SPACE advisory company

Potential Synthetic Aperture Radar applications of small satellites

United Nations / South Africa
Symposium on Basic Space Technology
"Small satellite missions for scientific and technological advancement"

Presented by: M. Inggs (Principal Radar Systems Engineer, SAC, Emeritus Prof. UCT)

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Stellenbosch

Overview

Aspects of SAR Operation

- Basic Radar theory and mechanics of Synthetic Aperture Radar (SAR).
- Why SAR from Space?
- Applications of Spaceborne SAR.
- SAR Wars

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Brief introduction to Radar and SAR

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Radar

- Repeated burst of EM waves: carrier wavelength of 1 cm to 23 cm (Ka Band down to L Band).
- Resolution determined by modulation bandwidth of pulse, typically Linear Frequency Modulated, bandwidth ***B***.
- Range resolution is **$\delta R = c / 2B$**
- Sensitivity depends on **Energy** radiated and **aperture** size.
- Received signals compete with thermal noise from receiver and the environment (some man-made).
- Moving targets result in a **Doppler** shift.
- Detection ability falls with the fourth power of range to target.
- Range is measured by time delay to target and back.
- Beamwidth of a real aperture antenna determined by **λ/D**

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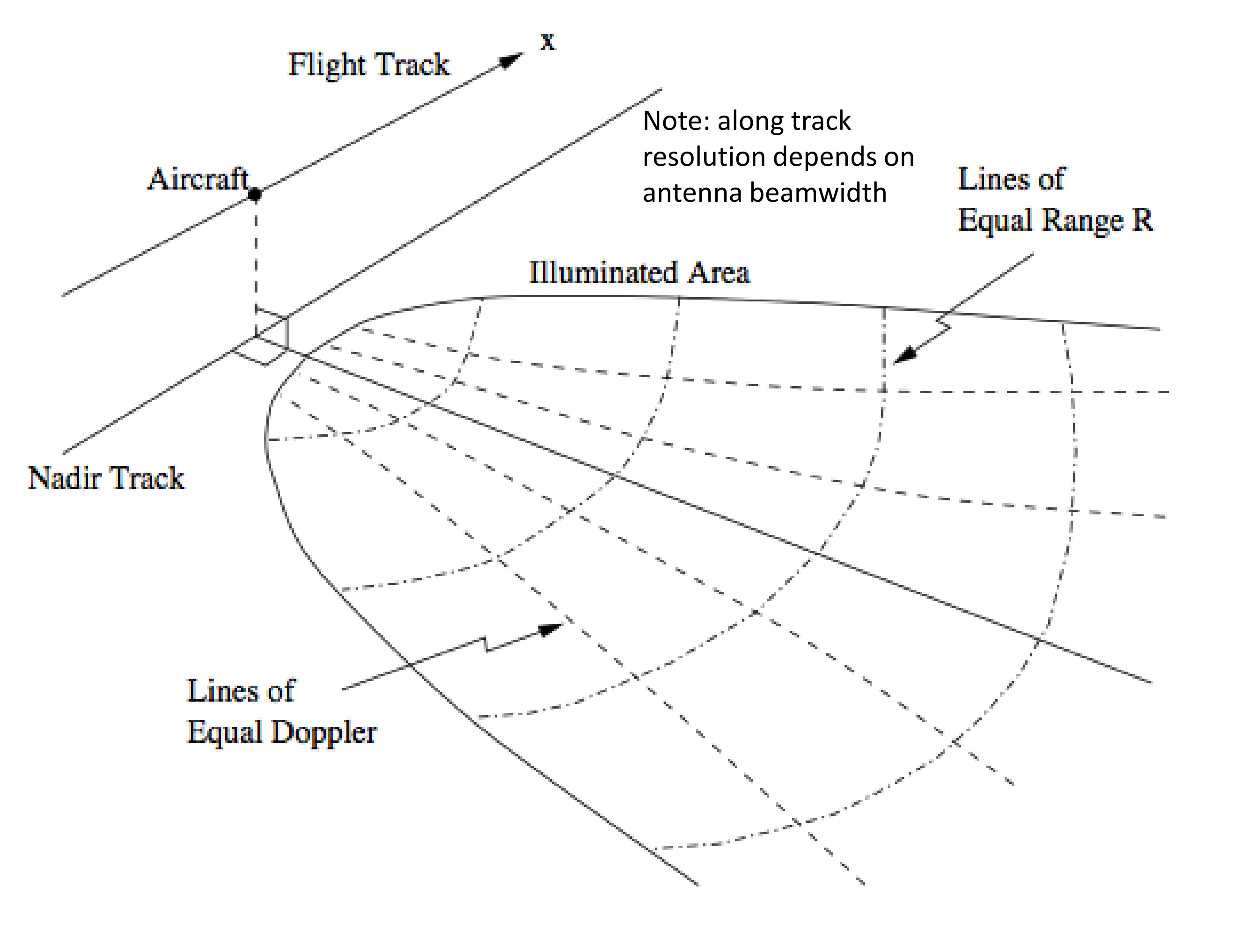
Generic Side Looking Imaging Radar



