Sentinel-1 System Capabilities and Applications

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European Space Agency, ESTEC

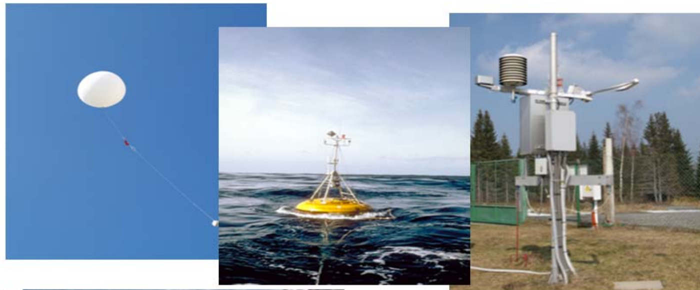
Global Monitoring for Environment and Security (GMES)

- EU/ESA co-funded program aiming at providing operational GMES services based on Earth observation and in-situ data
- Provides relevant information to policy-makers, institutional EU + Member States authorities (Core service), and local/regional users (Downstream)

Space Component – developed & coordinated by ESA

✓ **Sentinels (1-5)**

✓ Contributing (national) Missions – Data Access



In-situ component – coordinated by EEA

✓ Observations mostly within national responsibility, with coordination at European level

✓ Air, sea- and ground-based systems and instrumentations

Service component – coordinated by EC

✓ Mapping and forecasting services:

Land, Marine, Atmosphere, Emergency, Security and Climate Change

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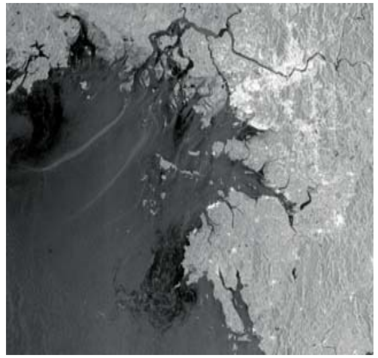
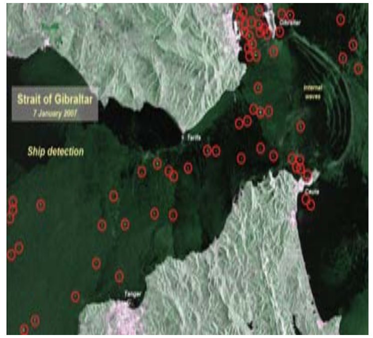
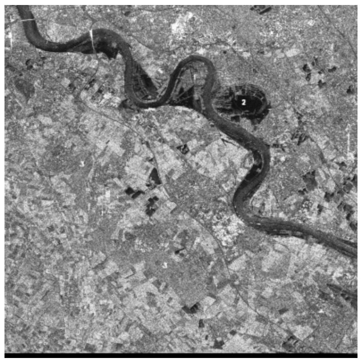
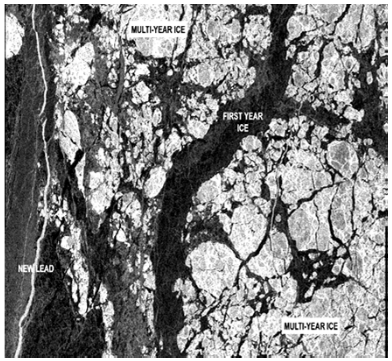
Sentinel-1 Mission Objectives and Requirements

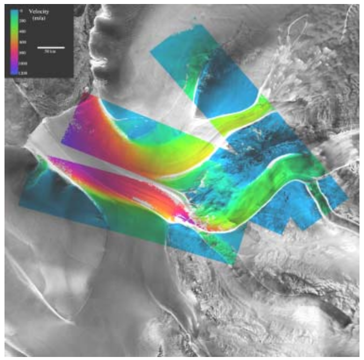
- Provide routinely and systematically SAR data to *GMES services* and *National services* focussing on the following applications:
  - ✓ Monitoring of marine environment (e.g. oil spills, sea ice zones)
  - ✓ Surveillance of maritime transport zones (e.g. European and North Atlantic zones)
  - ✓ Land Monitoring (e.g. land cover, surface deformation risk)
  - ✓ Mapping in support of crisis situations (e.g. natural disasters and humanitarian aid)
  - ✓ Monitoring of Polar environment (e.g. ice shelves and glaciers)

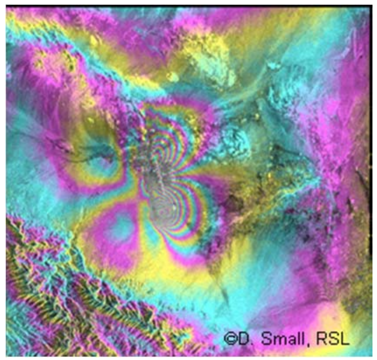












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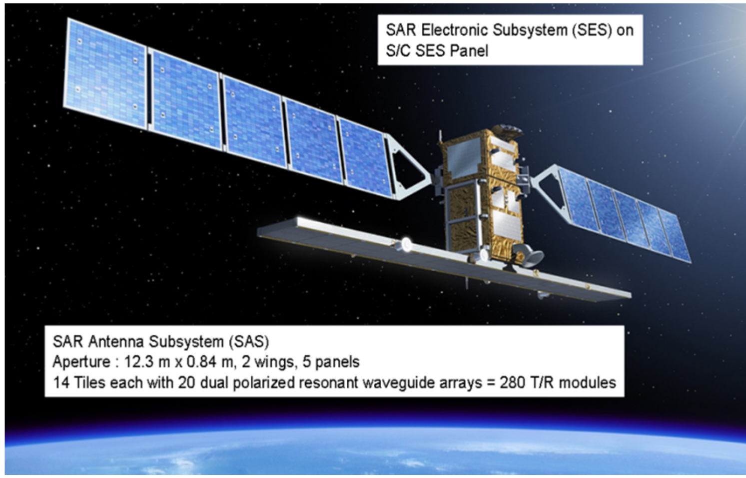
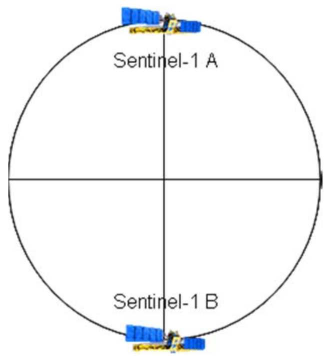
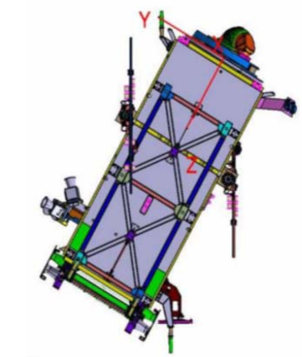
Sentinel–1 Mission Facts

- Constellation of two satellites (A & B units)
- C-Band Synthetic Aperture Radar Payload (at 5.405 GHz)
- 7 years design life time with consumables for 12 years
- Near-Polar sun-synchronous (dawn-dusk) orbit at 698 km
- 12 days repeat cycle (1 satellite), 6 days for the constellation
- Both S-1 satellites are in the same orbital plane (180 deg. phased in orbit)
- On-board data storage capacity (mass memory) of 1400 Gbit
- Two X-band RF channels for data downlink with 2 X 260 Mbps
- On-board data compression using Flexible Dynamic Block Adaptive Quantization (FDBAQ)
- Optical Communication Payload (OCP) for data transfer via laser link with the GEO European Data Relay Satellite (EDRS)
- Launch of Sentinel-1A scheduled for first Quarter of 2014 followed by Sentinel-1 B 18 months later







