Design of a geosynchronous SAR system for water-vapour maps and deformation estimation

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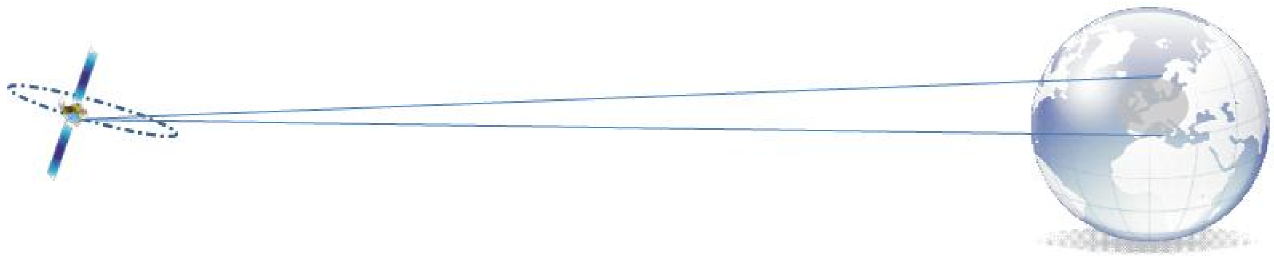
GEO-SAR concepts (I)

- **What?:** Synthetic Aperture Radar (SAR) system based on Geosynchronous satellites.
- **How?:** taking advantage of the slightly orbit perturbations (inclination and eccentricity) to form the Synthetic Aperture.
- **Why?:** Monitoring fast moving deformations "soft surfaces"

  Water-vapour maps

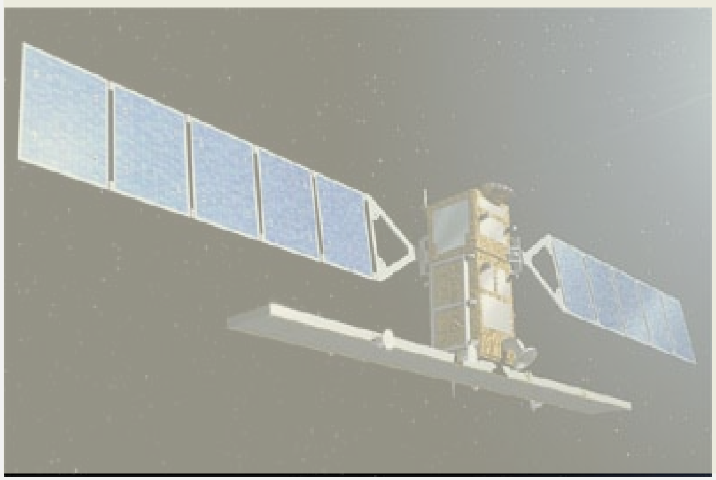
  change detection



GEOSAR versus LEO-SAR

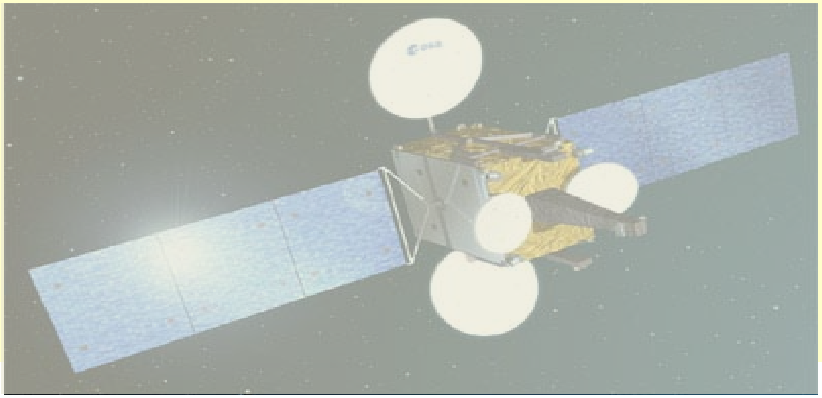
LEO - SAR:

- Global coverage (WORLD)
- Revisit: > 6 days (Sentinel-1, 2 satellites)
- View angle: mainly East - West
- Lifetime 7 years
- Dedicated satellite



Geosynchronous SAR:

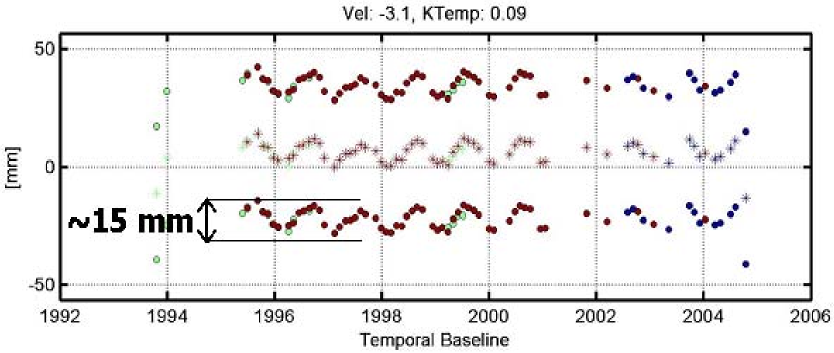
- Local coverage up to 2000 km
- Revisit: 12 hours full resolution
  20’ a quick look
- View angle: mainly North – South
- Lifetime 15 years
- Can be a payload on a TELECOM satellite
  ☞ scalable coverage versus cost



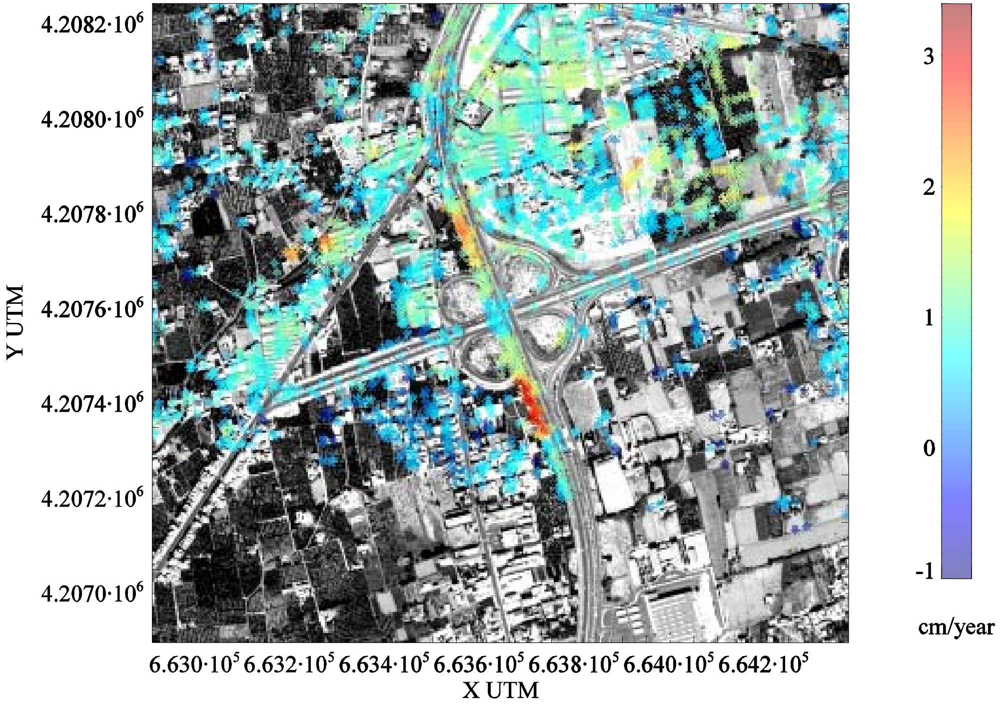
GEOSAR could provide water-vapor maps to comensate LEO APS

