• 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)
• 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 SCANSAR 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
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-1 A scheduled for October 2013 followed by Sentinel-1 B 18 months later
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• 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 of the imaging modes
  - up to 74 min in Wave mode

Main mode of operations: IW
designed to satisfy 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)

<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 Azimuth 20 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 Azimuth 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></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 Azimuth 5 m</td>
<td>80 km</td>
<td>HH+HV or VV+VH</td>
<td>87.60 – 42.20</td>
</tr>
<tr>
<td>Extra Wide Swath (EW 1-5)</td>
<td>20-44 deg.</td>
<td>Range 20 m Azimuth 40 m</td>
<td>400 km</td>
<td>HH+HV or VV+VH</td>
<td>22.20 – 10.40</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

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**Chirp Bandwidth**

- WV1: 74.5 MHz
- WV2: 48.2 MHz
- Strip Map: 87.60 – 42.20 MHz
- Extra Wide Swath: 22.20 – 10.40 MHz
TOPS (Terrain Observation with Progressive Scans in azimuth) for Sentinel-1 Interferometric Wide Swath (IW) and Extended Wide Swath (EW) modes

- Provides large swath width (ScanSAR) & and enhanced radiometric performance due to reduced scalloping effect
- Important because there is only 1 azimuth look available \( \Rightarrow \) radiometric look balancing is not possible (e.g. ENVISAT)

TOPS Mode implementation: ScanSAR + azimuth Scan:
- \( \pm 0.8^\circ \) azimuth scanning at PRI rate
- \( \pm 12^\circ \) elevation scanning and beam shaping capability

TSX-ScanSAR image  TSX-TOPS image
Sentinel-1 TOPS InSAR Capability (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)

- 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)

- Requirement for Burst Synchronization: ≤ 5ms

Image courtesy: P. Prats, DLR
Sentinel-1 TOPS InSAR Capability (2/2)

• Azimuth antenna sweeping causes Doppler centroid variations of about 5.5 kHz within bursts
• Introduces an azimuth phase ramp (azimuth fringes) for small co-registration errors

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

• Requires azimuth co-registration to be better than 0.001 samples in order to obtain phase error less than 3°

Image courtesy: P. Prats, DLR
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) is 50 m (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 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 $H_{\text{min}} = 697.6$ 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
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**Sentinel-1 C-SAR Instrument**

- **SAR Electronics Subsystem (SES)**
  - ENVISAT and RADARSAT-2 heritage
  - Real Sampling (digital I and Q demodulation)
  - High-efficient SAR data compression (FDBAQ)
  - Produces self-standing data packets

- **SAR Antenna Subsystem (SAS)**
  - (12.3 x 0.84 m) with 14 tiles in 5 deployable panels
  - Plated CFRP Waveguides (low-loss) - TerraSAR-X heritage
  - T-compensated T/R modules - COSMO-SkyMed heritage
  - Internal calibration for Radiometry – ERS/ENVISAT heritage
Sentinel-1 SAR Electronics Subsystem
Transmit Receive Modules
SAR Antenna Subsystem Tile

Active Gain in dBi

HP Rx Reference Boresight - Elevation Pattern @ 5.405 GHz

\[ v = \frac{k_y}{k_0} \]
SAR Antenna Testing
Central Structure with PCDU & CAPS Panels and with Propulsion S/S and Harness integrated

Solar Array deployment
End-to-End Spacecraft and 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 PCC techniques to monitor T/R modules
  - 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 and desert areas 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
- Measurement of phase stability in overlap area between bursts and sub-swaths
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)
Thank you for your attention