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Oil spill detection in compact polarimetry images

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Motivation & challenges

- It has been demonstrated that the use of polarimetric SAR
  - increases the oil spill detection performance
  - makes it possible to discriminate oil slicks from biogenic slicks (Migliaccio et al., 2009)
- In particular, the use of the co-polarized phase difference (CPD) between the VV and HH channels have shown to provide additional discrimination (Migliaccio et al., 2009)

Challenges:

- Limited spatial coverage of SAR images with CPD
  - Radarsat-2 quad-pol covers only 25x25 km !
- No polarimetric SAR images with CPD suitable for large-scale operational oil spill monitoring

Motivation & challenges

- Goal of compact polarimetry is to realize many (but not all) benefits of quad-pol, without the reduced swath width
- The coming C-band Radarsat Constellation Mission will be particularly tailored to compact polarimetry
  - maritime imaging mode with a swath width of 350 km and a resolution of 50 m
  - low noise mode with the same swath width and a resolution of 100 m.

Aim of this work

- Construct methodology for oil spill detection in compact polarimetry SAR images, and at the same time keeping the quad-pol discrimination properties of the CPD

Outline

- Compact polarimetry
- X-Bragg scattering
- Oil spill detection
  - Using measures for surface roughness and relative permittivity
  - Using compact polarimetry
- Results
- Conclusion

Compact polarimetry

- Received SLC pixel values in H- and V-channels

$$\mathbf{r}_p = \begin{bmatrix} E_{pH} \\ E_{pV} \end{bmatrix} = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \mathbf{u}_p$$

- (Right) circular transmit, linear receive (CTLR)

$$\mathbf{u}_R = 1/\sqrt{2}[1, -i]^T$$

- Assume that: $\mathrm{E}\{S_{VV} S_{HV}^*\} = 0$
- Covariance matrix of $\boldsymbol{r}_p$:

$$\mathbf{C}_{CTLR} = \frac{1}{2}\mathrm{E}\left\{\begin{bmatrix} |S_{HH}|^2 & i(S_{HH} \cdot S_{VV}^*) \\ -i(S_{VV} \cdot S_{HH}^*) & |S_{VV}|^2 \end{bmatrix}\right\} + \frac{1}{2}\mathrm{E}\left\{\begin{bmatrix} |S_{HV}|^2 & -i|S_{HV}|^2 \\ i|S_{HV}|^2 & |S_{HV}|^2 \end{bmatrix}\right\}. \quad (6)$$

Compact polarimetry

- Polarimetry state extrapolation (Souyris et al., 2005)
  - Aim:Estimate $X=|S_{HV}|^2$ from the CTLR-data
  - Constraint:

$$\frac{\langle |S_{HV}|^2 \rangle}{\langle |S_{HH}|^2 \rangle + \langle |S_{VV}|^2 \rangle} = \frac{1-|\rho|}{4}$$

$$\rho = \frac{\langle S_{HH} S_{VV}^* \rangle}{\sqrt{\langle |S_{HH}|^2 \rangle \cdot \langle |S_{VV}|^2 \rangle}}$$

  - Iterations:

$$\rho_{(i+1)} = \frac{iC_{12} + X_{(i)}}{\sqrt{(C_{11} - X_{(i)})(C_{22} - X_{(i)})}}$$

$$X_{(i+1)} = \frac{C_{11} + C_{22}}{2} \cdot \left(\frac{1 - |\rho_{(i+1)}|}{3 - |\rho_{(i+1)}|} \right)$$

  - Reconstruction: $\widehat{\mathbf{C}} = \begin{bmatrix} C_{11} - X & 0 & iC_{12} + X \\ 0 & 2X & 0 \\ (iC_{12} + X)^* & 0 & C_{22} - X \end{bmatrix}$

Bragg scattering model

- For large angle of incidence (20°-60°), the scattering mechanisms at the sea surface is often assumed to be Bragg

$$\mathbf{S}_B = m_s \begin{bmatrix} B_{HH}(\epsilon,\phi) & 0 \\ 0 & B_{VV}(\epsilon,\phi) \end{bmatrix}$$

$$B_{HH} = \frac{\cos\phi - \sqrt{\epsilon - \sin^2\phi}}{\cos\phi + \sqrt{\epsilon - \sin^2\phi}} \quad \text{and}$$

$$B_{VV} = \frac{(\epsilon - 1)(\sin^2\phi - \epsilon(1 + \sin^2\phi))}{\left(\epsilon\cos\phi + \sqrt{\epsilon - \sin^2\phi}\right)^2}$$

- Since S_{HV} is zero under Bragg, we have that:

$$\mathbf{r}_p = [S_{HH}, S_{VV}]^T = m_s[B_{HH}, B_{VV}]^T$$

X-Bragg scattering model

- Bragg model does not describe non-zero cross-pol and depolarization $\longrightarrow$ X-Bragg
- Introducing a roughness disturbance by tilting the mean reflection plane

$$\mathbf{S}_{XB} = \mathbf{R}(\theta)\mathbf{S}_B\mathbf{R}^T(\theta),$$

$$\mathbf{R}(\theta) = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$$

We often assume that θ is uniformly distributed between $-\beta$ and β.