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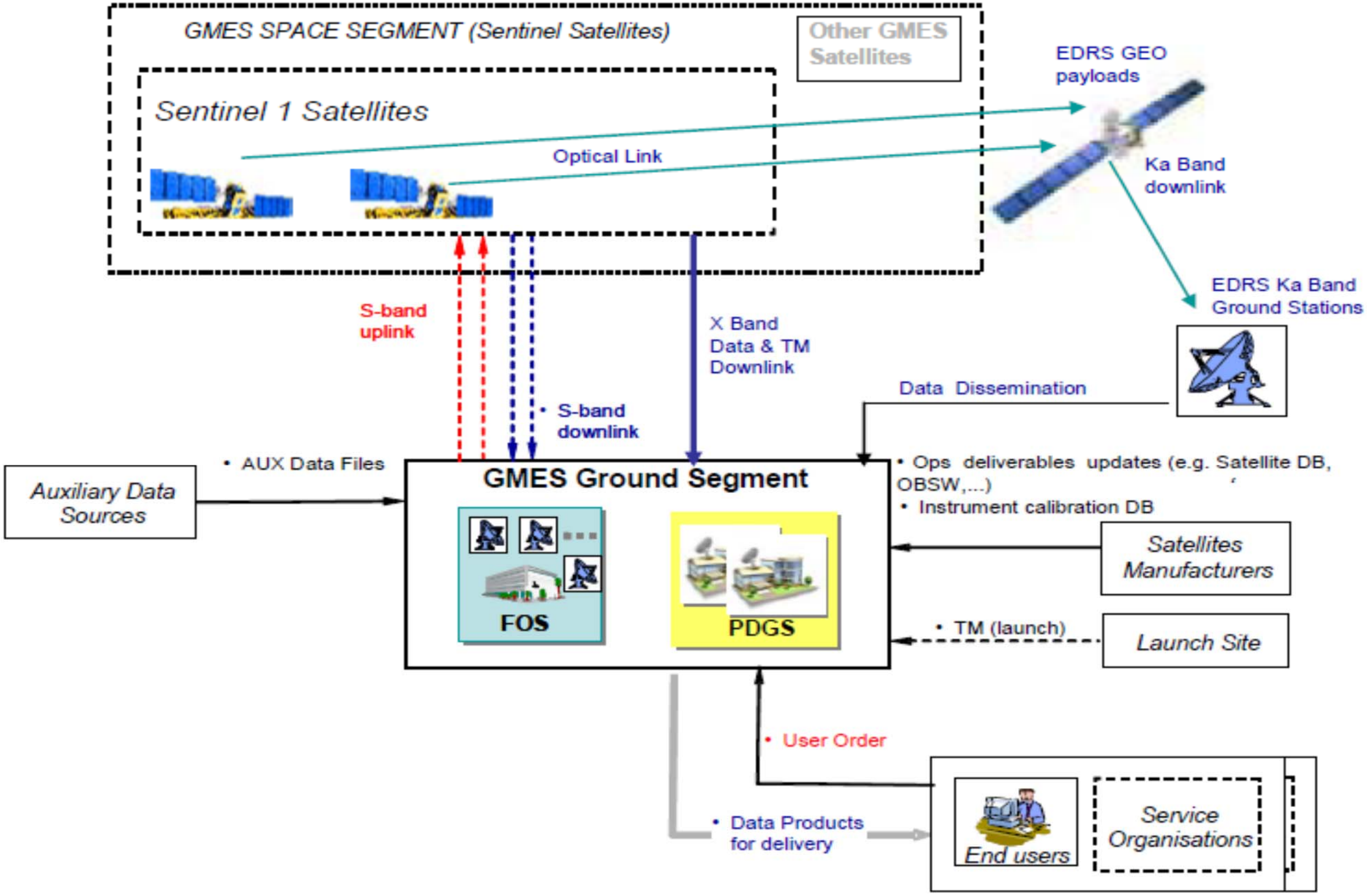
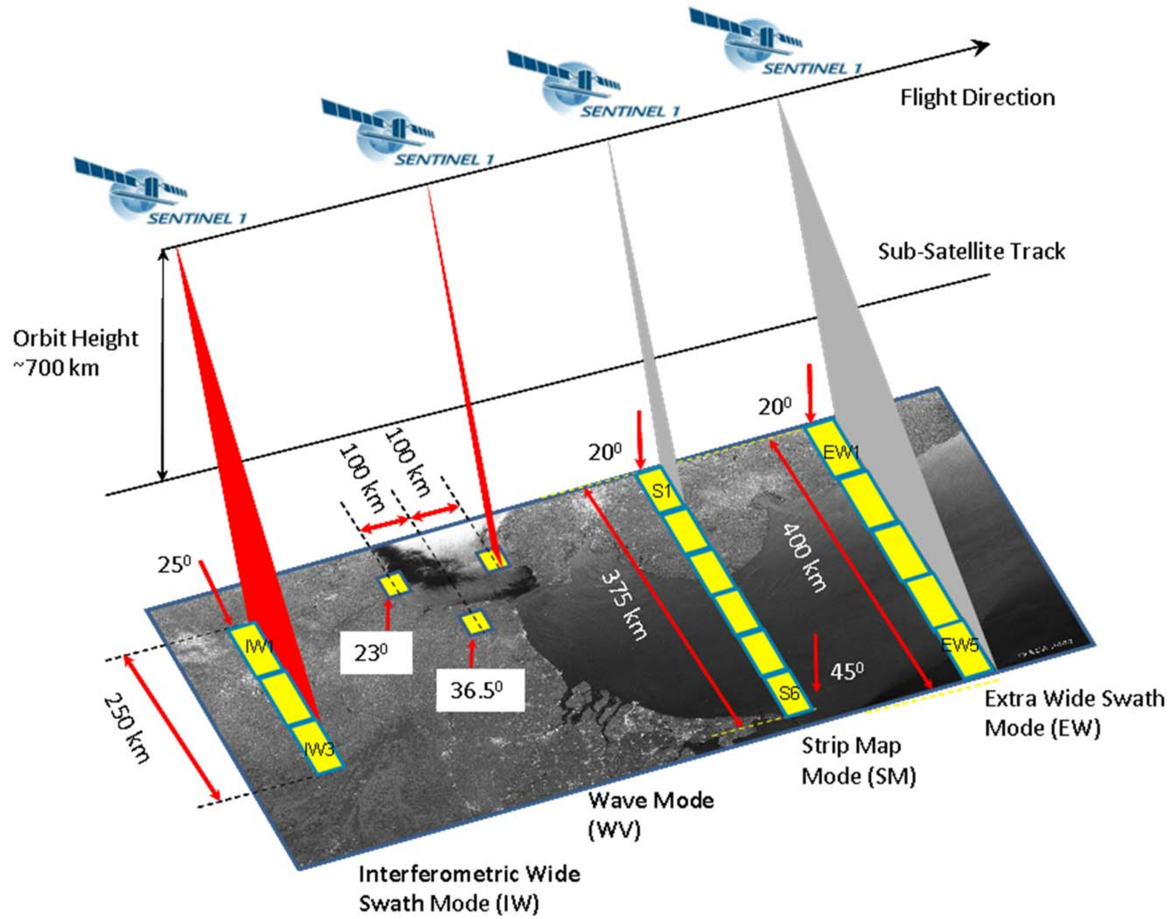
Sentinel–1 System Overview



Sentinel-1 SAR Imaging Modes (1/2)

- Instrument provides *4 exclusive SAR modes* with different resolution and coverage



- **Polarisation schemes** for IW, EW & SM:
  - ✓ single pol: HH or VV
  - ✓ dual pol: HH+HV or VV+VH
- Wave mode: HH or VV
- **SAR duty cycle per orbit**:
  - ✓ up to *25 min* in any imaging mode
  - ✓ up to *74 min* in Wave mode

Main mode of operations: *IW* satisfies most GMES user/service requirements (i.e. resolution, swath width, polarisation)

WV mode is continuously operated over open ocean

Sentinel-1 SAR Imaging Modes (2/2)

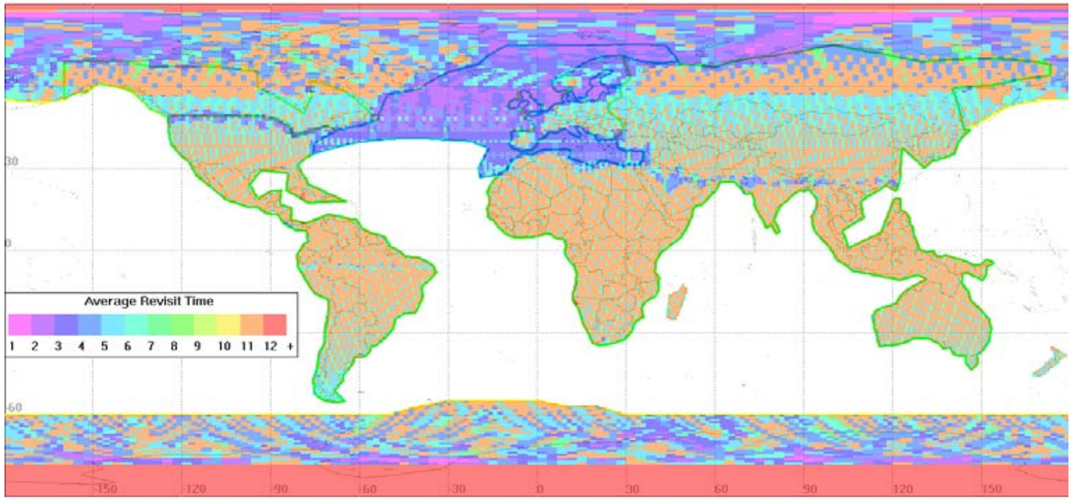
Mode	Incidence Angle	Single Look Resolution	Swath Width	Polarisation	Chirp bandwidth [MHz]
Interferometric Wide Swath (IW 1-3)	30-42 deg.	Range 5 m Azimuth 20 m	250 km	HH+HV or VV+VH	56.50 – 42.80
Wave mode WV1 WV2	23 deg. 36.5 deg.	Range 5 m Azimuth 5 m	20 x 20 km Vignettes at 100 km intervals	HH or VV	74.5 48.2
Strip Map S1-S6	20-43 deg.	Range 5 m Azimuth 5 m	80 km	HH+HV or VV+VH	87.60 – 42.20
Extra Wide Swath (EW 1-5)	20-44 deg.	Range 20 m Azimuth 40 m	400 km	HH+HV or VV+VH	22.20 – 10.40

Image Quality Parameters for all Modes (worst case)

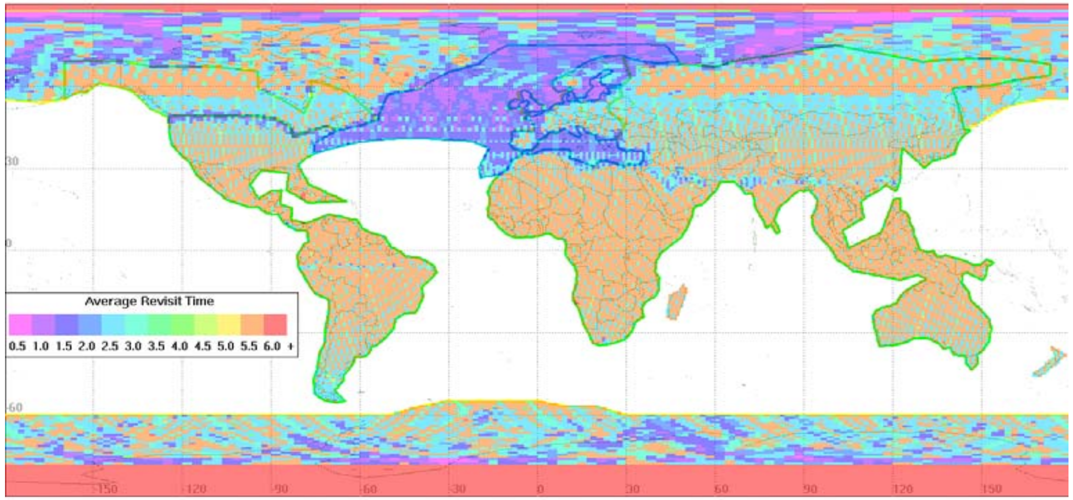
Radiometric Accuracy (3σ)	**1 dB**
Noise Equivalent Sigma Zero	**-22 dB**
Point/Distributed Target Ambiguity Ratio	**-25/ -22 dB**
Phase Error over 10 min	**5 deg**

Sentinel-1 Reference Scenario Coverage

Average Revisit Time S-1A Satellite



Average Revisit Time with S-1A + S-1B Satellites



	S-1A Satellite					S-1A + S-1B Satellites				
Complete global coverage	**After 12 days**					**After 6 days**				
	Ice	MTZ	Europe	Canada	Rest of Land	Ice	MTZ	Europe	Canada	Rest of Land
Number of acquisitions (range from - to)	**1-9**	**1-6**	**1-5**	**1-4**	**1-6**	**2-18**	**2-12**	**2-10**	**2-8**	**2-12**
Average Revisit Time [day]	**8,0**	**3,7**	**5,5**	**8,2**	**9,9**	**5,0**	**1,9**	**2,7**	**4,1**	**4,9**

