A Geosynchronous SAR Swarm for Continuous Observations

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Abstract

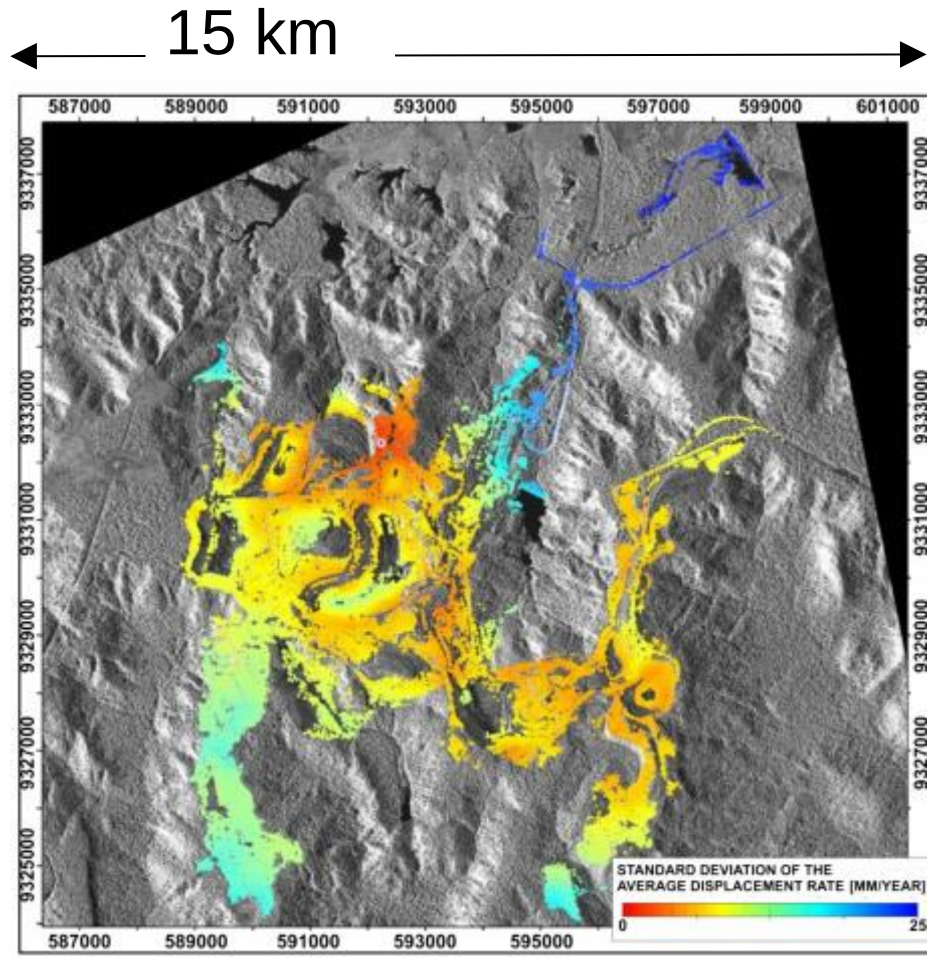
- RADAR applications: the value of revisit and resolution
- Options for short revisit SAR swarm in LEO-MEO-GEO
- The geostationary SAR swarm
- Solutions and performance evaluation

DInSAR, landslides and early warning

http://www.ksl.com/index.php?page=1&sid=24748916&nid=460

UTAH, APR. 2013. The biggest landslide ever in US: 165 millions tons

Predicted by GB RADAR



Paradella, Ferretti et. Al

Mapping surface deformation in open pit iron mines of Carajás Province (Amazon Region) using an integrated SAR analysis

DInSAR

Coherent change detection

Ampltitude

Coherence (10 mins)

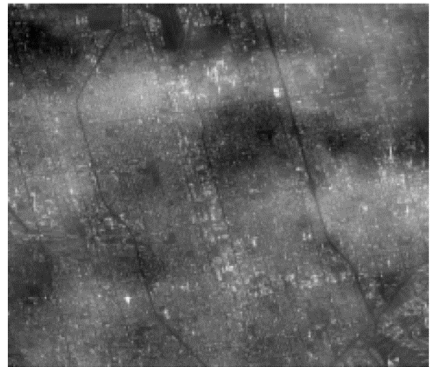
Coherent Change Detection:Theoretical Description and Experimental Results

