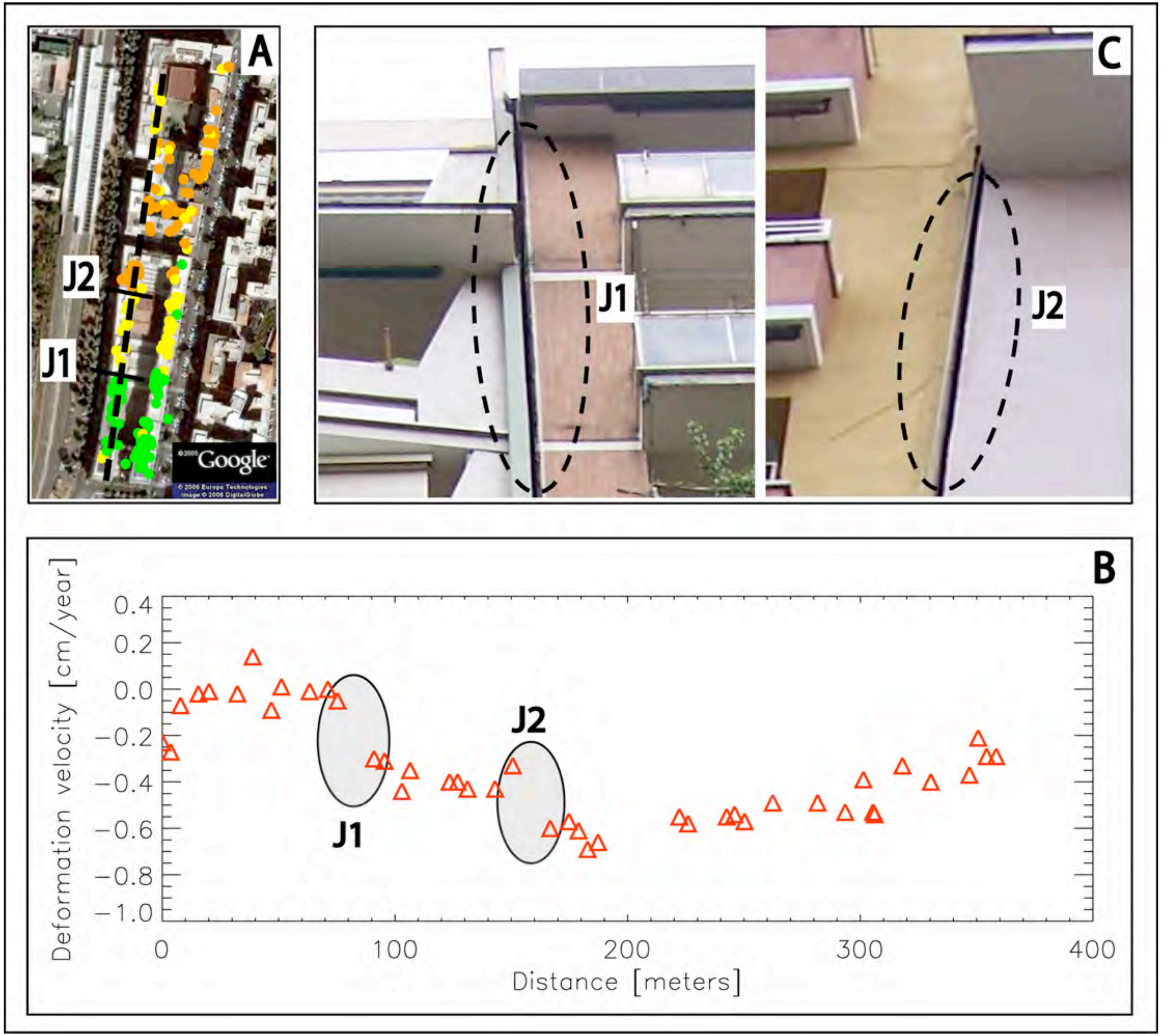
What multipass SAR Interferometry has made with data of medium resolution systems?



M. Manunta, et al, “Two-scale surface deformation analysis using the SBAS-DInSAR technique: a case study of the city of Rome, Italy”, *Journal of Remote Sens*, 29, 1665-1684, 2008.



A
J2
J1
©2005 Google
C
J1
J2
B
Deformation velocity [cm/year]
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0
100
200
300
400
Distance [meters]
J1
J2

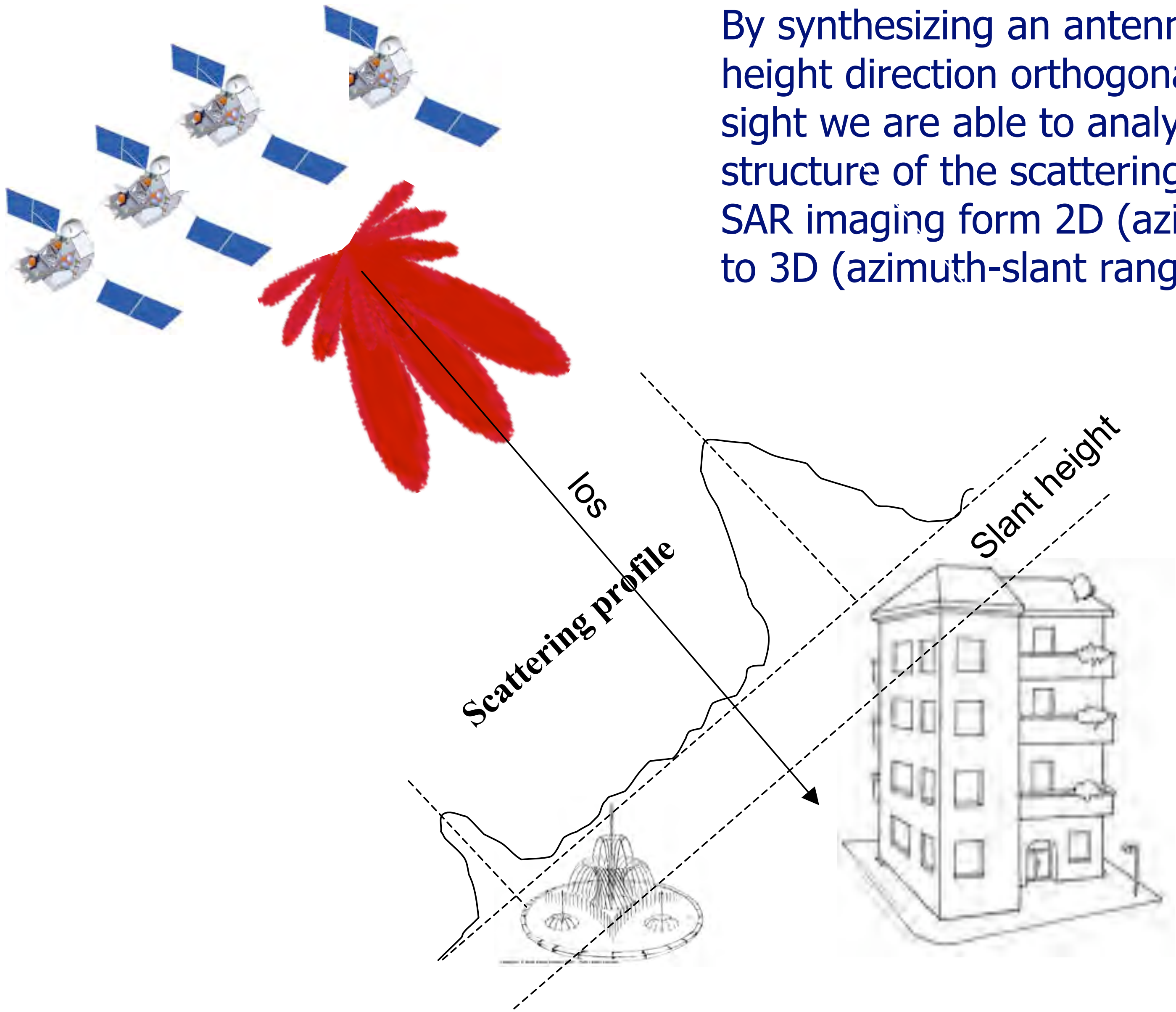
Considerations

- Application of multipass interferometric analysis to medium resolution data has shown a significant contribution to the objective of imaging and monitoring buildings and have dramatically boosted the applications of SAR.

HOW CAN WE IMPROVE THE RESULTS?

- HW: use higher resolution sensors.
- SW: use advanced techniques. Interferometry uses only the amplitude and assumes the presence only of one scatterer per range-azimuth pixel: we can move to multiD (3D and 4D imaging).
- Or both!

