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GMES Sentinel-1 Mission and System Performance

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European Space Agency
Sentinel-1 Mission Objectives

- Component of EU & ESA’s Global Monitoring for Environment and Security Programme (GMES)
- GMES Core Services:
  - GMES Marine Services
  - GMES Land Monitoring Services
  - GMES Emergency Response Services
  - GMES Atmospheric Monitoring Services
  - GMES Security Services
- GMES Downstream services
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– Thales Alenia Space Italia as Prime Contractor
– EADS Astrium GmbH as Instrument Responsible
– First (S-1A) satellite launch end of 2012, S-1B 18 months later

<table>
<thead>
<tr>
<th>Year</th>
<th>Sentinel-1A</th>
<th>Sentinel-1B</th>
<th>Sentinel-1C</th>
<th>Sentinel-1 Follow-on</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td></td>
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<td></td>
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<td>2012</td>
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<td>2028</td>
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<tr>
<td>2029</td>
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<tr>
<td>2030</td>
<td></td>
<td></td>
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</tbody>
</table>
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**Sentinel-1 System**

**Space Segment**
- A constellation of two satellites
- nominal lifetime in orbit of 7 years (consumables for 12)
- Global coverage
- Near-Polar Sun-Synchronous dusk-dawn orbit @ 693km.
- Repeat Cycle 12 days
- A second satellite in the same orbit but with a different Mean Anomaly
- C-Band Synthetic Aperture Radar Payload

**Ground Segment**
- Mission operations for a system of satellites over a period of 20 years
- S-Band station (Kiruna proposed), with a back-up for S/C contingencies
- Downlink currently assumes three X-Band receiving stations
Sentinel-1 System

- Sentinel-1 has two main operational modes, the Interferometric Wide Swath mode and the Wave mode, that:
  - satisfies most currently known service requirements
  - avoids conflicts and preserves revisit performance
  - provides robustness and reliability of service
  - simplifies mission planning & decreases operational costs
  - satisfies also tomorrow’s requests by building up a consistent long-term archive

- However
  - Mutually exclusive modes are provided for continuity reasons (w.r.t. ERS & Envisat) and for accommodation of emerging user requirements
  - Two other mutually exclusive dual polarisation modes are provided
# Sentinel-1 Performance Requirements

<table>
<thead>
<tr>
<th>Mode</th>
<th>Access Angle</th>
<th>Single Look Resolution</th>
<th>Swath Width</th>
<th>Polarisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interferometric Wide Swath</td>
<td>&gt; 25 deg.</td>
<td>Range 5 m Azimuth 20 m</td>
<td>&gt; 250 km</td>
<td>HH+HV or VV+VH</td>
</tr>
<tr>
<td>Wave mode</td>
<td>23 deg. and 36.5 deg.</td>
<td>Range 5 m Azimuth 5 m</td>
<td>&gt; 20 x 20 km Vignettes at 100 km intervals</td>
<td>HH or VV</td>
</tr>
<tr>
<td>Strip Map</td>
<td>20-45 deg.</td>
<td>Range 5 m Azimuth 5 m</td>
<td>&gt; 80 km</td>
<td>HH+HV or VV+VH</td>
</tr>
<tr>
<td>Extra Wide Swath</td>
<td>&gt; 20 deg.</td>
<td>Range 20 m Azimuth 40 m</td>
<td>&gt; 400 km</td>
<td>HH+HV or VV+VH</td>
</tr>
</tbody>
</table>

**For All Modes**

<table>
<thead>
<tr>
<th>Metric</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiometric accuracy (3 (\sigma))</td>
<td>1 dB</td>
</tr>
<tr>
<td>Noise Equivalent Sigma Zero</td>
<td>-22 dB</td>
</tr>
<tr>
<td>Point Target Ambiguity Ratio</td>
<td>-25 dB</td>
</tr>
<tr>
<td>Distributed Target Ambiguity Ratio</td>
<td>-22 dB</td>
</tr>
</tbody>
</table>
Sentinel-1 SAR Modes

Orbit Height
~700 km

Flight Direction

Sub-Satellite Track

Wave Mode

Interferometric Wide Swath Mode

Extra Wide Swath Mode

Strip Map Mode

Sentinel-1 SAR Modes

Orbit Height
~700 km

Flight Direction

Sub-Satellite Track

Wave Mode

Interferometric Wide Swath Mode

Extra Wide Swath Mode

Strip Map Mode
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Instrument Accommodation on Spacecraft

SAR Antenna Subsystem (SAS)
Aperture : 12.3 m x 0.84 m,
14 Tiles each with 20 dual polarized resonant waveguide arrays (5 SAS Panels)

SAR Electronic Subsystem (SES) on S/C SES Panel
S-1 Observation scenario

• Sentinel-1 instrument operations:
  - Imaging modes (SM/IW/EW) are operated for max 25 min / orbit
  - WV mode is operated continuously over ocean

• Sentinel-1 systematic observation scenario results in large acquisition segments (data takes of few minutes)
LEVEL-0 PRODUCTS
Compressed, unprocessed instrument source packets, with additional annotations and auxiliary information to support the processing.