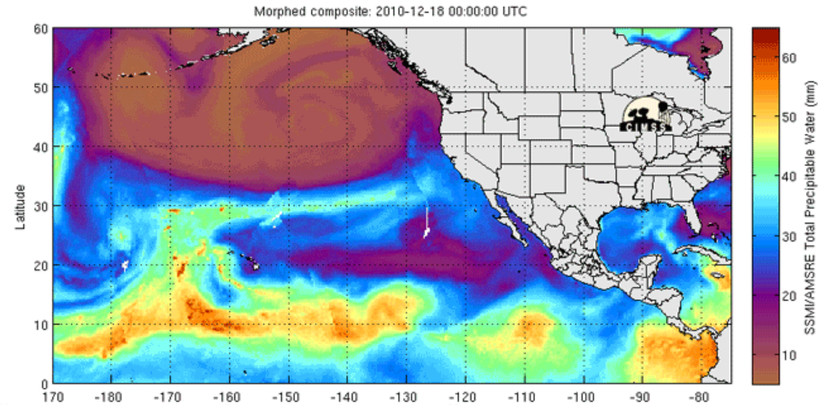
Mark Preiss and Nicholas J. S. Stacy

Intelligence, Surveillance and Reconnaissance Division Defence Science and Technology Organisation

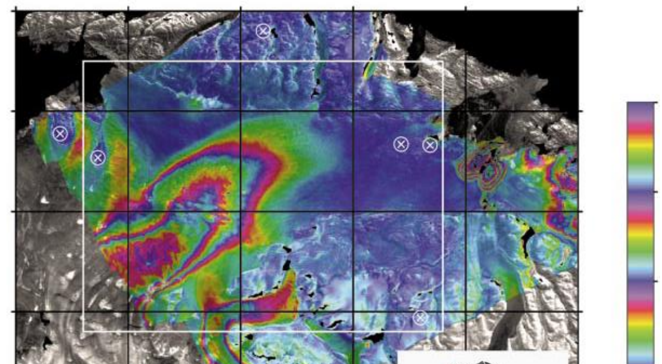
SAR applications

Water-vapor & soil moisture for Numerical Weather prediction





Modelling **glacier** hydraulics and rheology.

