Sentinel-1 Mission Overview and Status

ESA Polarimetry Course 2019
22 Jan 2019, ESRIN, Frascati
Copernicus – the European EO programme

European Earth Observation System, led by the EU

European response to global needs:

• to manage the environment
• to mitigate the effects of climate change
• to ensure civil security
**Sentinel Launches**

<table>
<thead>
<tr>
<th>S-1</th>
<th>S-2</th>
<th>S-3</th>
<th>S-4</th>
<th>S-5P</th>
<th>S-5</th>
<th>S-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar</td>
<td>High Resolution Optical</td>
<td>Medium Resolution Optical &amp; Altimetry</td>
<td>Atmospheric Chemistry (GEO)</td>
<td>Atmospheric Chemistry (LEO)</td>
<td>Atmospheric Chemistry (LEO)</td>
<td>Altimetry</td>
</tr>
<tr>
<td><strong>C</strong> 2022/23</td>
<td><strong>C</strong> 2022/23</td>
<td><strong>C</strong> 2023</td>
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<td><strong>C</strong> &gt; 2027</td>
<td><strong>D</strong> &gt; 2022/23</td>
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</tbody>
</table>
Sentinel-1 Constellation Mission Facts & Status

- Constellation of two identical SAR C-band (5.405 GHz) satellites (A & B units)
- **Sentinel-1A** launched on 3 April, 2014 & **Sentinel-1B** on 25 April, 2016
- Near-Polar, sun-synchronous (dawn-dusk) orbit at 698 km
- Instrument duty cycle of 25 min/orbit in High Bit Rate modes and 75 min/orbit in Low Bit Rate mode (Wave)
- **12-day** repeat cycle (each satellite), **6 days** for the constellation
- Systematic SAR data acquisition using a predefined observation scenario
- 7 years lifetime, consumables for 12 years at least

- Sentinel-1A and Sentinel-1B mission operations → **nominal**
- Sentinel-1 is operated close to its **full mission capacity** (i.e. difficulty to accommodate additional observations)
## Sentinel-1 SAR Operational Modes

<table>
<thead>
<tr>
<th>GRD Level 1 product resolution</th>
<th>Swath Width</th>
<th>Polarisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>50m (3 ENL)</td>
<td>&gt; 400 km</td>
<td>HH+HV or VV+VH</td>
</tr>
<tr>
<td>20m (5 ENL)</td>
<td>&gt; 250 km</td>
<td>HH+HV or VV+VH</td>
</tr>
<tr>
<td>9m (4 ENL)</td>
<td>&gt; 80 km</td>
<td>HH+HV or VV+VH</td>
</tr>
<tr>
<td>50m (140 ENL)</td>
<td>20 x 20 km² at 100 km spacing</td>
<td>HH or VV</td>
</tr>
</tbody>
</table>

**IW: main mode over land and coastal areas**

**EW**
- 50m (3 ENL)
- > 400 km
- HH+HV or VV+VH

**IW**
- 20m (5 ENL)
- > 250 km
- HH+HV or VV+VH

**SM**
- 9m (4 ENL)
- > 80 km
- HH+HV or VV+VH

**WV**
- 50m (140 ENL)
- 20 x 20 km² at 100 km spacing
- HH or VV
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, containing phase and amplitude information.

*Level-1 Ground Range Detected Geo-referenced Products (GRD):*
Focused data projected to ground range, detected and multi-looked. Data is projected to ground range using an Earth ellipsoid model, maintaining the original satellite path direction and including complete geo-reference information.

LEVEL-2 PRODUCTS
Level-2 Ocean products
Ocean wind field, swell wave spectra and surface radial velocity information as derived from SAR data.
Sentinel-1 Level 1 Operational Product characteristics

<table>
<thead>
<tr>
<th>Acq. Mode</th>
<th>Product Type</th>
<th>Resolution Class</th>
<th>Resolution [Rng x Azi] [m]</th>
<th>Pixel Spacing [Rng x Azi]</th>
<th>No. Looks [Rng x Azi]</th>
<th>ENL</th>
</tr>
</thead>
<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>
</tr>
<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>
</tr>
<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>
</tr>
<tr>
<td>EW</td>
<td>SLC</td>
<td>-</td>
<td>7.9 x 42 to 14.4 x 43</td>
<td>5.9 x 34.7 to 12.5 x 34.7</td>
<td>1 x 1</td>
<td>1</td>
</tr>
<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>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MR</td>
<td>93 x 87</td>
<td>40 x 40</td>
<td>6 x 2</td>
<td>12</td>
</tr>
<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>
</tr>
<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>
</tr>
</tbody>
</table>

- For Ground Range Products, the resolution corresponds to the mid range value at mid orbit altitude, averaged over all swaths.
- For SLC SM/IW/EW products, the resolution and pixel spacing are provided from lowest to highest incidence angle. For SLC WV products, the resolution and pixel spacing are provided for beams WV1 and WV2.
- For SLC products, the range coordinate is in slant range. All the other products are in ground range.
## Sentinel-1 Constellation systematic processing

