LINKING SENTINEL-1 LEVEL-1 DATA QUALITY WITH LEVEL-2 PERFORMANCE

Malcolm Davidson
Evert Attema
Nicolas Floury
Bjorn Rommen
Paul Snoeij

European Space Agency
Noordwijk
The Netherlands
Outline

- Context
- Methodology
- Level-1 data quality
- Level-2 performance assessments for selected products
- Summary
Geophysical information product accuracy assessment context

- Support design of mission and trade-off studies
- Verification of technical choices of the mission and system
- Basis for definition of calibration and validation activities
- Preparation user community for new data stream and its capabilities ahead of launch
- Framework to support joint exploitation of ESA GMES missions and national contributing missions (e.g. TerraSAR-X, COSMO/Skymed)
- Feedback to Agency in design of future SAR missions and integration of evolving user requirements
Assessment framework for Level-2 performance assessment

Mission and system performance

Level-1 product

Level-2 performance

Level-1 Quality

Radiometric uncertainty (system)

Radiometric Resolution

Phase Uncertainty

Effective Number of Looks (ENL)

Radiometric Accuracy

Instrument Noise (e.g. NESN)

Ambiguity

Quantisation Noise

Relative

Absolute

Range

Azimuth

Class. accuracy

Forest

Non-Forest

avgC

100

90

80

70

60

50

40

30

20

10

0

2 5 10 20 50 100

L

GMES

European Commission
## Sentinel-1 Level-1 data quality specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Strip-Map Mode (SM)</th>
<th>Interferometric Wide-Swath Mode (IW)</th>
<th>Extra Wide Swath Mode (EW)</th>
<th>Wave Mode (WV)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Polarisation</strong></td>
<td>Dual (HH+HV, VV+VH)</td>
<td>Dual (HH+HV, VV+VH)</td>
<td>Dual (HH+HV, VV+VH)</td>
<td>Single (HH, VV)</td>
</tr>
<tr>
<td><strong>Access (Incidence angles)</strong></td>
<td>20° - 45°</td>
<td>25° (min. incidence angle)</td>
<td>20° (min. incidence angle)</td>
<td>23° + 36.5° (mid incidence angle)</td>
</tr>
<tr>
<td><strong>Azimuth Resolution</strong></td>
<td>&lt; 5 m</td>
<td>&lt; 20 m</td>
<td>&lt; 40 m</td>
<td>&lt; 5 m</td>
</tr>
<tr>
<td><strong>Ground Range Resolution</strong></td>
<td>&lt; 5 m</td>
<td>&lt; 5 m</td>
<td>&lt; 20 m</td>
<td>&lt; 5 m</td>
</tr>
<tr>
<td><strong>Range Looks</strong></td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
</tr>
<tr>
<td><strong>Swath</strong></td>
<td>&gt; 80 km</td>
<td>&gt; 250 km</td>
<td>&gt; 400 km</td>
<td>Vignette 20 x 20 km</td>
</tr>
<tr>
<td><strong>NESZ</strong></td>
<td>-22 dB</td>
<td>-22 dB</td>
<td>-22 dB</td>
<td>-22 dB</td>
</tr>
<tr>
<td><strong>Radiometric Stability</strong></td>
<td>0.5 dB (3σ)</td>
<td>0.5 dB (3σ)</td>
<td>0.5 dB (3σ)</td>
<td>0.5 dB (3σ)</td>
</tr>
<tr>
<td><strong>Radiometric Accuracy</strong></td>
<td>1 dB (3σ)</td>
<td>1 dB (3σ)</td>
<td>1 dB (3σ)</td>
<td>1 dB (3σ)</td>
</tr>
<tr>
<td><strong>Phase Error</strong></td>
<td>5°</td>
<td>5°</td>
<td>5°</td>
<td>5°</td>
</tr>
<tr>
<td>Information Product (Level-2)</td>
<td>Origin of Product (Level-1)</td>
<td>Random &amp; Systematic Uncertainties to be Considered (List not exhaustive)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------</td>
<td>---------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>Absolute Value of Image Intensity</td>
<td>- Instrument Calibration, including Noise Bias and Non-linearity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean Wind Speed</td>
<td></td>
<td>- Radiometric Resolution, including Quantisation, Noise and Speckle (Effective Number of Looks)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ice Edge/Ice Map</td>
<td>Image Intensity Contrast</td>
<td>- Phase Errors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil Pollution at Sea</td>
<td></td>
<td>- Instrument Stability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snow Cover</td>
<td></td>
<td>- Atmospheric Effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest Map</td>
<td></td>
<td>- Geometrical Effects (orbit position, pointing)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Cover Map</td>
<td></td>
<td>- Temporal De-correlation of Interferometric Image Pairs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interferometric Products, e.g.</td>
<td>Complex Image (Amplitude &amp; Phase)</td>
<td>- Retrieval Uncertainties, including Retrieval Model Uncertainties and Validation Uncertainties</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Interferometry (1)