GEOSAR concepts (II): Interferometric Applications

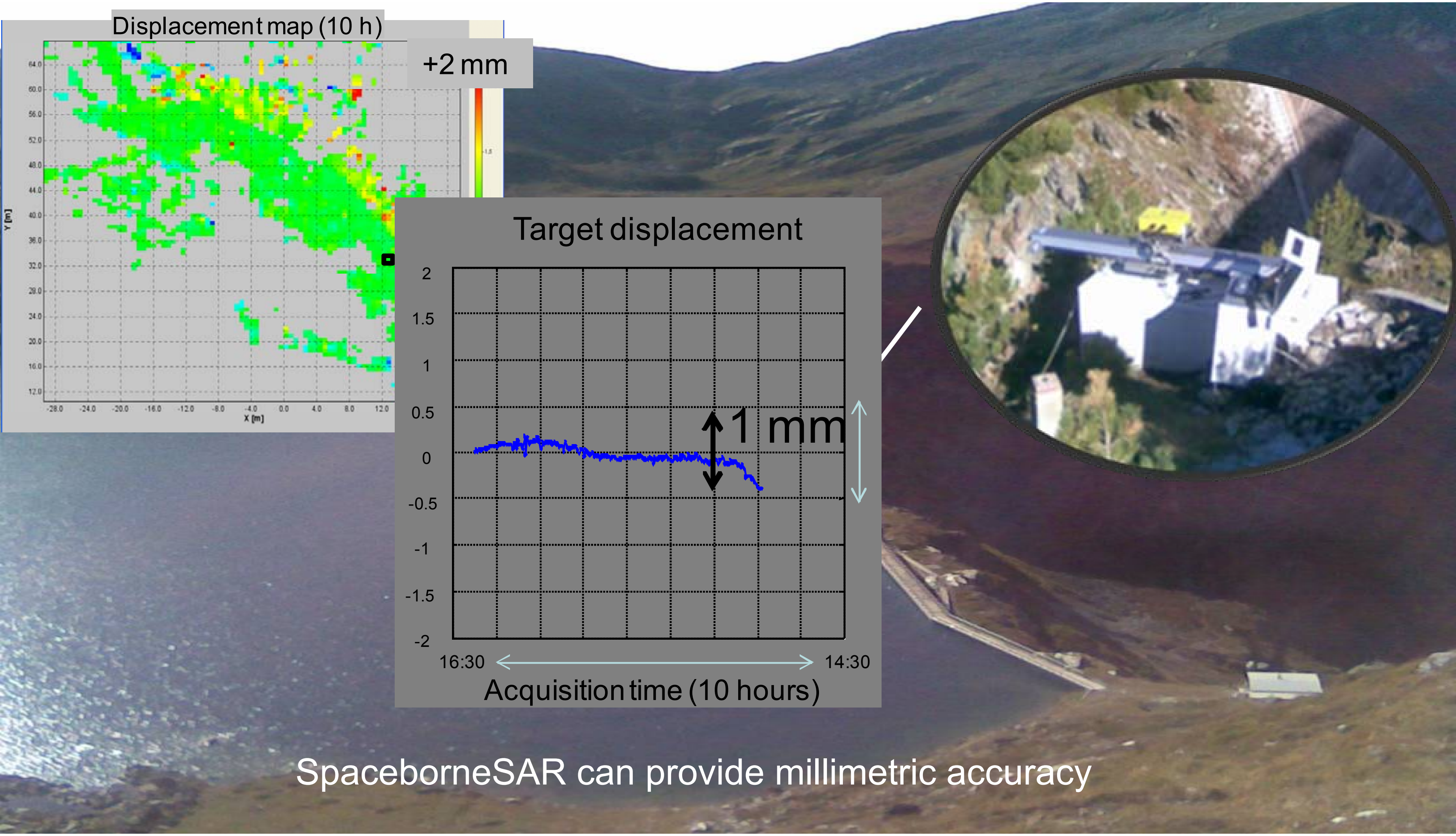
Millimetric accuracy building monitoring (Milano)



Infrastructure stability monitoring (Spain) TerraSAR-X



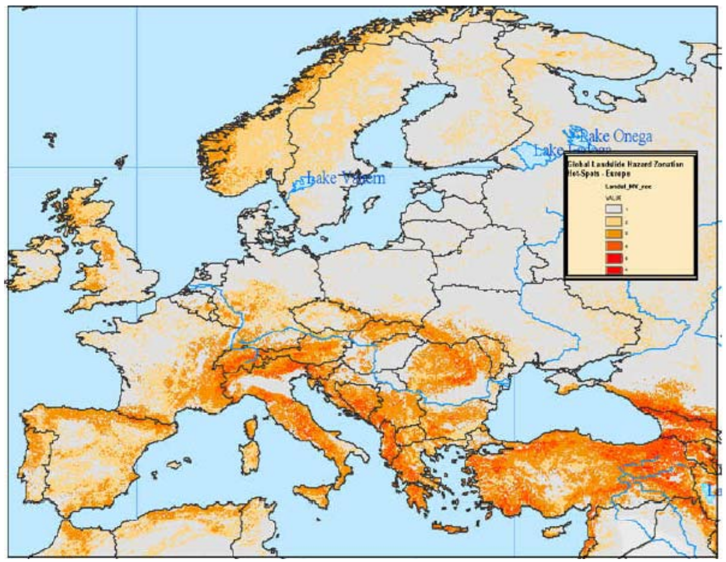
GEOSAR concepts (II): Interferometric Applications