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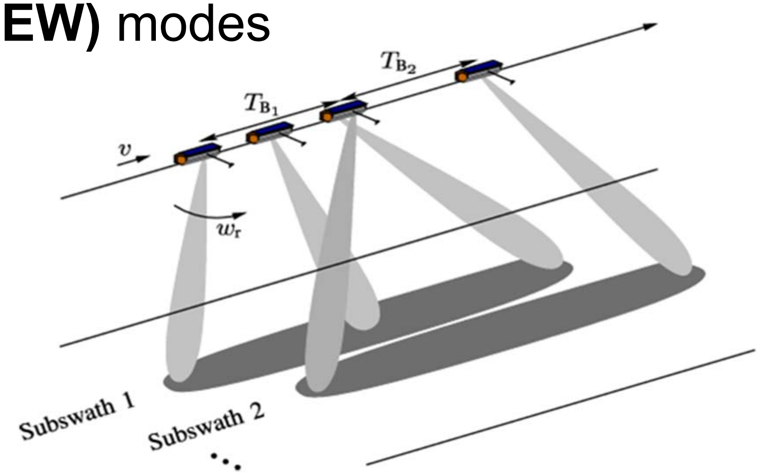
Sentinel-1 SAR TOPS Mode

TOPS (Terrain Observation with Progressive Scans in azimuth) for Sentinel-1 ***Interferometric Wide Swath (IW)*** and ***Extended Wide Swath*** **(EW)** modes

- *ScanSAR-type* beam steering in *elevation* to provide large swath width (IW: 250 and EW: 400km)
- Antenna beam is steered along *azimuth* from *aft* to the *fore* at a constant rate



✓ All targets are observed by the entire azimuth antenna pattern *eliminating scalloping effect* in ScanSAR imagery

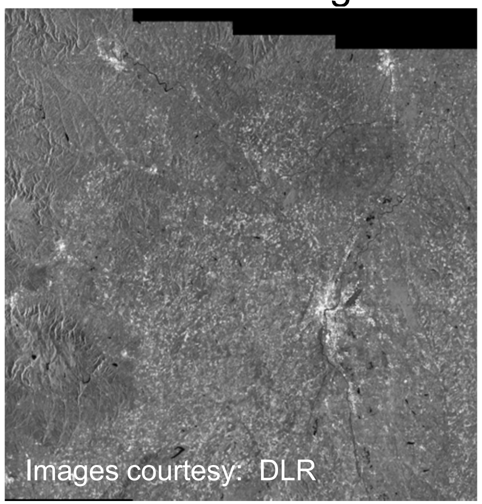
✓ *Constant SNR* and *azimuth ambiguities*

✓ Reduction of azimuth resolution (decrease in dwell time)

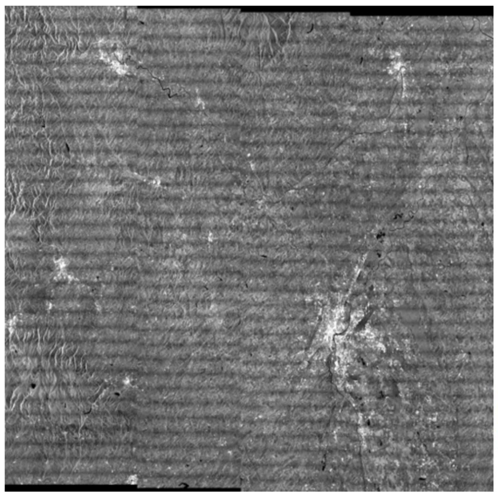
- S-1 TOPS mode parameters:
  $\pm 0.8^{\circ}$ azimuth scanning at PRI rate with step size of 1.6 mdeg

- TOPS was first demonstrated by DLR with TerraSAR-X through ESA funded study

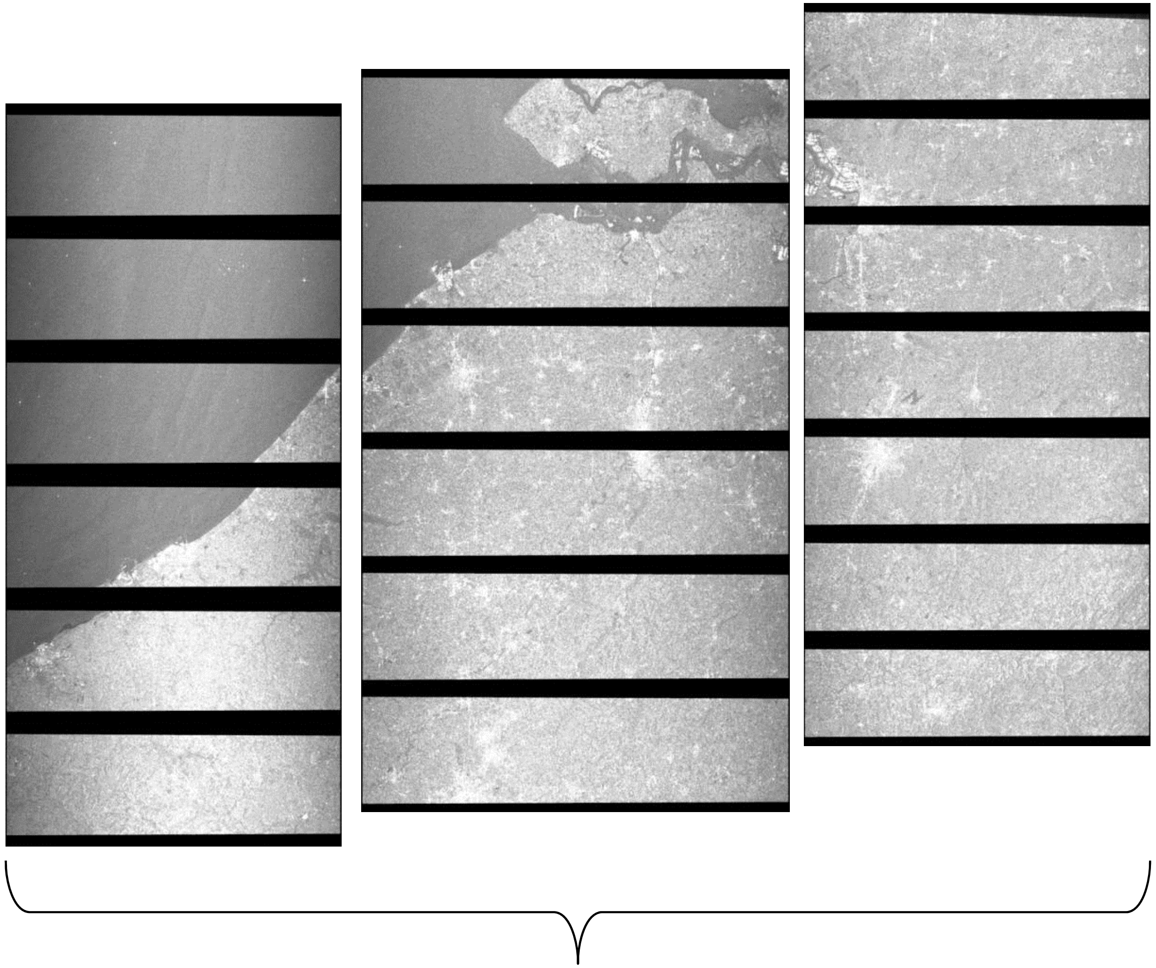
TSX-TOPS image



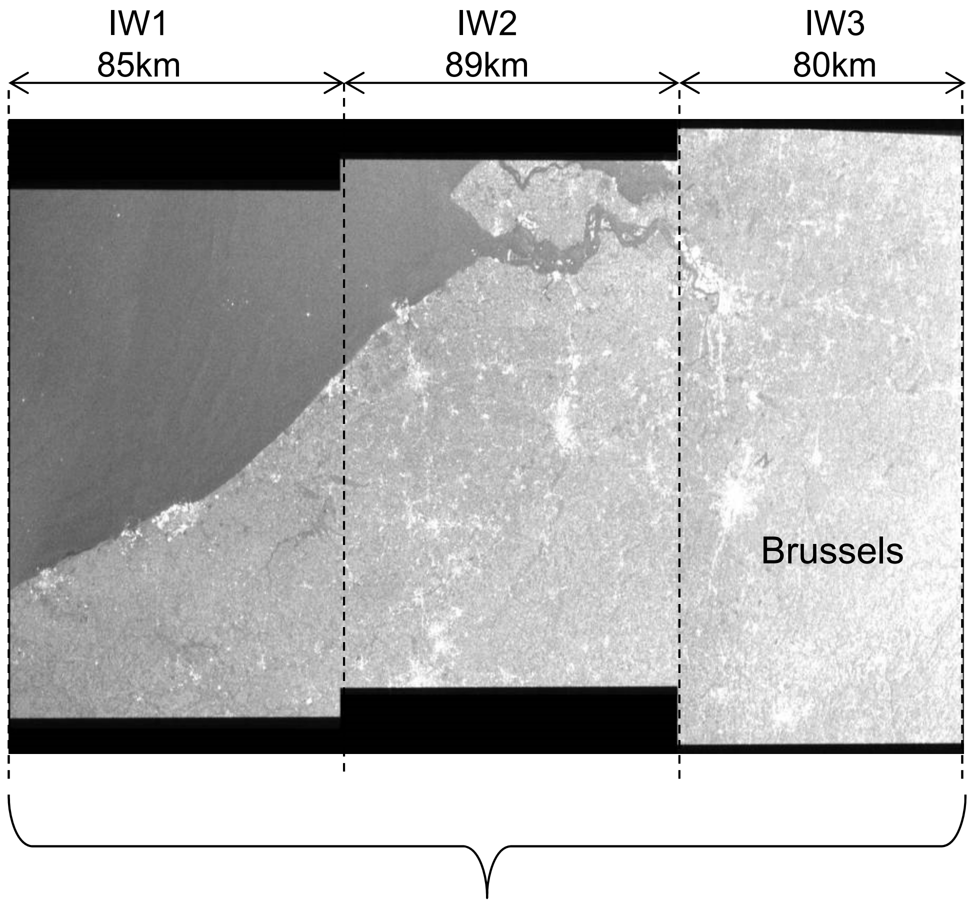
TSX-ScanSAR image



Sentinel-1 IW Mode Image Data Block



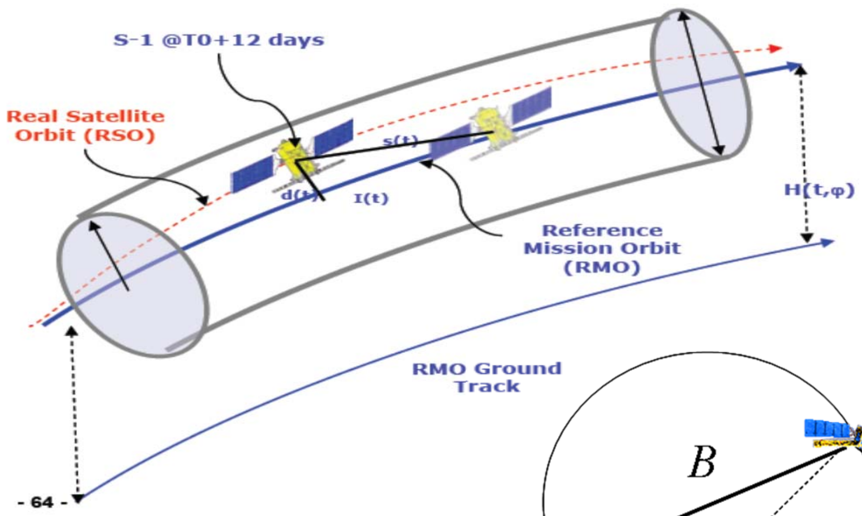
IW SLC: collection of focused burst per sub-swath