### GLOBAL & Regional Production & Dissemination Operations Scenario

#### Global Production scenario

<table>
<thead>
<tr>
<th>Processing scenario</th>
<th>Instrument mode</th>
<th>Systematic Product Type</th>
<th>Timeliness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic Global</td>
<td>SM, IW, EW</td>
<td>L0, L1 GRDH</td>
<td>Fast-24h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L0, L1 GRDH</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L0, L1 GRDM</td>
<td></td>
</tr>
<tr>
<td>WV</td>
<td></td>
<td>L2 OCN</td>
<td>Fast-24h</td>
</tr>
</tbody>
</table>

#### Regional Production scenario status

<table>
<thead>
<tr>
<th>Processing scenario</th>
<th>Instrument mode</th>
<th>Systematic Product Type</th>
<th>Timeliness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic Regional NRT</td>
<td>EW</td>
<td>L1 GRDM</td>
<td>NRT Fast24h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L1 SLC</td>
<td></td>
</tr>
<tr>
<td>Systematic Regional SLC</td>
<td>IW, SM</td>
<td>L1 SLC</td>
<td>Fast24h</td>
</tr>
<tr>
<td>Systematic Regional L2 OCN</td>
<td>SM, EW, IW</td>
<td>L2 OCN</td>
<td>Fast24</td>
</tr>
</tbody>
</table>
# Sentinel-1 Constellation systematic processing

## GLOBAL & Regional Production & Dissemination Operations Scenario

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<td>Fast-24h</td>
</tr>
<tr>
<td></td>
<td>WV</td>
<td>L1 SLC, L2 OCN</td>
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</tr>
<tr>
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<td></td>
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<td>L1 GRDM, L1 SLC</td>
<td>NRT Fast24h</td>
</tr>
<tr>
<td>Systematic Regional SLC</td>
<td>IW, SM</td>
<td>L1 SLC (=&gt; global)</td>
<td>Fast24h</td>
</tr>
<tr>
<td>Systematic Regional L2 OCN</td>
<td>SM, EW, IW</td>
<td>L2 OCN (=&gt; global)</td>
<td>Fast24</td>
</tr>
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</table>
Baseline starting Feb 2018

This map is related to SAR High Rate modes only. Wave mode operated by default over open oceans (not shown)
Baseline starting Feb 2018

This map is related to SAR High Rate modes only. Wave mode operated by default over open oceans (not shown)
Sentinel-1 observation scenario: detailed acquisitions

KML files providing detailed information on the planned acquisitions, regularly published on Sentinel Online

https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/observation-scenario/acquisition-segments
Sentinel-1 operational daily production volume is now exceeding 12 TB/day
Sentinel-1 Constellation operations are based on a set of operational services.

There is a large committed team and a set of efficient operational services contributing to the Sentinel-1 operations performance:

- COPERNICUS WAN Service
- Svalbard X-Band Acquisition Service
- Matera X-Band Acquisition Service
- Maspalomas X-Band Acquisition Service
- UK-PAC Long Term Archiving Service
- DLR-PAC Long Term Archiving Service
- Mission Performance Service
- Precise Orbit Determination Service
- Data Access Service
- E2E Production Operations Service
Operational use of European Data Relay System (EDRS)

The European Data Relay System service provides for the Sentinel-1 mission the following assets:

- increased data download capacity
- increased coverage
- enhanced timeliness
The operational use of EDRS-A in the Sentinel-1 routine operations has resulted in:

- Significant **increase of production volume** thanks to the additional downlink capabilities. Sentinel-1 products are being made available through the standard online data access mechanisms.

- **Increased observations** (e.g. revisit) and SAR dual polarisation acquisitions.

- Significant **increase of Sentinel-1 pass-through acquisitions in X-Band over Europe**
Sentinel Open Access Hub: Free and Open Access to Sentinel data
(previously called “Scientific” Hub)

https://scihub.copernicus.eu/

• Access through self-registration
• Automated download scripting capability and dedicated API-Hub
• Restriction on concurrent downloads

More than 200,000 users registered (all Sentinels)

3.4 Million Sentinel-1 products are available on-line for download, representing 5.5 PB of data.

23 PB of data downloaded by users.
Sentinel-1 observation scenario
Main thematic domains & components

- Land cover: agriculture, forestry, hydrology, etc.
- Maritime surveillance
- European coverage
- Calibration/validation
- Global land mapping
- PR actions (infrequent)
- Sea-ice, icebergs, lake-ice
- Sea state
- Ice sheets, glaciers, permafrost, snow, etc
- Ground deformation: Tectonic, volcanoes, landslides, subsidence... (InSAR applications)
- Security
- Emergency
Sierra Negra and Fernandina volcano eruption, Galapagos

6-day Interferograms showing ground deformation of Sierra Negra and Fernandina volcano eruption, Galapagos

© Contains modified Copernicus Sentinel data [2018], University of Miami / Courtesy Falk Amelung
Kīlauea volcano eruption and earthquake, Hawaii

Eruption and earthquake near Kīlauea volcano, Hawaii (3 May 2018)

Sentinel-1 interferogram (19 April – 1 May 2018)

Deformation due to magmatic intrusion → magma withdrawn from middle East Rift Zone and intruded beneath lower East Rift Zone.

