Towards Oil Slick Monitoring in the Arctic Environment

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NEW/THIN ICE COULD RESEMBLE OIL IN MIZ

Radarsat-2 June 2011

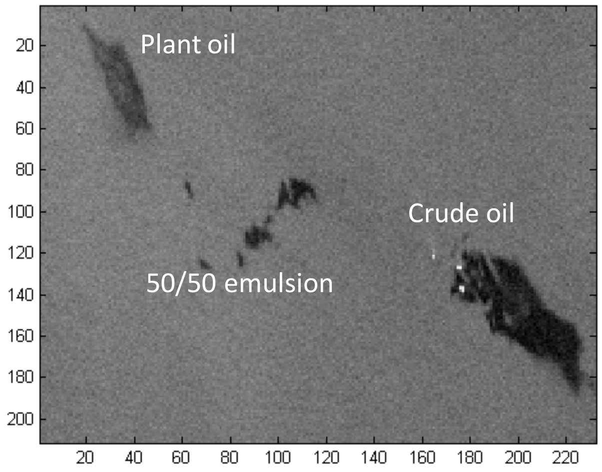


Photo: Kustbevakningen

ENVISAT November 2004

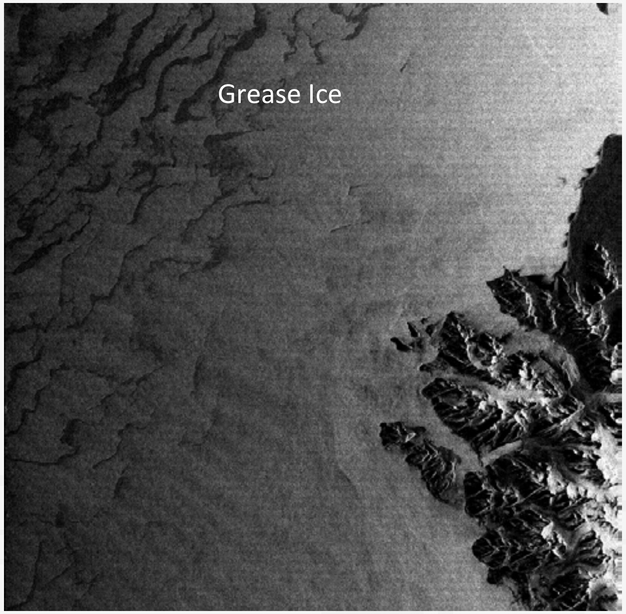


Photo: Benjamin Holt (JPL)

Both oil slicks and new/thin ice dampens Bragg waves and produces low NRCS.

Can multi-pol. and multi-frequency SAR data discriminate unmixed newly frozen sea ice from oil emulsified with sea water at the freezing point (-1.8˚C, salinity 33 ‰)?

OUTLINE OF TALK

Theory:

- Dielectric properties of relevant media
- Mixture modeling of oil/sea ice
- Co-polarization ratio

Analysis of real SAR data:

- RADARSAT-2: Oil pollution
- UAVSAR: Oil pollution
- AIRSAR: New/thin sea ice types

Summary

MIXTURE MODELING

Complex relative permittivity:

$$\varepsilon = \varepsilon^{'} - i\varepsilon^{''}$$

$i = \sqrt{-1}$

ε': real permittivity.

ε'': dielectric loss factor.

Linear mixture model (Ulaby et al., 1986):

$$\varepsilon_m^{\alpha} = \varepsilon_h^{\alpha} + v_o\left(\varepsilon_o^{\alpha} - \varepsilon_h^{\alpha}\right)$$

α = 1: linear model

ε_h: relative permittivity of unmixed sea ice (host material).

ε_o: relative permittivity of unmixed oil.

v_o: volume fraction of oil in the mixture.

DIELECTRIC PROPERTIES OF UNMIXED OIL AND ICE

Sea ice:

Dielectric properties of sea ice relative to brine volume, from Carsey (Ed.) (1992):

Frequency	ε'	ε''
1 GHz	$3.12 + 0.009 \cdot V_b$	$0.04 + 0.005 \cdot V_b$
4 GHz	$3.05 + 0.0072 \cdot V_b$	$0.02 + 0.0033 \cdot V_b$
10 GHz	$3.0 + 0.012 \cdot V_b$	$0.0 + 0.01 \cdot V_b$

Volume fraction of brine in sea ice, -0.5˚C>=T>=-22.9 ˚C , from Ulaby et al. (1986):

$$V_b = 10^{-3} S_i \left(-\frac{49.185}{T} + 0.532 \right)$$

where S_i is the salinity in ‰ of the sea ice mixture.