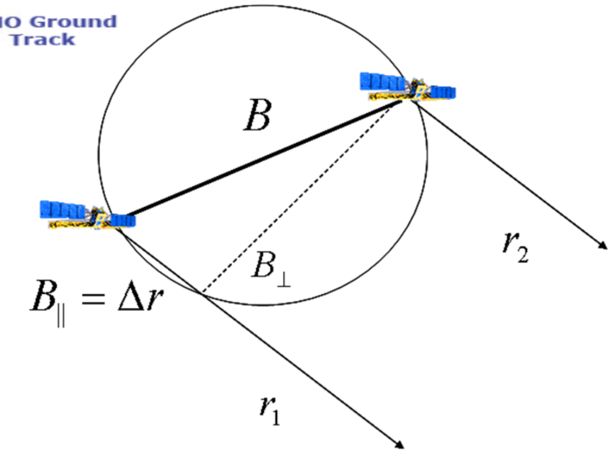


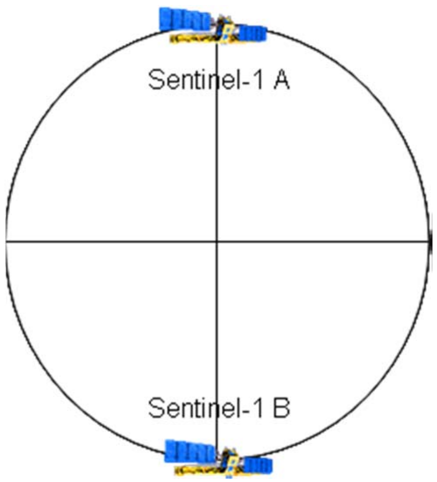
IW GRD : debursted and sub-swath merged

Sentinel-1 Orbital Tube and InSAR Baseline

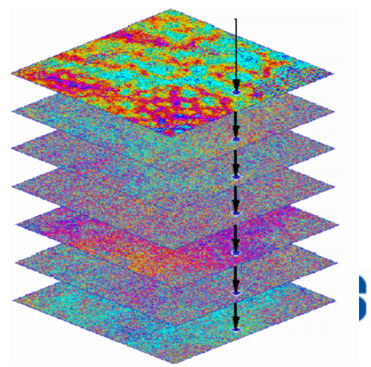
- Satellite will be kept within an *Orbital Tube* around a Reference Mission Orbit (RMO)
- *Orbital Tube* radius (statistical) with 50m (rms)
- Orbit control is achieved by applying *across-track dead-band* control at the most *Northern point* and *Ascending Note* crossing





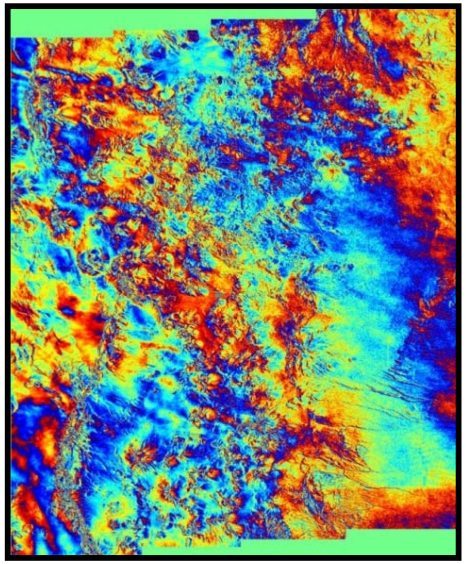


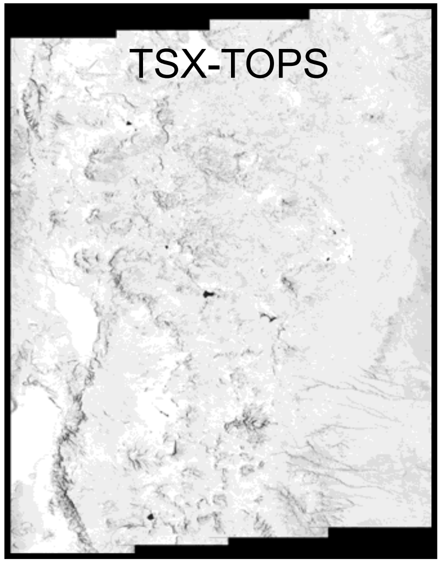
- Sentinel-1 A & B will fly in the same orbital plane with *180 deg.* phased in orbit
- *12-day repeat* orbit cycle for each satellite
- Formation of SAR interferometry (InSAR) data pairs having time intervals of *6-days*

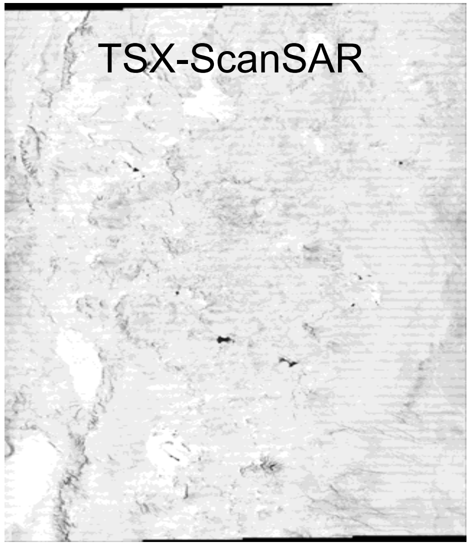


Sentinel-1 TOPS Interferometry Capabilities (1/2)

• S-1 TOPS InSAR study based on TerraSAR-X TOPS data, e.g. acquired over Atacama desert (Chile) having 11-day repeat pass interval







• Coherence loss in ScanSAR due to SNR degradation at burst edges (after azimuth pattern correction)

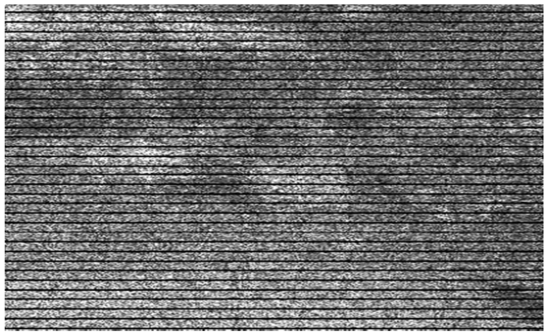
Image courtesy: P. Prats, DLR

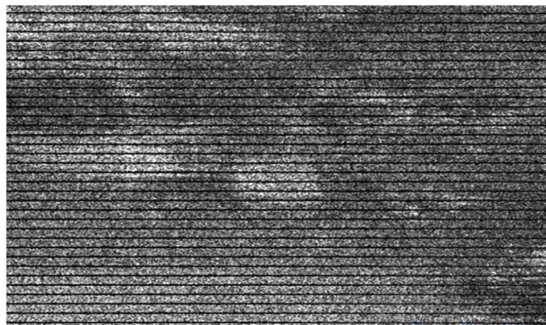
• TOPS interferogram generation requires burst synchronization of repeat-pass datatakes

• TOPS burst duration for:

- ✓ EW: 0.54 s (worst case)
- ✓ IW : 0.82 s (worst case)

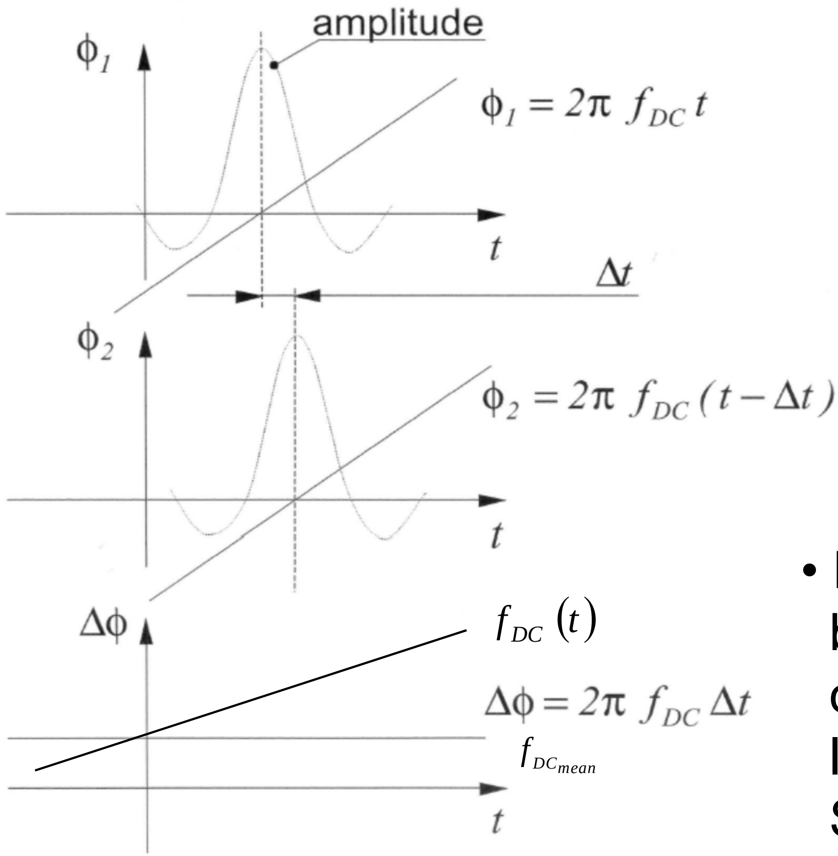
• S-1 requirement for Burst Synchronization: ≤ 5ms