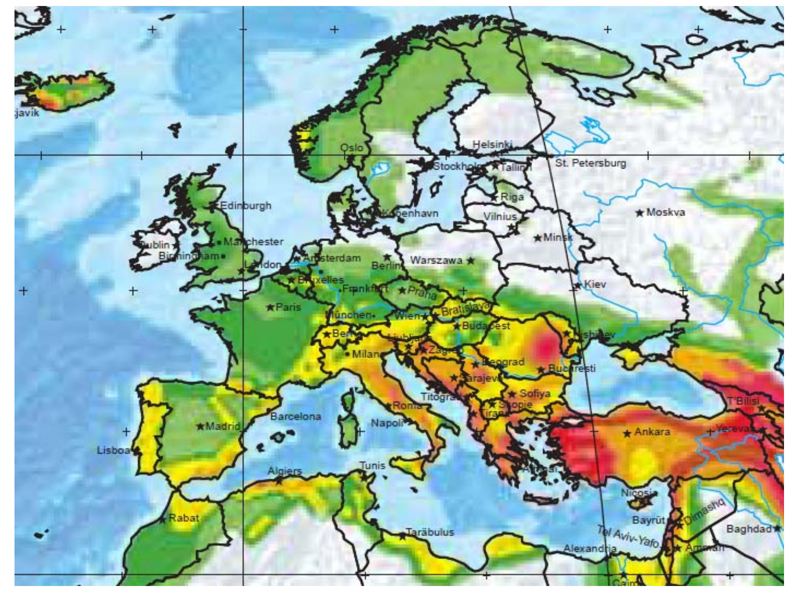


GEOSAR concepts (II): Interferometric Applications

Number of Lanslides

Geoseismic risk

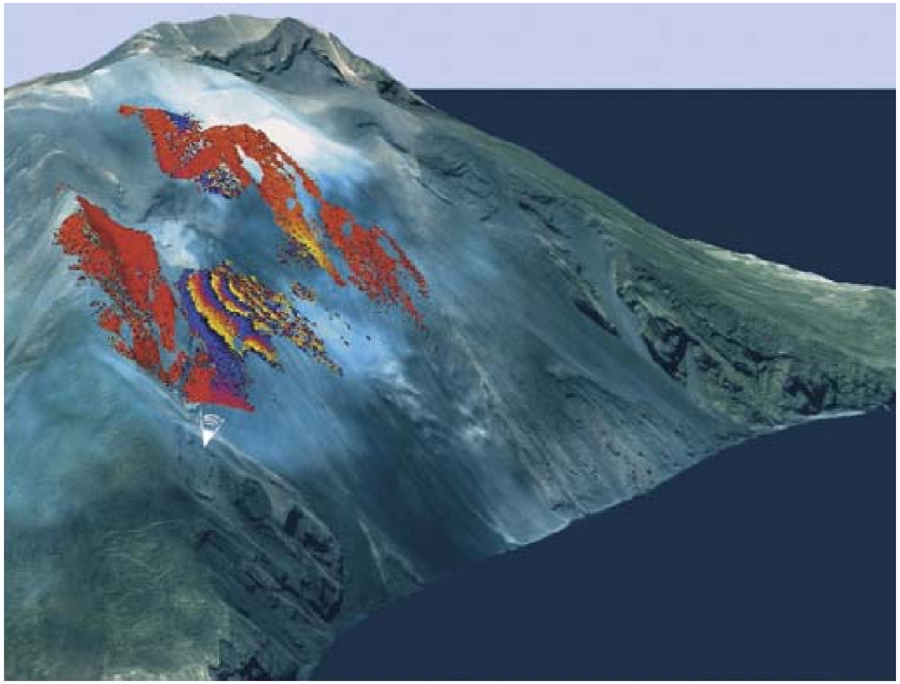




Over five hunderd millions landlsides in Italy.
Italy and Greece (plus Spain) are areas of major attention for geosesimic risk, landslides and active volcanos

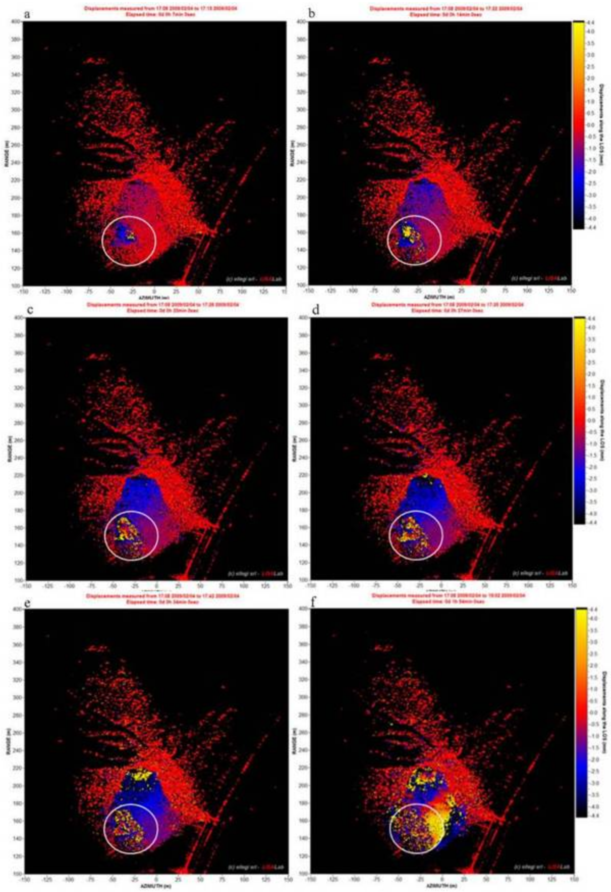
GEOSAR concepts (II): Interferometric Applications

Time scale for eruption and many landslides is from minutes to hours.
fast landslides are coarse resolution.



Stromboli, Italy
7 hours

[Casagli et. al]



LLandslide in Santa Trada, Italy,
7 min - 2 hours

GEOSAR concepts (II): Landslides facts - Italy

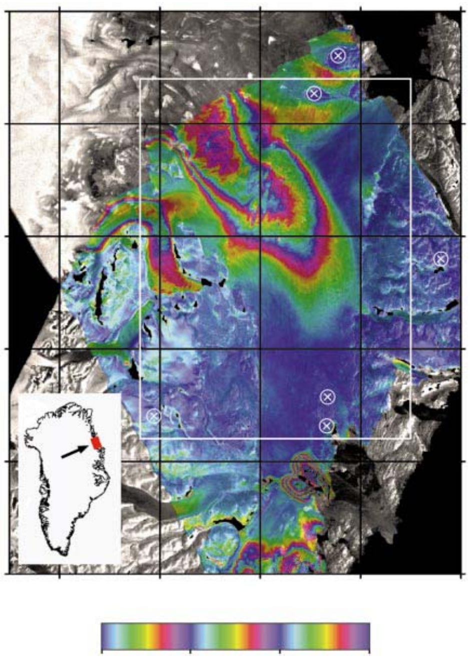
Victims:
10,555 since 1400
5,939 in the XX century (59.4 per year)
2,447 post-war (54.3 per year)
Government investments:
22.5 billion Euro (1945-1990)
0.5 billion Euro per year (0.05% of GDP)
Cost of damges:
ca. 1 - 2 billion Euro (0.15% of GDP)
Unstable urban areas:
1,306 to be stabilized,
323 to be moved (total 1,629) according to the Law 445/1908

