First TOPSAR image and interferometry results with TerraSAR-X

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Outline

Ø Introduction
Ø TOPSAR acquisition mode
Ø First TerraSAR-X TOPSAR images
Ø First TerraSAR-X TOPSAR interferometric fringe results
Ø Conclusions and future work
Introduction

Ø TOPSAR is a new acquisition mode proposed by E. Attema (ESA-ESTEC) and F. Rocca (POLIMI)
Ø Developed by POLIMI
Ø TOPSAR requires a fast rotation of the azimuth antenna pattern
Ø It aims at achieving the same coverage and resolution as ScanSAR, but with a nearly uniform SNR and DTAR
Ø It is going to be the operational mode for Sentinel-1 Interferometric Wide Swath (IWS) mode
Ø It is being successfully demonstrated with TerraSAR-X for the first time within the framework of an ESA project

TOPSAR acquisition mode
TOPSAR acquisition mode
Antenna array effects

Boresight case

Normalized angle of the steering angle equal to 0.2
Antenna array effects

Ø The azimuth array antenna pattern is amplitude weighted by the single element pattern

Ø When the array pattern is being steered, the effect of the grating lobes is increasing.

Ø A small residual scalloping effect can be introduced

Ø However, it is much smaller than the equivalent ScanSAR case and has a lower frequency due to extended burst image area
A DTAR variation and scalloping of less than 1 dB is expected in a typical TerraSAR-X TOPSAR configuration.
Inverse TOPSAR

The timeline equation are the same for TOPSAR and inverse TOPSAR

Steering rate higher in inverse TOPSAR, therefore higher scalloping and DTAR variation to be expected
First TOPSAR images with TerraSAR-X
TerraSAR-X TOPSAR configuration

Ø four subswaths
Ø ~80 km swath coverage
Ø 16 m azimuth resolution

TerraSAR-X parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency</td>
<td>9.65 GHz</td>
</tr>
<tr>
<td>Along-track antenna length</td>
<td>4.8 m</td>
</tr>
<tr>
<td>TR modules in along-track</td>
<td>12</td>
</tr>
<tr>
<td>One-way azimuth beamwidth (3 dB)</td>
<td>0.33 deg</td>
</tr>
<tr>
<td>Satellite velocity</td>
<td>7608 m/s</td>
</tr>
<tr>
<td>Height</td>
<td>514 km</td>
</tr>
<tr>
<td>Maximum steering angle</td>
<td>± 0.75 deg</td>
</tr>
</tbody>
</table>
## TerraSAR-X TOPSAR acquisition example

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>SS 1</th>
<th>SS 2</th>
<th>SS 3</th>
<th>SS 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean look angle - [deg]</td>
<td>28.464</td>
<td>30.426</td>
<td>32.075</td>
<td>34.086</td>
</tr>
<tr>
<td>Slant middle range – [km]</td>
<td>591.8</td>
<td>604.6</td>
<td>616.5</td>
<td>632.5</td>
</tr>
<tr>
<td>Ground velocity – [m/s]</td>
<td>6976</td>
<td>6970</td>
<td>6966</td>
<td>6960</td>
</tr>
<tr>
<td>PRF – [Hz]</td>
<td>4063</td>
<td>3761</td>
<td>4368</td>
<td>4035</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calculated parameters</th>
<th>SS 1</th>
<th>SS 2</th>
<th>SS 3</th>
<th>SS 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration beamwidth – [deg]</td>
<td>0.329</td>
<td>0.329</td>
<td>0.329</td>
<td>0.329</td>
</tr>
<tr>
<td>Steering angle rate – [deg/s]</td>
<td>3.479</td>
<td>3.404</td>
<td>3.337</td>
<td>3.251</td>
</tr>
<tr>
<td>Burst Time – [s]</td>
<td>0.300</td>
<td>0.301</td>
<td>0.303</td>
<td>0.305</td>
</tr>
<tr>
<td>Target Doppler Bandwidth – [Hz]</td>
<td>455.31</td>
<td>455.13</td>
<td>455.01</td>
<td>454.79</td>
</tr>
<tr>
<td>Maximum steering angle - [deg]</td>
<td>0.522</td>
<td>0.513</td>
<td>0.506</td>
<td>0.4977</td>
</tr>
<tr>
<td>Number of Pulses per Burst – [ ]</td>
<td>1220</td>
<td>1136</td>
<td>1326</td>
<td>1234</td>
</tr>
<tr>
<td>Burst image length – [m]</td>
<td>9471.4</td>
<td>9469.1</td>
<td>9467.9</td>
<td>9464.9</td>
</tr>
</tbody>
</table>
Vendome: inverse TOPSAR image