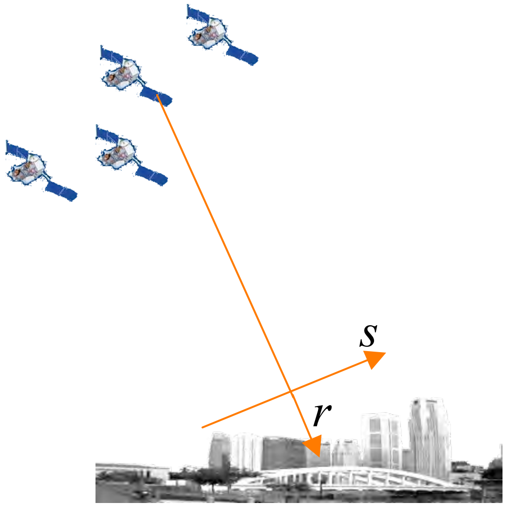
Multidimensional imaging: 3D



By synthesizing an antenna also in the slant height direction orthogonal to the line of sight we are able to analyze the vertical structure of the scattering thus extending SAR imaging form 2D (azimuth-slant range) to 3D (azimuth-slant range-slant height)

3D SAR Imaging

N acquisitions with spatial baseline distribution $b_1 \ldots\ldots b_N$



backscattering distribution in the slant height

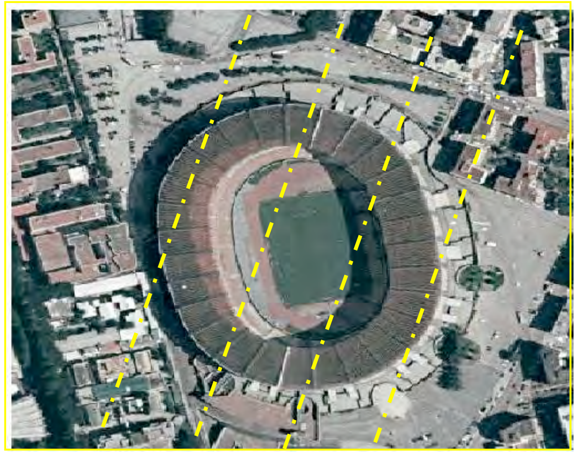
$$g_n = \int_{-s_{\max}}^{s_{\max}} \gamma(s) e^{j2\pi\xi_n s} ds \qquad \xi_n = 2b_n/(\lambda r) \qquad n = 1,\ldots N$$

signal to the *n*-th antenna

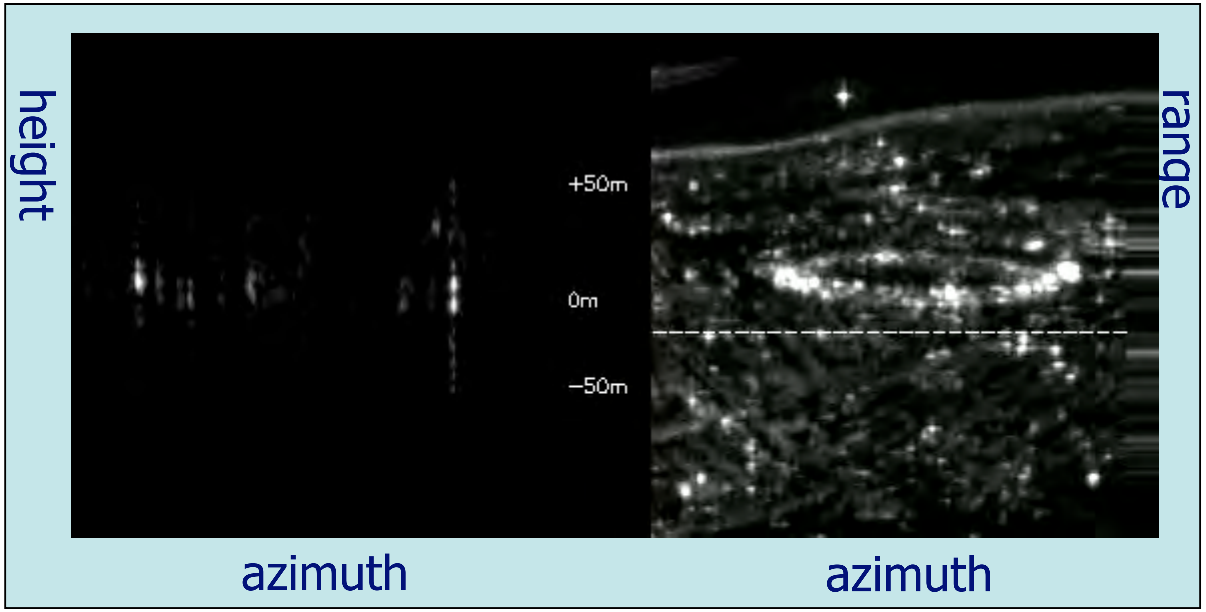
Fourier inversion from irregular samples:

- BeamForming
- Regularized inversion
- Adaptive Beamforming (Capon)
- Compressive sensing

3D images: the Stadium of Napoli

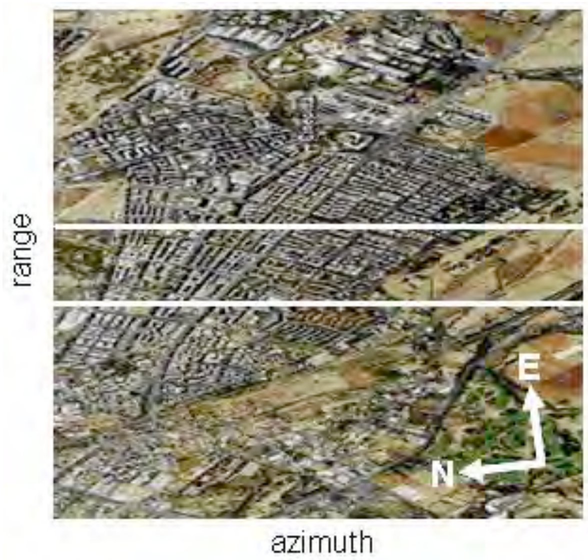


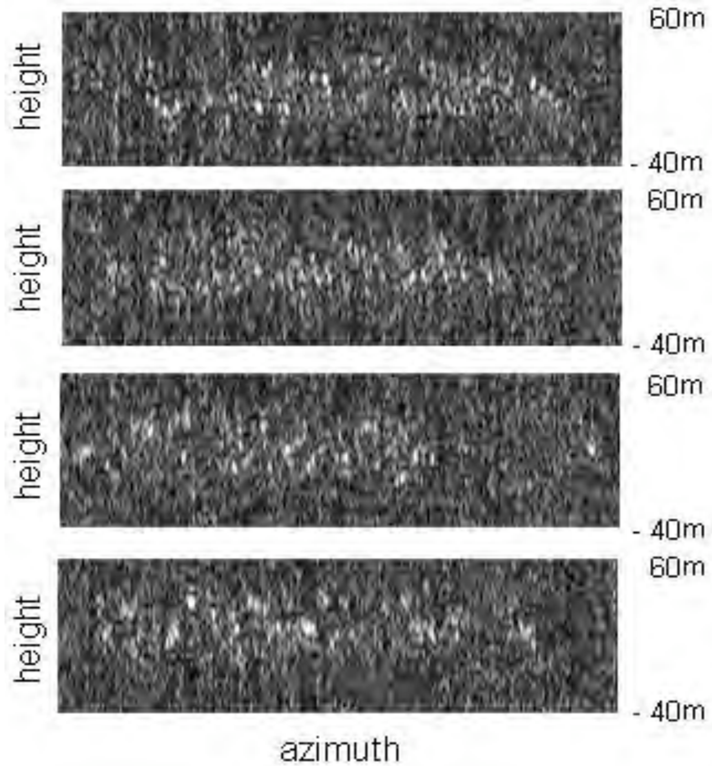
- Passes:30
- Baseline span: 1100m
- Elevation resolution: 22m (8m in height)



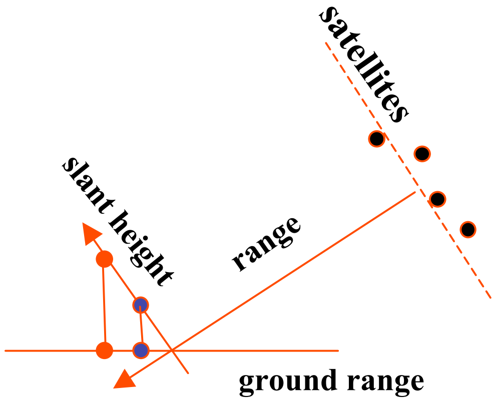
Experiments on real data (Rome)

ERS1 ERS2 satellites (43 images from 1995-2000)
Temporal span: about 5 years;
Baseline span: about 1500m





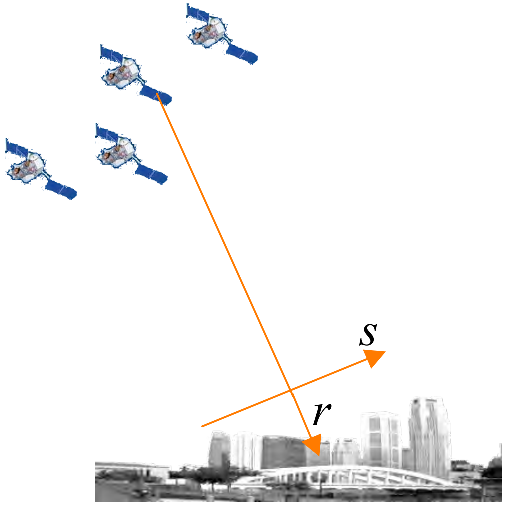
Separation of scatterers in layover



ERS1 ERS2 satellites (43 images from 1995-2000) over Rome
Temporal span: about 5 years;
Baseline span: about 1500m

4D SAR Imaging (Differential SAR Tomography)

N acquisitions with spatial baseline distribution $b_1 \ldots\ldots b_N$ and temporal distribution $t_1 \ldots\ldots t_N$