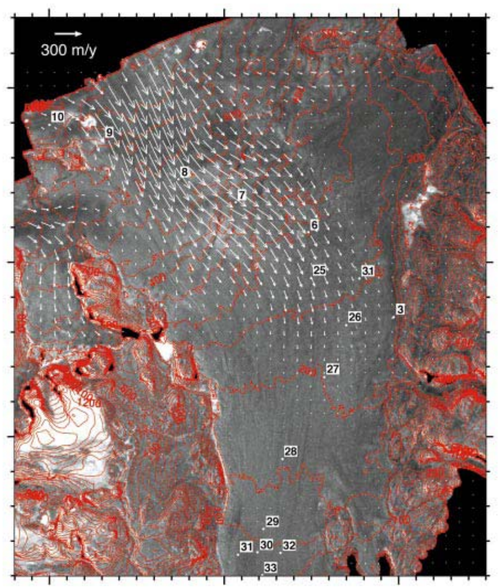
Place	Date of re-activation	Area [m^2]	Volume [m^3]
Vajont (PN)	October 1963	1,500,000	270,000,000
Montaguto (AV)	Spring 2010	675,000	10,000,000
Ricasoli (AR):	Active-continuous	50,000	1,000,000
San Fratello (ME)	February 2010	1,000,000	12,000,000
Maierato (VV)	February 2010	150,000	2,000,000
Cavallerizzo di Cerzeto (CS):	March 2005	305,000	

- Fast landlsides cannot be monitored by LEO SAR: with revisit of days.
- Ground Based SAR are in use, but not for unsolicited events, and not cost-effective due to the large number of landslides
- GEOSAR would provide a better solution: where fine geometric resolution is not relevant.
- For volcanoes GEOSAT would enable measure* of:
  - the short-period deformation around new fissures and cyclic vents.
  - lava flow advances to be assimilated into lava flow models

[*G Wadge].

Ice flows were measured by space-borne SAR during ERS tandem mission (1 day revisit) and ERS ICE phase (3 days revisit).





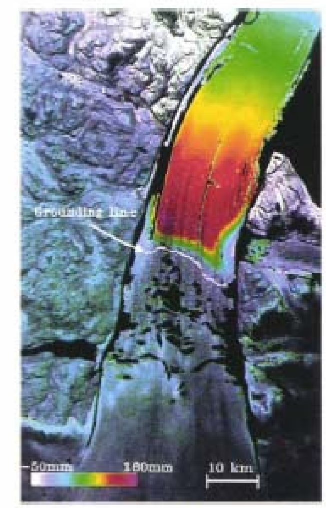
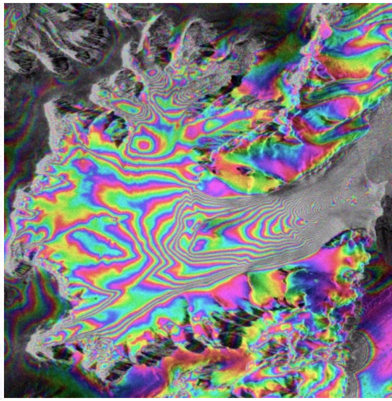
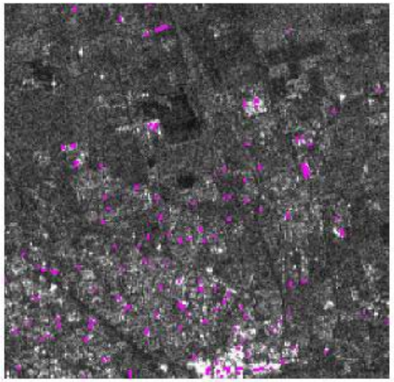


Fig. 3. Tidal displacements (color-coded between −50 and 180 mm and modulated by the radar brightness for display purposes), and hinge line (continuous white line) of Petermann Gletscher. Dark patches indicate areas with no interferometric data.

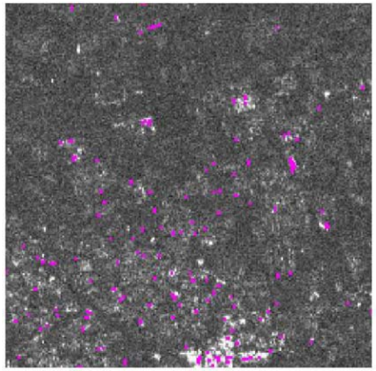


Johan J. Mohr, Niels Reeh & Søren N. Madsen - Three-dimensional glacial flow and surface elevation measured with radar interferometry - Nature

GEO-SAT: PSI Products - summary

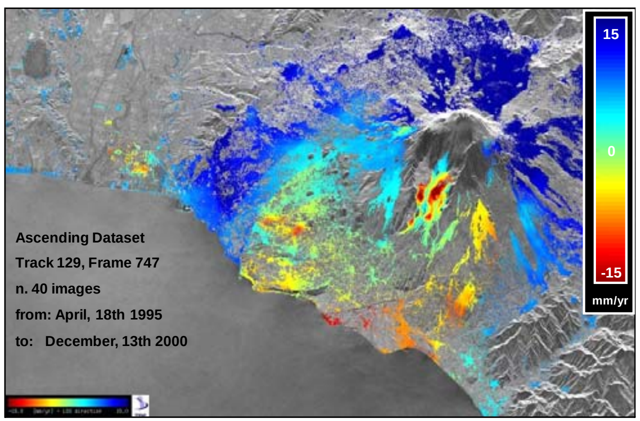


LEO-SAR



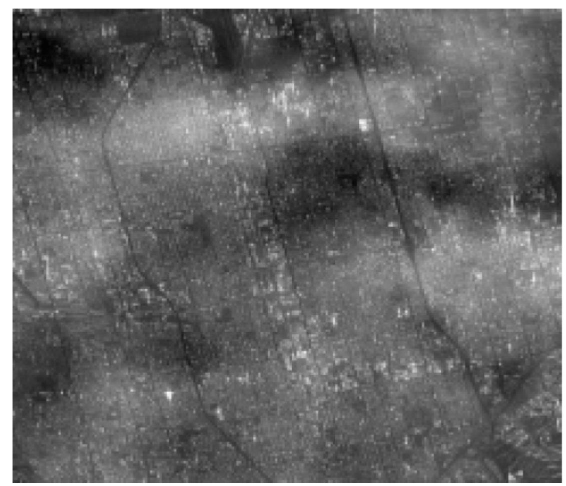
GEO-SAR

Amplitude products: only stable targets in the integration time (20 min – 8 hours depending on the resolution). Moving targets vanishes.