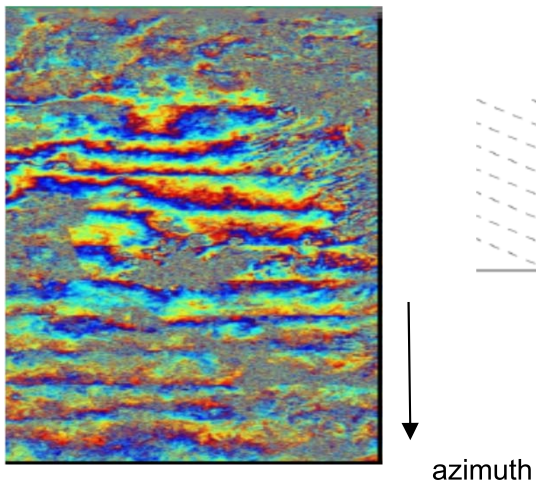




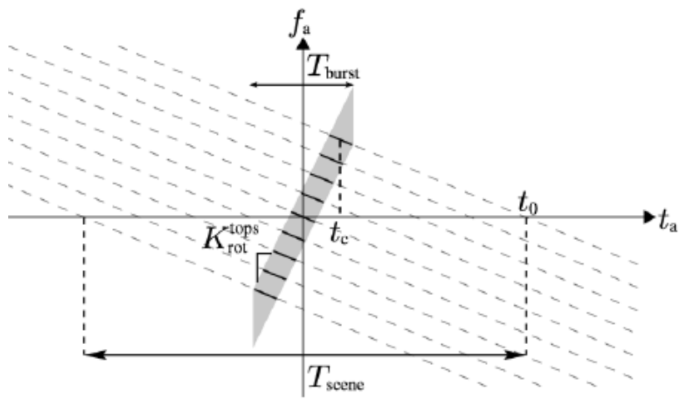
Sentinel-1 TOPS InSAR Capabilities

- Antenna squint in *Stripmap* mode images induces linear phase ramps in the *Impulse Response Function (IRF)* ⇒ small co-registration error causes InSAR phase offset
- *TOPS mode*: Azimuth phase ramp (azimuth fringes) is introduced due to small co-registration errors along with Doppler centroid variations (5 kHz) due to azimuth scanning





$$\phi_{az_{err}} = 2\pi\ f_{DC}\ \Delta t$$



- Requires azimuth co-registration to be better than *0.0027 samples* in order to obtain phase error less than 10° , e.g. using Spectral Diversity approach

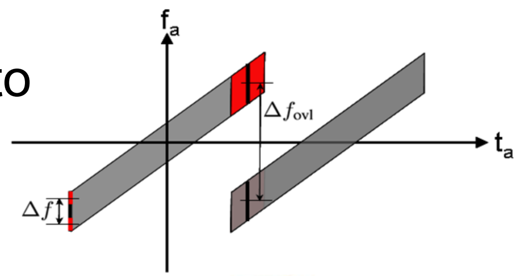
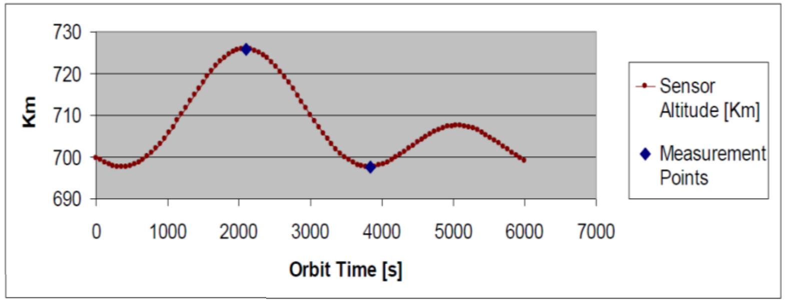


Image courtesy: P. Prats, DLR

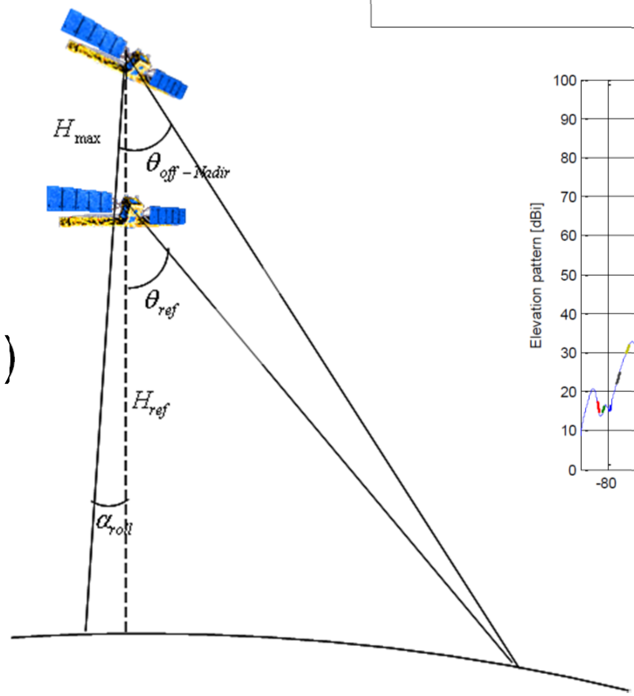
Sentinel-1 Attitude Steering Modes

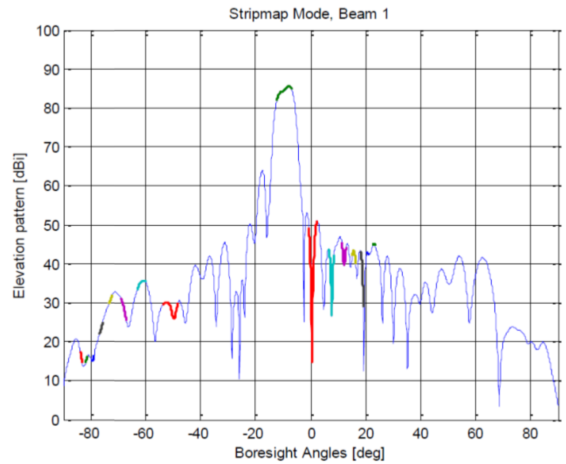
Roll-steering mode

- Sensor altitude changes around the orbit
- Introduction of additional satellite *roll angle* depending on latitude to maintain a quasi "*constant*" *slant range*



at H_{min} = 697.6 km $\Rightarrow \theta_{off\text{-}Nadir}$ = 30.25°
at H_{max} = 725.8 km $\Rightarrow \theta_{off\text{-}Nadir}$ = 28.65°

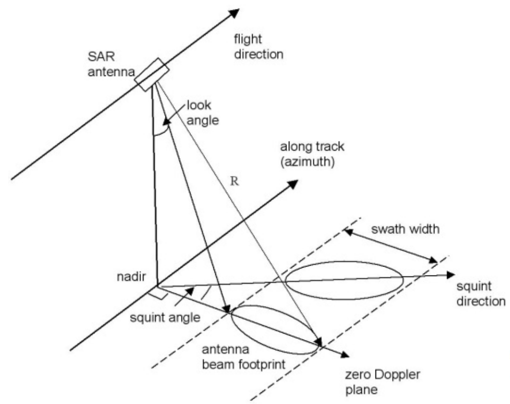




Advantages:

- *Single PRF* round orbit per swath or subswath (except for S5 (S5-N and S5-S)
- Fixed set of constant *Elevation antenna beam patterns*

Total zero-Doppler steering mode

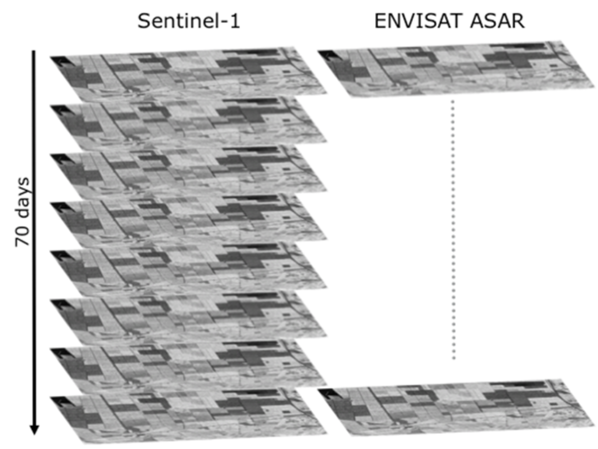


- Yaw and pitch adjustments around the orbit to account for Earth rotation effect
- Provides Doppler centroid at about 0 Hz

Sentinel-1 Observation Strategy

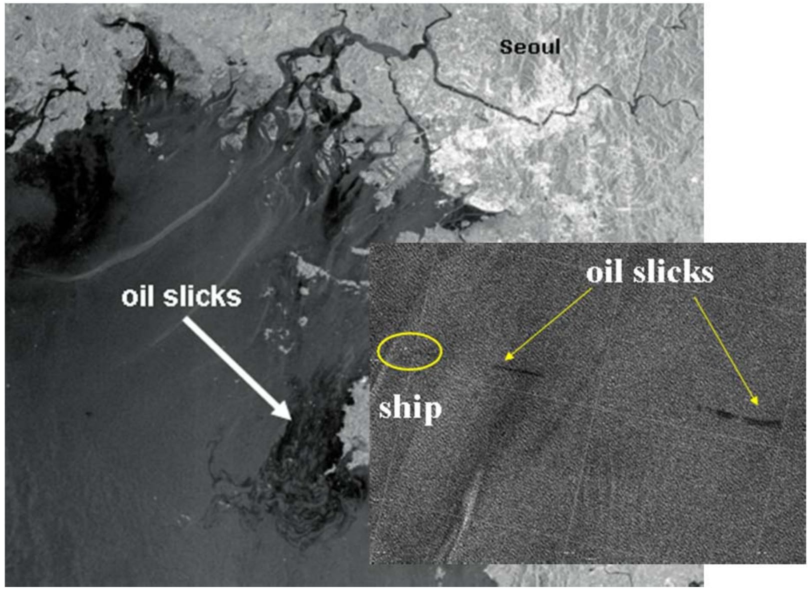
SAR mode selection is based on optimum use of SAR duty cycle (25 min/orbit)