Oil pollution:

Dielectric peroperties of oil, from Minchew et al. (2012):

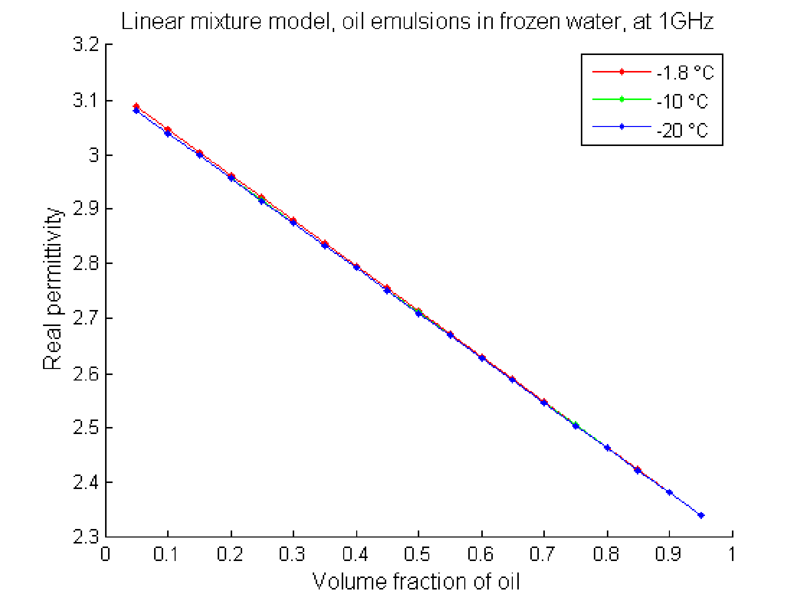
$$\varepsilon_r = 2.3 - i0.02$$

The dependence of the relative permittivity of oil on temperature is considered negligible.

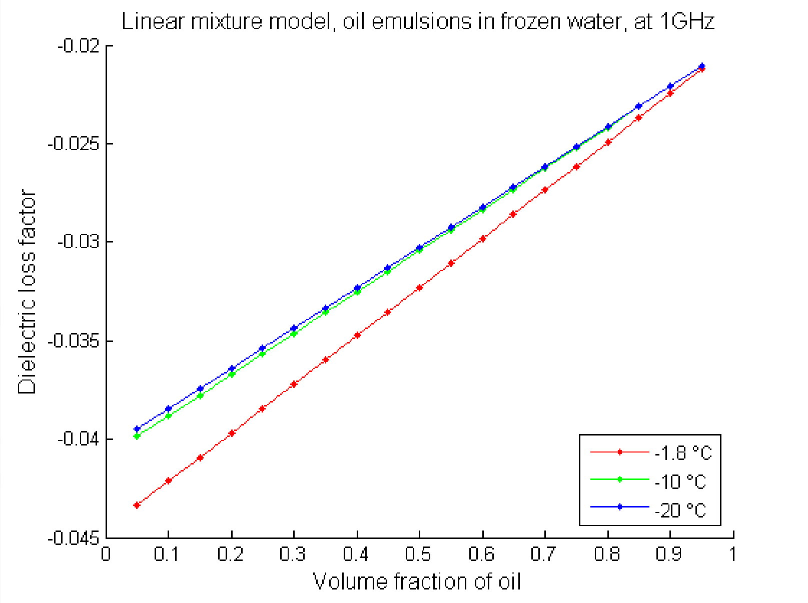
LINEAR MIXTURE MODELING - OIL IN SEA ICE

Unmixed values

Oil	Sea ice $-1.8^\circ C$	Sea ice $-10^\circ C$	Sea ice $-20^\circ C$
2.3-i0.02	3.1283-i0.0446	3.1216-i0.0409	3.1209-0.0405



Real part decreases



Imaginary part increases (less negative)

