Using Sentinel-1 to detect aquaculture structures in Spain

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Outline

✓ Aquaculture

✓ Polarimetric detectors Models
  ✓ HV-iDPolRAD
  ✓ HH-iDPolRAD

✓ Results
  ✓ COSMO-SkyMed
  ✓ Sentinel-1

✓ Conclusions
Motivations
Aquaculture are a very **valuable asset** for many coastal countries

- The industry is worth $150bn in 2017 (Financial Times).
- In the future they will play an important role in **food security**.

**Satellite remote sensing** can improve the temporal and geo-spatial analysis of such marine facilities.

- Detecting platforms used for fish and shellfish farming provides a way to **monitor assets** and check they do not get damaged by **storms**.
- It also allows to identify **illegal placement** of structures in areas which should not host farms.

- As the most of human enterprises aquaculture is not immune to illegal activities: e.g. the illegal bluefin tuna market is double the legal market (Europol)
Aquaculture

In this work we are interested in monitoring **platforms** used for **shellfish** farms (called bateas).

We also focus on the aria of **Vigo, Spain**.
Radar polarimetry
Scattering from platforms

Credits: ESA/ATG Medialab
Scattering from platforms

- Volume scattering
- Surface scattering
- Oriented Multiple reflections

Credits: ESA/ATG Medialab
SAR polarimetry

Different targets *generally* interact in a different way when illuminated by differently polarised plane waves

We can use polarimetry to:
- Classify
- Detect
- Separate returns
Single targets: same as before, but with math

- We can arrange the 4 acquisitions discussed before in a matrix: the Scattering or Sinclair matrix.
  - H: horizontal linear
  - V: vertical linear

- The matrix will represent a transformation from transmitted polarised waves to received waves: i.e. it describe the polarimetric behaviour of the target.

The Scattering matrix is:

\[ S = \begin{pmatrix} S_{HH} & S_{HV} \\ S_{HV} & S_{VV} \end{pmatrix} \]

Cross-polarisations

Co-polarisations

Scattered (received) wave: \[ \vec{E}_r = C(r)[S]\vec{E}_i \]

Incident (transmitted) wave

Complex scalar depending on distance and medium where the wave propagates (e.g. air)
Depolarisation Anomaly Detector (DePolAD)

This algorithm is specially tailored for detection of volume.
It is based on the idea that a platform will produce an anomaly in the volume scattering.
It only needs dual pol detected images. Perfect for Sentinel-1!

\[ \Lambda = \frac{\langle |HV|^2 \rangle_{test} - \langle |HV|^2 \rangle_{train}}{\langle |HH|^2 \rangle_{train}} \]

The detector \( \Lambda \) is large if:

- HV increases between the small and large window
- If the ratio HV/HH increases between the small and large window.

Both components are indicators of volume scattering.

Differentiate between the targets based on anomalies in volume scattering.
Physical interpretation

\[ \Lambda = \rho_{ring} \frac{1 + c}{R\rho^{-1} + cRHV^{-1}} - \rho_{tot} \]

\( \rho \): cross-over-co polarization ratio, or depolarisation ratio
\( R\rho \): ratio between \( \rho \) in the test window over the ring window
\( RHV \): ratio between HV intensity in the test window over the ring window
\( c \): ratio between number of samples in the total area over the test area

\checkmark If the target does not change between ring and test, than \( \Lambda \) is zero

\[ \Lambda_{\text{homogeneous}} = \rho \frac{1 + c}{1 + c} - \rho = 0 \]

\checkmark If the volume/reflection increases between ring and test, than \( \Lambda \) is positive and large

\[ \checkmark R\rho \text{ and } RHV \text{ will be very large} \quad \lim_{R\rho, RHV \to \infty} \Lambda = \rho_{ring} \frac{1 + c}{0 + c0} - \rho_{tot} = \infty \]

\checkmark If the volume/reflection decreases between ring and test, than \( \Lambda \) is negative

\[ \lim_{R\rho, RHV \to 0} \Lambda = \rho_{ring} \frac{1 + c}{\infty + c\infty} - \rho_{tot} = -\rho_{tot} \]
Intensity DePolAD (iDPolRAD)

✓ The detector DPolRAD is **normalised**.
  ✓ In some situations it may be better to work with not normalised distances.

✓ We can use DPolRAD to obtain an **intensity image with enhanced contrast** platform vs sea and use this as the distance

\[
I_{HV} = \left( \frac{\langle |HV|^2 \rangle_{test} - \langle |HV|^2 \rangle_{train}}{\langle |HH|^2 \rangle_{train}} \right) \langle |HV|^2 \rangle_{test}
\]

✓ If there is an **increase** of volume the pixels will be multiplied by a **large number**. If it is **homogeneous** or there is a **decrease**, the pixel is multiplied by a **small number**.
For some target, the HV does not scatter much, although they are mostly composed by volume scattering.

Using the HH intensity may be more advantageous. We combine:

- the reduction of background of DPolRAD
- The stronger target return of HH

\[ I_{HH} = \left( \frac{\langle |HV|^2 \rangle_{test} - \langle |HV|^2 \rangle_{train}}{\langle |HH|^2 \rangle_{train}} \right) \langle |HH|^2 \rangle_{test} \]

If there is an increase of volume the pixels will be multiplied by a large number. If it is homogeneous or there is a decrease, the pixel is multiplied by a small number.
Results
Shellfish farm locations

They are located in the Rias of Vigo and Pontevedra (Galicia, NW Spain)
In the following we will concentrate on the red area

We will compare two acquisitions:

- 29/12/2018: Wind speed 15 km/h, direction 75°. No rain
- 1/1/2019: Wind speed 5 km/h, direction 100°. No rain
Sentinel-1 data: HV

X magnitude

0.0000
0.0001
0.0002
0.0003
0.0004
0.0005
Sentinel-1 data: HH-iDPoIRAD
Sentinel-1 data: iDoIRAD
Sentinel-1 data: ROC curves

Doing a 1x4 average

We used validation data to evaluate the probabilities
Sentinel-1 data

We applied a Cell-Averaging-CFAR, visually there are many missing targets.
We applied a Cell-Averaging-CFAR, visually there are many missing targets
Acquired on the 1\textsuperscript{st} January 2019. The resolution is 10x10m
COSMO SkyMed Pingpong

[iDPolAD]

[iDPolAD HH]

[iDPolAD CA-CFAR]

[iDPolAD-HH CA-CFAR]
COSMO SkyMed Pingpong: ROC

ROC curves

Red: Co
Green: Cross
Blue: iDPolRAD
Yellow: HH-iDPolRAD

Probability of False Alarms
Probability of detection

0.000 0.025 0.050 0.075 0.100 0.125 0.150 0.175 0.200

0.800 0.825 0.850 0.875 0.900 0.925 0.950 0.975 1.000
Conclusions

✓ We tested the iDPolRAD ship detector for the detection of shellfish platforms

✓ The methodology improves the contrast, ROC curve and CA-CFAR detection
  ✓ However, the CA-CFAR is still missing several platforms.

✓ Sentinel-1 seems to provide very good detection performance despite the lower resolution of COSMO-SkyMed

Future work:

✓ We need to design a local methodology that detect targets very close to each other.
Thank you very much for your attention.

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