LEVEL-1 PRODUCTS
Level-1 Slant-Range Single-Look Complex Products (SLC)
Focused data in slant-range geometry, single look with phase and amplitude information.

Level-1 Ground Range Detected Geo-referenced Products (GRD)
Focused data projected to ground range using an Earth ellipsoid model, detected and multi-looked. Original satellite path direction preserved and with complete geo-reference information.

LEVEL-2 PRODUCTS
Level-2 Ocean (Wind, Wave and Currents) products (OCN)
Ocean wind field, swell wave spectra and surface currents information as derived from SAR data. L2 ocean products are available for all modes.
## S-1 SAR L1 product characteristics

<table>
<thead>
<tr>
<th>Acq. Mode</th>
<th>Product Type</th>
<th>Resolution Class</th>
<th>Resolution $^{1,2}$ [Rng x Azi] $^3$ [m]</th>
<th>Pixel Spacing $^2$ [Rng x Azi] [m]</th>
<th>No. Looks [Rng x Azi]</th>
<th>ENL $^4$</th>
</tr>
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<tbody>
<tr>
<td>SM</td>
<td>SLC</td>
<td></td>
<td>1.7 x 4.3 to 3.6 x 4.9</td>
<td>1.5 x 3.6 to 3.1 x 4.1</td>
<td>1 x 1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>GRD</td>
<td>FR</td>
<td>9 x 9</td>
<td>4 x 4</td>
<td>2 x 2</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HR</td>
<td>23 x 23</td>
<td>10 x 10</td>
<td>6 x 6</td>
<td>34.4</td>
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<tr>
<td></td>
<td></td>
<td>MR</td>
<td>84 x 84</td>
<td>40 x 40</td>
<td>22 x 22</td>
<td>464.7</td>
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<tr>
<td></td>
<td></td>
<td>BRW</td>
<td>336 x 336</td>
<td>160 x 160</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>IW</td>
<td>SLC</td>
<td></td>
<td>2.7 x 22 to 3.5 x 22</td>
<td>2.3 x 17.4 to 3 x 17.4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>GRD</td>
<td>HR</td>
<td>20 x 22</td>
<td>10 x 10</td>
<td>5 x 1</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MR</td>
<td>88 x 89</td>
<td>40 x 40</td>
<td>22 x 5</td>
<td>105.7</td>
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<td></td>
<td></td>
<td>BRW</td>
<td>1056 x 1044</td>
<td>480 x 480</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>EW</td>
<td>SLC</td>
<td></td>
<td>7.9 x 42 to 14.4 x 44</td>
<td>5.9 x 34.7 to 12.5 x 34.7</td>
<td>1 x 1</td>
<td>1</td>
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<tr>
<td></td>
<td>GRD</td>
<td>HR</td>
<td>50 x 50</td>
<td>25 x 25</td>
<td>3 x 1</td>
<td>2.9</td>
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<td></td>
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<td>MR</td>
<td>93 x 87</td>
<td>40 x 40</td>
<td>6 x 2</td>
<td>12.7</td>
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<td></td>
<td></td>
<td>BRW</td>
<td>1860 x 1740</td>
<td>800 x 800</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>WV</td>
<td>SLC</td>
<td></td>
<td>2.0 x 4.8 and 3.1 x 4.8</td>
<td>1.7 x 4.1 and 2.7 x 4.1</td>
<td>1 x 1</td>
<td>1</td>
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<tr>
<td></td>
<td>GRD</td>
<td>MR</td>
<td>52 x 51</td>
<td>25 x 25</td>
<td>13 x 13</td>
<td>139.7</td>
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</table>
For Sentinel-1, continuation of ENVISAT ASAR, users expect systematic access to long product stripes (e.g. similar to ASAR MR WSM or IMM products today systematically disseminated).

Product size for L1 Image Modes would be hardly manageable.