β – describes the degree of roughness.

- Received data assuming X-Bragg

$$E_{RH} = B_{HH}\cos^2\theta + B_{VV}\sin^2\theta + i(B_{HH} - B_{VV})\cos\theta\sin\theta$$

$$E_{RV} = -iB_{HH}\sin^2\theta - iB_{VV}\cos^2\theta - (B_{HH} - B_{VV})\cos\theta\sin\theta$$

X-Bragg and CTLR-mode

- Propose to consider the quanties:

$$E_{RH} + iE_{RV} = B_{HH} + B_{VV}$$
$$E_{RH} - iE_{RV} = (B_{HH} - B_{VV})\exp(i2\theta)$$

- Corresponding covariance matrix:

$$\mathbf{D} = \begin{bmatrix} D_{11} & D_{12} \\ D_{12}^* & D_{22} \end{bmatrix}$$

$$\begin{aligned} D_{11} &= \langle |E_{HH} + iE_{VV}|^2 \rangle = \langle |B_{HH} + B_{VV}|^2 \rangle \\ D_{22} &= \langle |E_{HH} - iE_{VV}|^2 \rangle = \langle |B_{HH} - B_{VV}|^2 \rangle \\ D_{12} &= \langle (E_{HH} + iE_{VV})(E_{HH} - iE_{VV})^* \rangle \\ &= \langle (B_{HH} + B_{VV})(B_{HH} - B_{VV})^* \rangle \langle \exp(-i2\theta) \rangle \end{aligned} \quad (23)$$

D_{11} and D_{22} only depend on B_{HH} and B_{VV}

D_{12} only depend on θ via the average of complex exponentials

Oil spill detection – quad-pol data

- Two interesting features for oil spill detection (see poster by Rudjord and Salberg, *SeaSAR-2012*)

$$RP = \frac{T_{22} + T_{33}}{T_{11}} = \frac{\langle |B_{HH} - B_{VV}|^2 \rangle}{\langle |B_{HH} + B_{VV}|^2 \rangle}$$

Relative permittivity

$$Coh = \frac{|T_{12}|}{\sqrt{T_{11} T_{22}}} = \frac{\mathrm{sinc}(2\beta)}{\sqrt{\frac{1+\mathrm{sinc}(4\beta)}{2}}}$$

Coherence between S_{HH}+S_{VV} and S_{HH}-S_{VV}

  - ***T*** is the quad-pol coherency matrix

- *RP* depends only on the relative permittivity (and the incidence angle)

- *Coh* depends only on the surface roughness

Oil spill detection – CTLR-data

- The *RP*-measure may be exactly reconstructed from the CTLR-data

$$RP = \frac{D_{22}}{D_{11}} = \frac{\langle |B_{HH} - B_{VV}|^2 \rangle}{\langle |B_{HH} + B_{VV}|^2 \rangle}$$

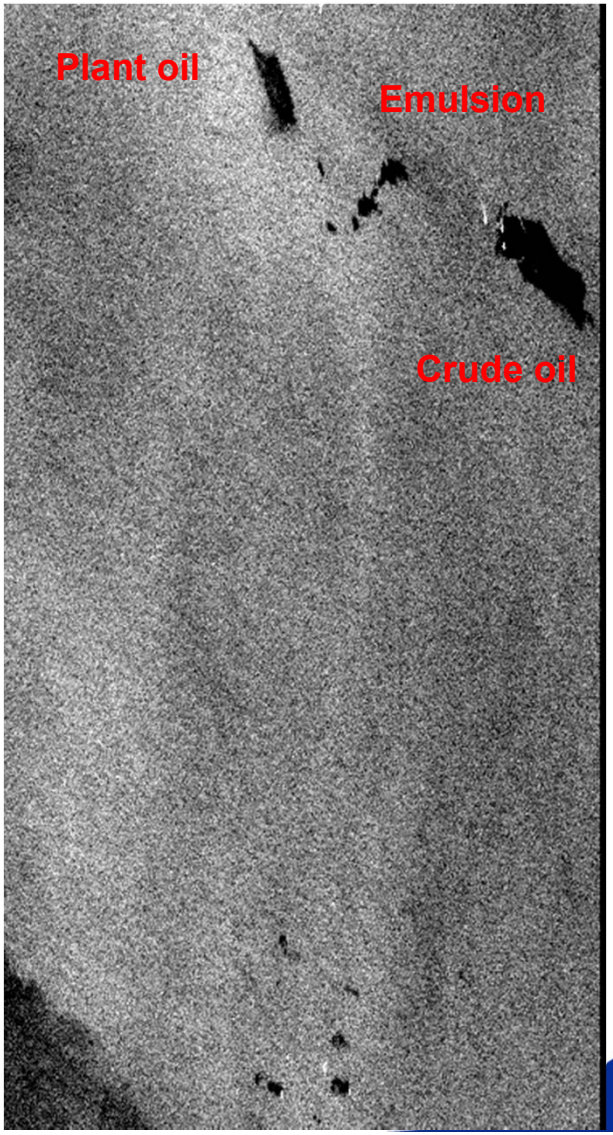
- A similar *Coh*-measure may be constructed as