<u>Increased oil volume fraction in the mixture:</u>

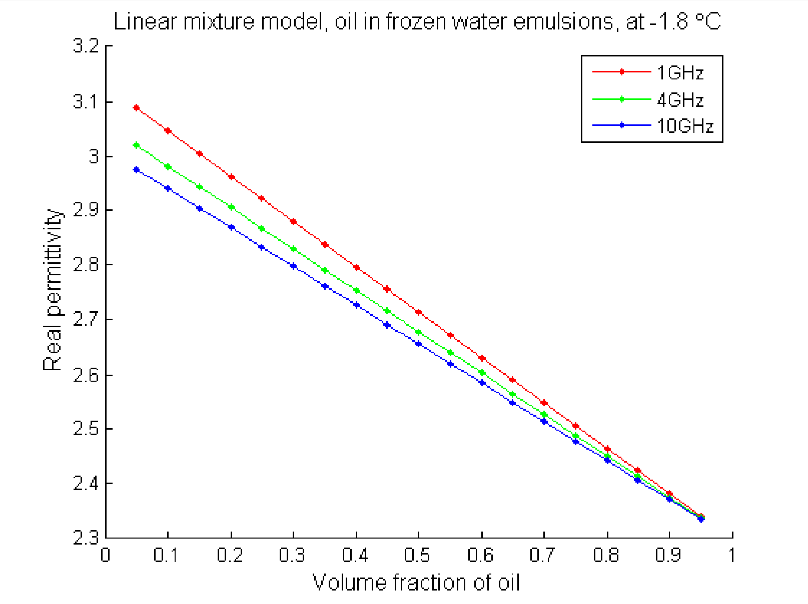
-> real part moderately affected.

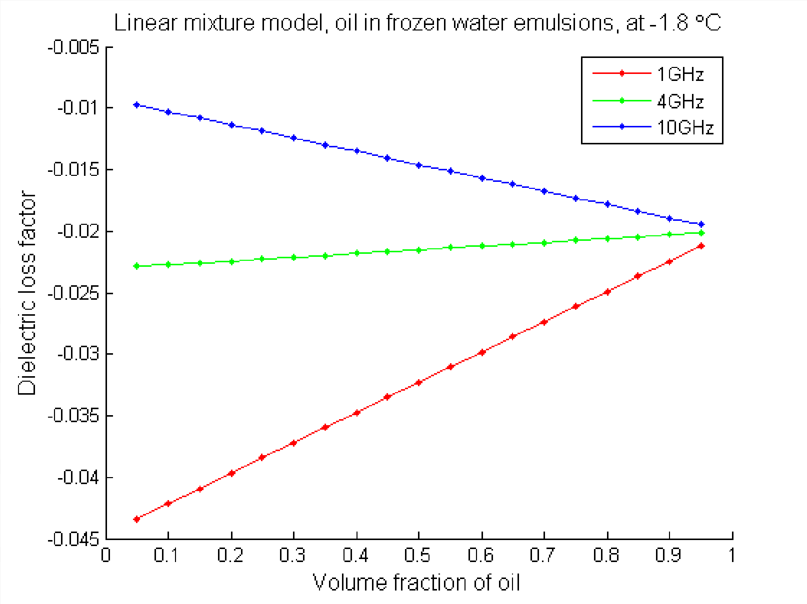
-> attenuation of signal in medium reduced.

LINEAR MIXTURE MODELING - OIL IN SEA ICE

Unmixed values

Oil	Sea ice 1 GHz	Sea ice 4 GHz	Sea ice 10 GHz
2.3-i0.02	3.1283-i0.0446	3.0566-i0.0230	3.0110-i0.0092