Deformation maps and LOS velocities: available at the same quality of LEO-SAR (mm), with twice daily sampling

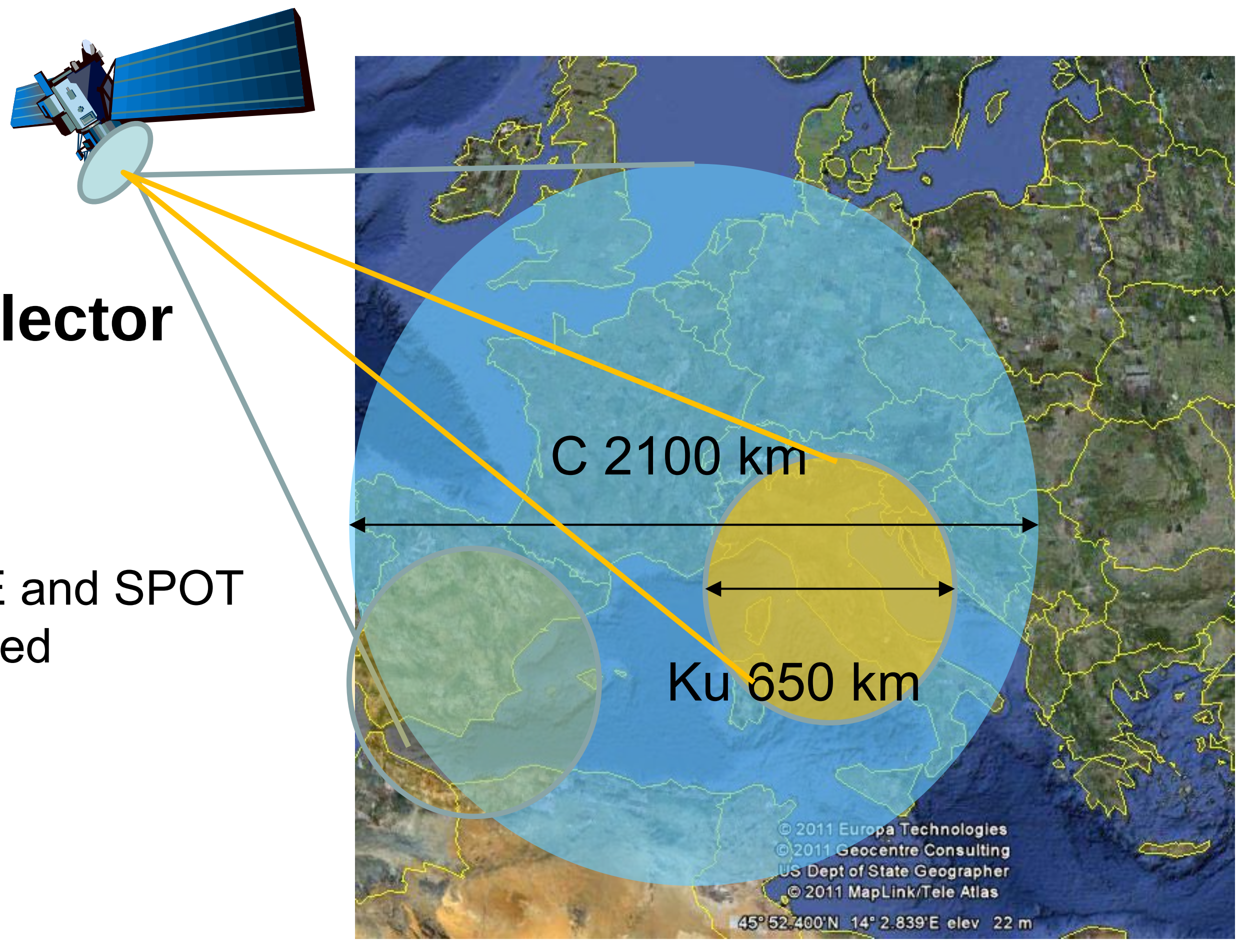
Atmospheric Phase Screen: available with fine temporal and spatial sampling (20’, 500 m). Unavailable with other sensors on this scale.



GEOSAR Concept: Dual Frequency single antenna

C + Ku – same reflector

∅=1.5 m reflector



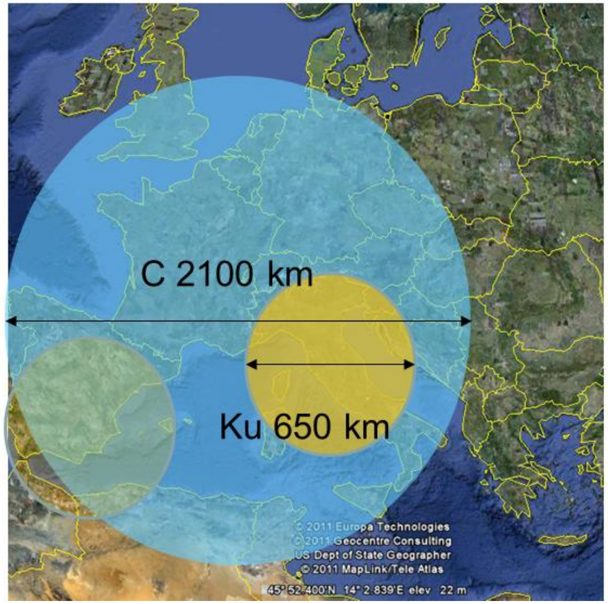
Dual beam: WIDE and SPOT
Can be repositioned

GEOSAR Concept: Dual Frequency single antenna

C band EUROPE WIDE beam:

2100 km
coarse resolution: 30 x 30 m
good coherence from day to day
➔water vapor maps
➔large scale deformation

C + Ku – same reflector



Ku band SPOT beam:

650 km
fine resolution 10 x 10 m
vegetation decorrelates
high return from user antenna
water vapor compensation by WIDE beam
unwrapping simplified by C

RCS of parabolic antennas.

- Parabolic antennas as targets of opportunity

High RCS for GEOSAR acquisition.