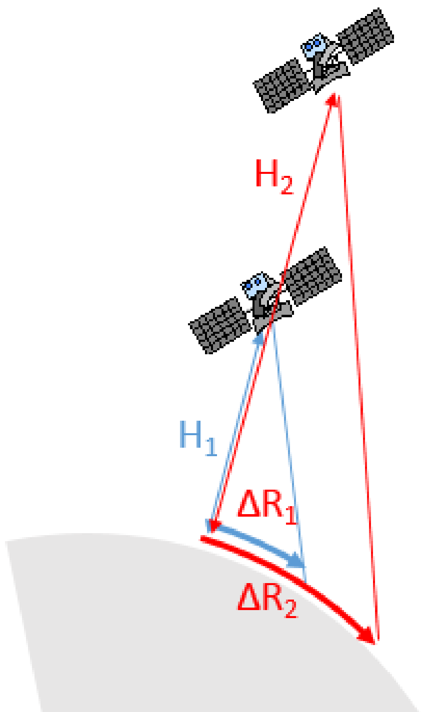


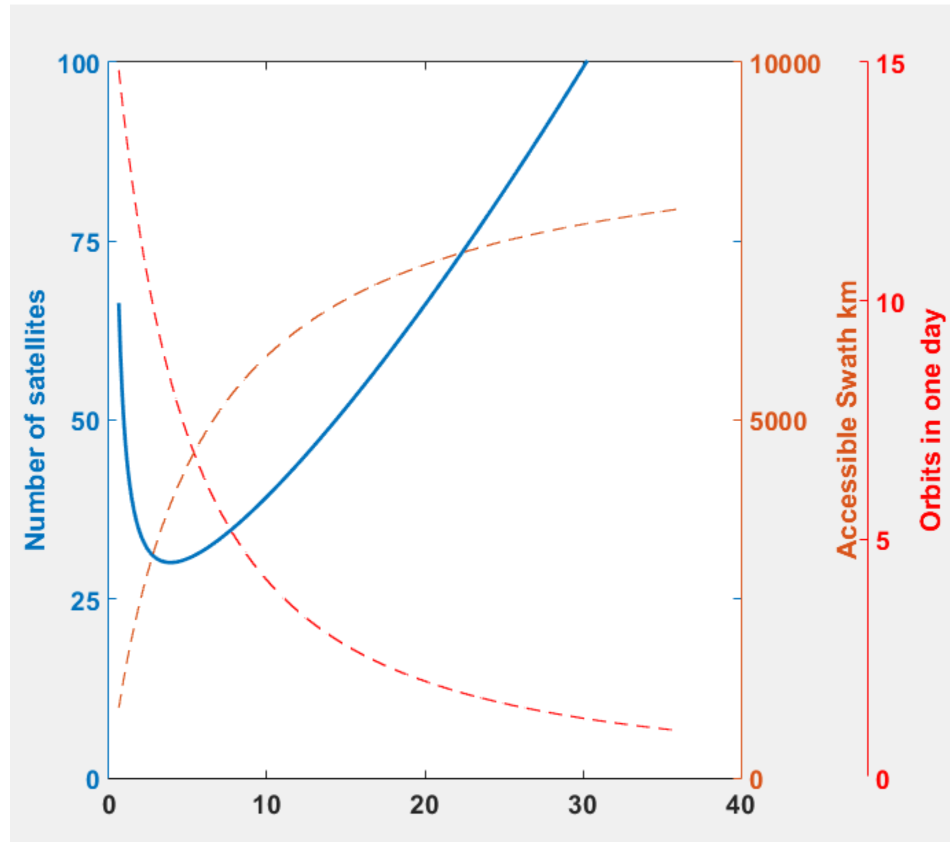
Flooding

Synthetic Aperture Radar is unique for all-day-all-weather monitoring & surveillance

Optimal orbit heigh for shortest revisit

The swath increases with height, but the velocity reduces. The minimum of 30 satellites is at MEO, 4000 km, for 1 hour revisit, by assuming 400+400 km accessible swath (L+R).

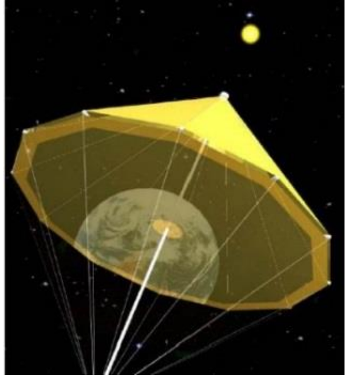




Orbit height × 1000 km

[Madsen, Chen, Edelstein Radar options for global earthquake monitoring]

Geo-synchronous SAR: continental coverage



- Faster revisit is traded for access (no more world-wide)
- The combination of short image time (1 min and huge swath demands for challenging technologies
- The constellation is extremely expensive
- The orbit crosses the graveyard orbit

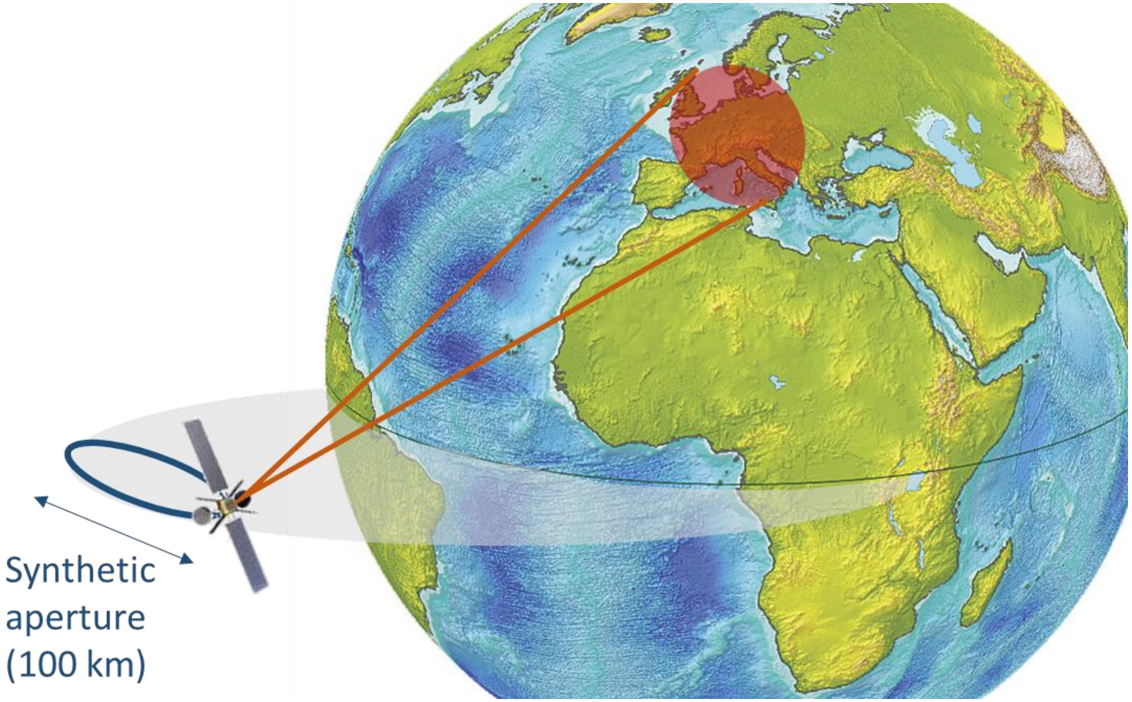
Mass Estimate	5 years	10 years	20 years
Antenna	2700 kg (3 kg/m^2)	1800 kg (2 kg/m^2)	900 kg (1 kg/m^2)
Support electronics	200 kg	50 kg	25 kg
Solar panels	200 kg	Shared with antenna	Shared with antenna
Platform (30% of PL)	870 kg	560 kg	230 kg
Total Mass	**3970 kg**	**2410 kg**	**1155 kg**