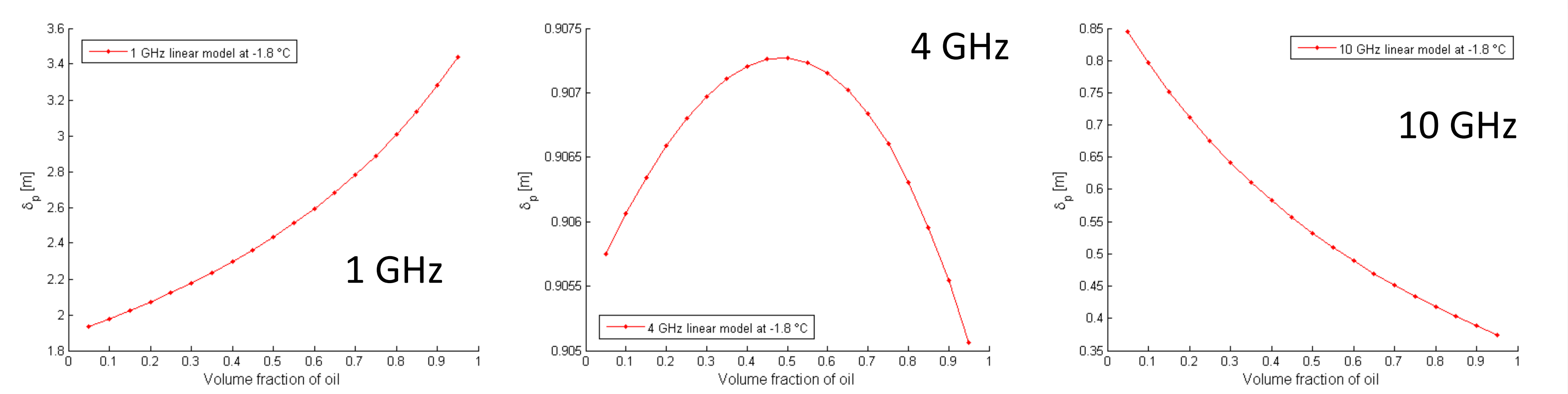
The dielectric loss factor is sensitive to frequency.

PENETRATION DEPTH

Depth at which radiation falls off to a certain level.

$$\delta_p = \frac{c}{2\omega \left| \mathrm{Im}\left\{ \sqrt{\varepsilon_r} \right\} \right|}$$

δ_p: penetration depth.
ε_r: complex dielectric constant.
c: speed of light in vacuum.
ω: radian frequency of radiation.



L-band: increasing penetration depth into mixture as a function of oil volume fraction.

CO-POL RATIOS FOR RELEVANT MEDIA

Scattering matrix for a Bragg surface scatterer (slightly rough untilted surface):

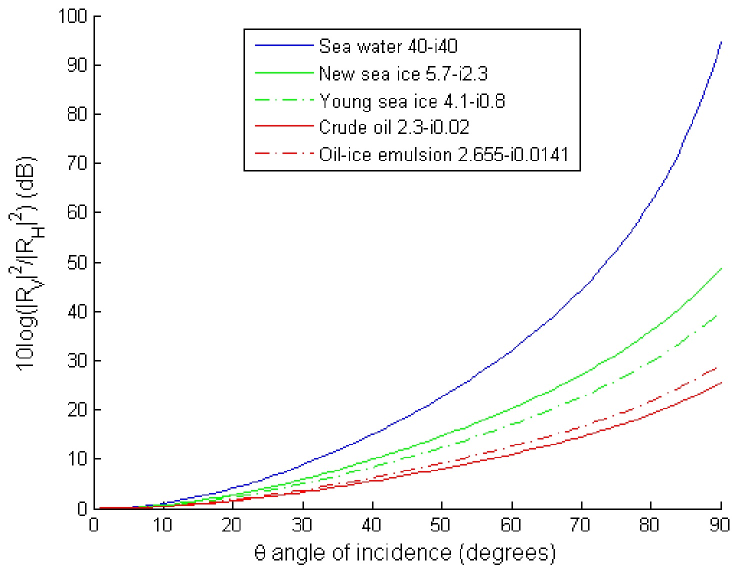
$$S = \begin{bmatrix} R_H(\theta,\varepsilon_r) & 0 \\ 0 & R_V(\theta,\varepsilon_r) \end{bmatrix}$$

$$R_H(\theta,\varepsilon_r) = \frac{\cos(\theta) - \sqrt{\varepsilon_r - \sin^2(\theta)}}{\cos(\theta) + \sqrt{\varepsilon_r - \sin^2(\theta)}}$$

$$R_V(\theta,\varepsilon_r) = \frac{(\varepsilon_r - 1)(\sin^2\theta - \varepsilon_r(1+\sin^2\theta))}{(\varepsilon_r\cos\theta + \sqrt{\varepsilon_r - \sin^2\theta})^2}$$