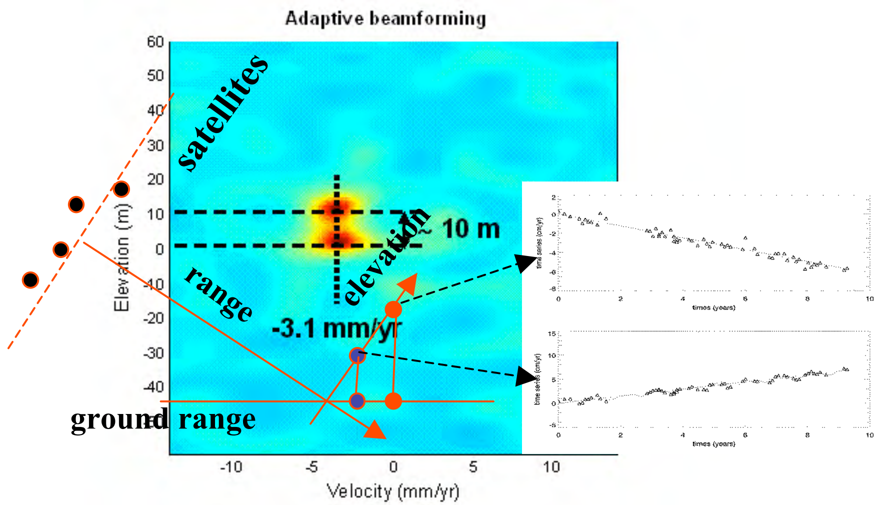


Deformation term

$$g_n = \int_{-s_{\max}}^{s_{\max}} \gamma(s) e^{j2\pi\xi_n s} e^{j\frac{4\pi}{\lambda} d(s,t_n)} ds$$

Signal to the *n*-th antenna

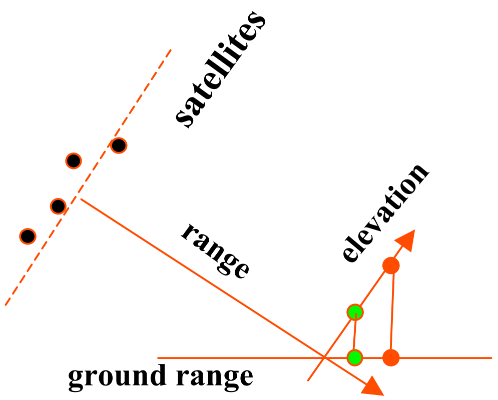
$$g_n = \int_{-s_{\max}}^{s_{\max}} \int_{-v_{\max}}^{v_{\max}} a_\gamma(s,v) e^{j2\pi\xi_n s + j2\pi\eta_n v} dv ds$$

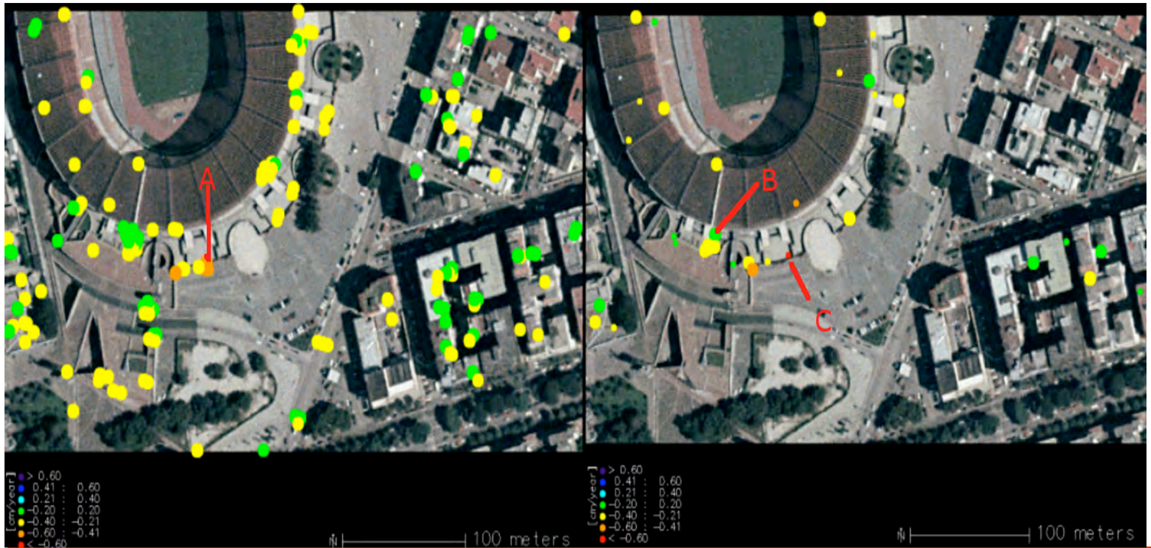


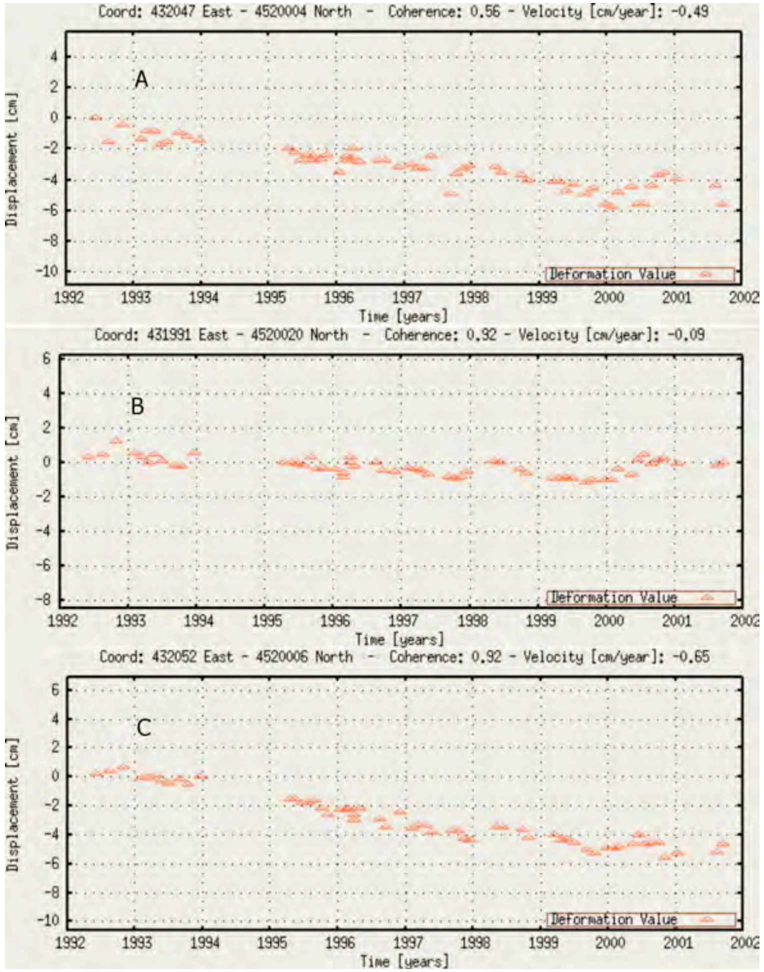
F. Lombardini, “Differential Tomography: a New Framework for SAR Interferometry “, IEEE Trans. Geosci. Remote Sens., 43, pp. 37-44, 2005.

G. Fornaro, D. Reale, F. Serafino, "Four-Dimensional SAR Imaging for Height Estimation and Monitoring of Single and Double Scatterers", IEEE Trans. Geosci. Remote Sens., Jan. 2009, vol. 47 (1), 224-237

Experiments of 4DI on real data (Naples)





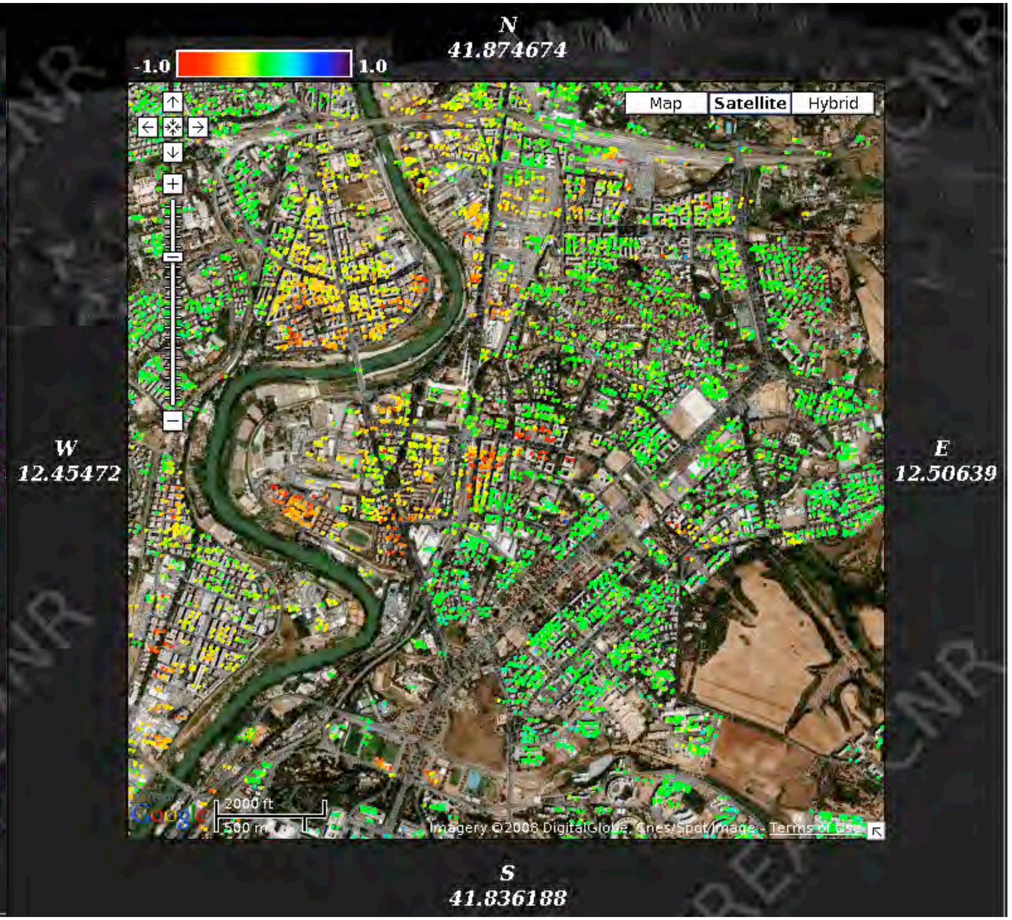


ERS1 ERS2 satellites (58 images from 1992-2000)