Application context
- Geo-Hazard Land Motion Services

Main mission parameters affecting performance
- Phase errors
- Quantisation noise
- Instrument noise

Phase Error as a Function of Signal-to-Noise Ratio
– Methods for evaluation of geophysical accuracy as a function of mission and system parameters well established
– Example reference scenario given on right
Ship detection (1)

- Application context
  - Security
  - Oil-spill monitoring
  - Fisheries/Transport

- Main mission parameters impacting performance
  - Swath Width
  - Timeliness of data (< 1 hour)
  - Resolution
  - Instrument Noise

- Performance models exist linking Level-1 data quality with ship detection performance
We care for a safer world

Ship Detection (2)

- Detection performance better than existing C-band SAR satellites (ERS-2, Radarsat, ENVISAT)
- For the main IWS mode, ships with length > 40m can be detected with 90% accuracy
- For SM mode ships with length > 24m can be detected with 90% accuracy
- Methodology developed to explicitly calculate classification errors through integration of area/volume of overlap
- Maximum likelihood criteria
- Classification error estimated as function of
  - radiometric contrast
  - level of bias (due to radiometric uncertainties)
- Applicable to wide variety of classification-based (thematic maps) applications
**Ice monitoring (1)**

**Application context**
- ice services
- manual interpretation of SAR images

**Main mission parameters impacting performance**
- Swath Width
- Timeliness of data
- Polarisation
- Instrument Noise

**Geophysical accuracy**
- combination of large swath and high resolution to provide needed coverage and input for interpretation
- dual-polarisation useful in detecting and mapping ice regimes

From Flett and De Abreu, Canadian Ice Service
- Errors in ice classification estimated using previous methodology
  - S1 IWS Mode
  - Level-2 product scale = 20 x 20m
  - 4 looks
  - 2 polarisations (VV+VH)
- Radiometric contrast between ice classes extracted from ESA IceSAR 2007 airborne campaign
- Main source of error: radiometric resolution
We care for a safer world

Land cover based on temporal signatures

- Robust land cover classification enabled through frequent revisit and multi-temporal metrics
  - Mean annual variation (MVA)
  - Min/Max/Mean backscatter
  - Texture
- High classification accuracies for basic land classes for sufficient temporal coverage (example with 8 acquisitions during growing season)