Co-polarization ratio:

$$\frac{|R_V(\theta,\varepsilon_r)|^2}{|R_H(\theta,\varepsilon_r)|^2}$$

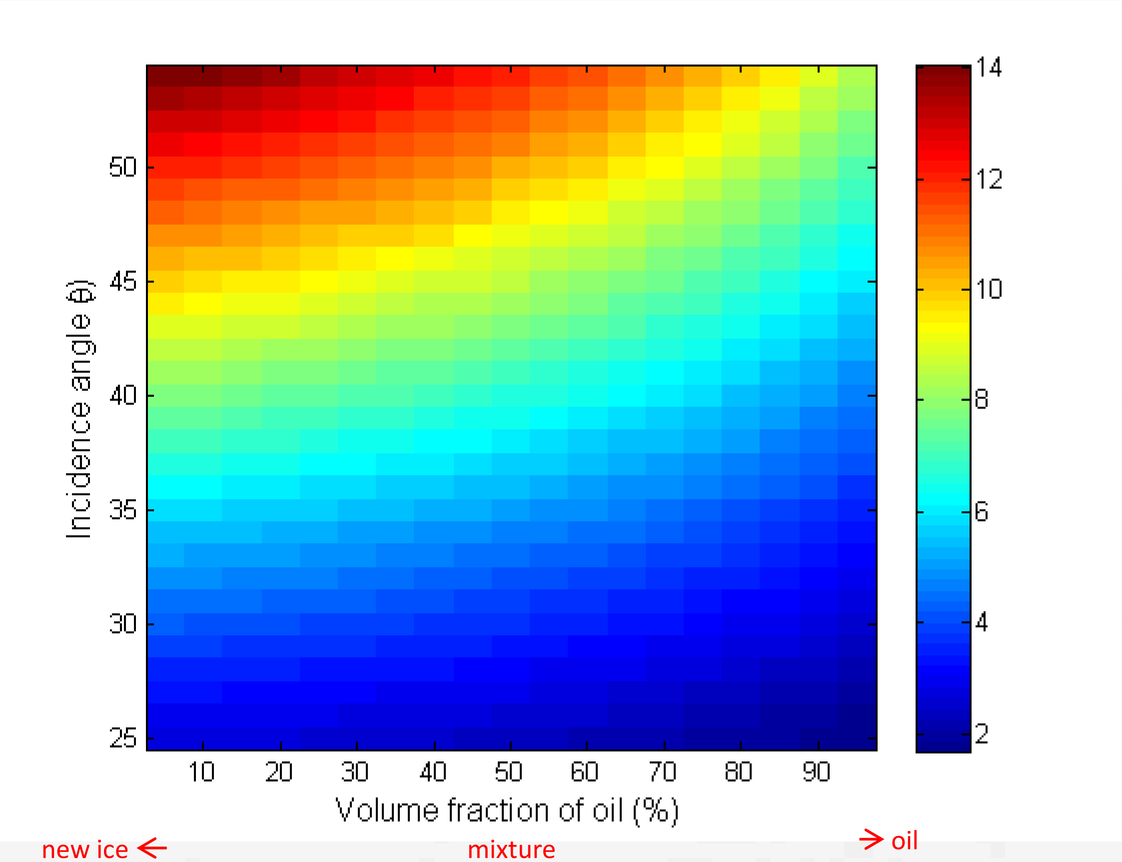


The co-pol ratio is independent of roughness and increases with θ dependent upon the complex relative permittivity of the surface.

<u>Observations:</u>

- New ice is closer to sea water while young ice is closer to 50/50 oil-ice mixture and crude oil.
- The distinction between the different media becomes more pronounced as θ increases.