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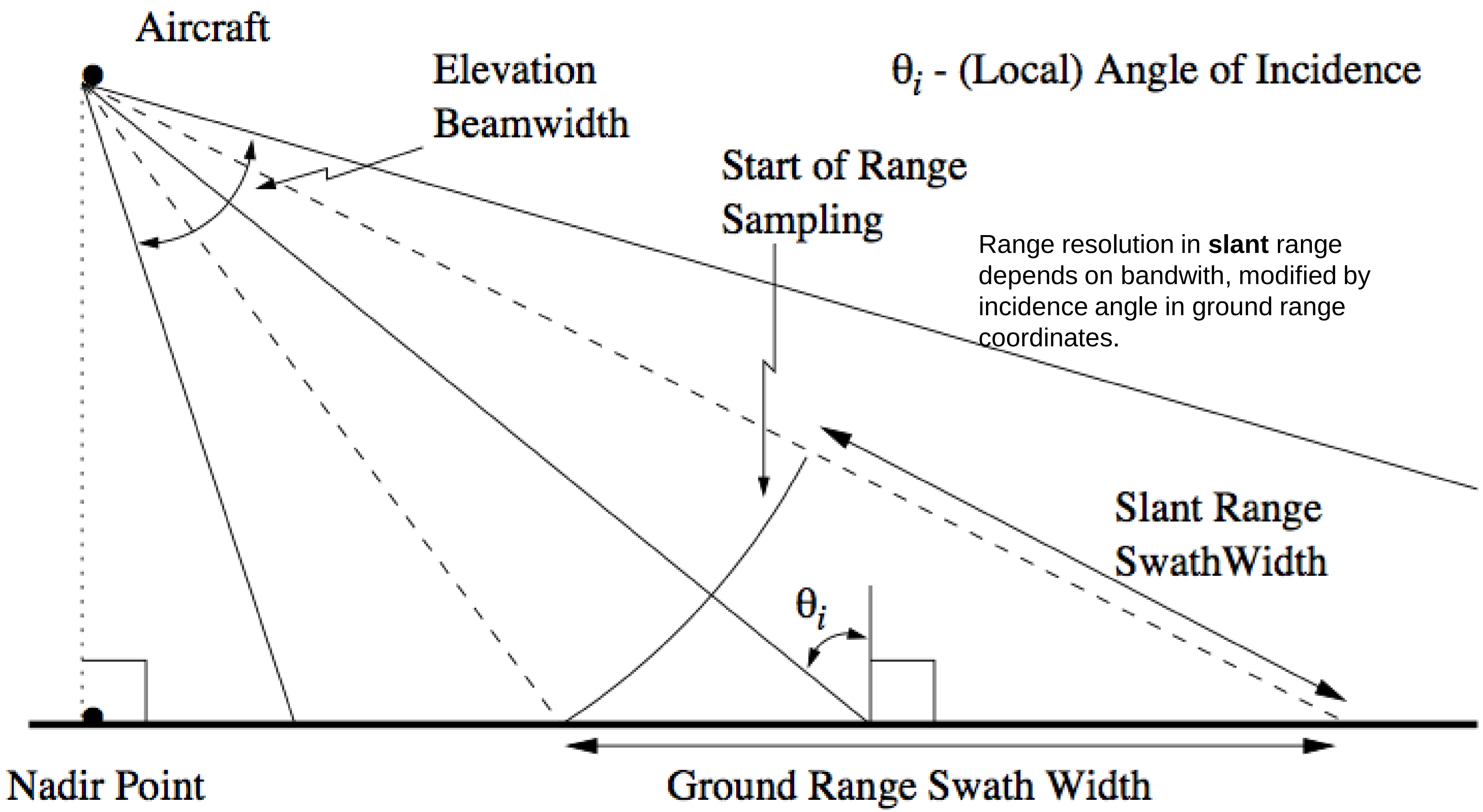
Side View