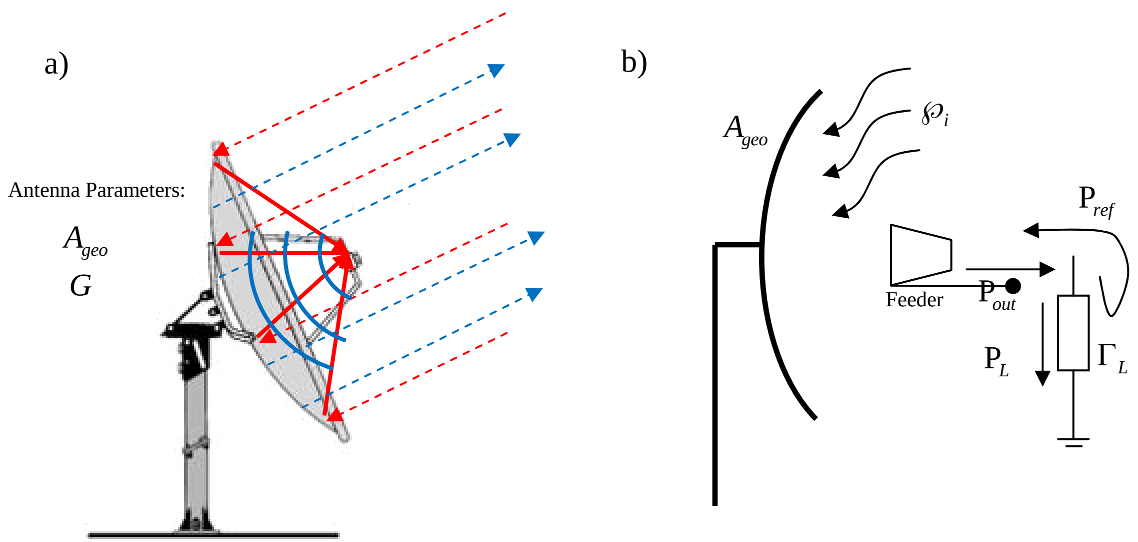


Fig. . a) Parabolic antenna working as an scatterer. b) Feeder mismatch: power reflected and not delivered to the load.

$$\sigma_{ant} = \frac{4\pi}{\lambda^2} A_{geo}{}^2 \eta_{eff}{}^2 \left|\Gamma_L\right|^2$$

$$\phi = 60\,cm,\ \eta_{eff} = 0.7,$$

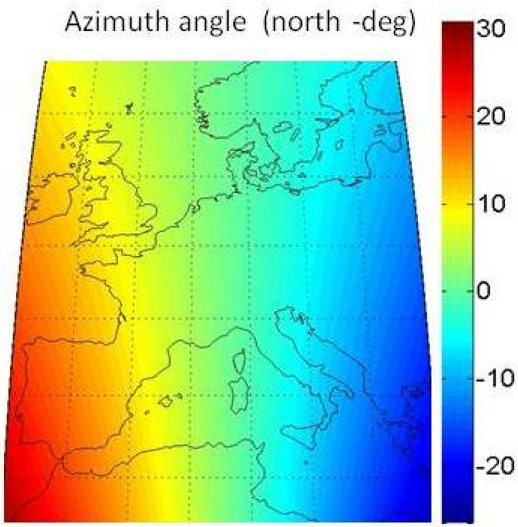
$$\Gamma_L = -10dB,\ f = 20GHz$$

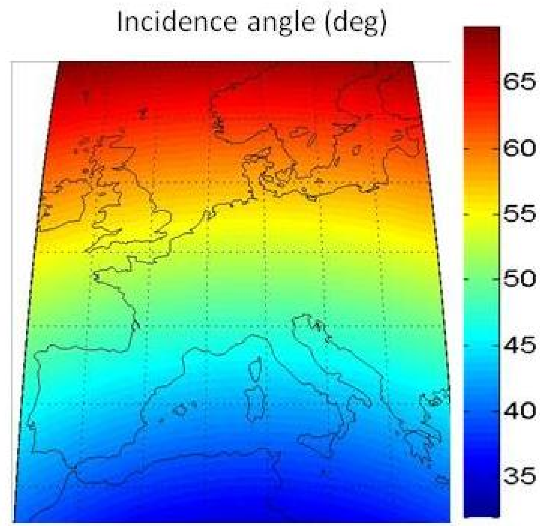
$$\boxed{\sigma_{ant} = 23.4dBsm}$$

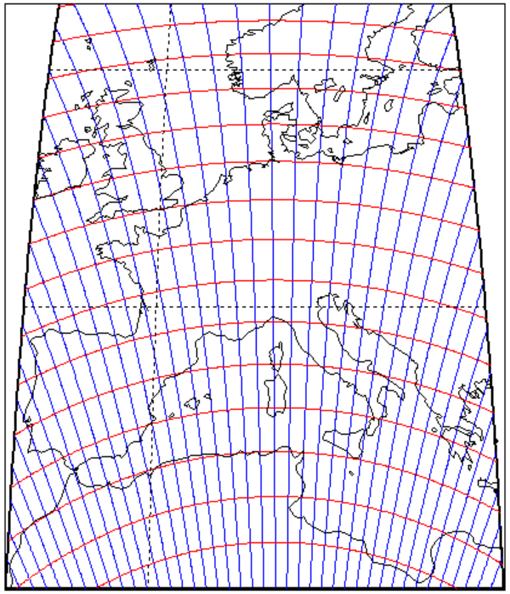
All antennas become good reflectors

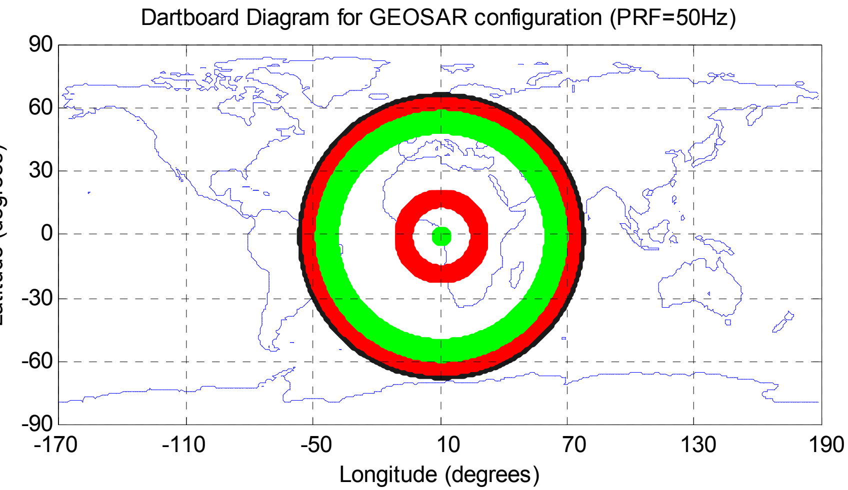
47 Millions of users parabola in Europe (2002)