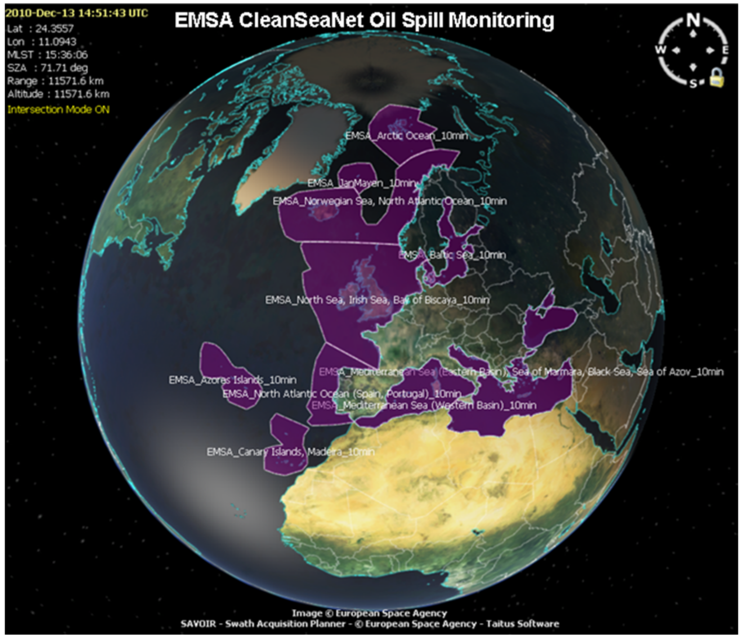
✓ satisfies most GMES user/service requirements (i.e. resolution, swath width, polarisation)
✓ increases revisit time and coverage
✓ enables build-up of long time series of data
✓ high level of automation for mission planning
✓ pre-defined operations to the maximum extent possible
✓ minimize potential conflicts during operations, considering constraints (e.g. mode transition time, X-band switches)

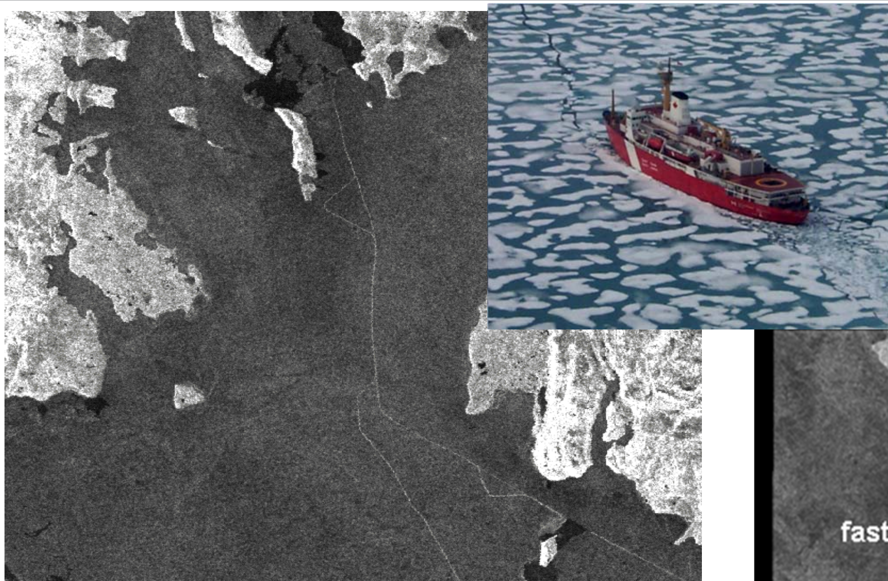


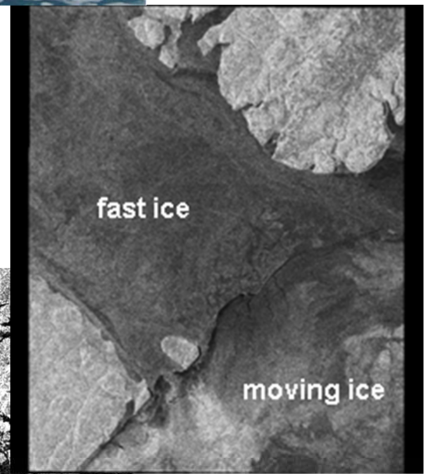
- Over ***land*** and ***maritime shipping routes***: ***IW*** is pre-defined mode
- Over ***Polar areas*** (i.e. sea ice): ***IW* (or *EW)*** is pre-defined mode
- ***Emergency* observation** requests may alter the pre-defined observation scenario: use of the ***SM*** mode
- Over ***open ocean***: ***WV*** mode is continuously operated

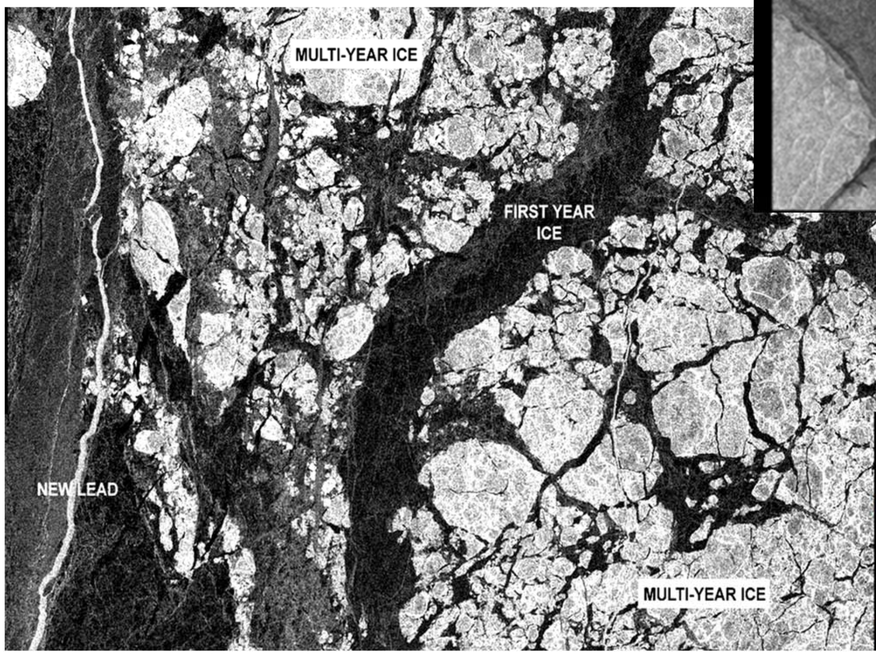
Sentinel-1 Marine Applications: Oil Spill & Sea-Ice Monitoring











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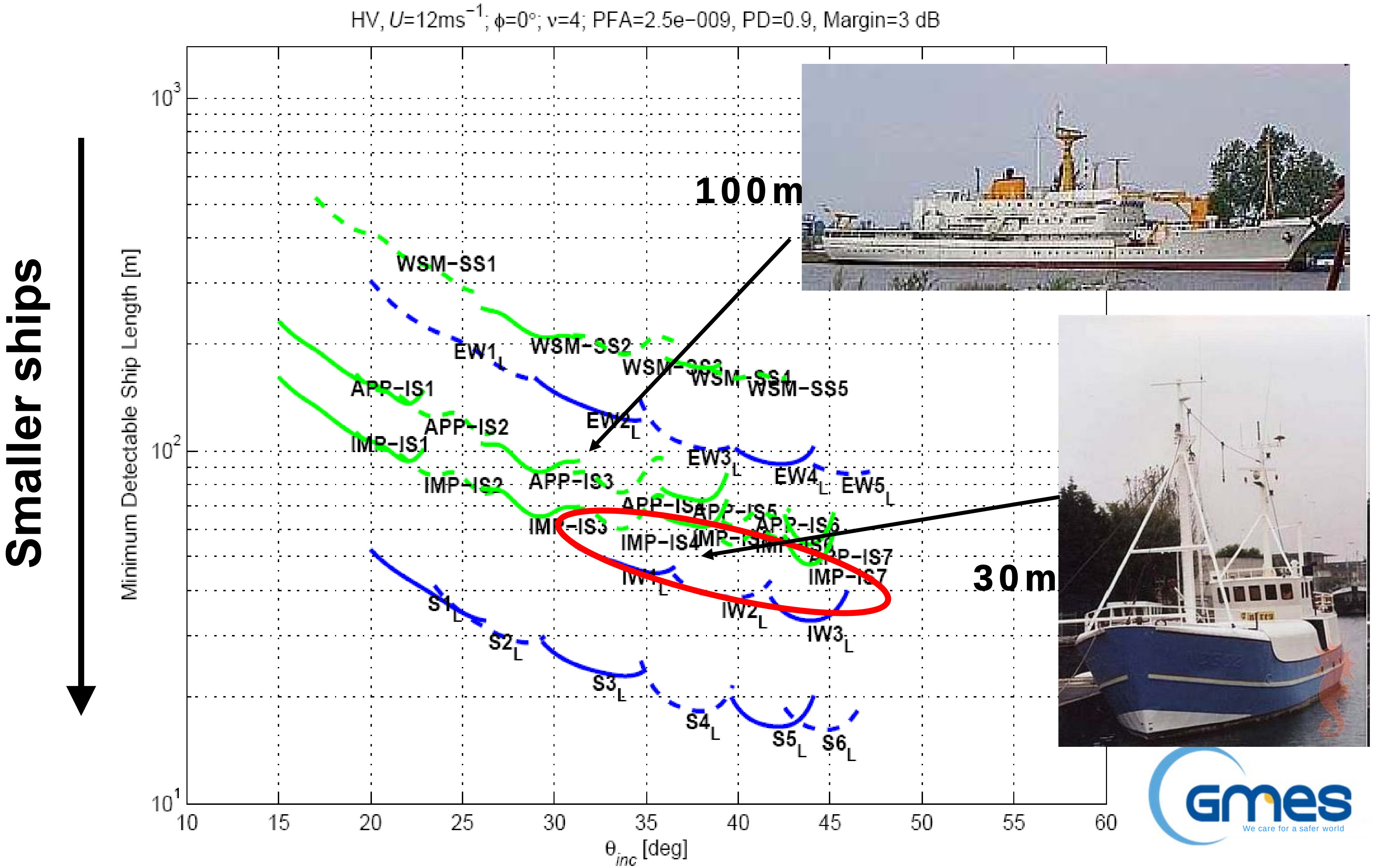
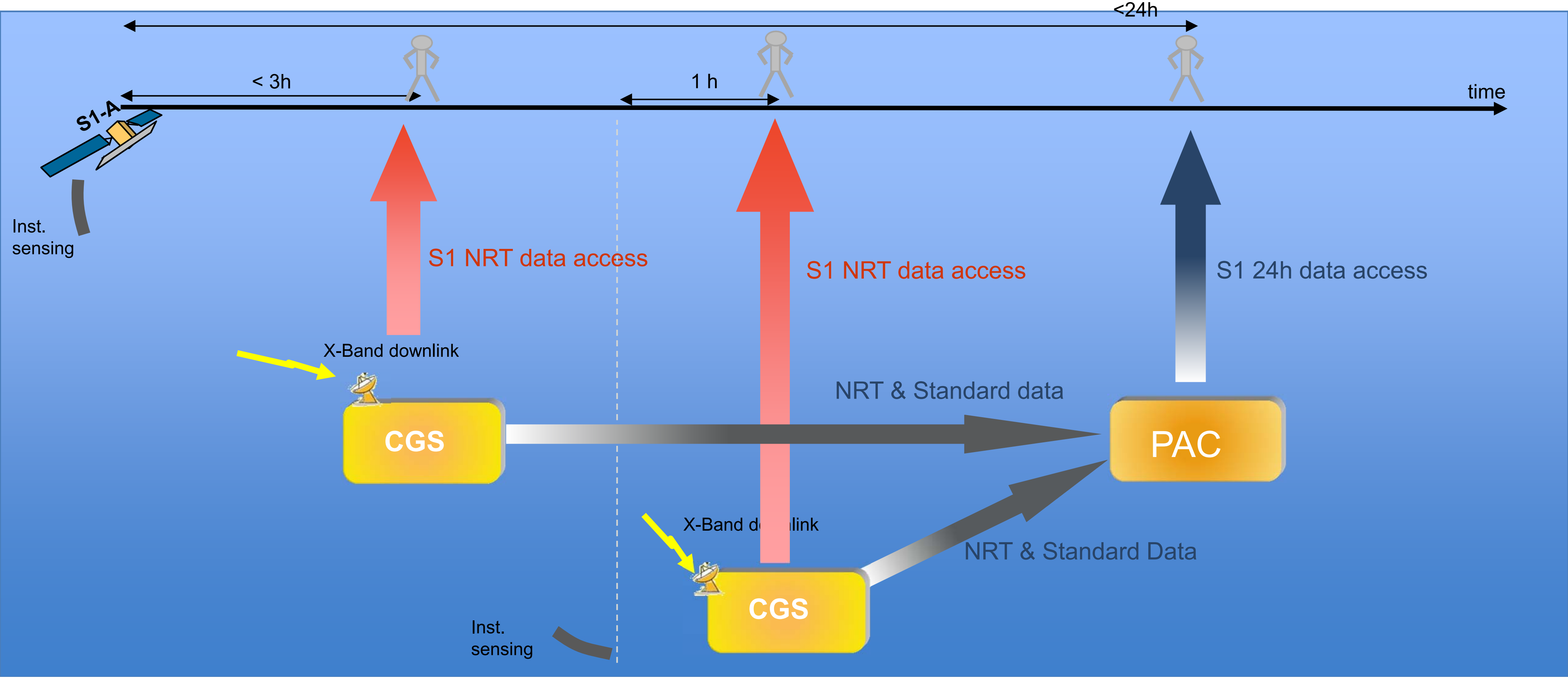
Sentinel-1 Mission Performance Analysis
Example: Ship Detection



