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**
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)
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
Sentinel–1 System Overview
We care for a safer world

• 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

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

## 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

<table>
<thead>
<tr>
<th>Complete global coverage</th>
<th>S-1A Satellite</th>
<th>S-1A + S-1B Satellites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>After 12 days</strong></td>
<td><strong>After 6 days</strong></td>
</tr>
<tr>
<td></td>
<td>Ice</td>
<td>MTZ</td>
</tr>
<tr>
<td>Number of acquisitions (range from - to)</td>
<td>1-9</td>
<td>1-6</td>
</tr>
<tr>
<td>Average Revisit Time [day]</td>
<td>8,0</td>
<td>3,7</td>
</tr>
</tbody>
</table>
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:
  ±0.8° 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

Images courtesy: DLR
Sentinel-1 IW Mode Image Data Block

IW SLC: collection of focused burst per sub-swath

IW GRD: deburstsed and sub-swath merged
• 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
We care for a safer world

Sentinel-1 TOPS Interferometry Capabilities

• 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)

• 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: \( \leq 5\)ms

Image courtesy: P. Prats, DLR
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
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 \( H_{\text{min}} = 697.6 \) km \( \Rightarrow \theta_{\text{off-Nadir}} = 30.25^\circ \)

at \( H_{\text{max}} = 725.8 \) km \( \Rightarrow \theta_{\text{off-Nadir}} = 28.65^\circ \)

**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
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
Sentinel-1 Mission Performance Analysis
Example: Ship Detection

HV, \( U = 12 \text{ms}^{-1} \); \( \phi = 0^\circ \); \( \gamma = 4 \); PFA = 2.5e-009, PD = 0.9, Margin = 3 dB
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
• 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!)
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
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).
- 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.
We care for a safer world

Sentinel-1 Data Acquisition Scenario

- Systematic data acquisition in main high rate LW/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

- 16 GB for SLC
- 4 GB for GRD-HR
- 46 GB for SLC
- 12 GB for GRD-HR

46 GB for SLC
12 GB for GRD-HR

2 min LW
15 min LW
6 min LW
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