GEOSAR Geometry & timing









PRF: 6-100 Hz

GEOSAR Power Link Budget Monostatic Example

Peak power: 2.4 kW (peak) x 15 % = 360 W (average)
Pointing accuracy ±0.1^0

$$R/S = \frac{\rho_a \times \rho_r}{SNR}$$

C Band

R/S= 470 @9 hours
➔SNR=0 dB @22m x 22m

R/S=25400 @10 minutes
➔SNR=0 dB @160m x 160m

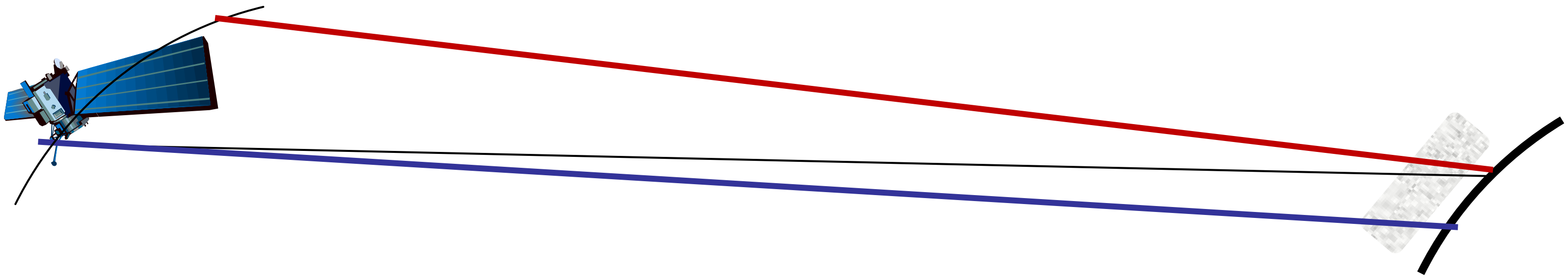
Ku band

R/S=33 @9 hours
➔SNR=0 dB @6m x 6m

@80 cm user parabola,
SNR = 21dB @ 9h
= 4.4 dB @ 10'

The system is simplified by using the downlink as illumination

GEO-SAT: APS estimation



The atmospheric phase screen changes in every position and every time::

φ(time, P)

For a single range bin, we have to estimate a 2D signal: φ(time, azimuth)

But we have 1D measures

➔The problem is ill-conditioned

LEO-SAR acquires in very short time, thus they sense: $\varphi(t_0, P)$

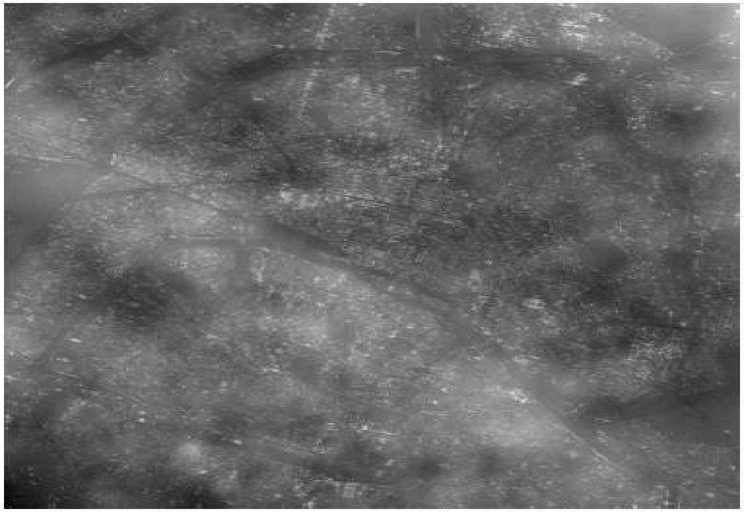
and the APS at the acquisition time is superposed to the focused data.

Ground Based RADAR may acquire in long time, but from small areas: $\varphi(t, P_0)$

and all the pixels senses the same APS, due to the small antenna lobe.

For GEO-SAT the Atomspheric Screen is both a liability and an asset:
it is the only one having potentials to sense and estimate the 2D APS

APS: impact

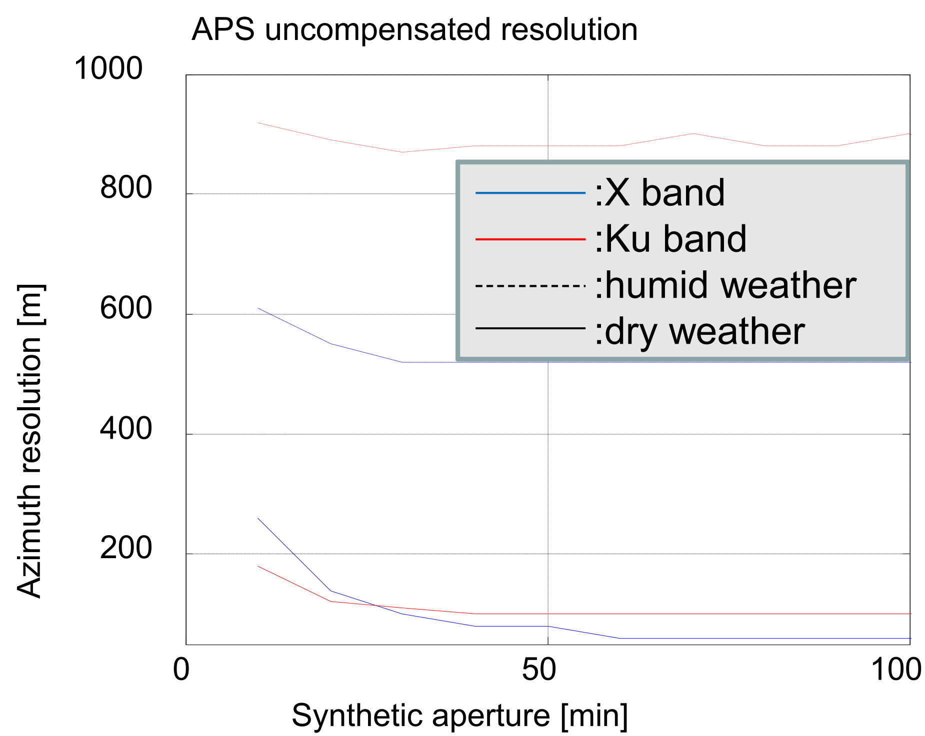


APS may lead to delay fluctuation of centimeters in one day and in the space extent of few km.

As the delay becomes comparable with say 1/10 of the wavelength (2 mm in Ku band) the signal totally decorrelates.

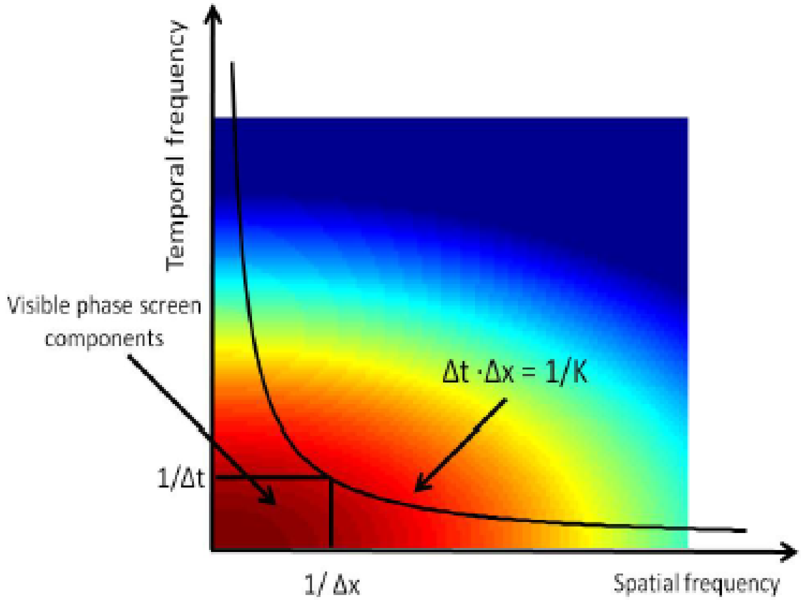
A non compensated APS in GEOSAT results in a resolution loss, dependent on the wavelength and the weather conditions.