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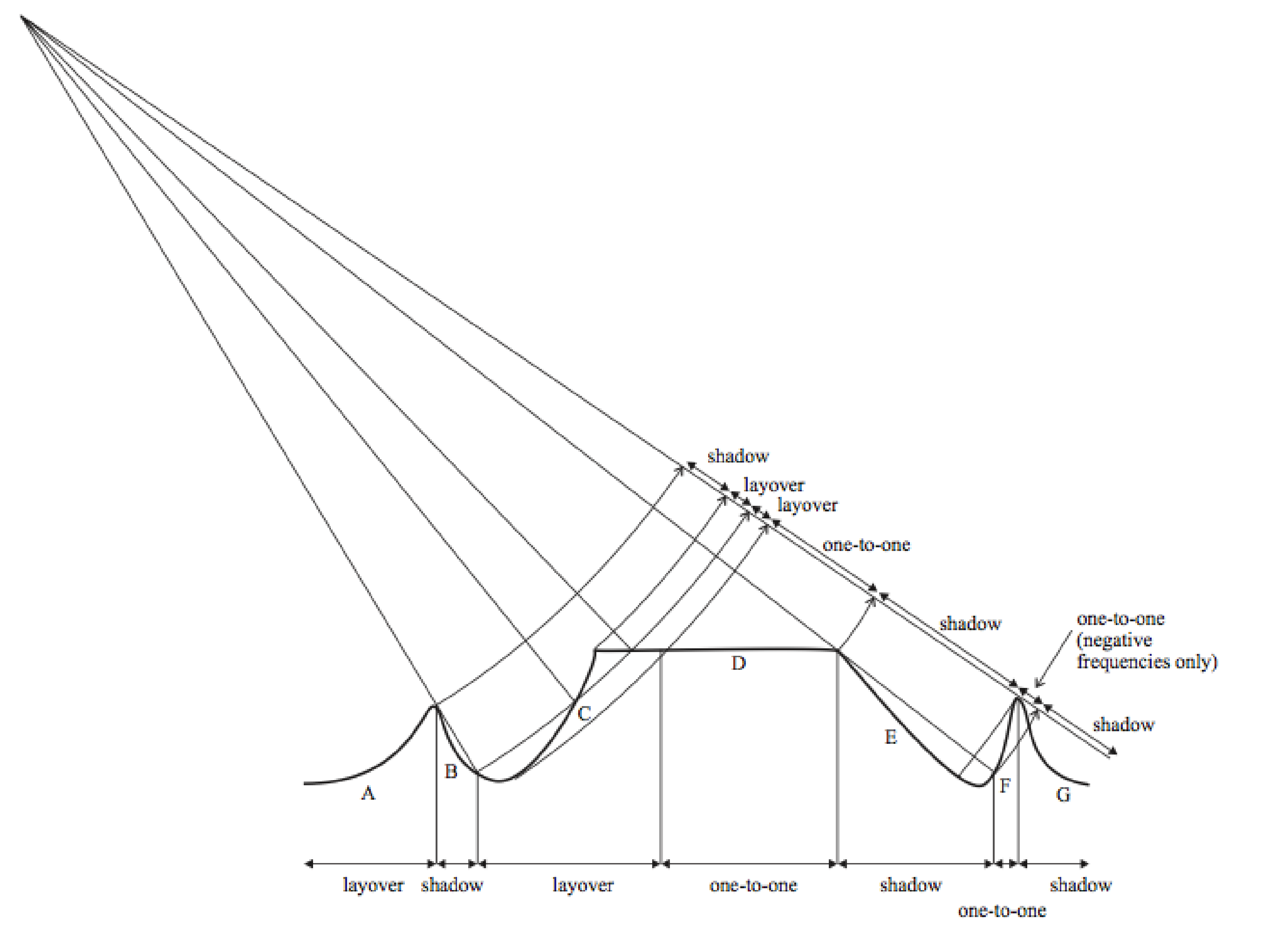
Imaging Problems



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Synthetic Aperture Formation

- An antenna of dimension d results in a beamwidth of **$\theta = \lambda/d$.**
- A real azimuth antenna pattern results in an along track or azimuth resolution that is poor unless the azimuth dimension is extremely large (especially from space).
- The azimuth resolution degrades with range (**$\delta x = R\,\theta$**), thus:
  - Store the range echoes in the azimuth direction.
  - For each range resolution cell, form a synthetic, large aperture antenna.
  - Results in a synthetic, narrow beam view of the swath.
- Can be shown that the best azimuth resolution is **$\delta x = l_a / 2$,** where **l_a** is the azimuth dimension of the real antenna.
- Sensitivity depends on Energy and Aperture as before, but decreases with cube of range, since many samples are added to form the synthetic aperture.

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Point and Distributed Targets

- A point target backscatter is measured by its "radar cross section", **σ_0 [m^2]**.
- A distributed target is measured by **σ^0 [m^2/m^2]** i.e. the backscatter per illuminated area. Example, a field of maize, rocky, flat terrain.
- The backscatter depends on incidence angle.
- The backscatter for SAR is the vector sum of a large number of scatterers in the resolution cell.
- Results in a magnitude that fluctuates from cell to cell, even for a uniform target area: called **"speckle"**.
- Characteristic of all coherent imaging systems.

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SAR key parameters

- The range and azimuth resolution of the sensor is specified. Generally the processing is arranged so that these are equal, i.e. “square pixels”.
- The probability of detection (**P_d**) of a single object within a resolution cell, with given probability of false alarm (**P_{fa}**) should be stated.
  - This is import when detecting, for example, vehicles in a field, ships on the ocean.
- The value of “**Sigma Zero**” when a resolution cell’s response is equal to the system noise floor is known as the “Noise Equivalent Sigma Zero” (**NESZ**).
  - This is important when discriminating against different types of surface being imaged, for classification.
- More technical are the **ambiguities** caused during image formation: discussed in a more advance forum.

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Why SAR from Space?

