Monitoring rivers and lakes with a Ka-band Interferometric Radar Altimeter: an assessment of the performances

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Recall of the WatER (Water Elevation Recovery) / Hydrosphere Mapper / SWOT (Surface Water Topography) mission

- Scientific objectives over inland waters
- Main instrument and mission parameters

Implementation of a Virtual Mission to validate the instrument performances

- Data simulator
- First Ground Processing
- Three case studies

Main results of the Virtual Mission

Conclusions and perspectives
River discharge, lake and wetland storage of water are critical terms in the surface water balance, but are poorly observed.

Two ways of observation, not appropriate:
- Gauges
- Profiling altimetry

Need for a global dataset of discharge and storage changes, concomitant with other missions (Precipitation: TRMM; Land: Landsat, Modis; Soil Moisture: SMOS)

Proposition of the WatER mission, wide-swath interferometric imaging radar altimeter
- Heritage from SRTM, WSOA
- More complex instrument to access more complex area

Objectives: 10 cm, 10 μrad
<table>
<thead>
<tr>
<th></th>
<th>Ocean Wide Swath</th>
<th>HR Wide Swath</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Altitude (km)</strong></td>
<td>815/950</td>
<td>824/950</td>
</tr>
<tr>
<td><strong>Inclination (°)</strong></td>
<td>98.67/80</td>
<td>98.70/80</td>
</tr>
<tr>
<td><strong>Frequency (GHz)</strong></td>
<td>13,5</td>
<td>36,5</td>
</tr>
<tr>
<td><strong>Bandwidth (MHz)</strong></td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td><strong>Peak Power (W)</strong></td>
<td>120</td>
<td>1500</td>
</tr>
<tr>
<td><strong>PRF per antenna (Hz)</strong></td>
<td>1000</td>
<td>4400</td>
</tr>
<tr>
<td><strong>Antenna Length (m)</strong></td>
<td>2.2</td>
<td>3.8</td>
</tr>
<tr>
<td><strong>Mast length (m)</strong></td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><strong>Range resolution (cm)</strong></td>
<td>750</td>
<td>75</td>
</tr>
<tr>
<td><strong>Ground resolution (m)</strong></td>
<td>700-100</td>
<td>70-10</td>
</tr>
<tr>
<td><strong>Azimuth single-look resolution (m)</strong></td>
<td>13000</td>
<td>5</td>
</tr>
<tr>
<td><strong>Swath Width (km)</strong></td>
<td>85</td>
<td>50</td>
</tr>
<tr>
<td><strong>Datarate (Mbit/s)</strong></td>
<td>0.01-0.1</td>
<td>310</td>
</tr>
</tbody>
</table>
WatER instrumental (random) error budget

4 Looks Processing

Correlated errors (a few meters…)

20m*70m to 20m*10m pixel

10 cm
Virtual Mission

- Developing a scene creation tool (use of ancillary data)
- Simulating data products
- Implementing data processing
  - Going from raw products to science data (height and slope)
  - Reducing the impact of correlated external errors
  - Reducing the impact of random instrumental noise

- Three case studies
  - Two rivers
    - Meuse: very narrow, limiting case
    - Lena
  - A lake: lake Leman

- Answering the mission objectives (10 cm, 10 μrad)
Going from raw data to science data

Amplitude threshold
Localization of water extent

Interferometric phase selection

From interferometric phase to topography (phase unwrapping)
- Low frequency signatures are major contributors
- **Objective**: extract them from the products
- **Idea**: Use a stable topographic reference as a way of comparison (SRTM)
- Interferometric phase maps difference and smoothing over 1 by 1 km (random errors from instrument and DEM erased through the process)
Random instrumental error reduction

- A priori known pixels contaminated by land not used in the selection step
- Two independent processes applied over height profiles
  - Across River: same curvilinear abscissa = same elevation
  - Along River: 2 parameters: correlation length and polynomial model

**Legend**

- **Red**: Land contamination
- **Yellow**: Across River Processing
- **Blue**: Along River Processing
Results on Meuse

Ground Processing Trade Off on Meuse

<table>
<thead>
<tr>
<th>Residual Height Error (m)</th>
</tr>
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<tbody>
<tr>
<td>U &lt;&lt; 1 m/s</td>
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</tbody>
</table>

Along River Processing Length (km)

Ground Processing Trade Off on Meuse (slope)

<table>
<thead>
<tr>
<th>Residual Slope Error (μrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U &lt;&lt; 1 m/s</td>
</tr>
</tbody>
</table>

Along River Processing Length (km)

10 μrad = 1 cm/1 km
Results on lake Leman

Ground Processing Trade Off on Lake Leman

- Blue: $U \ll 1 \text{ m/s}$
- Green: $U = 1.3 \text{ m/s}$
- Red: $U = 2.9 \text{ m/s}$
- Cyan: $U > 15 \text{ m/s}$

Residual Height Error (cm) vs. Lake Area in Swath (km²)
A Virtual Mission has been developed
- River Meuse especially is very constraining!
- Scientific objectives are met

A publication is currently reviewed in IEEE TGRS:

A perspective is the determination of the quality of the end products from that of the height and slope profiles obtained
Interferometric Measurement Concept

• Conventional altimetry measures a single range and assumes the return is from the nadir point.
• For swath coverage, additional information about the incidence angle is required to geolocate.
• Interferometry is basically triangulation.
  • Baseline B forms base (mechanically stable).
  • One side, the range, is determined by the system timing accuracy.
  • The difference between two sides ($\Delta r$) is obtained from the phase difference ($\Phi$) between the two radar channels.

$$\Phi = 2\pi \frac{\Delta r}{\lambda} = 2\pi B \sin \frac{\Theta}{\lambda}$$

$$h = H - r \cos \Theta$$

No waveform fitting is required for interferometry. The phase is unique for each resolved pixel.
Over ocean

Instrumental Error Budget over oceans

- **Distance in the swath (km)**
- **Height error (cm)**

- **Pixel 1\(^{\circ}\)1 km**
- **Pixel 2\(^{\circ}\)2 km**