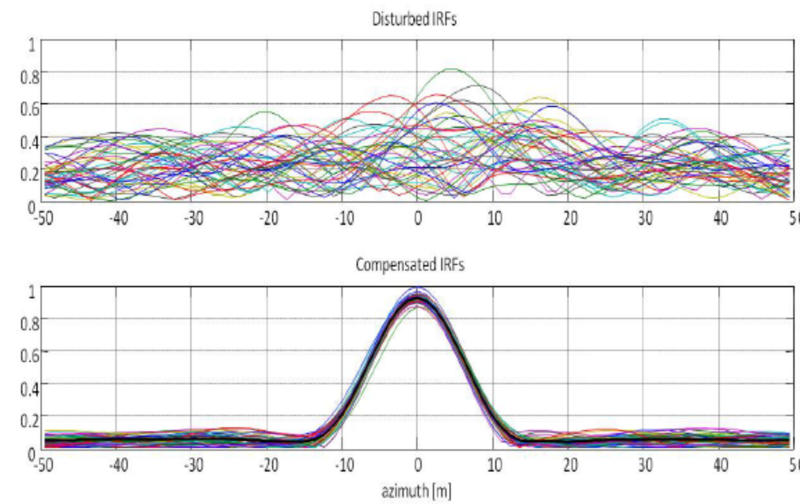
In Ku band resolution drops to 100-900 m if not compensated.



APS: compensation

Different sub-apertures, with different time-space bandwidth leads to the estimation of the components below the region with constant product, that is most of the APS energy.





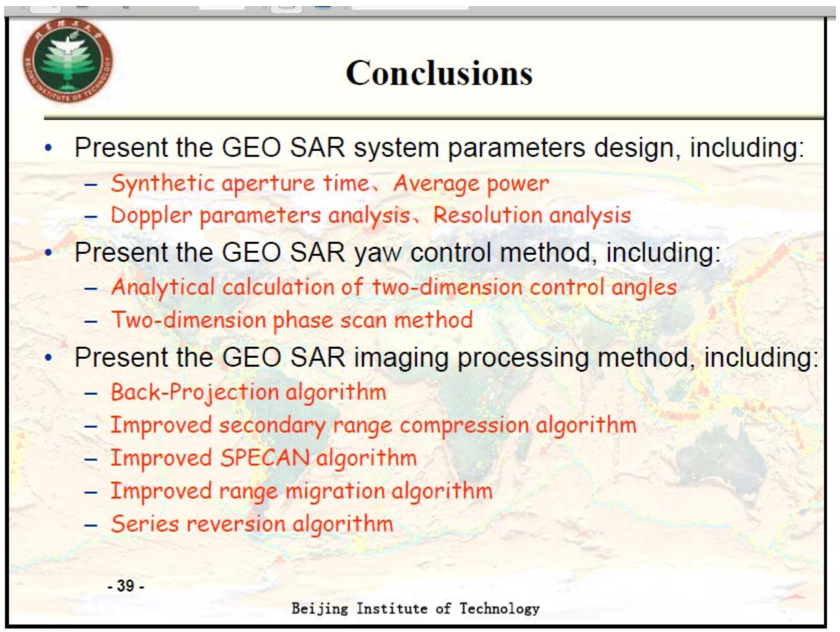
Focusing cannot be performed by matched filter: an inversion scheme is required.

Recovering Time and Space Varying Phase Screens through SAR Multi-Squint Differential Interferometry
EUSAR 2012

GeoSAR & science

K. Tomiyasu, Synthetic aperture radar in geosynchronous orbit.. IEEE Antennas and Propagation Symp., U.Maryland, pp.42-45, **May 1978**.

Ferretti, A., Prati, C., Rocca, F.. Permanent Scatterers in SAR Interferometry. IEEE Trans. Geoscience And Remote Sensing, 39(1), 8 – 20, **2001**



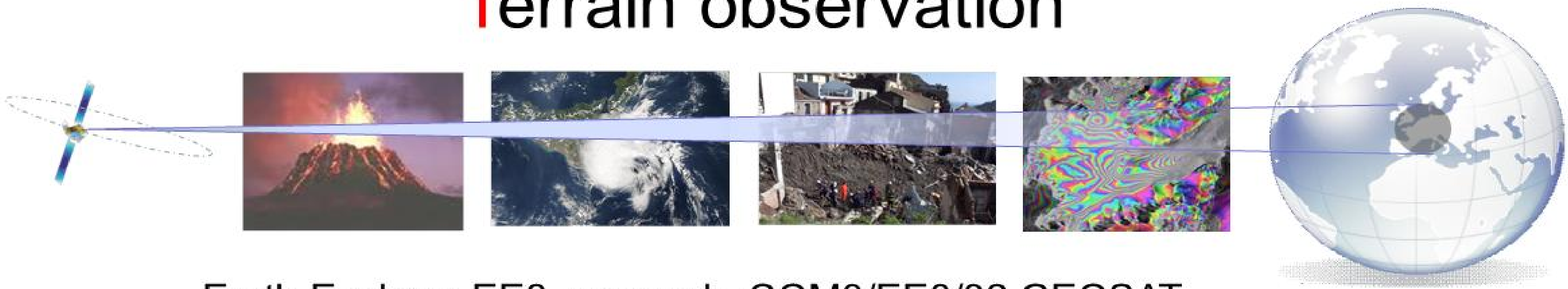
GEO SAR Research Progress in BIT - Cheng Hu – Oct 2010

MODIFICATION OF SLANT RANGE MODEL AND IMAGING PROCESSING
IN GEO SAR *Cheng Hu, Feifeng Liu, Wenfu Yang, Tao Zeng, Teng Long*

IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 8, NO. 3, MAY 2011 511 A New Method of Zero-Doppler Centroid Control in GEO SAR - Teng Long, Xichao Dong, Cheng Hu, and Tao Zeng

RADAR design example: GEOSAT

GEOsynchronous SAR for Atmosphere and Terrain observation



Earth Explorer EE8 proposal: COM3/EE8/32 GEOSAT

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Conclusions

GEO-SAT complements LEO satellites in coverage, look direction and revisit interval.

Water-vapor maps could be procuded with resolution 20' x (1 x 1) km

Dual-illumination concept: C and Ku for WIDE and SPOT beams

Simple design: reuse of downlink as illumination

Atmospheric estimation & compensation is to be integrated in the focusing kernel

➔ Concept is mature and needing for a demonstration