<table>
<thead>
<tr>
<th>Maximum Likelihood VV &amp; HV / 8 acq. dates</th>
<th>Water</th>
<th>Grassland</th>
<th>Cropland</th>
<th>Forest</th>
<th>Settlement</th>
<th>User accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>97.88</td>
<td>1.217</td>
<td>0.27</td>
<td>0.22</td>
<td>0.85</td>
<td>89.35</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.53</td>
<td>97.28</td>
<td>2.27</td>
<td>0.10</td>
<td>0.08</td>
<td>75.37</td>
</tr>
<tr>
<td>Cropland</td>
<td>1.24</td>
<td>1.503</td>
<td>95.99</td>
<td>0.64</td>
<td>16.82</td>
<td>97.73</td>
</tr>
<tr>
<td>Forest</td>
<td>0</td>
<td>0</td>
<td>1.15</td>
<td>98.92</td>
<td>0.085</td>
<td>99.21</td>
</tr>
<tr>
<td>Settlement</td>
<td>0.35</td>
<td>0</td>
<td>0.32</td>
<td>0.12</td>
<td>82.16</td>
<td>91.09</td>
</tr>
<tr>
<td>Prod. Accuracy</td>
<td>97.88</td>
<td>97.28</td>
<td>95.99</td>
<td>98.92</td>
<td>82.16</td>
<td>97.34</td>
</tr>
</tbody>
</table>
Radiometric resolution is often a limiting factor on SAR-based classification performance.

- Multi-temporal filtering exploiting image temporal stacks expected to significantly improve the radiometric resolution and classification performance.

![Graph showing ENL vs. No. of Images for Test area A]
**Context**
- Forest/Non-forest mapping algorithms based on high temporal stability of forest with respect to other land cover classes

**Main mission parameters impacting accuracy**
- Radiometric resolution

**VV image**
- Raw ASAR AP product
- Multitemporal filter
- 6 dates x 2 channels
Synthetic classification performance potential based on ideal multi-temporal filtering

- Single look SAR image
- ERS-1/2 Multi-temporal 70 days
- ASAR - AP Multi-temporal 70 days
- Sentinel-1 IWS Multi-temporal 70 days

Filter from Quegan and Yu (2001)

Accuracy:
- -10 dB: 58%
- -8 dB: 79%
- 79%
- 96%
## Performance prediction for geophysical products

<table>
<thead>
<tr>
<th>S1 Level-2 Product</th>
<th>Resolution</th>
<th>Performance</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsidence Rate</td>
<td>5 x 20 m2</td>
<td>1.3</td>
<td>mm/year</td>
</tr>
<tr>
<td>Land Cover Classification (2 dB contrast)</td>
<td>100 x 100 m2</td>
<td>96</td>
<td>% correct classification</td>
</tr>
<tr>
<td>Forest Non-Forest Classification</td>
<td>30 x 30 m2</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>100 x 100 m2</td>
<td>1.2</td>
<td>volume %</td>
</tr>
<tr>
<td>Flood Mapping</td>
<td>30 x 30 m2</td>
<td>79</td>
<td>% correct classification</td>
</tr>
<tr>
<td>Snow Cover Classification</td>
<td>30 x 30 m2</td>
<td>75</td>
<td>% correct classification</td>
</tr>
<tr>
<td>Ship Detection</td>
<td>5 x 20 m2</td>
<td>40</td>
<td>ship length (m) for 90% detection probability</td>
</tr>
<tr>
<td>Sea Surface Wind Speed</td>
<td>100 x 100 m2</td>
<td>0.8</td>
<td>m/s (1 sigma)</td>
</tr>
<tr>
<td>Sea Surface Currents</td>
<td>5 Hz</td>
<td>30</td>
<td>cm/s</td>
</tr>
</tbody>
</table>
Summary

- Sentinel-1 data products maintain the data quality of ESA’s previous SAR missions (ERS-1/-2, ENVISAT ASAR)
  - Continuity in performance for geophysical products secured
- Evaluation of accuracy of geophysical products indicates improvements due to frequent revisit, coverage and dual-polarisation capabilities
  - System impact on Level-2 (and higher) evaluated based on Level-1 specifications
  - User requirements met or exceeded
  - Results documented in ESA Sentinel-1 Error Budget document
- Future work focus on development and standardisation of methodologies for accuracy assessment, product prototyping and (post-launch) verification of accuracy (e.g. through validation)