$$Coh = \frac{|D_{12}|}{\sqrt{D_{11} D_{22}}} = \mathrm{sinc}(2\beta)$$

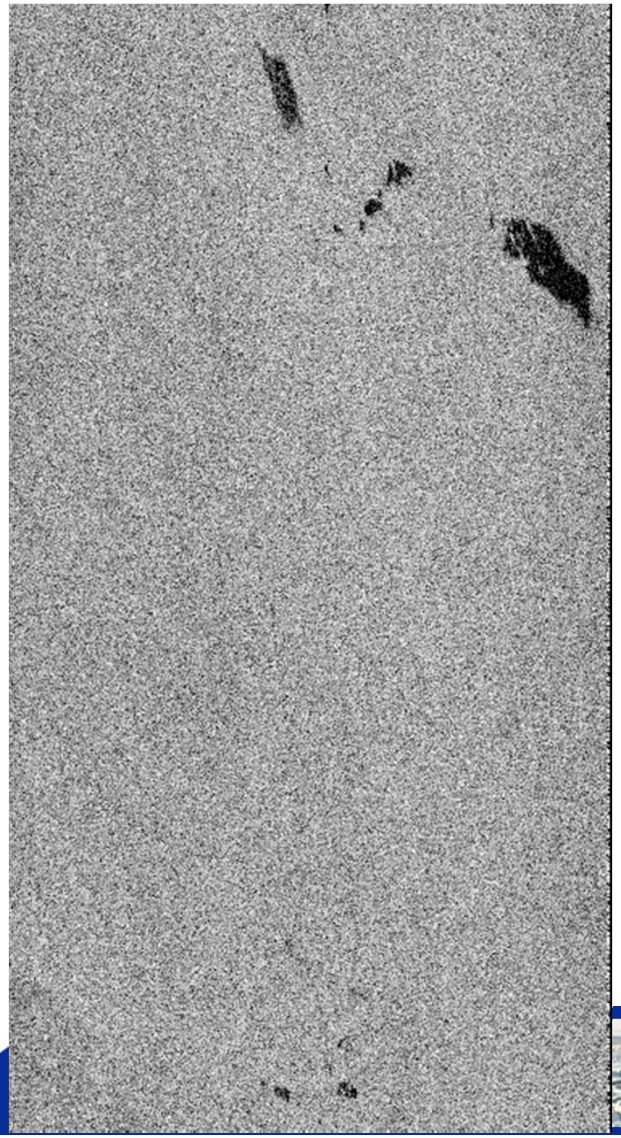
- Other features like the *coformity index* may also be constructed (Zhang et al., 2011; Truong-Loï et al., 2009)