CO-POL RATIOS FOR MIXTURES OF OIL-IN-ICE

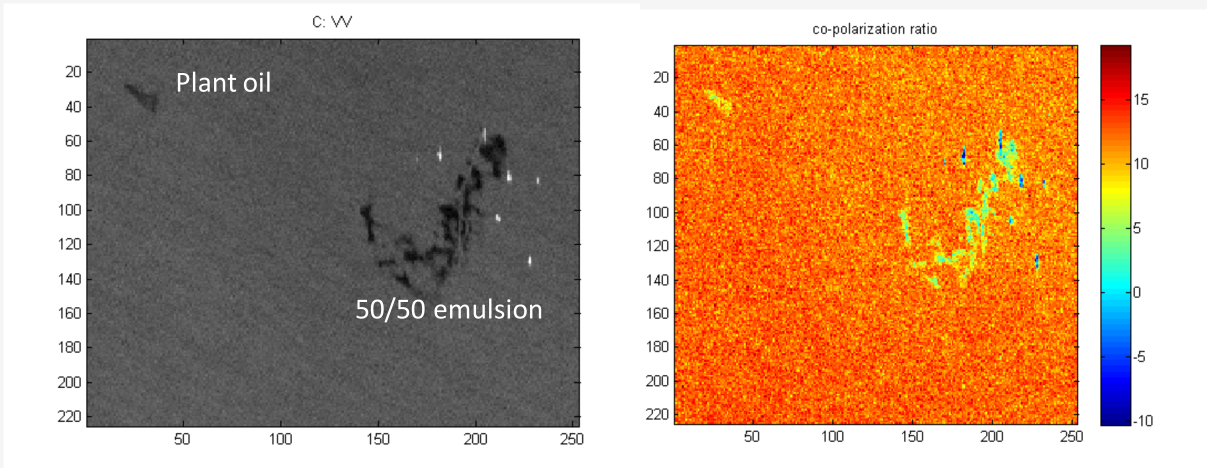


Larger θ and larger oil %: Better contrast between oil emulsion and unmixed ice (several dB).
Smaller θ and smaller oil %: Oil emulsion becomes indistinguishable from unmixed ice.

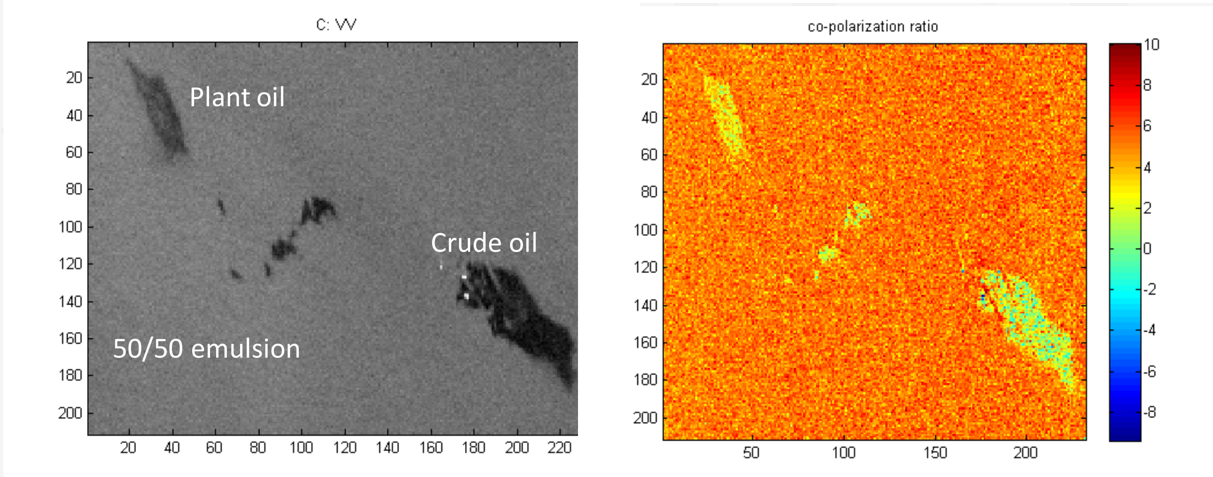
OIL SLICK EXPERIMENT AT SEA – RADARSAT2

North Sea Experiment - June 2011. C-band VV/HH.