Level-1 Image Modes products are segmented in “slices” of defined length along track, optimised per mode and product type.

<table>
<thead>
<tr>
<th>Data volume in GB</th>
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<tr>
<td>segment length [min]</td>
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<td>SLC</td>
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<tr>
<td>Dual Pol</td>
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<tr>
<td>GRD HR</td>
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<tr>
<td>Dual Pol</td>
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<td>6</td>
</tr>
<tr>
<td>GRD HR</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
S-1 slice products

- Level-1 slices cover a sub-set of the data take in along-track direction and the complete data take area in the across track direction.

- Slices are referred to the start of each acquisition segment.

- 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 or “stripe” covering up to the complete data take.

- Slice concatenation may be performed before dissemination to deliver a concatenated stripe or after dissemination by the user.
SLC products are images in the slant range by azimuth imaging plane.

Each SLC image pixel is represented by a complex (I and Q) magnitude value and therefore contains both amplitude and phase information.

The processing for all SLC products is phase preserving and it results in a single look in each dimension using the full available TX signal bandwidth.

SLC images are geo-referenced using orbit and attitude data from the satellite and provided in zero Doppler geometry.

SM SLC Products contain one image per polarisation channel (i.e. one or two images).

SM SLC images are sampled at the natural pixel spacing (i.e. pixel spacing determined in azimuth by the pulse repetition frequency (PRF) and in range by the radar range sampling).
TOPS SLC products are the legacy of ASAR Scansar complex and inherits from the main characteristics.

IW and EW SLC products contain one image per sub-swath and one per polarisation channel, for a total of:
- 3 (single polarisation) or 6 (dual polarisation) images for IW data
- 5 (single polarisation) or 10 (dual polarisation) images for EW data

Each sub-swath image consists of a series of bursts, where each burst has been processed as a separate SLC image.

The individually focused complex burst images are included, in azimuth-time order, into a single sub-swath image, with black-fill demarcation in between.

Due to the one natural azimuth look inherent in the data, the imaged ground area of adjacent bursts will only marginally overlap in azimuth - just enough to provide contiguous coverage of the ground.

The images for all bursts in all sub-swaths of an IW and EW SLC products are re-sampled to a common pixel spacing grid in range and azimuth.

Burst synchronisation is ensured for both IW and EW products.

Processing is phase preserving.
TOPS SLC products

IW1 SLC

IW1 SLC debursted

Burst cycle ≈ 2.7s

Near range azi. Overlap ~50 samples → 700m

Far range azi. Overlap ~100 samples → 1400m
Sentinel Data Policy Principles

FREE and OPEN

✓ 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

In the event security restrictions would apply to specific Sentinel data affecting data availability or timeliness, specific operational procedures would be activated
Aims

- To simulate Sentinel-1 (S1) data products (frequent observations, resolution, polarisation)
- To evaluate performance of S1 for agricultural and land cover products exploiting dense time series
- To evaluate the added value of multi-polarimetry for the same information products
- To support adaptation of methodology for land products to S1 products

Experiment details

- Barrax (Spain), Flevoland (Netherlands), Indian Head (Canada)
- Continuous acquisition of multi-temporal RADARSAT 2 imagery in fully-polarimetric fine mode (MDA)
- RapidEye optical images to support interpretation and product synergy
- Simulated S1 products and analysis
- Co-incident ground measurements
• Plot of achievable accuracy of NRT crop classification derived from the S-1 IW simulated dual-pol products through the growing season
• Colour indicates number of acquisitions used in each classification
• Good (70%) classification can be provided in mid July
• Best accuracy (80%) requires acquisitions from August/Sept
• Need to consider the AgriSAR temporal sampling when extrapolating results to Sentinel-1.
• With the selected number of classes, quad-pol data provides some improvement in classification accuracy as compared to dual-pol data
  - Exception, Field-Pea has slightly better classification with dual-pol
• Classification of the combined grass class is better with single acquisitions, dual- or quad-pol!
Conclusions

- Sentinel-1 data products maintain data quality of ESA’s previous SAR missions (ERS-1/-2, ENVISAT ASAR)
  - Continuity in performance for geophysical products secured
- In response to user needs substantial improvements are expected in
  - Revisit frequency
  - Coverage
  - Timeliness and reliability of service
- The same mission plan for every cycle, no need for acquisition requests
- Sentinel-1 will be the main C-band mapping machine
- AgriSAR 2009 campaign data gives a first glimpse of Sentinel-1 revisit improvement