Results – Oil spill exercise

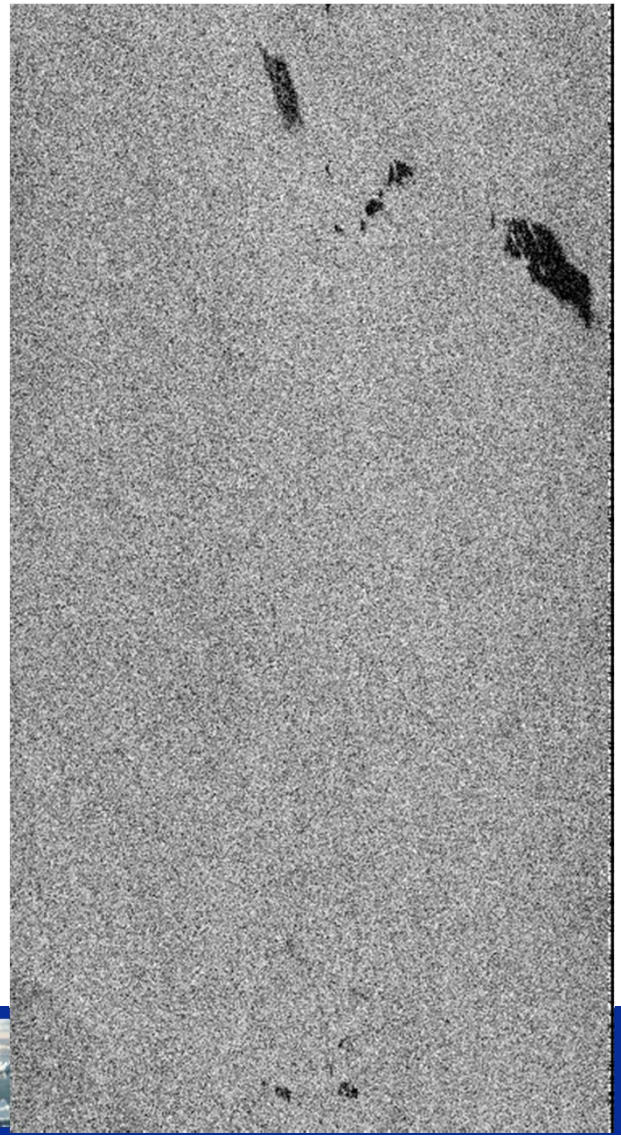
VV-image



***Coh*-image, quad-pol**



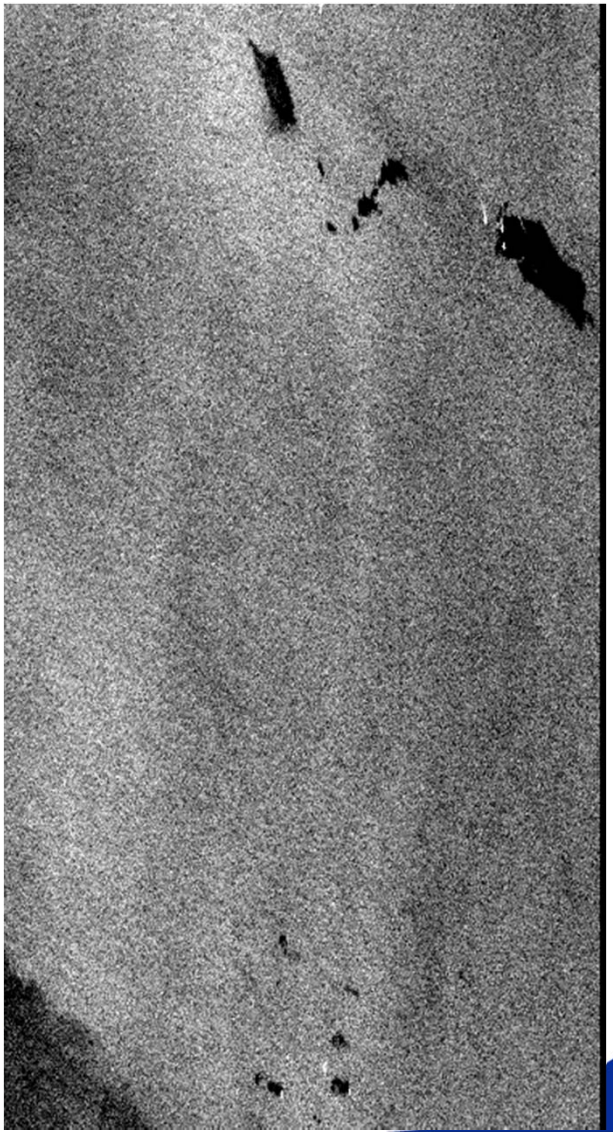
***Coh*-image, CTLR**



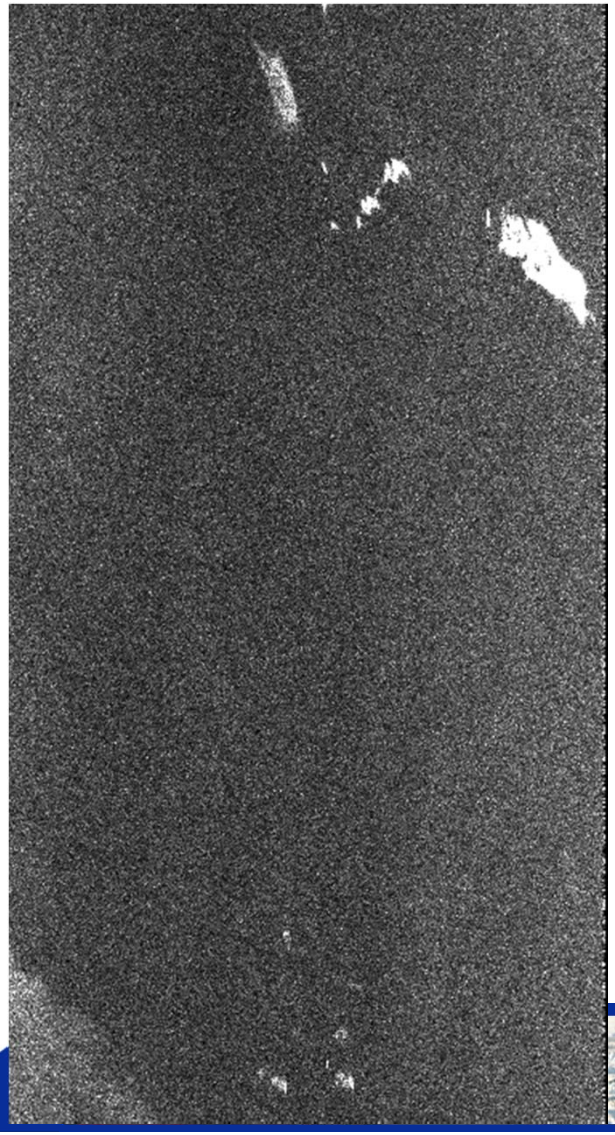