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Imaging with Radar from Space

EM wave advantages

- Penetrates cloud and hardly affected by rain.
- Can detect moving targets i.e. discriminate against a background.
- Millimetric changes in phase between consecutive images can be used for change detection.

Free Access to all of the Earth’s Surface

- Day / night operation (own illumination).
- Not restricted by aircraft operational limitations (range, airspace control).
- No legislative control

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Applications of SAR

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Numerous SAR Applications

- Cryosphere
  - Ice / snow
  - Navigation
- Land
  - Vegetation
  - Geology / Tectonics
  - Land Use
  - Change detection
- Oceans
  - Currents
  - Wind and Waves
  - Maritime Domain Awareness

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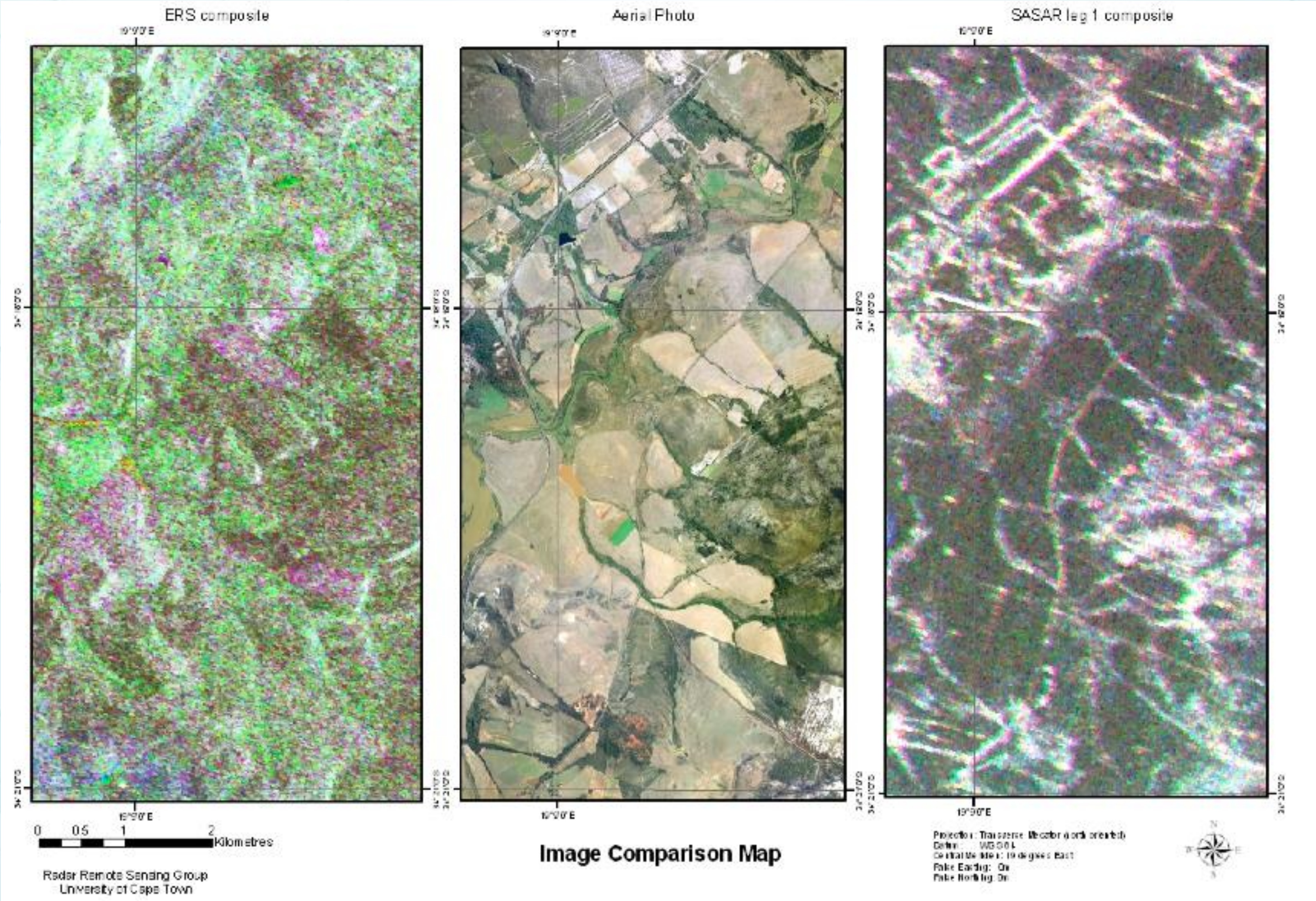
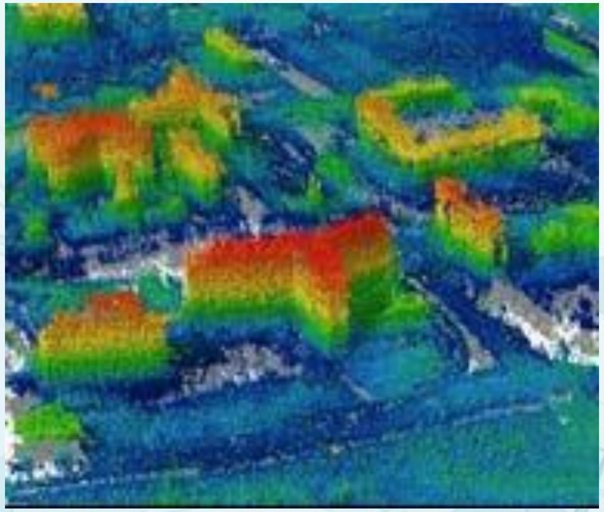
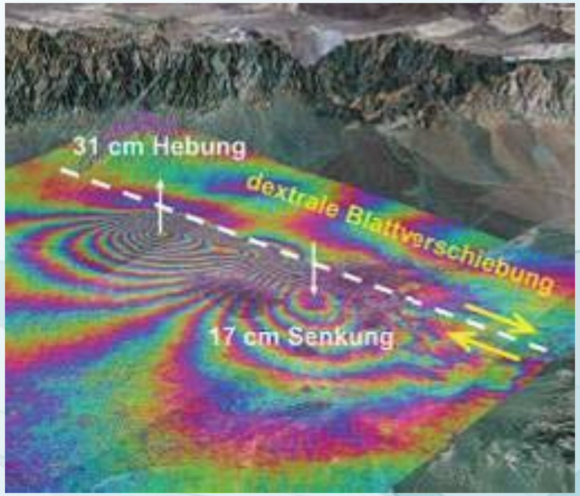