Sentinel-1
Data Access Timeliness

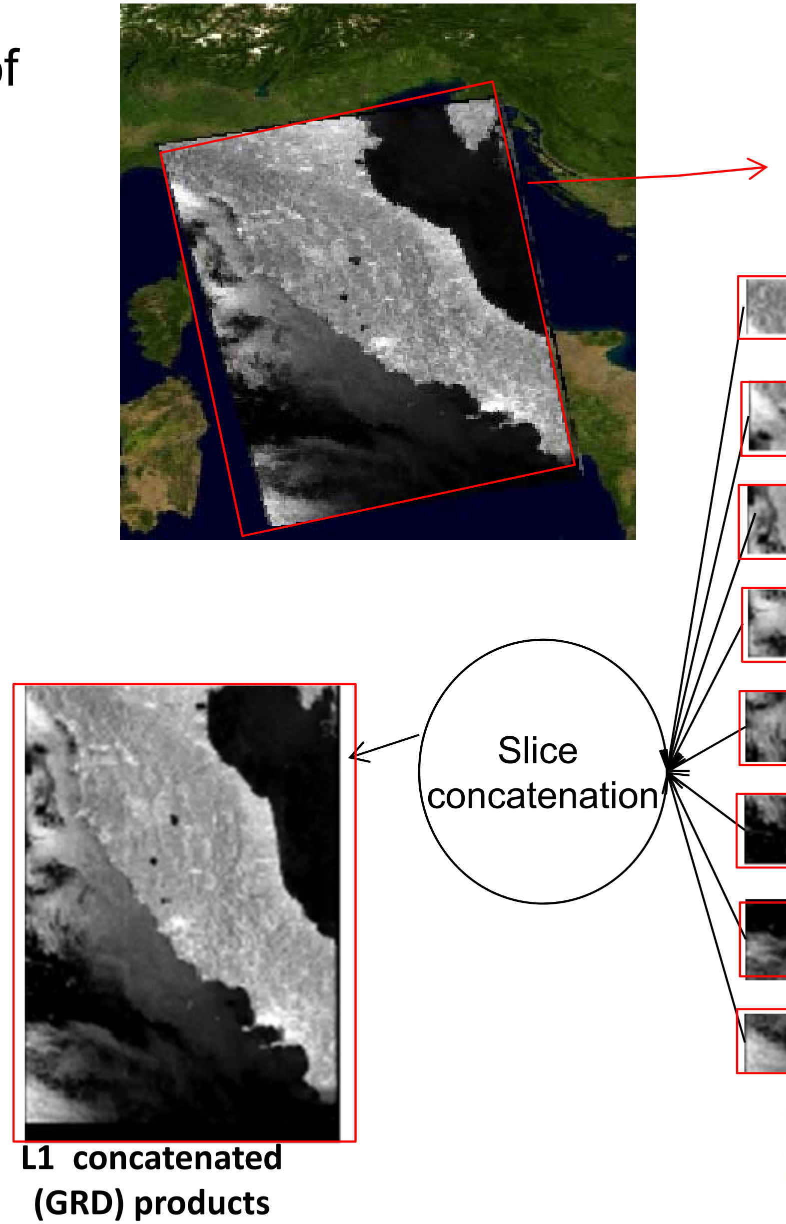
Data access to systematically generated products is provided according to the following timeliness:

- Standard timeliness: within 24h from sensing for all systematic products
- NRT timeliness:
  - < 3h from sensing (within 1h from downlink)
  - < 1h from sensing for data acquired in direct downlink



Sentinel-1 SAR Product Slicing

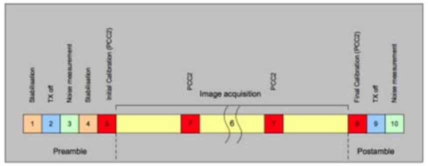
- Level-1 products are segmented in “slices” of defined length along track, optimised per mode and product type
- Level-1 slices cover a sub-set of the data take in along-track direction and the complete datatake area in the across-track direction
- Slices are in the nominal product type projection (slant-range for SLC, ground range for GRD)
- Slices are stand-alone products and can be handled separately in terms of archiving and dissemination
- Slices are seamlessly “concatenable” into a continuous product covering the complete datatake

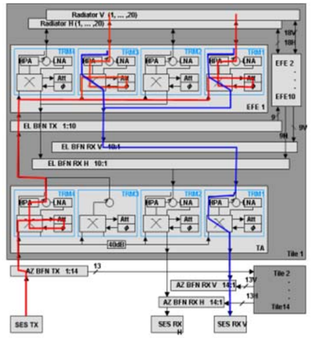


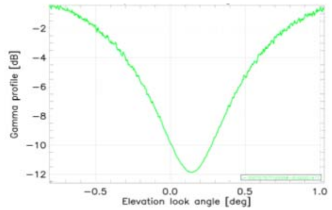
Sentinel-1 In-Orbit Commissioning Phase Activities

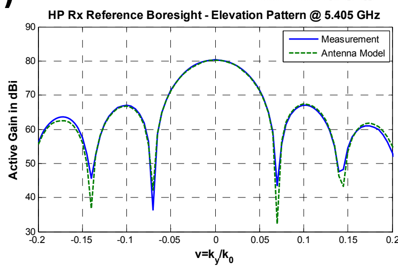
Spacecraft and end-to-end SAR System performance verification and calibration

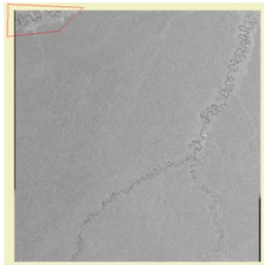
- Check-out of spacecraft and ground segment
- In-orbit verification of instrument performance and calibration:
  - ✓ Internal instrument calibration using network of calibration pulses to monitor drift in Tx & Rx signal paths, and the entire antenna system (T/R modules) using pulse coded techniques (PCC)
  - ✓ Antenna pointing calibration (< 0.01°)
  - ✓ Antenna model verification (0.2 dB (3σ) for absolute 2-way gain)
  - ✓ Absolute radiometric calibration (< 1 dB (3σ))
  - ✓ Radiometric stability (<0.5 dB (3σ))
  - ✓ Geometric calibration (pixel localization: 2.5m (3σ))
  - ✓ Polarimetric calibration
  - ✓ Interferometric verification
- Level 0 and Level 1b SAR product verification (i.e. wrt SAR instrument performance)

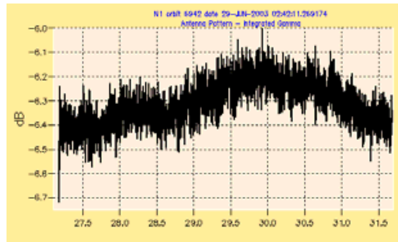






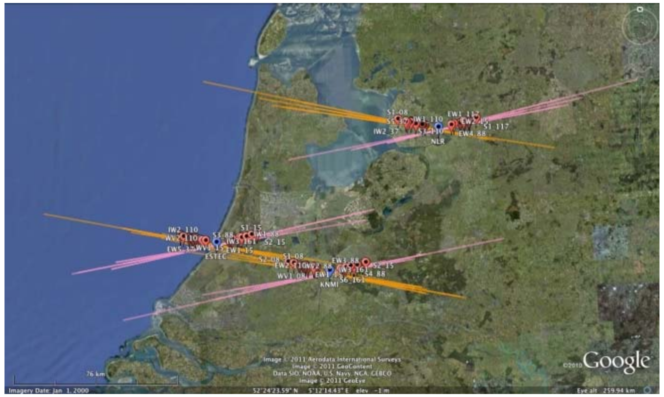






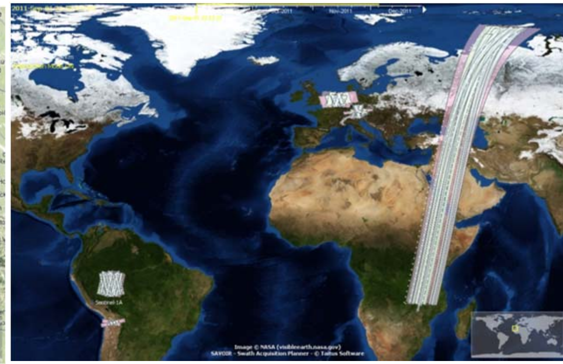
To be completed within *3 months* (Challenge!)