Results – Oil spill exercise

June 8, 2011

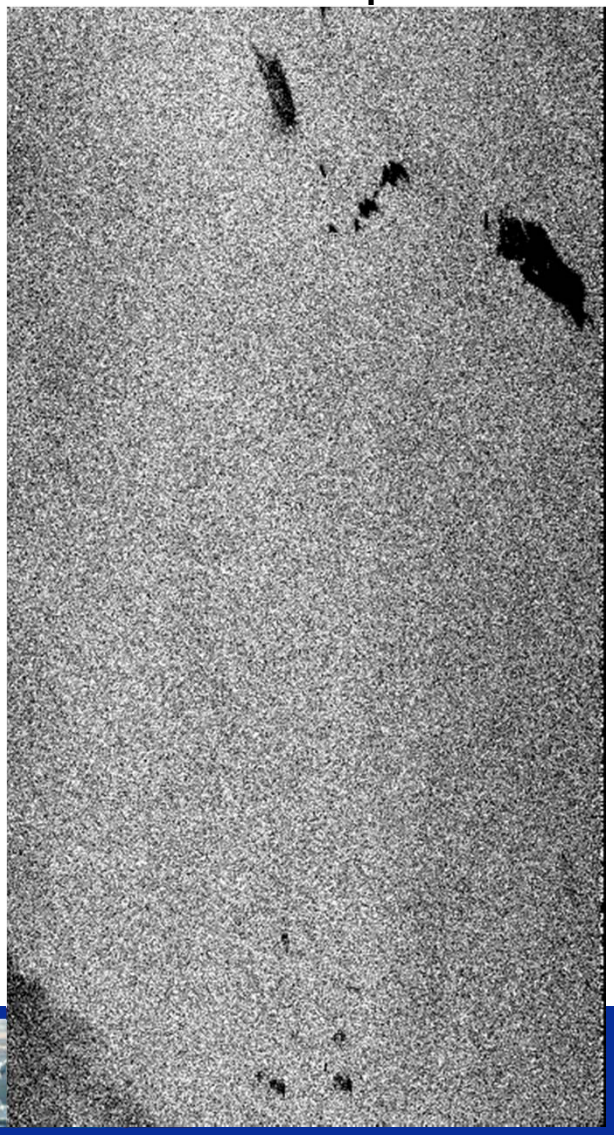
VV-image



***RP*-image, CTLR**



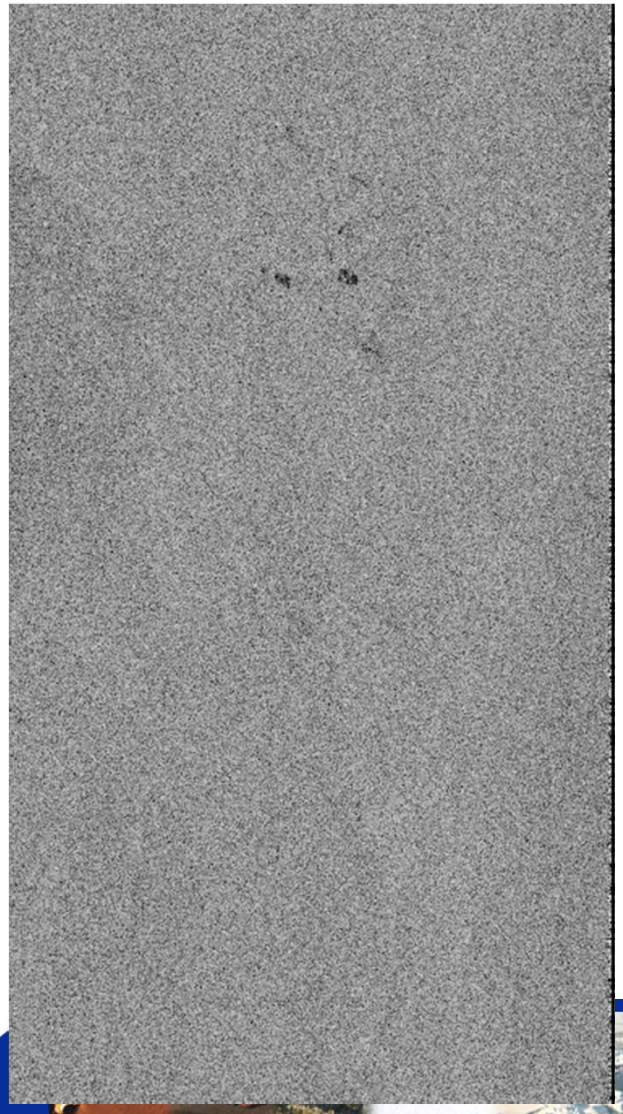
***RP*-image, CTLR, Pol. state extrapolation**