Temporal span of about 10 years; baseline span of about 1700m,

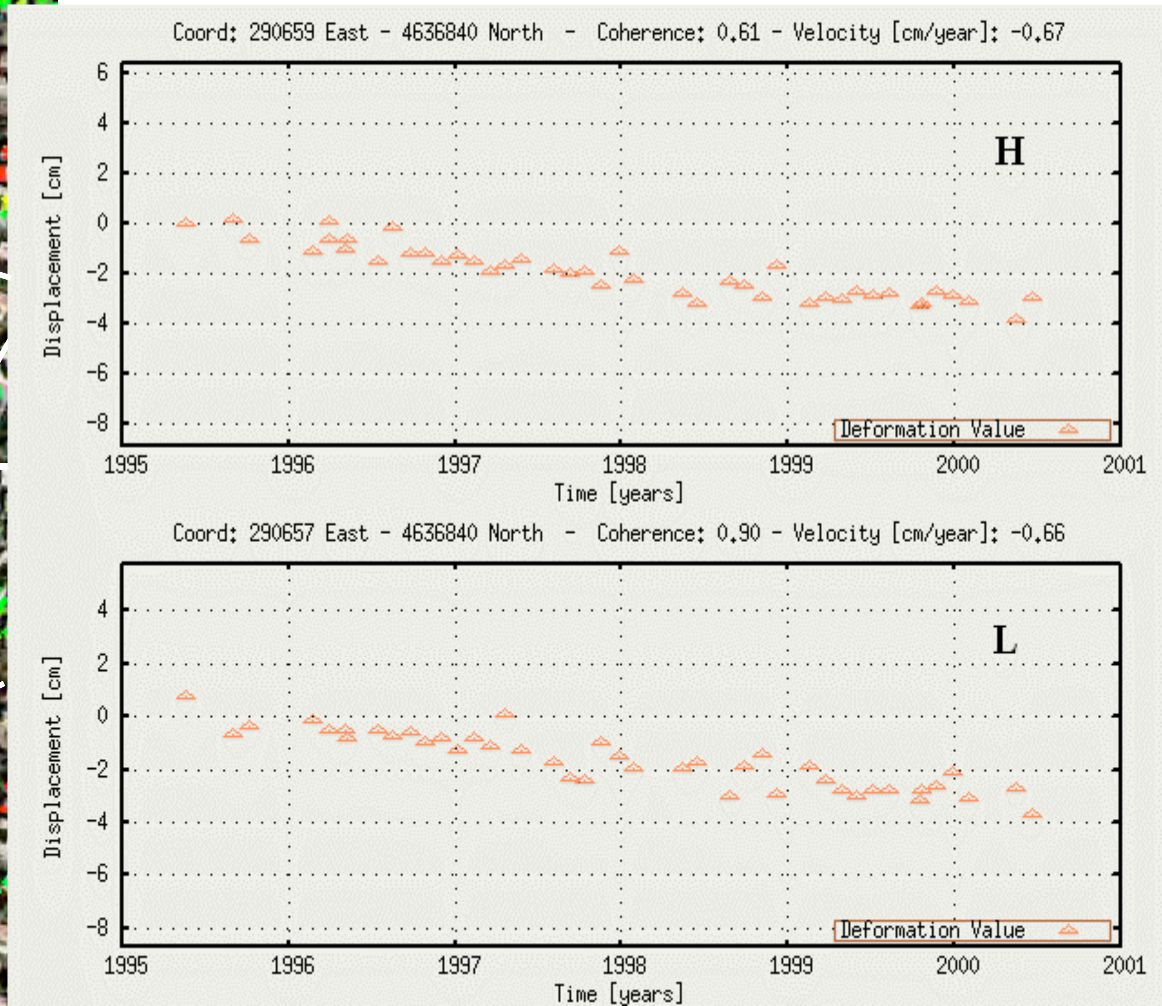
Experiments of 4DI on real data (Rome)

Single scatterers with 4DI



Double scatterers with 4DI

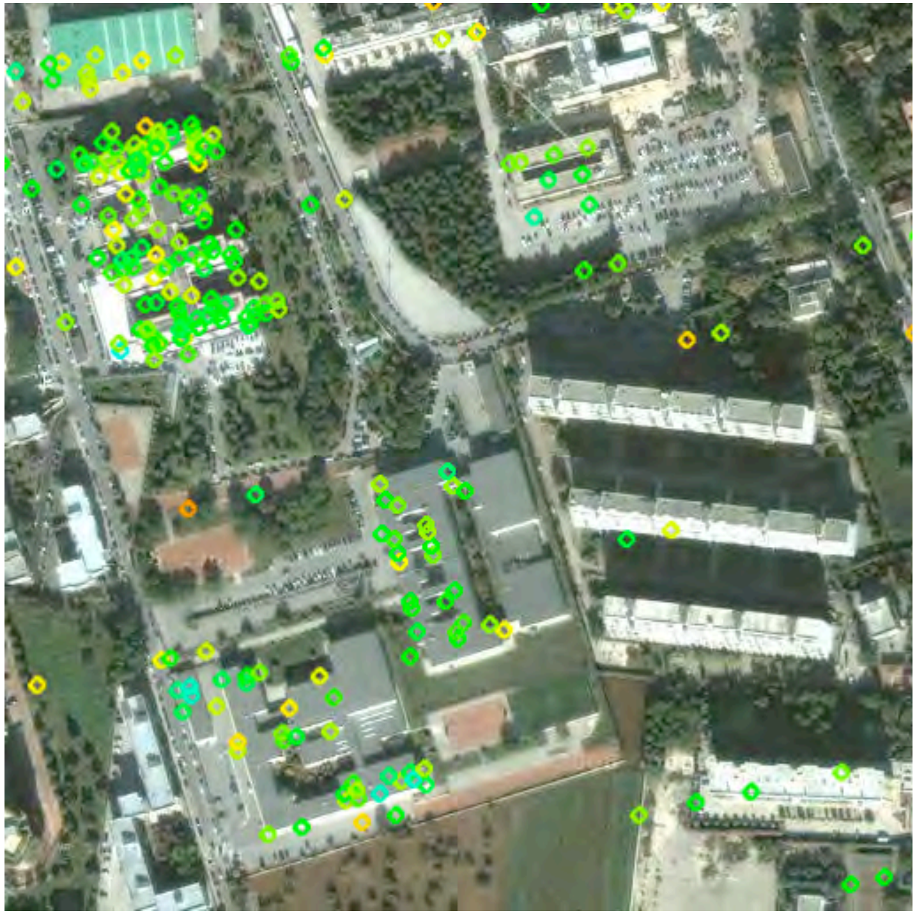
Localization and monitoring of scatterers in layover with the 4DI