Power Estimate	5 years	10 years	20 years
RF Power (peak/avg)	15 KW / 3 KW	35 KW / 7 KW	65 KW / 13 KW
Radar Overall Power Efficiency	20%	40%	70%
Radar DC Power	15 KW	17 KW	19 KW
Spacecraft DC Power	5 KW	2 KW	1 KW
Total Power	20 KW	19 KW	20 KW

Geo-stationary SAR: continental access

The tiny orbit still allows for a synthetic aperture with metric resolution:

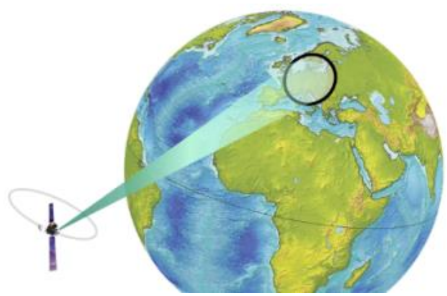
- Long integration times allows for moderate power
- Immediate data download and exploitation
- Continuous trade-off: resolution ↔ image time
- Compatible with COMSAT (can be hosted)
- Safer orbit than LEO-SAR



Geo-stationary SAR: the MIMO swarm

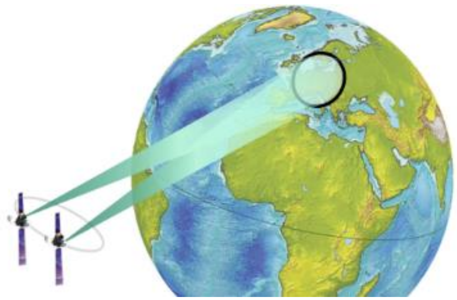
- Each of the N sensors transmits one signal and receives N.
- The coherent MIMO combination leads to N×(N-1)/2 phase centers
- For geostationary SAR, this reduces the image and revisit time

Scalability and evolution



1× GeoSTARe

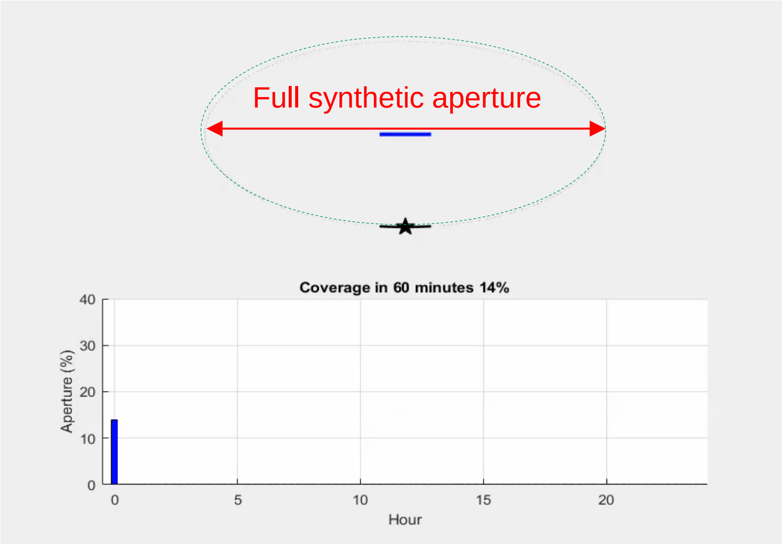
1 hr orbit arc (image time)