Sentinel-1 interferogram (1 May – 7 May 2018)

Copyright: Contains modified Copernicus Sentinel data (2018) / processed by USGS

Copyright: Contains derived products of Copernicus data (Sentinel-1)
6.0 magnitude Taiwan's earthquake, 6 Feb 2018
Surface deformation of Hualien area

© Contains modified Copernicus Sentinel data [2018], processed by the Eastern Taiwan Earthquake Center (ETEC)

Mount Agung Volcano eruption

© Contains modified Copernicus Sentinel data [2018], processed by COMET, University of Bristol
Etna eruption that started 24 Dec 2018 and earthquake of 26 Dec 2018

Example of contribution of Sentinel-1

Interferograms in Line Of Sight (LOS) and deformation maps

(A1) interferogram map obtained from ascending pass between 22/12/2018 and 28/12/2018

(A2) interferogram obtained from descending pass between 22/12/2018 and 28/12/2018

(B1) ground deformation map in LOS corresponding to interferogram (A1)

(B2) ground deformation map in LOS corresponding to interferogram (A2)

© Contains modified Copernicus Sentinel data [2018] / processed by CNR IREA and INGV

Courtesy CNR IREA / INGV / ASI
Both satellites are maintained within +/- 120m ground track.
Operational support to the Copernicus Marine Environment Monitoring Service (CMEMS), since start of Sentinel-1A operations.
Operational generation of SAR Wave products recently implemented by CMEMS

Systematic generation of Level 3 products since end 2017, derived from the Sentinel-1A/B Level 2 Wave/OCN

SAR-derived swell measurement trajectories from the source to the coast. Measured Hs shown by blue dots
CMEMS Waves product content from SAR

Sentinel-1A&B Level-3 demo NRT  26–NOV–2017 00:00 UTC

wavelength (m)
Wind fields

S1A evening and morning passes
Typhoon Mangkhut
https://datastore.cls.fr/monitoring-typhoon-mangkhut-from-space/

SAR: the only sensor able to characterize extreme winds (greater than 70 m/s) at very high resolution.

These activities may become part - at a later stage - of a Copernicus Service, e.g. CMEMS or CEMS...

Courtesy CLS / Ifremer
First Oil Spills Detected by Sentinel-1

Sentinel-1A TOPS EW VV/VH acquired on 19 April 2014

Sentinel-1A TOPS EW HH/HV acquired on 25 April 2014
Sentinel-1 is operationally used by EMSA since June 2016 for the CleanSeaNet service.

CleanSeaNet: the European satellite-based **oil pollution and vessel detection monitoring** system

→ Operated by the **European Maritime and Safety Agency (EMSA)**

Sentinel-1 currently represents 85% of satellite imagery used for CleanSeaNet.
Sentinel-1 mission status

Oil Spill North of Corsica, 8 September

Copyright: Contains modified Copernicus Sentinel data (2018) / processed by ESA
Monitoring ice sheets with Sentinel-1

A routine observatory of ice sheet margins
Greenland Ice velocity maps from S-1

Annual Ice Velocity Maps for Greenland derived from Sentinel-1 Data for the years 2014/15 to 2017/18.
Antarctica Ice velocity map from S-1

Antarctic Icesheet Wide Velocity Map from Sentinel-1 (2015 to 2018)
Example of Land Cover application

Example of UK map of crop classification based on Sentinel-1 and Sentinel-2 data
Sentinel-1 applications → ever increasing

**Maritime surveillance:** oil spill monitoring, ship detection, illegal fisheries, etc.

**Ground deformation:** subsidence, landslides, earthquakes, volcanoes, infrastructure monitoring

**Sea state:** wind, wave

**Sea ice and iceberg monitoring**

**Ice sheets, glaciers, climate change**

**Land use, agriculture, forestry, logging, land classification, urban planning**

**Emergency management**

**Soil moisture, wetland**

**Snow, permafrost, avalanches,**

**Sentinel-1 applications** → ever increasing
Concluding remarks

- Sentinel-1 mission routine operations on-going, overall mission in a very good shape
- High quality data routinely provided to Copernicus Services, Member States / Copernicus Participating States, International partners and to a wide spectrum of user communities worldwide for various thematic applications
- The mission provides:
  - global and routine coverage, with a systematic production scenario,
  - open and free data access,
  - the long-term perspective,
  - complementarity to higher resolution SAR missions

  ➔ to further bring SAR applications into the operational domain, at local, national, regional, continental and global scale
Thank you for your attention!

Copernicus Programme: copernicus.eu
Sentinel Online: sentinels.copernicus.eu
CSC Data Access: spacedata.copernicus.eu
ESA Sentinel app: available for iOS and Android