SHIP DETECTION AND SEA CLUTTER CHARACTERISATION USING X&L – BAND FULL-POLARIMETRIC AIRBORNE SAR DATA

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CNES/ONERA study of Space System Concept for maritime surveillance.

Allow observation of non-cooperative boats with temporal revisits compliant with the objectives of reactivity for maritime surveillance.

Concept proposed by CNES (French Space Agency) based on radar operating with a very wide swath -> implies grazing conditions of acquisition.

Only few radar data on maritime surfaces available with this geometry: CNES decided to carry out dedicated campaigns, with ONERA airborne SAR sensor:

- February 2009 – Mediterranean sea
- November / December 2011 – Atlantic Ocean
CNES/ONERA study of Space System Concept for maritime surveillance.

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- February 2009 – Mediterranean sea
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Sea clutter Sigma0 vs:

- Incidence angle (mainly **low grazing angle**)  
- Azimuth angle  
- Sea state  
- Polarization state  
- Frequency band

Ship signature:

- Depending on size, polarization, line of sight ...

Detection capability

Absolute measurements: **calibration**
SAR facility / ONERA airborne sensor

- **Airborne platform:** SETHI (ONERA)
  - 2 pods under the wings (Falcon 20)
  - Campaign: 5 flights during 6 days

- **Acquisition parameters:**
  - Waveform -> PolSAR dual-frequency *simultaneously*
    - X-band (Hh, Hv, Vh, Vv): B=300 MHz (rés 0.5m)
    - L-band (Hh, Hv, Vh, Vv): B=100 MHz (rés 1.5m)
  - Trajectory -> linear, octogonal and **circular**

- **Incidence angle:** 80, 70 and 60°

**Internal looking:** Ship RCS study

**External looking:** Sea clutter study
Dedicated calibration area: Lann-Bihoue

14 reflectors along the swath: 1 dihedral and 13 trihedrals

X-band ($H_h$, $H_v$, $V_v$)
Response stability in the swath: Amplitude stability

Calibration assessment - Incidence 80° - B = 300 MHz
RCS measurement

Theoretical RCS - Experimental RCS (dB)

Range (m)

-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

4000 4200 4400 4600 4800 5000 5200 5400 5600 5800 6000

Hh
Vv
Response stability in the swath: Co-polar phase stability

Calibration assessment - Incidence 80° - B = 300 MHz
Co-polar phase measurement
Campaign of acquisition: region of interest

#1 Ushant traffic separation scheme:
3 flights -> sea state 4-5 & 5-6
Boat    -> large size (>100m)

Ground truth:
• Sea state: buoy, Météo France, ...
• AIS (provided by CETMEF)
#1 Ushant traffic separation scheme: incidence 80°

X-Hh

30 km

PolSAR Sigma0 – Incidence 80° – Sea state 5–6
#1 Ushant traffic separation scheme: incidence 80°

X-Hh

<table>
<thead>
<tr>
<th>AIS</th>
<th>Ship #1</th>
<th>Ship #2</th>
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</thead>
<tbody>
<tr>
<td>Lenght</td>
<td>105m</td>
<td>89m</td>
</tr>
<tr>
<td>Heading</td>
<td>212°</td>
<td>212°</td>
</tr>
<tr>
<td>Speed</td>
<td>7.2knts</td>
<td>7knts</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Experimental RCS</th>
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<tbody>
<tr>
<td>Hh</td>
<td>50 dBm²</td>
<td>48 dBm²</td>
</tr>
<tr>
<td>Hv</td>
<td>25 dBm²</td>
<td>26 dBm²</td>
</tr>
<tr>
<td>Vv</td>
<td>42 dBm²</td>
<td>42 dBm²</td>
</tr>
</tbody>
</table>
Campaign of acquisition: region of interest

#2 10 NM South of Le Guilvinec:

1 flight -> sea state 3-4
Boat -> 2 cooperative boats (15 & 20m)
Circular acquisitions over clutter & cooperative boats

Ground truth:

- Tracking GPS for both cooperative ships and an Inertial Measurement Unit installed into one of them.
- AIS signal from the non-cooperative boat (CETMEF).
- Sea state: buoys, Signal station, Météo France, ...
Ground truth for #2: sea state information

Wind from South

Swell from West

Circular acquisition
Azimuth step: 15°
Sea clutter over the full 360° in azimuth: 80°

Sea clutter Sigma0 vs azimuth angle, X-band
Incidence 80° - Sea state 3-4

Azimuth 0° ⇔ Upwind / Azimuth 180° ⇔ Downwind
Sea clutter response: the physical behavior

Incidence 80°

Hh polarization

Vv polarization
Ground truth for #2: cooperative boat

Rescue (15.5 m)

Trawler (16m)
Ship measurements over the full 360° in azimuth: 70°

Flight 2 run 8: incidence 70° - cooperative boat (SNSM)

RCS (dBm²) against observation angle (deg)

90° : cross viewing
0° : front viewing
180° : back viewing

Maximum RCS: cross viewing
Dihedral effect (max Hv) in one of the two sides
#3 Around Quiberon:

1 flight -> sea state 2-3

Boat -> opportunity and 4 Speedboats

Ground truth:

- Tracking GPS for cooperative ship
- AIS signal from the non-cooperative boat (CETMEF).
- Sea state: buoys, Signal station, Météo France, ...
#3: Quiberon bay: incidence 70°

X-band polarimetric SAR imagery \((R, G, B) = (H_h, H_v, V_v)\)
#3 : Quiberon bay : incidence 70°

X-band polarimetric SAR imagery \((R, G, B) = (Hh, Hv, Vv)\)

Opportunity boat (48m, 12 knts):

\[
\begin{align*}
\text{RCS}(Hh) &= 41.2 \text{ dBm}^2 \\
\text{RCS}(Hv) &= 22.0 \text{ dBm}^2 \\
\text{RCS}(Vh) &= 22.3 \text{ dBm}^2 \\
\text{RCS}(Vv) &= 36.9 \text{ dBm}^2
\end{align*}
\]
Sea clutter response: the physical behavior

Incidence 70°

Hh polarization

Vv polarization
#3 : Quiberon bay : incidence 70°

**X-band polarimetric SAR imagery (R, G, B) = (Hh, Hv, Vv)**

**L-band polarimetric SAR imagery (R, G, B) = (Hh, Hv, Vv)**
Sea response: multi-temporal analysis

Sea clutter $\Sigma_0$ vs Sea state
X-band, incidence 70°
Ongoing and future work

X-band SAR data now processed and calibrated

Ongoing work:

- Sea clutter response analysis (sea state, angles, polarization) – done
- Ship RCS measurements (type of boat, angles, polarization) – ongoing
- Detection capability (Ship to Clutter ratio) – to do

Future work:

- Polarization synthesis -> study the best polarization state (Em & Re)
- Detection algorithm
- Multy-frequency analysis
Conclusion

ONERA has performed an extended airborne SAR campaign of acquisition dedicated to maritime surveillance analysis

PolSAR data perfectly calibrated (amplitude and phase) at low grazing angle

A special effort has been made on ground truth (sea state, wind, boat ...)

Step 1 : Sea clutter response is being analysed,
Step 2 : Ship response will be analysed soon,
Step 3 : Detection capability study, polarization synthesis ...
Speedboats ....

X-band polarimetric SAR imagery \((R, G, B) = (Hh, Vv, Vv)\)