Envisat Data over the city of Bari

Single scatterers with 4DI

Double scatterers with 4DI

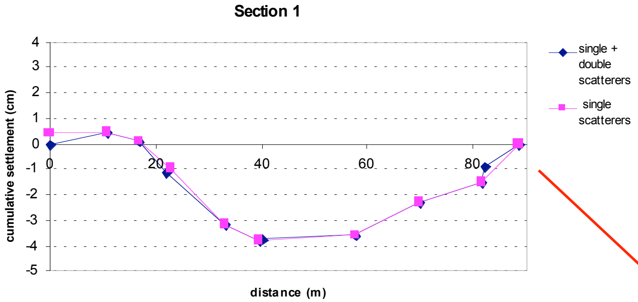


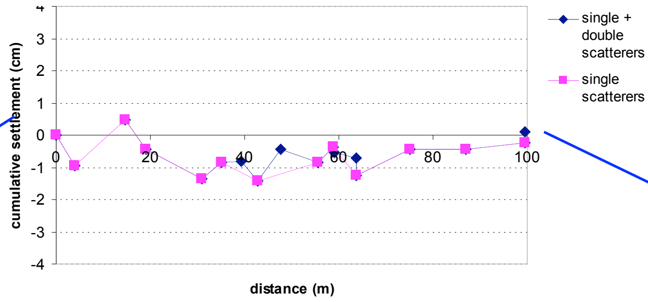
-6mm/y 6mm/yr

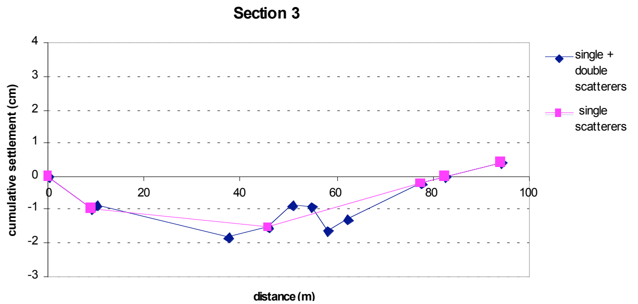
31 images

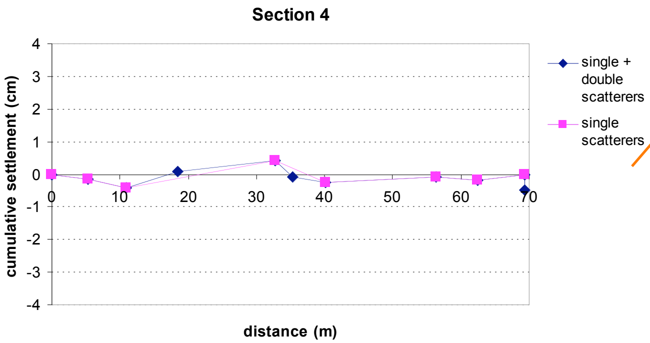
June 2003 – April 2008

Single scatterers with 4DI

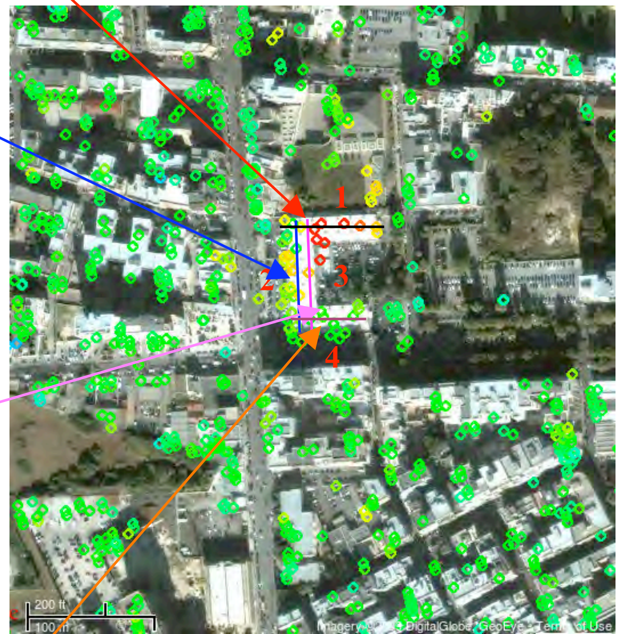








Double scatterers with 4DI



-6mm/y  6mm/yr

June 2003 – April 2008

About detection performances

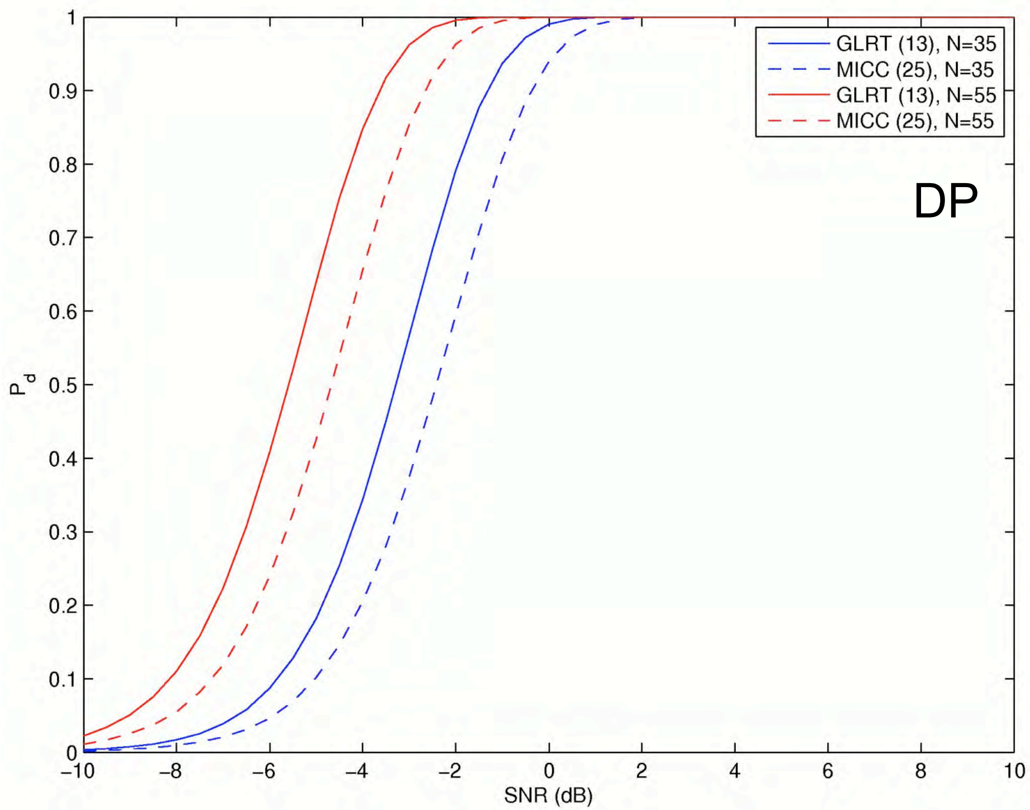
Tomographic (continuous lines) and classical interferometric (dashed lines) detector comparison.

FAP: False Alarm Probability

For a fixed False Alarm Probability

the tomgprahic amplitude and phase based detector achieves better performances in the Detection Probability (DP) wrt interferometric detector because it uses amplitude and phase of the information.

1dB Gain



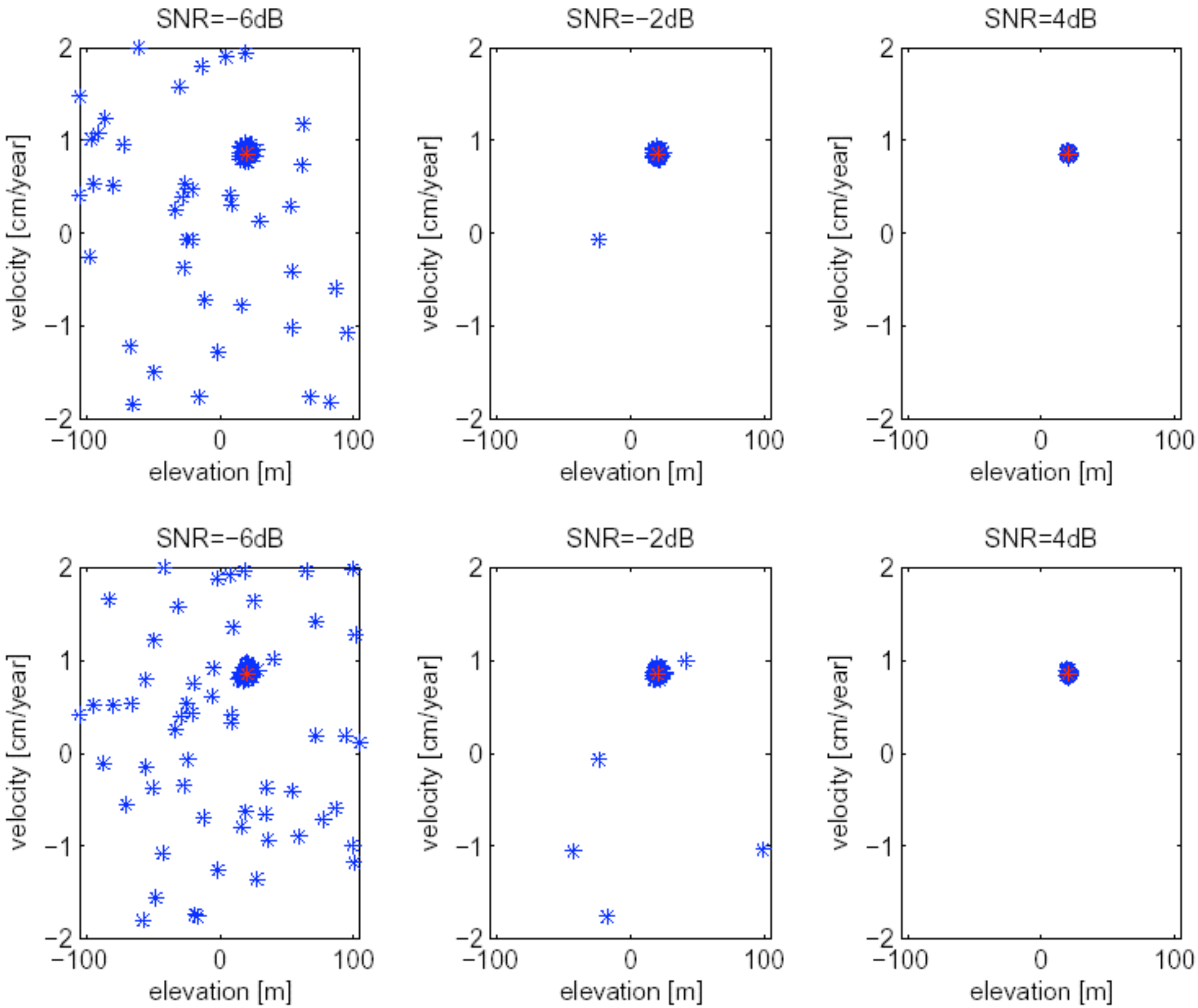
A. De Maio, G. Fornaro, A. Pauciullo, “Detection of Single Scatterers in Multi-Dimensional SAR Imaging”, IEEE Trans. on Geosci. and Remote Sens., vol 47 (7), pp. 2284-2997, June 2009.