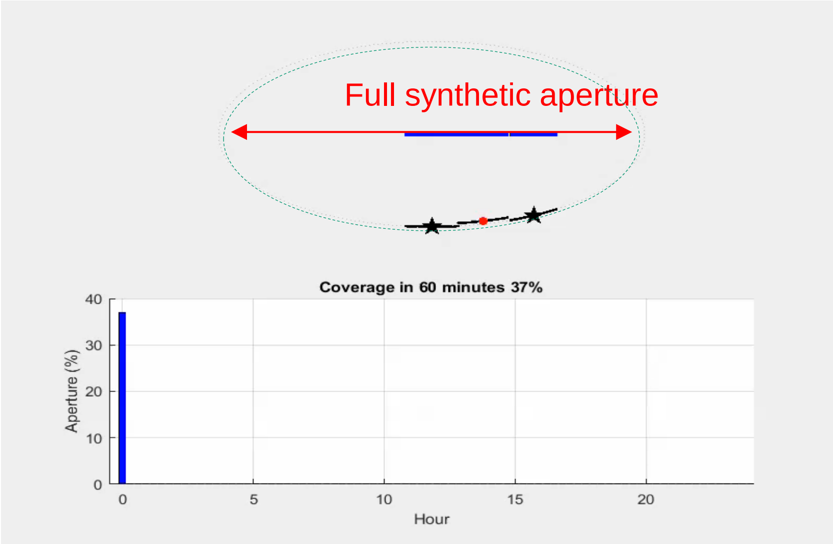


2× GeoSTARe MIMO

= 3 phase centers

2 real ★ + 1 virtual o





Resolution is 1% - 15% of full

Inteferometric revisit: 12 h

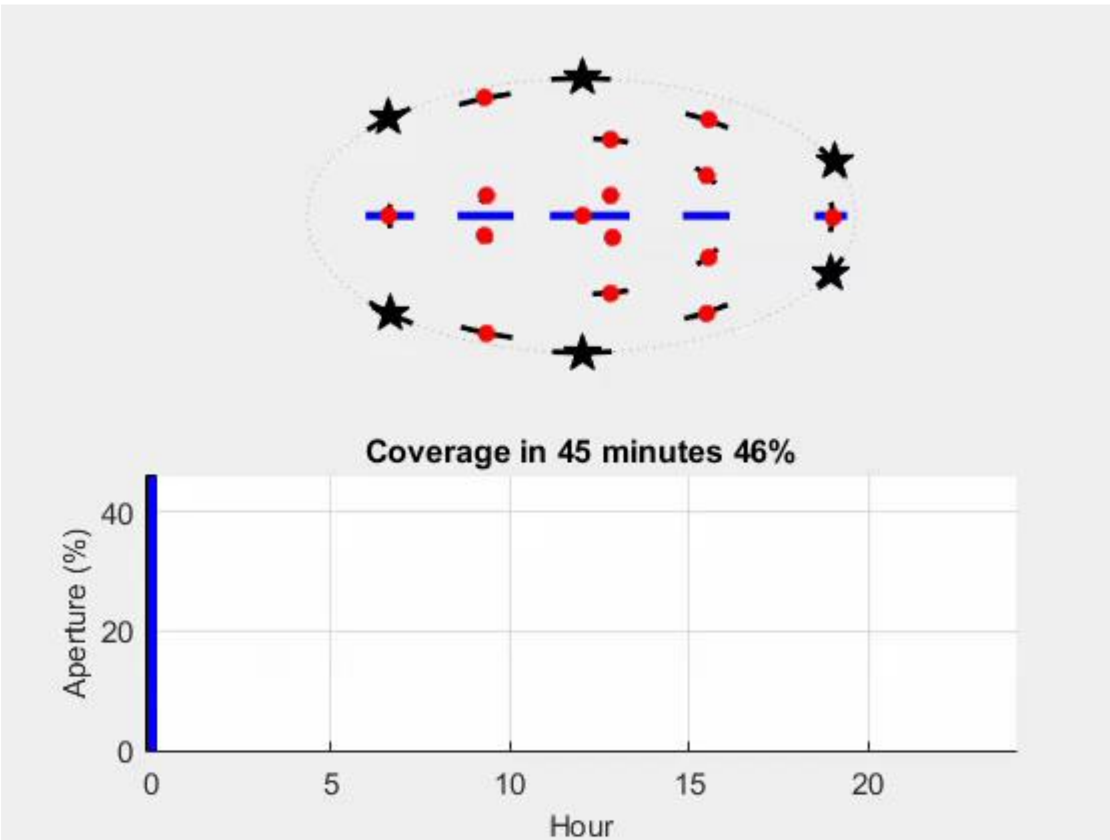
Resolution is: 5% - 40% of full

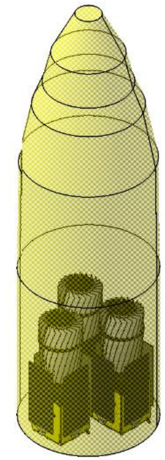
Power: ×4

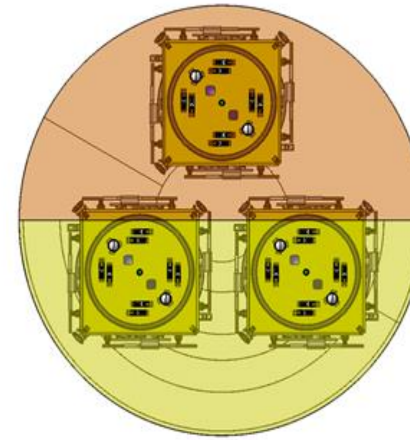
Inteferometric revisit: 1 h + 2 h + 12 h

Advanced Radar Geosynchronous Observation System ARGOS

Six mini-satellites, fitting in a single Ariane launch.