- Scene size: 84 km in azimuth and 72 in slant range
- 8 bursts
- Antenna steering from +0.71 deg to -0.71 deg
- Burst image steering from +0.67 deg to -0.67 deg
- Small scalloping effect visible
- No scalloping correction applied
- Data Take acquired on June 29th, 2007, only two weeks after the TerraSAR-X launch
Neuville: TOPSAR image

- Scene size: 90 km in azimuth and 75 in slant range
- 9 bursts
- Antenna steering from +0.55 deg to -0.55 deg
- Burst image steering from +0.44 deg to -0.44 deg
- Difficult to see scalloping effects
- No scalloping correction applied
Azimuth profiles

Inverse TOPSAR azimuth profile example
~0.8 dB scalloping

Nominal TOPSAR azimuth profile example
~0.4 dB scalloping
Challans: Google image
**Challans: TOPSAR image**

*Time acquisition: July 9th, 2007 at 6.26 am*
Challans: ScanSAR image

Time acquisition: September 2\textsuperscript{nd}, 2007 at 6.26 am
First TOPSAR Interferometry results with TerraSAR-X
**TerraSAR-X TOPSAR interferometry**

A squint error $\delta \vartheta$ translates into a Doppler shift

$$f_{\text{shift}} = \frac{\delta \vartheta 2v}{\lambda}$$

**The TerraSAR-X characteristics:**

Ø Along-track position accuracy is within $\sim 50$ m ($0.005$ deg at 620 km)

Maximum Doppler shift of approximately 40 Hz

For a processed Doppler bandwidth of 455 Hz (16 m res.), a maximum interferometric resolution loss of less than 9% is expected due to band filtering.

Accurate coregistration is required due to high Doppler centroids at the edges of the burst images.
Uyuni salt lake
Uyuni salt lake
Uyuni salt lake: TOPSAR master image

- Scene size: 110 km in azimuth and 74 in slant range
- 8 bursts
- Look angle is varying from 32.9 degree to 37.9 degree
**Uyuni salt lake: TOPSAR slave image**

- Same configuration as the master data take acquisition
- Coarse misalignment of 70 pixel in range and 3 in azimuth
- Along-track misalignment around 22 m.
Uyuni salt lake: TOPSAR coherence image
Uyuni salt lake: TOPSAR interferogram

- The estimated range frequency is linearly decreasing with increasing range and with along-track position.
- Estimated perpendicular baseline varying from 67 to 38 meter.
- The resulting ambiguity height is varying from approximately 92 to 173 meter.
Uyuni salt lake: TOPSAR final interferogram
Unwrapped phase
Doppler centroid variation effects

\[ \varphi_{rg\_err} = \frac{4\pi}{\lambda} \Delta r_{mis} \left( 1 - \sqrt{1 - \left( \frac{\lambda f_{DC} (r_0)}{2v} \right)^2} \right) \]

Negligible effect

\[ \varphi_{az\_err} = 2\pi f_{DC} \Delta t \]

Very important

0.1 pixel azimuth misregistration
Next steps

Ø Calibration of the TOPSAR interferometry phase and quantitative analysis

Ø Processing of TerraSAR-X data takes for Sentinel-1 simulations in terms of coverage, steering angle, scalloping

Ø Final results will be used for suggestions for the TOPSAR IWS of the ESA Sentinel-1 sensor
Conclusions
Conclusions

Ø TerraSAR-X TOPSAR data takes have been successfully generate, commanded and executed

Ø First TOPSAR images have been produced with the experimental processor developed at DLR

Ø First TOPSAR interferometric fringe have been successfully generated over the Uyuni salt lake

Ø Unique validation approach by joining the knowledge and expertise of TerraSAR-X SEC, processing and airborne groups at the DLR – Microwaves and Radar Institute
Thanks for your attention