And the accuracy?

Tomographic processing

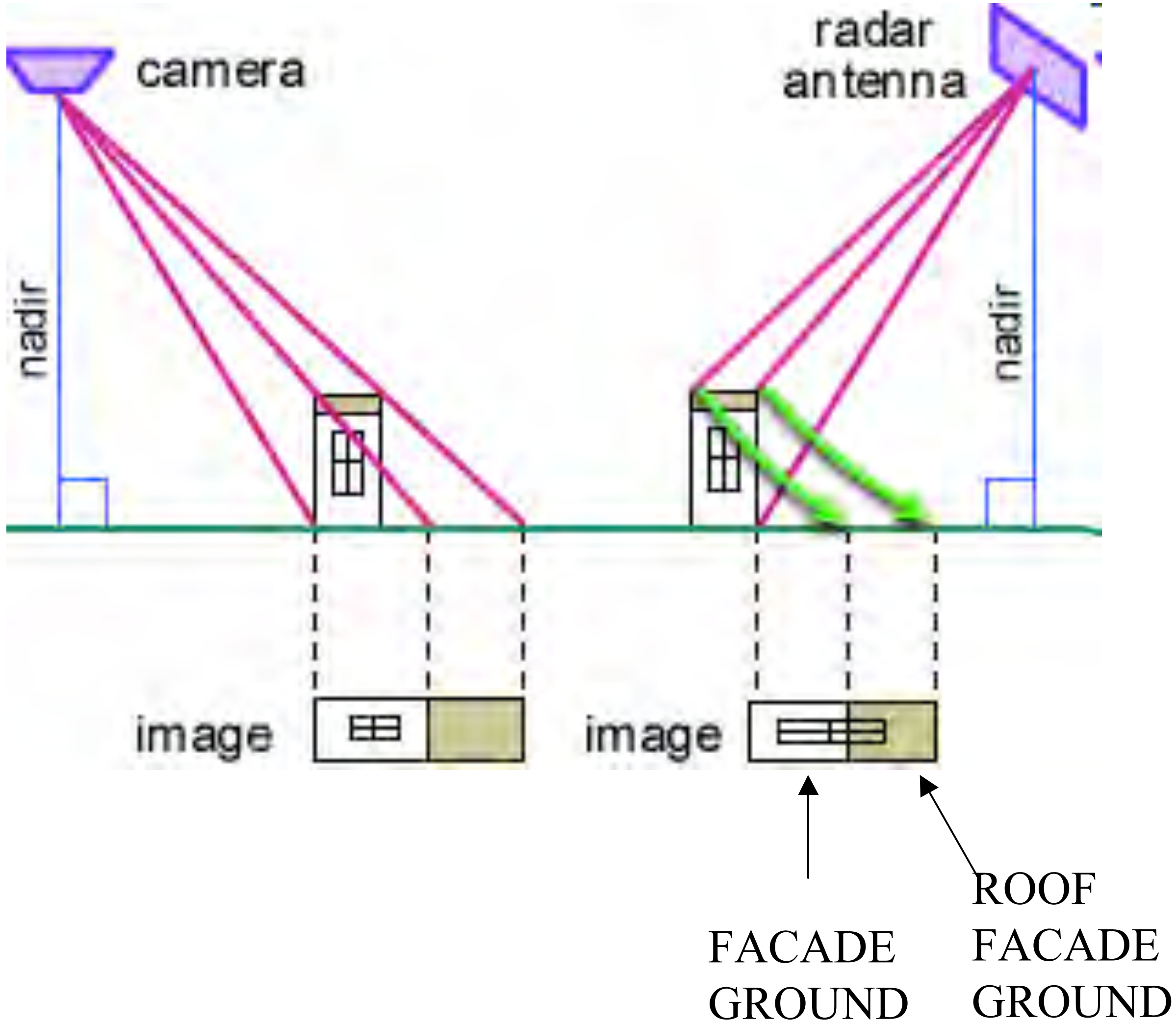
Estimation of the elevation and velocity of a single scatterer.

Interferometric processing



A. De Maio, G. Fornaro, A. Pauciullo, "Detection of Single Scatterers in Multi-Dimensional SAR Imaging", IEEE Trans. on Geosci. and Remote Sens., vol 47 (7), pp. 2284-2997, June 2009.

Application to high resolution data



The TERRASAR-X dataset over Las Vegas

- 25 TerraSAR-X Spotlight acquisitions over the city of Las Vegas USA (from 2008. 02. 02 to 2009. 04. 06)

- Imaging Mode: HS (High Resolution Spotlight)

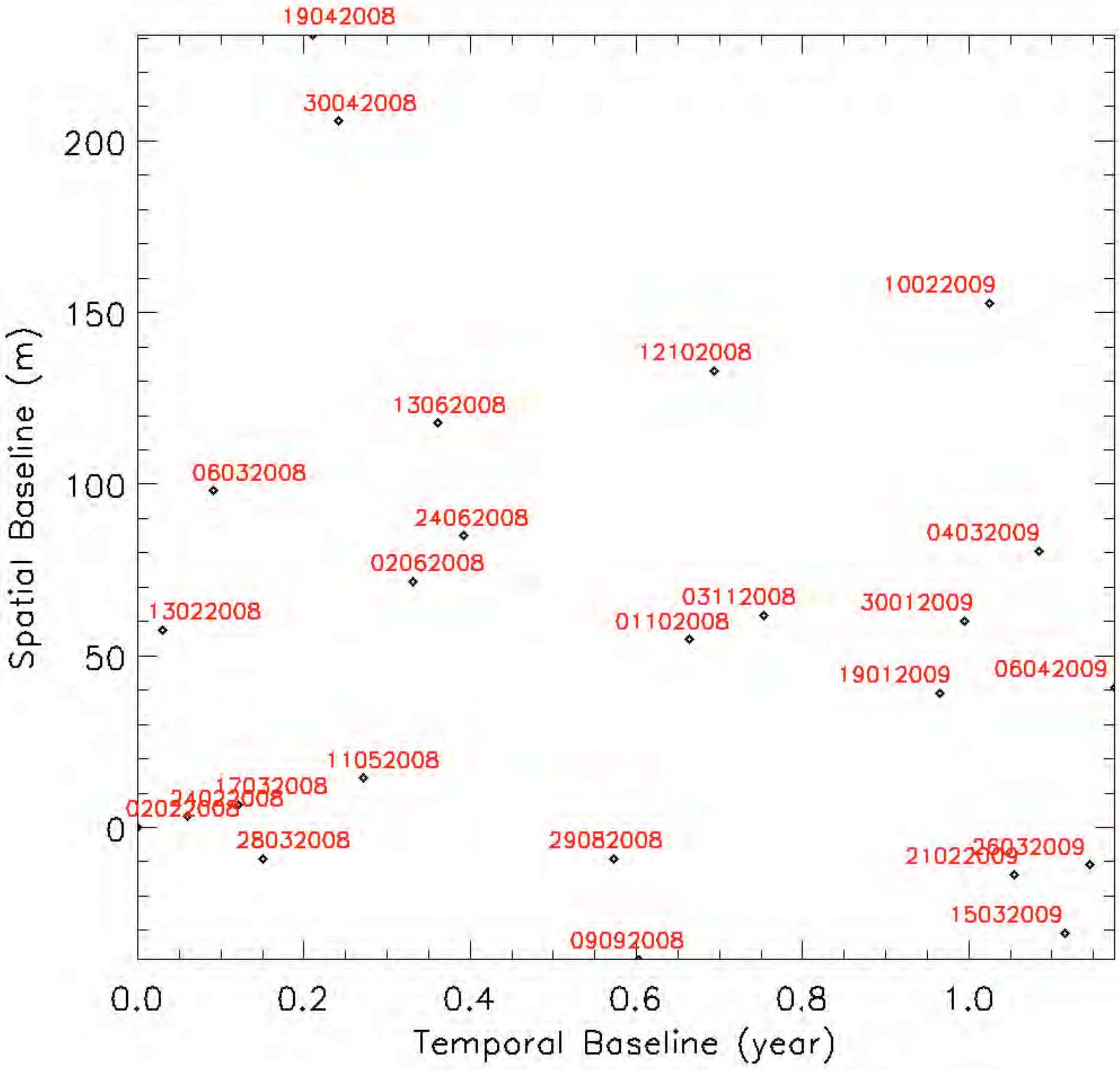
- Orbit Direction: Ascending
- Beam Identification: spot_042
- Orbit Number: 3522