ERS composite
Aerial Photo
SASAR leg 1 composite
0 0.5 1 2 Kilometres
Radar Remote Sensing Group
University of Cape Town
Image Comparison Map

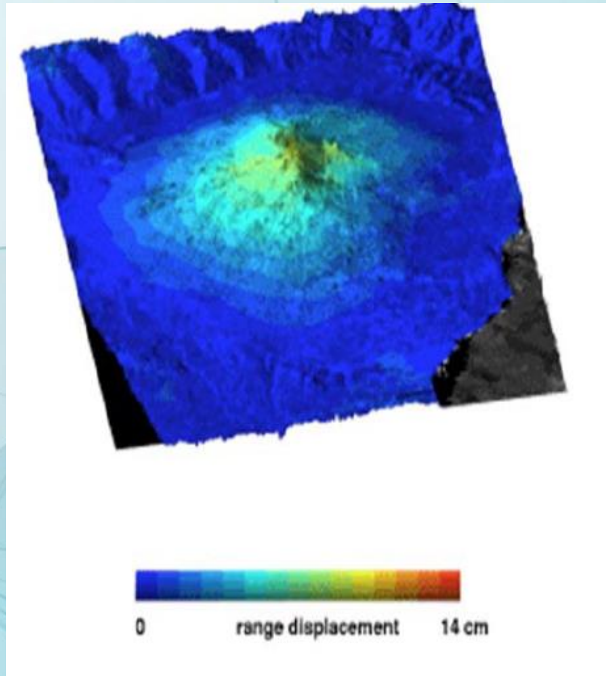
3-d modelling (digital elevation Model).



Tomography (Urban Modelling).



Differential Interferometry (for tectonic analysis).



Repeat pass inteferometry.

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Brief History of Spaceborne SAR

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SAR in Space

- NASA
  - SEASAT 1978
  - SIR A/B/C
- German Government and Industry
  - DLR Tandem X
  - PPP TerraSAR X
  - Military SAR Lupe
- European Countries
  - ESA ERS1/2
  - ESA Envisat
  - ISA COSMO Skymed
  - Russia, India, Japan
  - Now, “SAR Wars”, the march of the miniature systems.

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Mass!

Satellite	Agency/Country	Year	Band	Az Res	Range Res	Pol	Weight
SEASAT-SAR	NASA/USA	1978	L	6	25	HH	2290
SIR-A1	NASA/USA	1981	L	7	25	HH	
SIR-B1	NASA/USA	1984	L	6	13	HH	
ERS-1/2	ESA	1991/1995	C	5	25	VV	2400
ALMAZ-1	USSR	1991	S	8	15	HH	3420
HH	(payload)						
JERS-1 SAR	NASDA/Japan	1992	L	6	18	HH	1400
SIR-C/X-SAR1	NASA/USA	1994	C/L	7.5	13	quad	11000 (approx.)
	DLR/Germany/ASI/Italy		X	6	10	VV	
RADARSAT-1	CSA/Canada	1995	C	8	8	HH	3000
SRTM1	NASA/USA	2000	C	15	8	dual	13600 (payload)
	DLR/Germany		X	8	19	VV	
ENVISAT-ASAR	ESA	2002	C	10	30	dual	8211
ALOS-PALSAR	JAXA/Japan	2006	L	5	10	quad	3850
SAR-Lupe (5)	Germany	2006–2008	X	0.5	0.5	quad	770
RARDASAT-2	CSA/Canada	2007	C	3	3	quad	2200
Cosmo-SkyMed (4)	ASI/Italy	2007–2010	X	1	1	quad	1700
TerraSAR-X	DLR/Germany	2007	X	1	1	quad	1230
TanDEM-X	DLR/Germany	2009	X	1	1	quad	1230
RISAT-1	ISRO/India	2012	C	3	3	dual	1858
HJ-1-C	China	2012	S	5	20	VV	N/A
KOMPsat 5	KARI/South Korea	2013	X	1	1	quad	1400
Sentinel 1A/B	ESA	2014/16	C	5	5	dual	2300
ALOS 2	JAXA/Japan	2014	L	1	3	quad	2120
PAZ	Hisdesat/Spain	2015	X	1	1	quad	1230