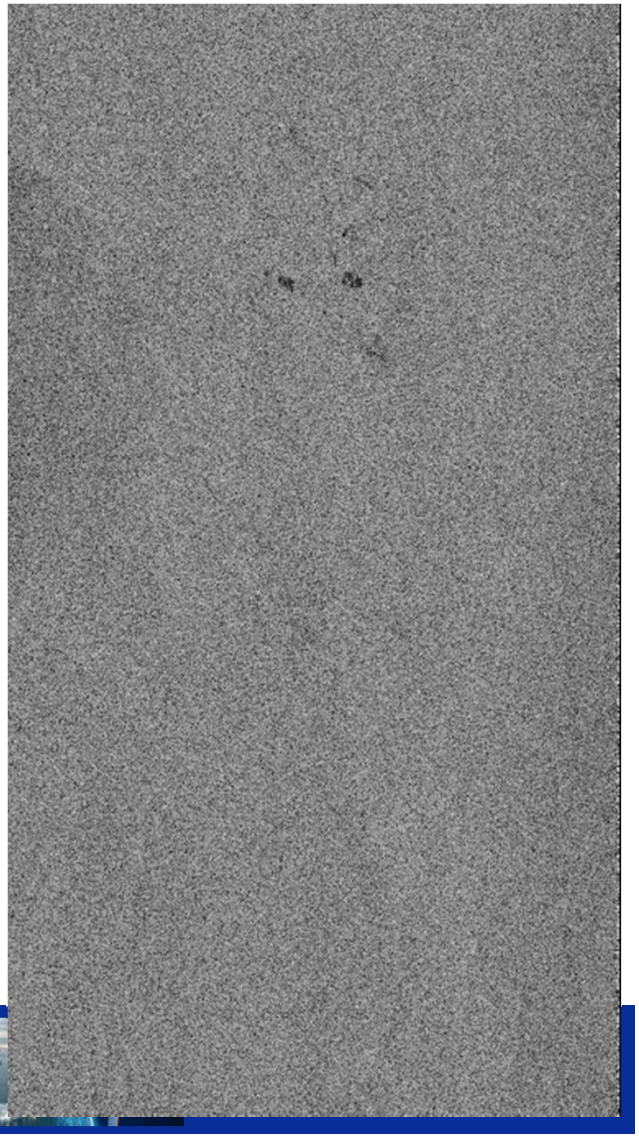
Results – Clean sea, June 8, 2011

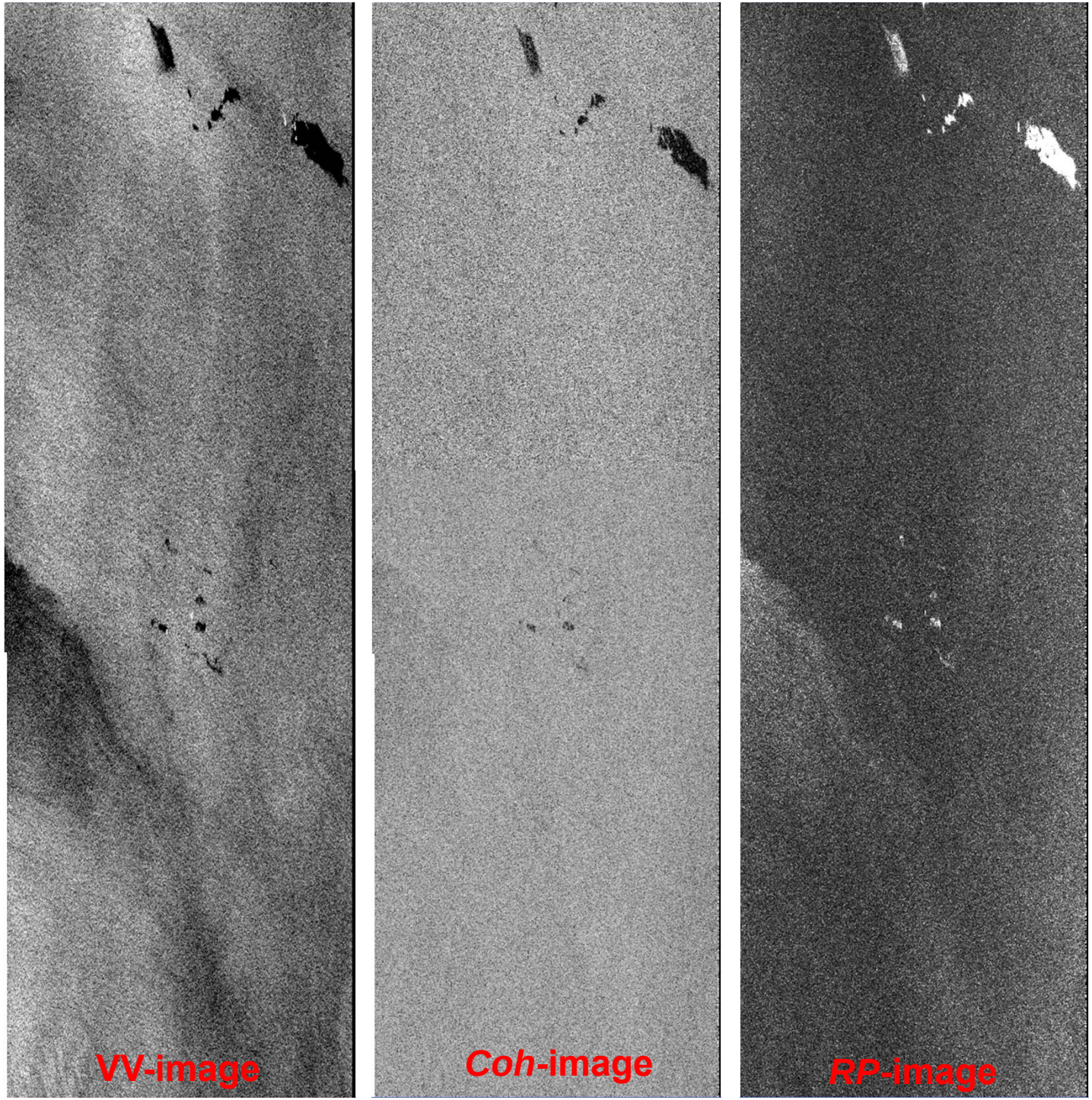
VV-image

***Coh*-image, quad-pol**



***Coh*-image, CTLR**



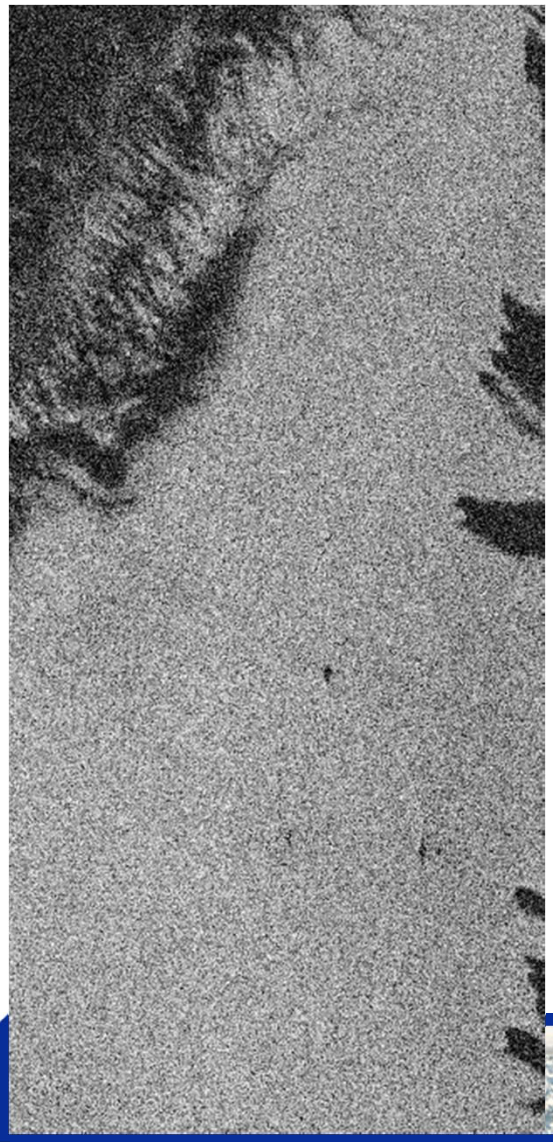

VV-image
Coh-image
RP-image

Results – Gulf of Mexico

May 15,2010

VV-image

***Coh*-image, quad-pol**

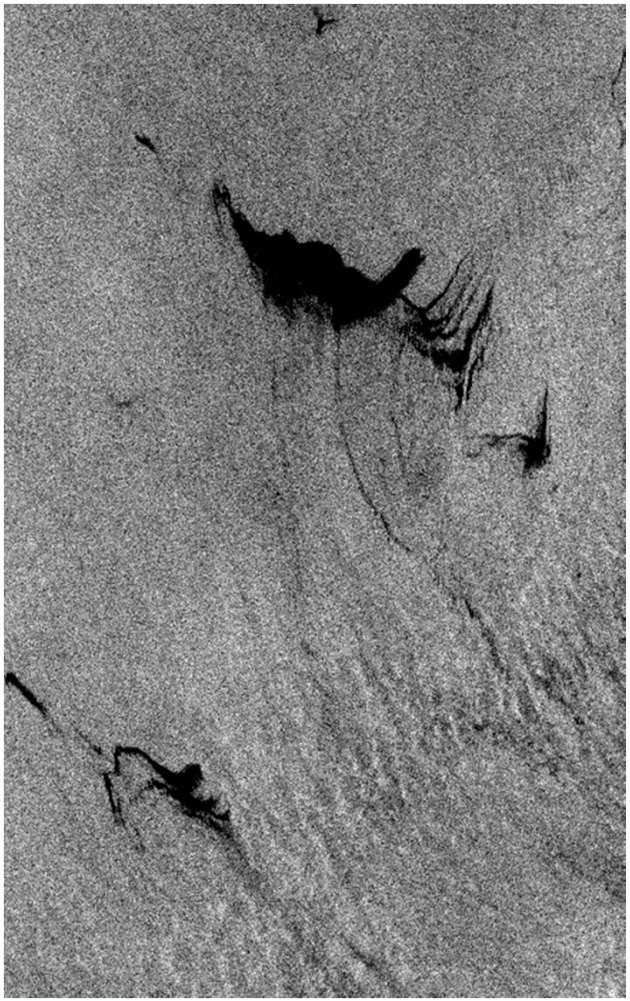