- Incidence Angle: 35.8°
- Look Direction: Right

- Azimuth resolution: ~ 1.1 meters
- Slant Range resolution: ~ 0.6 meters

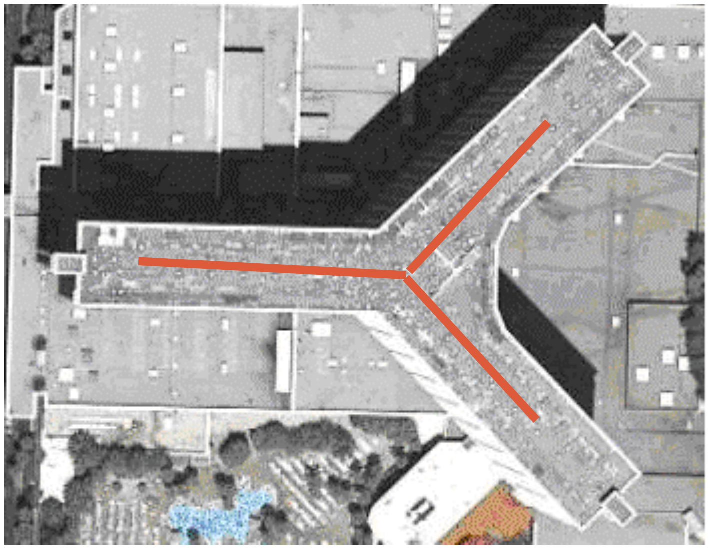
- Polarisation Mode: Single
- Polarisation: VV

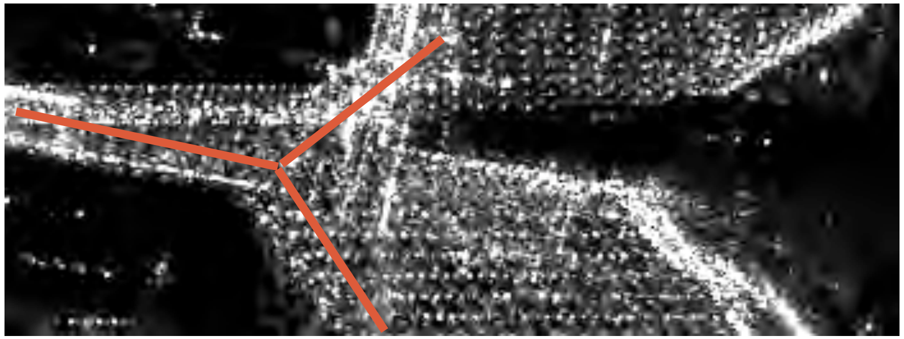
Acquisition distribution of the Las Vegas dataset



Slant Height Rayleigh resolution: 40m

Application to high resolution data



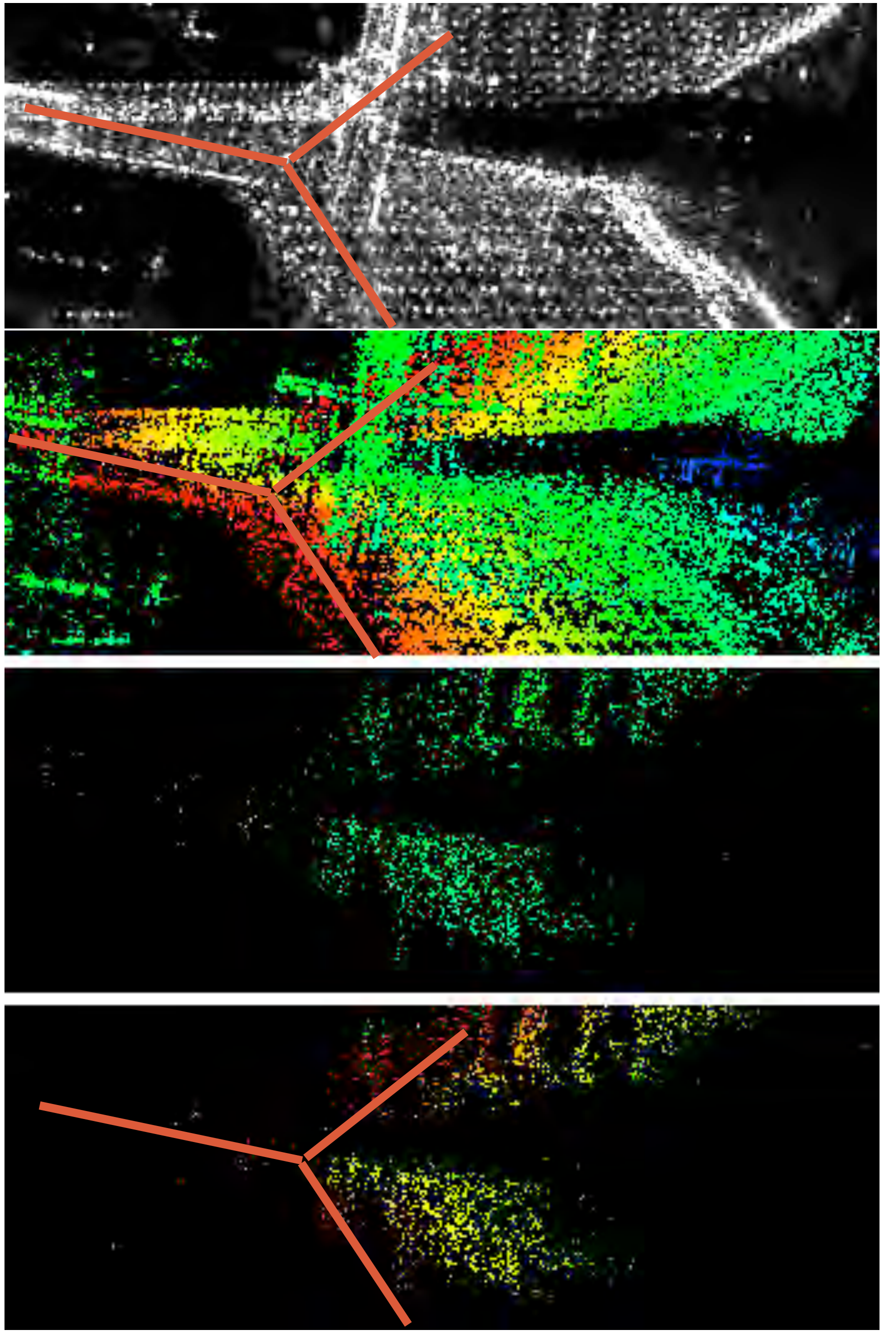


Amplitude image

Single scatterers

Double scatterers: bottom

Double scatterers: upper



RECONSTRUCTED TOPOGRAPHY

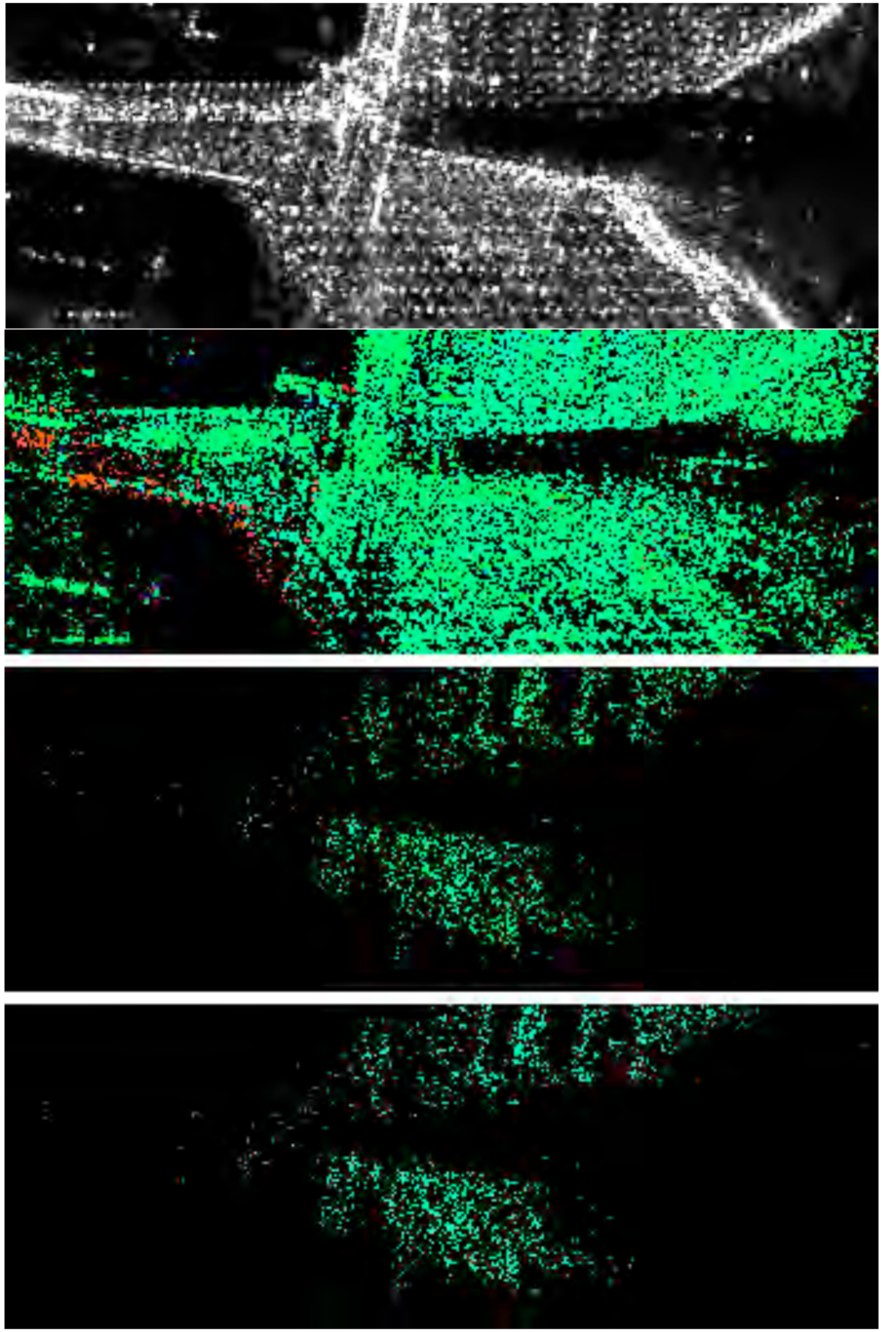
First demonstration of resolving a distributed layover