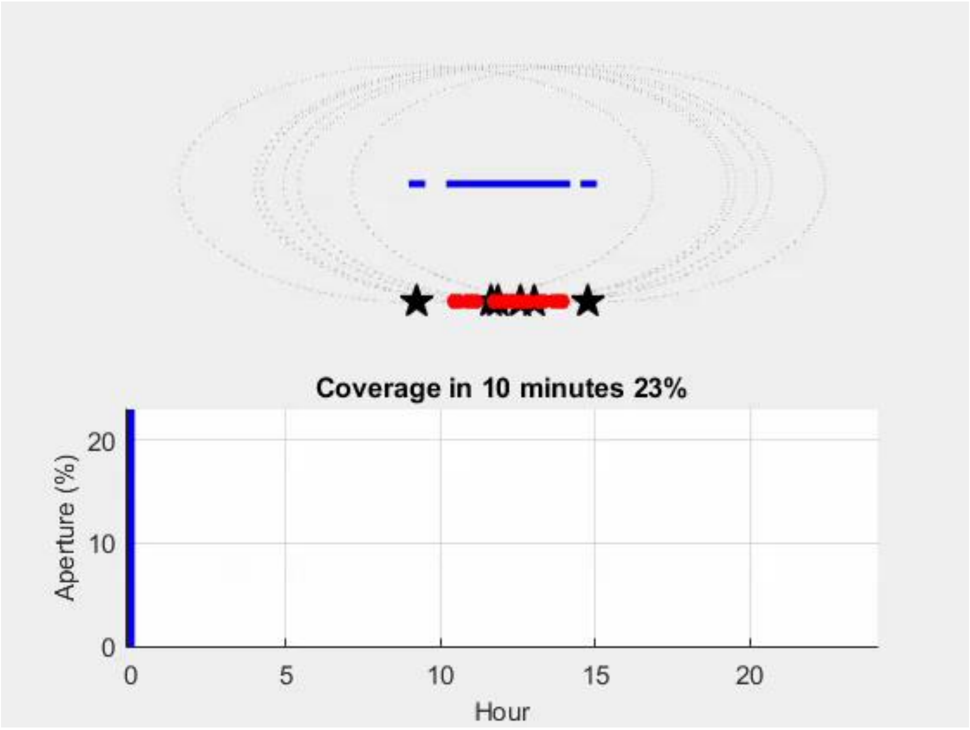


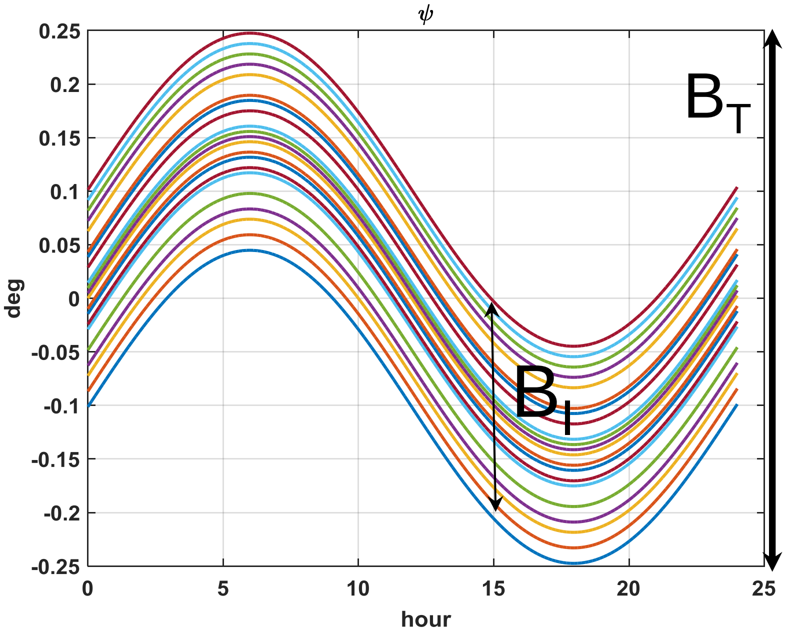




A. Monti Guarnieri, O. Bombaci T. F. Catalano C. Germani C. Koppel F. Rocca G. Wadge *ARGOS: a Fractioned Geosynchronous SAR, submitted to Acta Astronauta, EO Distributed Mission, special issue*

Swarm design: the sliding configuration





The bandwidth spanned in 10', B_I, is a fraction of the total, B_T, spanned in one day. At the end of the day we have the full resolution image.