***Coh*-image, CTLR**

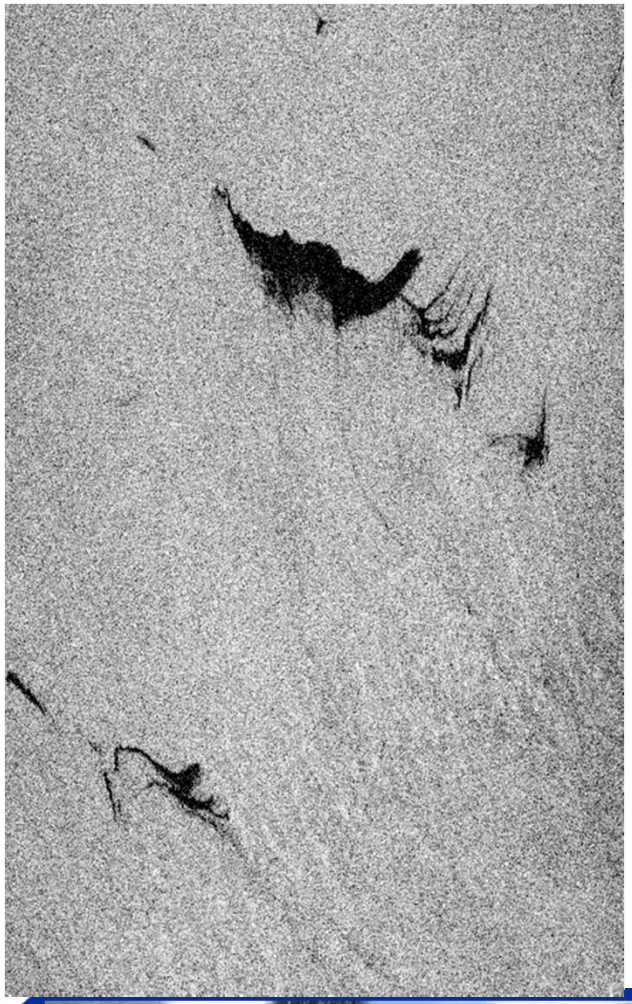
Results – Gulf of Mexico

May 8, 2010

VV-image



***Coh*-image, quad-pol**



***Coh*-image, CTLR**

Conclusions

- We have demonstrated that by proper processing of the CTRL-data, we may obtain similar oil spill detection results as obtained using quad-pol SAR data.
- The coherence between $S_{HH}+S_{VV}$ and $S_{HH}-S_{VV}$ have proved to be a very interesting feature for discrimination of oil slicks from lookalikes, for both quad-pol and CTLR-data
  - may be derived from the CTLR SAR data without any additional assumptions
- Closed from solution of *RP,* which was not achieved in the $\pi/4$-mode method proposed by (Williams, 2008).
- Additional processing for ship detection necessary

Anknowledgement

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