8 June 2011 05:58 UTC RS2 FQ
ϴ: 46.4 - 47.1 deg .



8 June 2011 17:27 UTC RS2 FQ
ϴ: 35.1 - 36.1 deg .



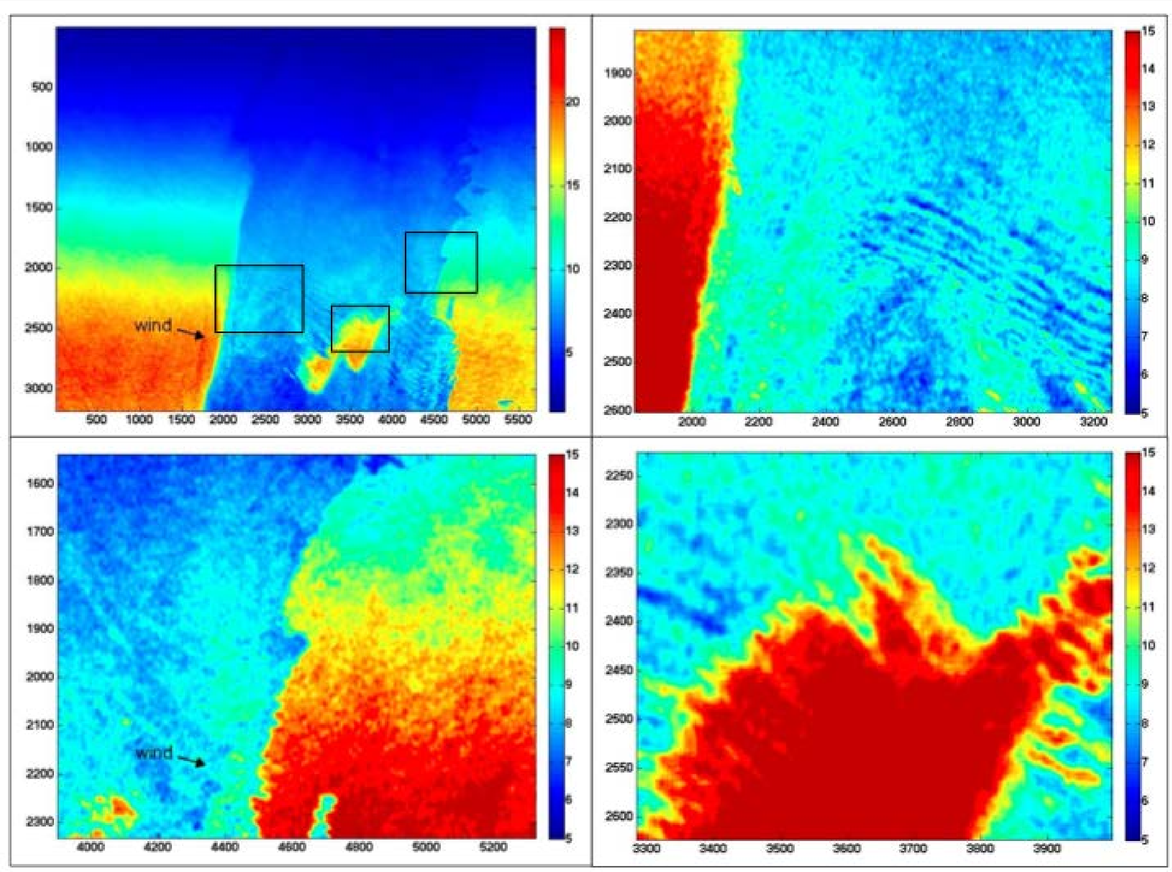
Both mineral and monomolecular slicks discriminated from sea water, Skrunes et al. (2012).

OIL POLLUTION AT SEA – UAVSAR

Deepwater horizon accident, Gulf of Mexico - June 2010. L-band VV/HH.

UAVSAR 23 June 2010.
Θ: 23 – 65 deg.

Better contrast between oil and water at larger θ.



Wind-rows and internal variations visible.