Fractioning the antenna

+ The power is fractioned into N active sensors

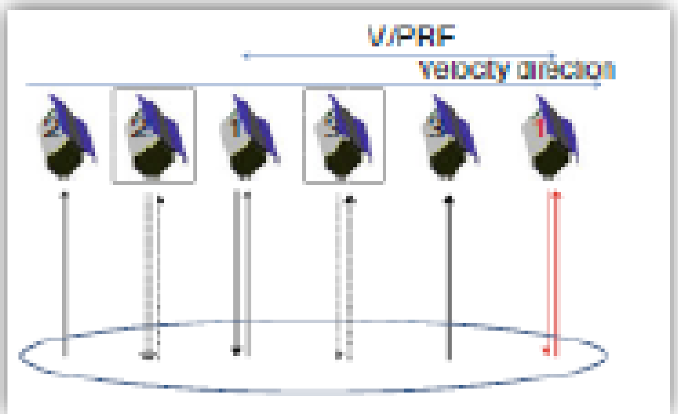
+ The antenna area is fractioned in N active + M passive sensors

➔ The total gain is (N^2+M)

The number of pixels (ratio between coverage and resolution) increases with the square of the number of sensors

$$SNR_{MONO} = \frac{P_t G A \eta_T}{\left(4\pi R^2\right)^2} \frac{\sigma^0 \rho_{az} \rho_{rg}}{\sin\theta} \frac{T_S}{N_0}$$

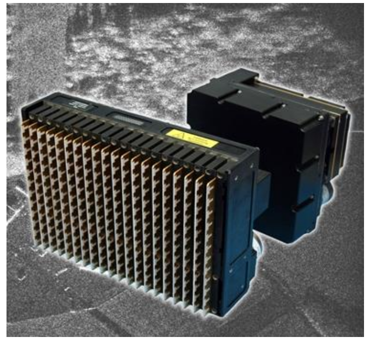
$$SNR_{N\_MIMO} = N^2 SNR_{MONO}$$

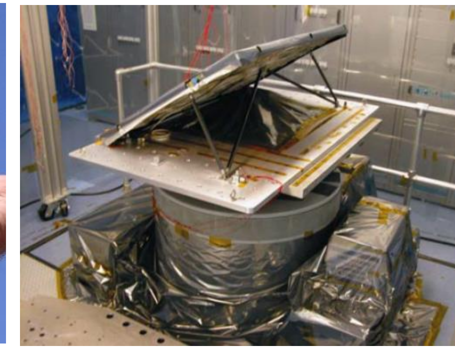


P-Band Distributed SAR

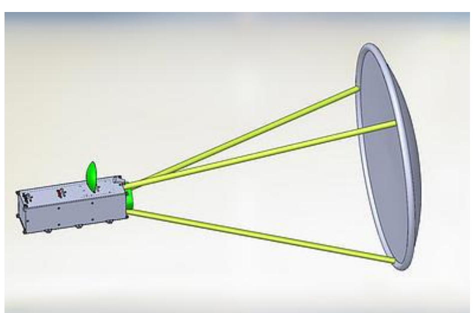
Giancarmine Fasano, Marco D'Errico, Giovanni Alberti, Stefano Cesare, and Gianfranco Sechi

Fractioning the antenna: nano-pico-mini SAR





Manufac	Name	Antenna	Appl.	Rng. res	Weigth	Power	Freq
MSAR	NanoSAR-B	1.1×0.2	UAV	< 0.3 m	1 kg	15 W	Ku,X,UHF
Barnard	miniSAR	0.3×0.1	UAV		1 kg	15 W	X
	Mini-SAR	0.9×1.5	Moon	2 MHz	9 kg	11 W	S
Thales	I-Master		UAV	< 0.3 m	30 kg	~ 100 W	Ku
Selex	PicoSAR		UAV	< 1 m	10 kg	~ 100 W	X