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The "SAR Wars"

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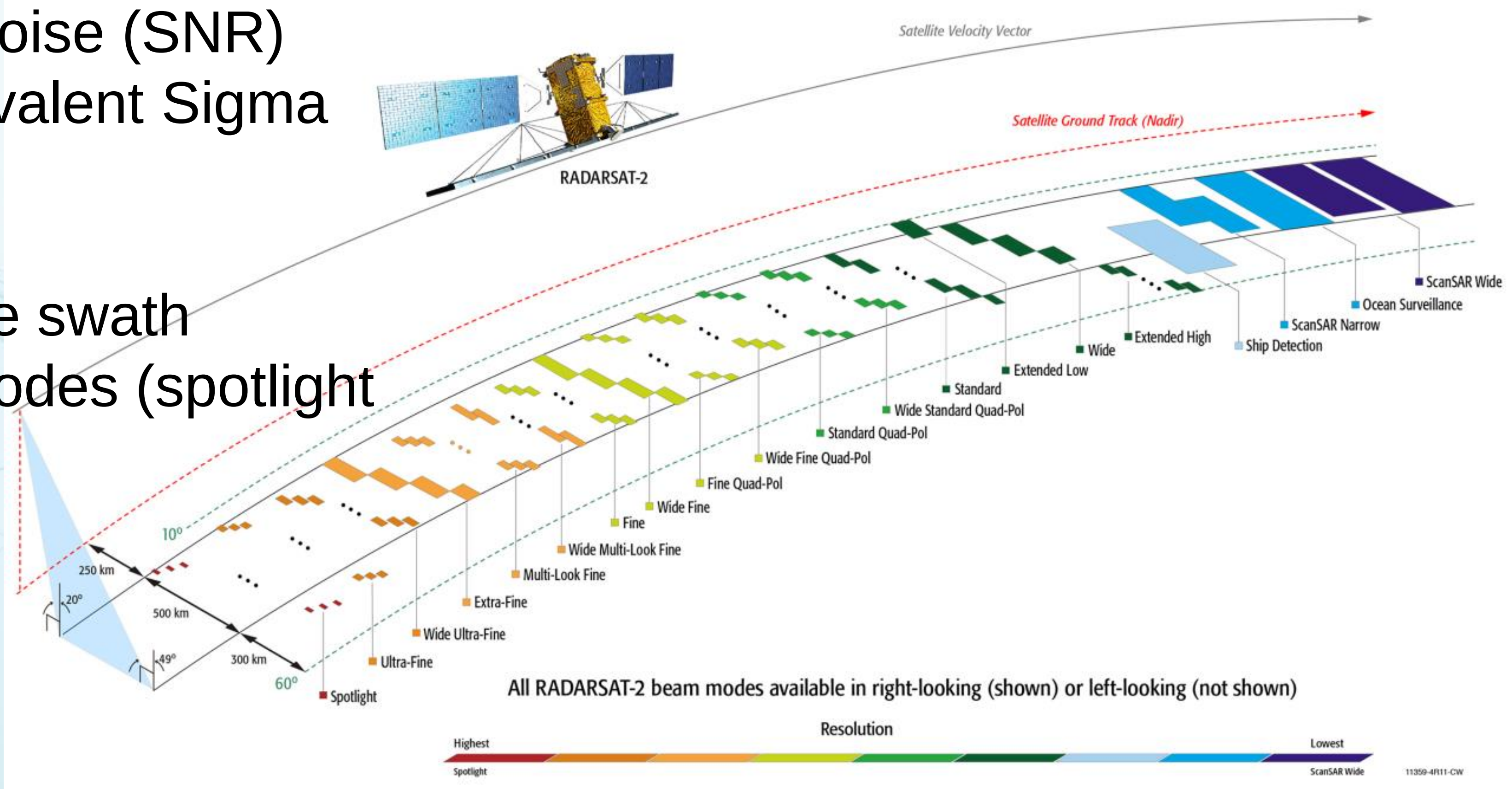
SAR Performance

- Resolution
- Coverage per orbit, per day, per month, often quoted in terms of swath width.
- Target detection Signal to Noise (SNR)
- Area sensitivity: Noise Equivalent Sigma Zero (NESZ)
- Ambiguity rejection
- Illumination angle across the swath
- Specialist high resolution modes (spotlight mode)