Amplitude image

Single scatterers

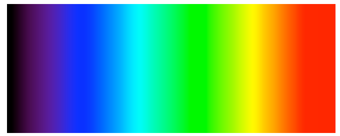
Double scatterers:
bottom

Double scatterers:
upper



RECONSTRUCTED
MEAN VELOCITY

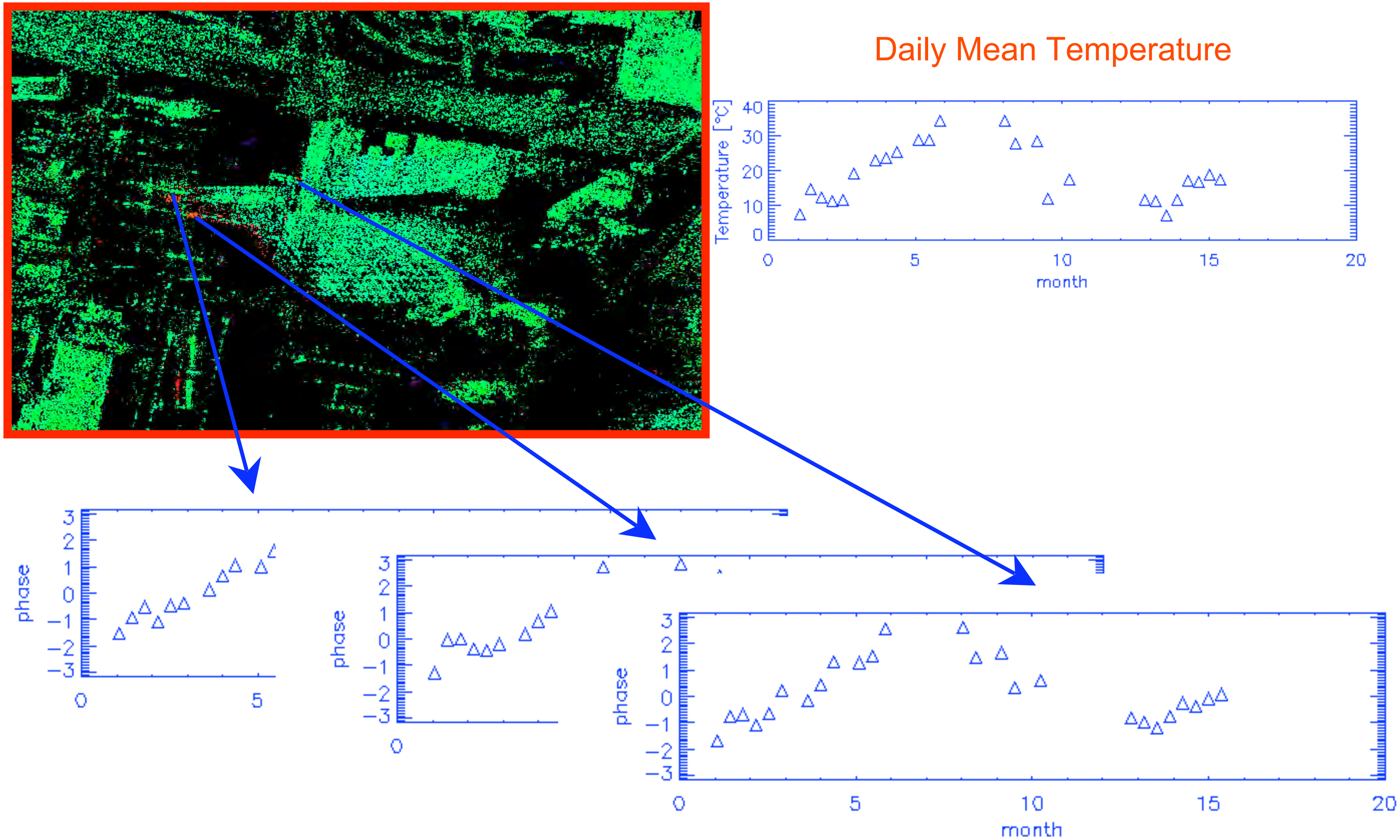
-2cm/y 2cm/y



What about deformation?

What about deformation?

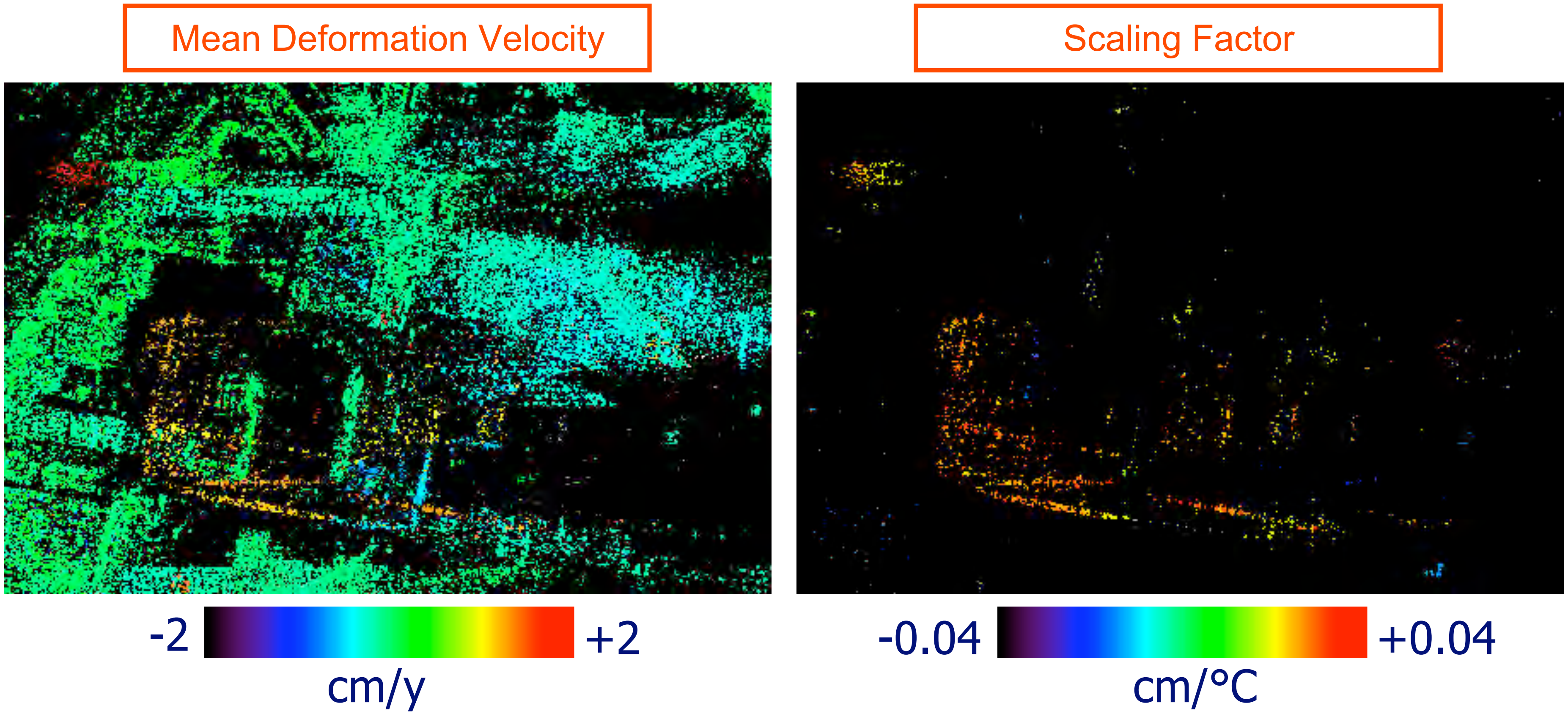
Is this building roof really going up?



Thermal dilations

Estimation of the scaling factor k_T between deformation and temperature

[redacted]



Conclusions

- Multitemporal and multipass interferometric analysis has allowed opening the framework of imaging and monitoring of deformations of buildings and urban areas structures.
- Higher resolution systems give further boosting of these techniques by dramatically increasing the density of monitored pixels.
- With the tomographic analysis on TSX data we have demonstrated for the first time the possibility to separate distributed layover on buildings thus allowing the improvement of the density and the accuracy of the measurements.
- Development of the technique must be carried out to account also for the presence of thermal dilation effect in the identification of scatterers.
- Simultaneous data from the Tandem-X formation acquired repeatedly "should be" worth to be processed with these techniques!!!

THANK YOU