The Origin of SAR Calibration Requirements

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Outline

- Technology driven versus Science & Applications driven SAR Requirements
- The Soil Moisture Case
- Conclusions
Technology driven versus Science & Applications driven SAR Requirements

- Technology Driven SAR Requirements
  - Technically Challenging
  - Up-to-date Specifications
  - Best Possible Performance
  - Not Worse than Predecessors (SEASAT)

- Science & Application Driven SAR Requirements
  - Data Availability
  - Coverage and Revisit
  - Timeliness
  - Characteristics of Data Products
  - Error Budget associated with Uncertainty of User Service Information Product
Implications for Calibration Requirements; the Recommended Approach

1. Obtain Information Product Accuracy Requirements
   - Marine: wind/waves, ice type, ship & pollution detection
   - Land: land surface motion, soil moisture, land cover
   - Cryosphere: ice type classification, ice edge, ice motion

2. Apply Retrieval Models to relate to
   - Radiometric Accuracy & Stability
   - Phase Error
   - Polarisation Purity
   - Doppler Stability

3. Define Technical Specification
Difficulty associated with the recommended approach: Communication Problem

Service Provider

Scientist

Systems Engineer
Frustration of System Engineer

- Service Provider “doesn’t know what he wants”
  - End-User Requirements not in technical units e.g.
    - Accuracy [dB]
    - Phase Error [Deg.]
- Scientist “doesn’t have robust retrieval algorithm”
- CEOS does not (yet) provide (application dependent) internationally accepted standards
  - Radiometric Accuracy (1 dB)
  - Phase Error (5 Deg.)
  - Sensitivity (NESZ -20....-30 dB)
  - Polarisation Purity (30 dB)
  - Ambiguity Ratio (25 dB)
  - Doppler Error (10 Hz)
  - Etc.
Case Study: Sentinel-1 Soil Moisture Product

1. End-User Requirements
2. Soil Moisture Retrieval
3. Sentinel-1 Performance
4. Soil Moisture Accuracy
End-User Requirements

- For typical Western Europe mid-latitude conditions, volumetric soil moisture varies roughly between 20 and 40 volume %
- A widely accepted uncertainty for satellite soil moisture estimation is 5% uncertainty which means that 4 classes could be identified (dry, medium dry, medium wet, wet)
- Tighter specifications would be difficult to achieve and hard to validate
- Spatial Resolution 100 to 1000 m
Simplified Soil Moisture Retrieval Model (Bare Soil)

\[ \sigma^0 = \{Ce^{Dm_s}\} \cos \theta \]

<table>
<thead>
<tr>
<th>( \theta )</th>
<th>Incidence Angle</th>
</tr>
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<tbody>
<tr>
<td>( m_s )</td>
<td>Soil moisture</td>
</tr>
</tbody>
</table>

Sigma Naught as a Function of Soil Moisture (bare soil)
Sigma Naught [dB] = -16.917 + 0.347 x MS
C-Band 23 deg. Incidence
Canopy Effects on the Soil Moisture Retrieval Model

\[ \sigma^0 = \left\{ A \left(1 - e^{-\frac{m_b B}{\cos \theta}}\right) + C e^{-\frac{m_b B}{\cos \theta} + D m_s} \right\} \cos \theta \]

- \( \theta \) = incidence angle
- \( m_s \) = soil moisture
- \( m_b \) = total vegetation water content (biomass) per unit area
  This could be expressed as \( m_b = \frac{W}{h} \)
  where
- \( W \) = volumetric water content (biomass) of the vegetation per unit volume
- \( h \) = vegetation height
Impact on Soil Moisture Retrieval

Sigma Naught as a Function of Soil Moisture for Different Values of Biomass [kg/m²]  
C-Band 23 deg. Incidence
Sentinel-1 Observation Geometry

- Orbit Height: ~700 km
- Flight Direction
- Sub-Satellite Track
- Wave Mode
- Interferometric Wide Swath Mode
- Extra Wide Swath Mode
- Strip Map Mode
## 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>
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<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</td>
<td>HH or VV</td>
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<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>
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<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

- **Radiometric accuracy (3 σ):** 1 dB
- **Noise Equivalent Sigma Zero:** -22 dB
- **Point Target Ambiguity Ratio:** -25 dB
- **Distributed Target Ambiguity Ratio:** -22 dB
Radiometric Resolution (Noise & Speckle) for 150 x 150 m Product

Radiometric Resolution of 150 m Spatial Resolution Product

- Sentinel-1 Interferometric Wide Swath 20*5 1 Look
- Sentinel-1 Extra-wide Swath 20*40 1 Look
- ASAR Wide Swath 150*150 11.5 Looks
- Sentinel-1 Stripmap 5*5 1 Look

Radar Backscatter Coefficient $\sigma^0$ [dB]
Radiometric Resolution (Noise & Speckle) for 500 x 500 m Product

Radiometric Resolution of 500 m Spatial Resolution Product

- Sentinel-1 Interferometric Wide Swath 20*5 1 Look
- Sentinel-1 Extra-wide Swath 20*40 1 Look
- ASAR Wide Swath 150*150 11,5 Looks
- Sentinel-1 Stripmap 5*5 1 Look

Radar Backscatter Coefficient $\sigma^0$ [dB]
End-to-End Performance of 150 * 150 m spatial resolution product

<table>
<thead>
<tr>
<th></th>
<th>Envisat</th>
<th>Sentinel-1</th>
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<tr>
<td></td>
<td>ASAR WS</td>
<td>EWS</td>
<td>IWS</td>
<td>Strip Map</td>
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<td>Unit</td>
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<td>Radiometric Resolution</td>
<td>1.16</td>
<td>0.79</td>
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<tr>
<td>Radiometric Accuracy</td>
<td>0.33</td>
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<td>dB</td>
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<tr>
<td>Soil Moisture Sensitivity</td>
<td>0.34</td>
<td>0.34</td>
<td>0.34</td>
<td>0.34</td>
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<td>dB/Volume %</td>
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<tr>
<td>Soil Moisture Measurement Uncertainty (3 * standard deviation)</td>
<td>10.66</td>
<td>7.58</td>
<td>3.91</td>
<td>3.22</td>
<td></td>
<td>Volume %</td>
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Conclusion and Recommendation

- System calibration requirements can be related to the estimation uncertainty of SAR information products such as geophysical variables (soil moisture)

- To arrive at a balanced compliant system design the dialogue between service providers, scientists and system engineers is essential

- If there are generally accepted performance levels in terms of Radiometric Accuracy & Stability (1 dB), Phase Error (5 deg.), Polarisation Purity (30 dB), Doppler Uncertainty (10 Hz), CEOS should consider a recommendation