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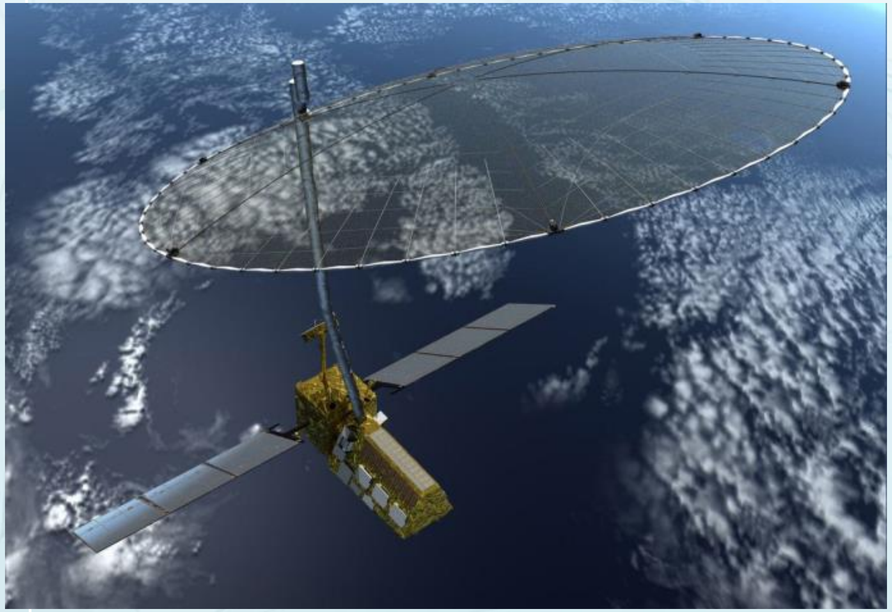
The "SAR Wars"

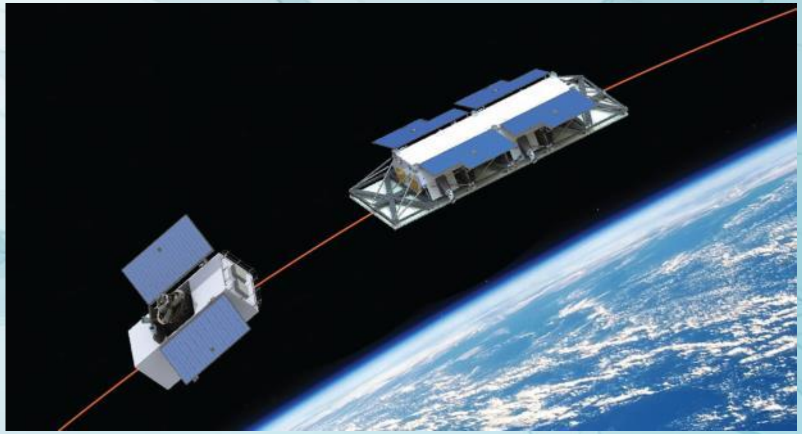
Capella Space

- No published specifications
- Launch in 2017 (83 days to go…)
- More than USD 12m in venture capital.
- "Hourly images of anywhere on earth".
- Detect millimetre surface deformations.
- 36 satellites
- Below 50 kg satellite
- 1 m resolution



Urthecast

- The OptiSAR (trademark) Constellation comprises 8 tandem pairs of SAR and Optical Satellites divided into two orbit planes.
- The 4 tandem pairs will be equi-spaced around an orbit plane, where each tandem pair consists of a leading SAR satellite, which uses UrtheCast's SAR-XL technology for its payload.
- A trailing Optical satellite that is following approximately 2 minutes behind the SAR satellite..
- Phased array technology.
- Narrow strips (7 km) but out to 140 km in scansar.
- Resolution around 1 m X 1 m.
- NESZ around -20 dBm in X, closer to -26 dBm in L Band.



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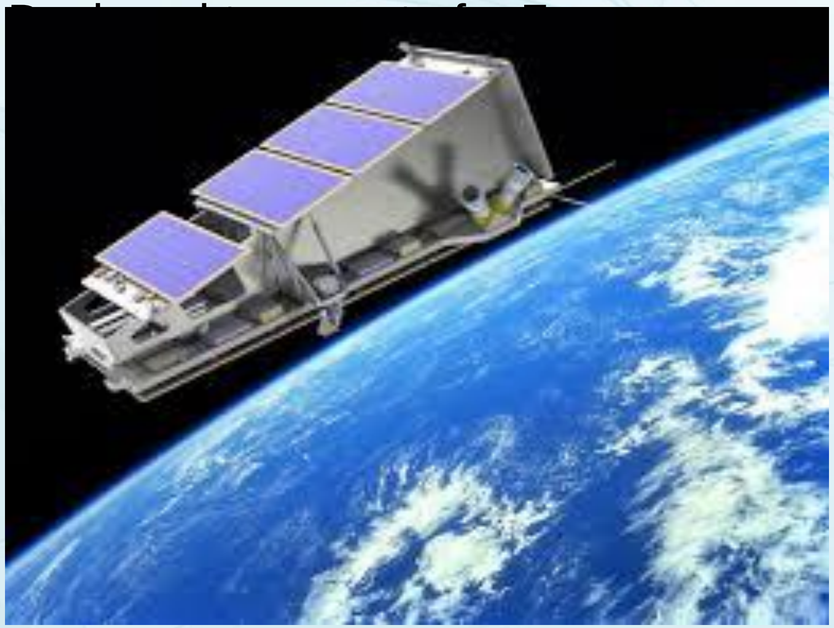
The "SAR Wars"