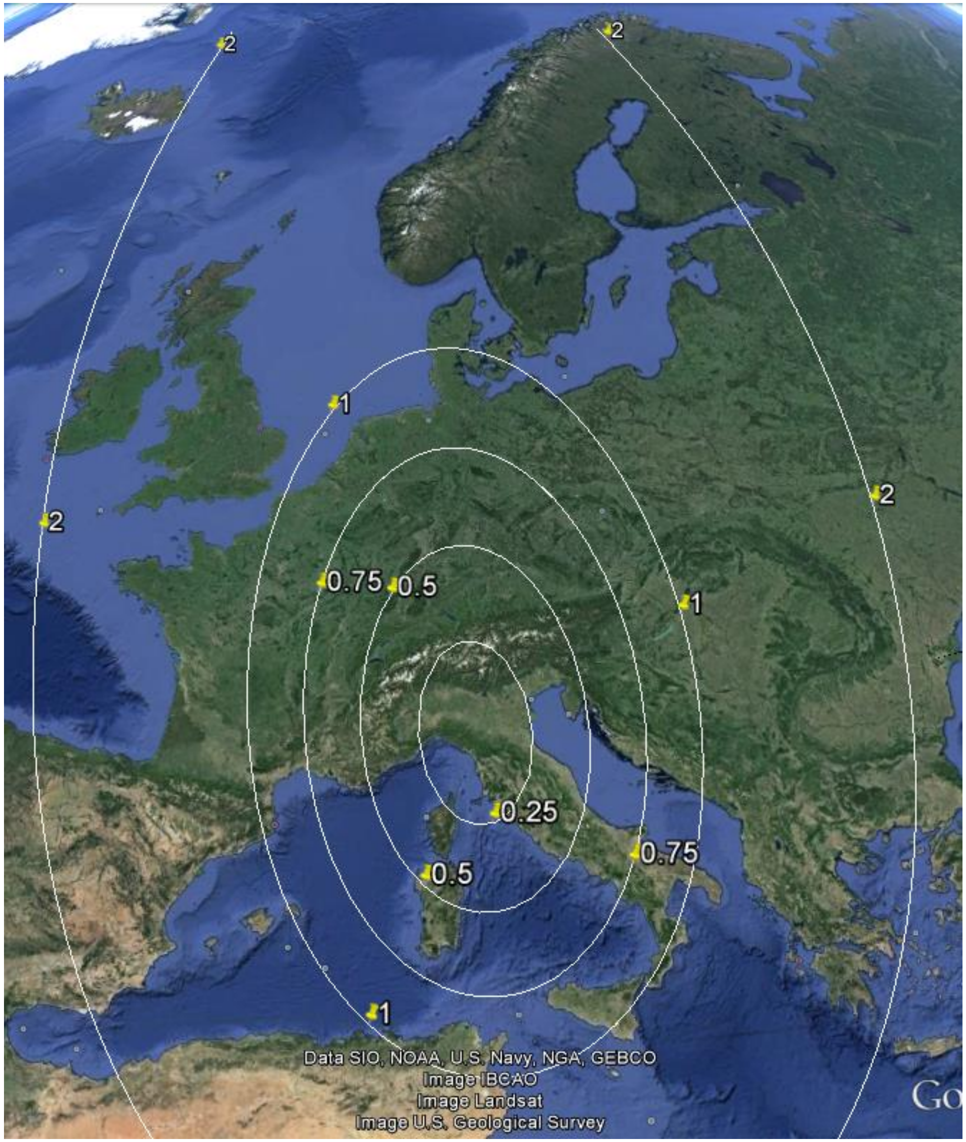


Expandable large aperture antenna, 1 m

Folded volume is under 1/4 of the material volume [**NsIcomm**]

Issues and technological challenges

- Electric propulsion for constellation keeping & redesign
- Flexible beam pointing for continental access
- Separation of iso-frequency signals in (Doppler, time) space
- On ground synchronization
- Use of the RADAR pulse for data download



Design & performance examples

To achieve SNR = 1 (far range):

$$N_{sat}^2 \times P_T \times L^2_{ant} \times T_{imm} \times \frac{\rho_a \times \rho_r}{D_a \times D_r} =$$

$$20^2 \times 50\ W \times 1.5^2\ m \times 15' \times \underbrace{\frac{10m \times 10m}{450km \times 720km}}_{12\ Mpixel}$$

#	Ant. diam	Tx Power	Image Time	Az res.	Rng res.	Notes
1	6 m	300 W	7 hours	10 m	3 m	GeoSTARe*
6	5 m	300 W	30 min	3 m	3 m	ARGOS
20	1.5 m	50 W	15 min	10 m	10 m	Microsat

(*) GeoSTARe is ESA contracted study, leader SES. To proposed for next EE9 call

Conclusions

The proposed system combines three concepts:

Geostationary orbit	Synthetic Aperture RADAR	MIMO - Swarm
✓ Huge access region	✓ **Day and night all-weather**	✓ Gain N^2 in SNR
✓ **Continuous scene visibility**	✓ **Sensitive to:**	✓ Gain $N \times (N+1)/2$ in revisit
✓ Real time download	Millimeter deformations	✓ Scalable
✓ Safer from debris than LEO	Columnar water – vapor	✓ Robust: gentle degradation
✓ Efficient keeping – long lasting	Coherent changes	✓ Reconfigurable & flexible
	Moisture and roughness	

- The geosynchronous SAR concept, studied since '78, is much too demanding (but for the geo-stationary case)
- The MIMO & swarm LEO SAR have been proposed for extended swath, tomography and DEM generation (Cartwheel, TanDEM-X, HRWS, …)
- The geo-stationary swarm SAR is an unique system using current technologies and providing continuous capabilities in imaging, water vapor and deformation