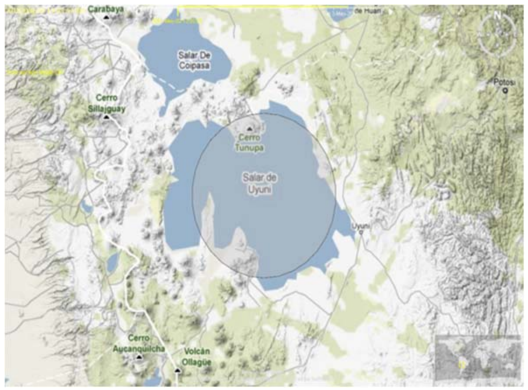
Sentinel-1 Commissioning Phase Calibration Sites



Current timeline consists of data acquisitions over:

- Transponder sites (3) in NL
- Lake area in NL for NESZ measurement
- Rainforest for antenna model verification and radiometric calibration
- Long data takes (25 minutes) for all modes
- DLR test site for complementary calibration activities (Corner reflectors and transponders)
- InSAR verification sites (systematic generation repeat-pass interferograms (e.g. Lake Uyuni, Atacama desert, Death Valley)
- Measurement of InSAR phase stability (closed loop phase) over Corner Reflector site at DLR





GMES We care for a safer world

Sentinel Data Policy

ESA Member States have adopted a *FREE* and *OPEN* data policy

Anybody can access Sentinel data; no difference is made between public, commercial and scientific use

→ **open access**

Sentinel data will be made available to the users via a 'generic' online access mode

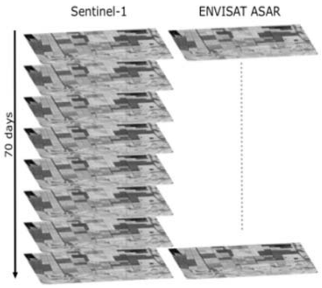
→ **free of charge**

Data Policy still needs approval by the European Commission

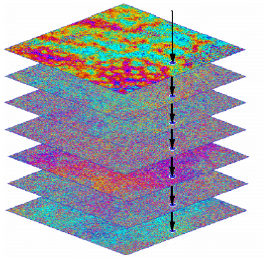
→ **security restrictions might be implemented on data distribution**

Conclusions

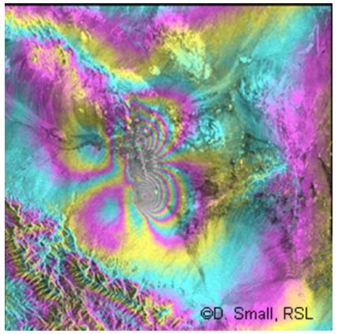
- Sentinel-1 will provide routinely and systematically SAR data for operational monitoring tasks especially for GMES Services and National services
- Using the same SAR imaging mode (instrument settings, e.g. IW) facilitates the build-up of *data time series* for long-term continuity of observations with *equidistant* and *short time intervals (interferogram stacks)*



- TOPS burst synchronization to enable TOPS InSAR



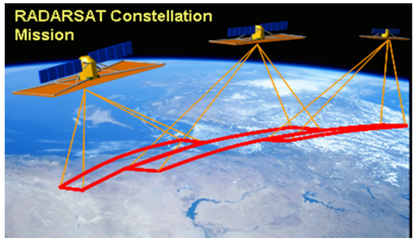
- Sentinel-1 A & B will fly in the same orbital plane with *180 deg.* phased in orbit, each with*12-day repeat* orbit cycle
- Formation of InSAR data pairs having time intervals of *6-days*
- Small orbital tube with radius of 50m (rms) provides small InSAR baselines



⇒ **Coherent Change Detection Monitoring applications**

Monitoring of geophysical phenomena related to surface displacements and/or changes in scattering properties having different time scales (mm/year – m/day)

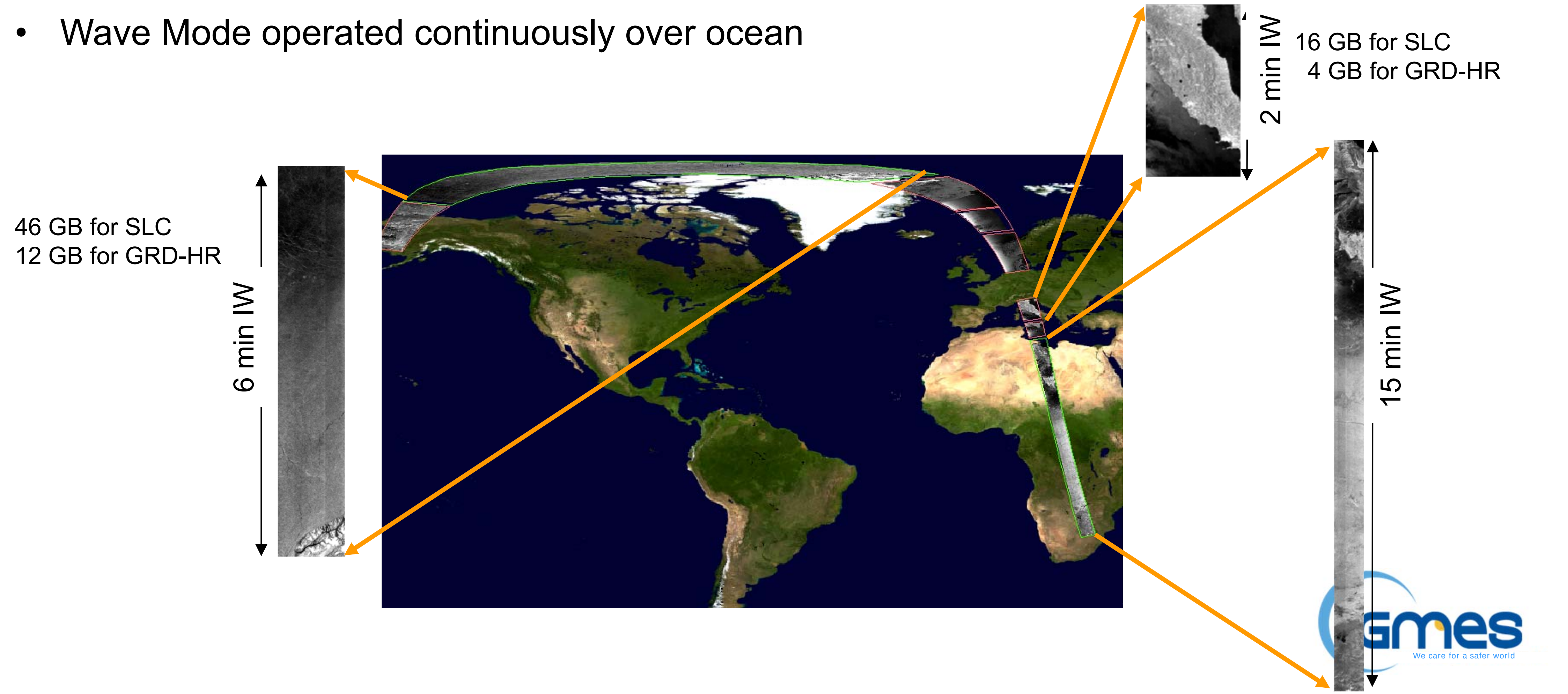
- Collaboration with CSA's RADARSAT Constellation Mission (RCM) to facilitate *multi-satellite SAR monitoring* ⇒ requires harmonization of data acquisition strategies and interfaces



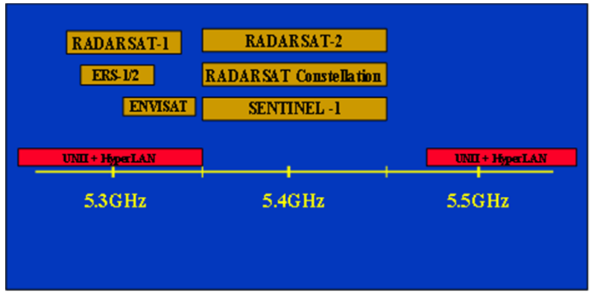
Backup Slides

Sentinel-1 Data Acquisition Scenario

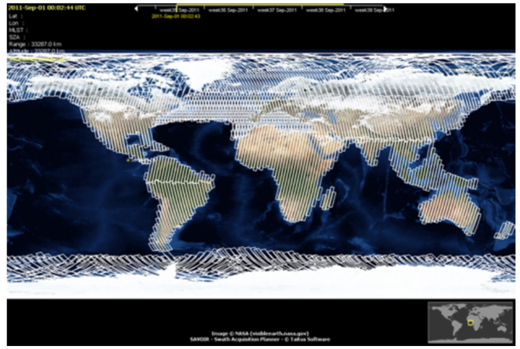
- Systematic data acquisition in main high rate IW/EW modes of max 25 min per orbit will generate large data acquisition segments
- Leads to about 2.4 TB/per day of compressed raw data for Sentinel-1 A & B
- Wave Mode operated continuously over ocean



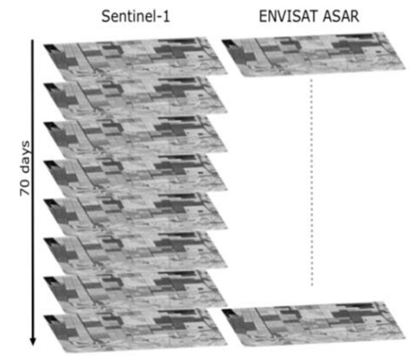
Sentinel-1 Mission Objectives and Requirements



- Provide C-band SAR data continuity (at 5.405 GHz)
- Data quality similar or better than ERS/ENVISAT
  (e.g. equalized performance across the swath)
- Complete global coverage within a single repeat orbit cycle (175 orbits in 12 days) and systematic revisit (greatly improved as compared to ENVISAT)



- Capability for repeat-pass SAR interferometry (i.e.TOPS InSAR)
- Systematic data acquisition to enable build-up of long observation time series
- High system availability (i.e. SAR duty cycle)



- Conflict-free operations w.r.t. SAR mode selection for data acquisition (swath width and polarization)
- On-board data latency (i.e. downlink) requires:
  - max 200 min (2 orbits)
  - One orbit for support of near real time (3h) applications
  - Simultaneous SAR acquisition and data downlink for real time applications