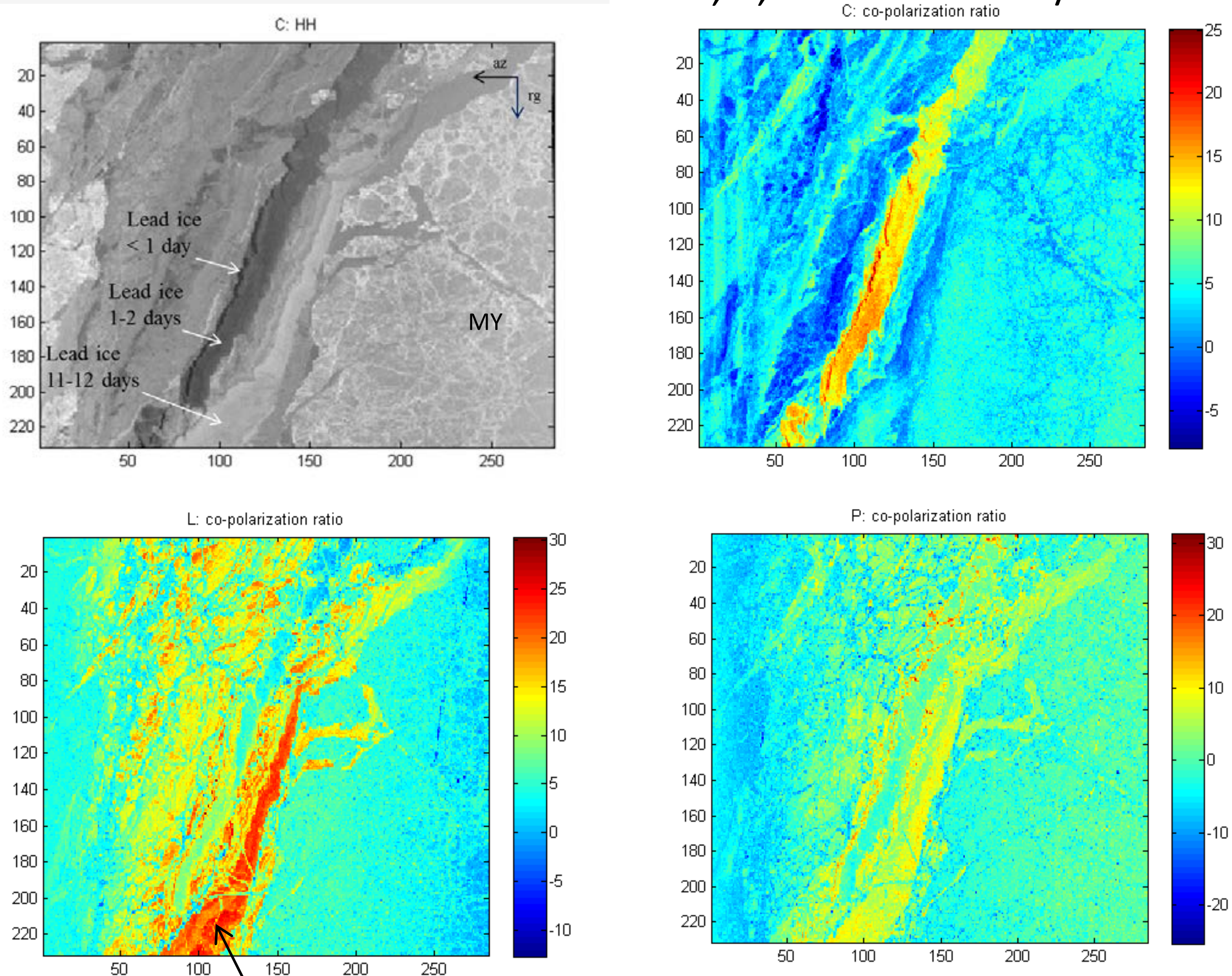
UAVSAR L-band co-pol ratio sensitive to the oil volume fraction.

Oil % sucessfully estimated by fitting co-pol ratio to the tilted Bragg model, Minchew et al (2012).

NEW AND YOUNG LEAD ICE - AIRSAR

Beaufort Sea - 2 December 2004. C-,L-, and P-band VV/HH.

Beaufort sea
2 December
2004.



Roughned by frost flowers high in salinity?

<u>C-band:</u>
Highlights lead ice that is young and thin (0-9 cm).

<u>L-band:</u> Highlights lead ice types that are a few days older and thicker (25-36 cm).

<u>P-band</u>:
Less interesting for this purpose?

PRELIMINARY CONCLUSIONS

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Theory:

- Greater penetration depth into oil-ice mixture for L-band.
- Oil-ice mixtures have lower relative permittivity and lower VV/HH ratio than unmixed new/thin and young sea ice.
- Better unmixed ice vs. oil-ice emulsion separability at larger θ and larger oil %.

C-band (4 GHz):

- VV/HH ratio low for plant oil, oil-water emulsion and crude oil as compared to open sea water.
- VV/HH ratio high for new/thin sea ice compared to older ice types.

L-band (1 GHz):

- VV/HH ratio sensitive to oil volume fraction (oil-water emulsions).
- Surfaces roughened by frost flowers could be a problem.

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