Surrey Space Systems Limited (SSTL)

- Close to Launch
- NovaSAR will consist of four state of the art SAR satellites able to operate day and night in all weather conditions.
- The first of these satellites is being funded by the UK government and is currently in development.
- Government investment announced in November 2011
- Mass less than 500kg



Iceye

- Aerial imaging with Jet aircraft 2017 - Selected countries 4 week response 3m resolution
- Phase 1 3 satellite constellation 2018 - Global access 24 hour response 10m resolution
- 1st Generation 6+ satellite constellation 2019 - Global
- access 6 hour response 3m resolution
- Mass of less than 100kg
- Raised around USD18M in funding
- Launch mid 2018

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MicroSAR Constellation

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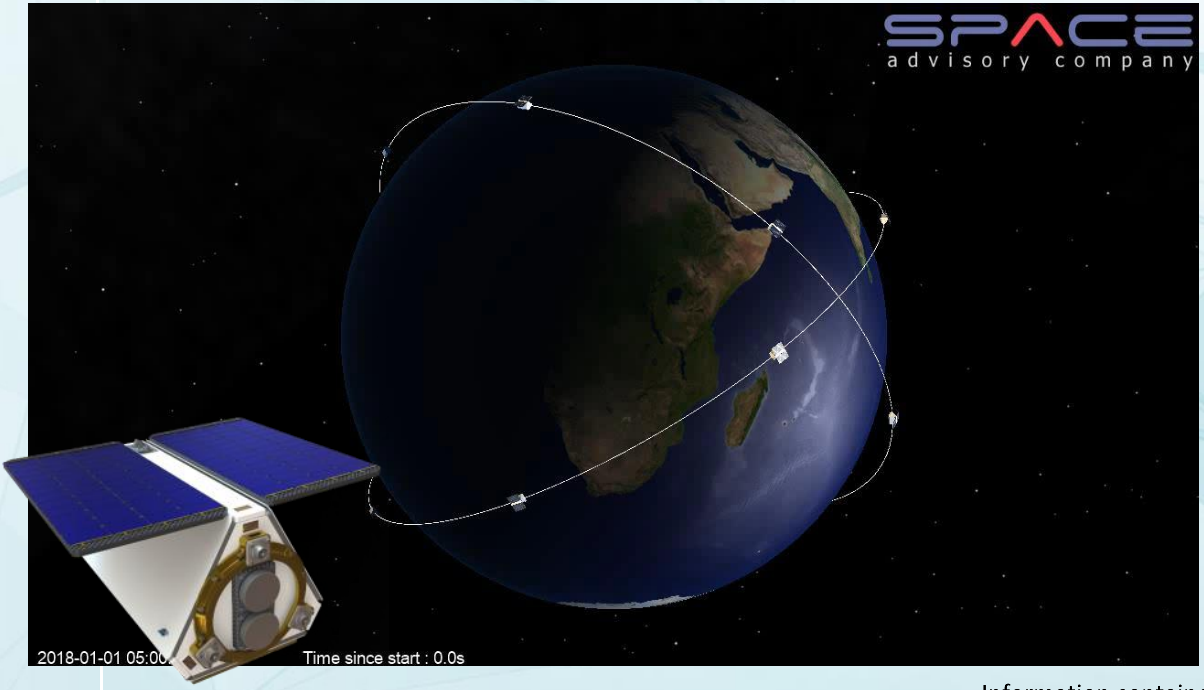

Scenario	1	2	3	4
Constellation				
Number of planes	1	1	1	2
Number of SAR satellites per plane	2	4	8	8
Total number of satellites	1	4	8	16
SAR coverage 24 hrs				
Number of SAR passes over CT	12	24	49	97
% Area covered by SAR satellites	73.7	96.7	99.9	100
Overlapping Scans across ROI (revisits)	1.2	2.4	4.8	9.6

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Conclusions

- SAR is a mature field and currently occupies 60% of Earth Observation applications research:
  - the diversity has been shown in this presentation.
- The number and diversity of applications is huge.
- To some extent, the population of earth is well served with research instruments but:
  - niche applications in surveillance required a large number of spaceborne instruments to achieve 24/7 coverage,
  - with frequent updates.
- Spaceborne SAR technology is very well understood: note that high sensitivity systems require large apertures / energy.

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Designing a Radar Imaging Satellite: Pitfalls and Trade-offs

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