

Realistic Electromagnetic Modeling of SAR's Capability for Oil Spill Thickness Measurement

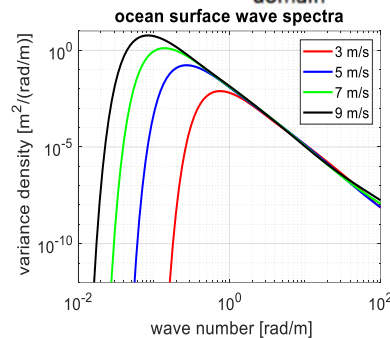
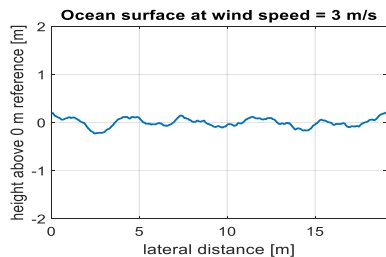
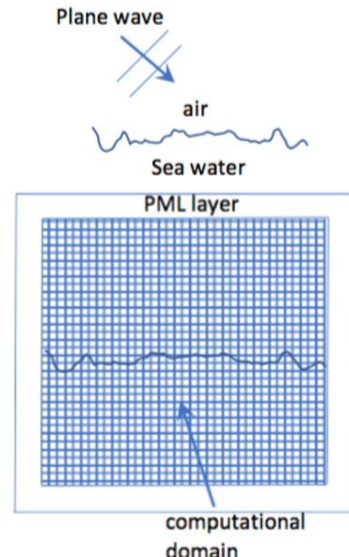
Sermasak Jaruwatanadilok, Xueyang Duan, Benjamin Holt, and Cathleen Jones

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

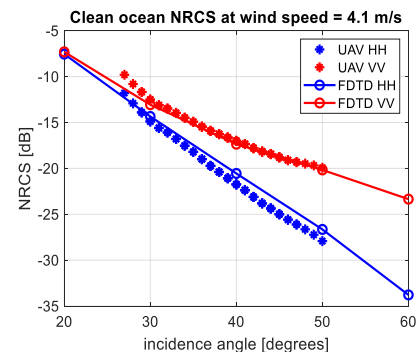
EM modeling : Finite Difference Time Domain (FDTD)

Computational domain is discretized. Then, Maxwell's equation of E and H fields are calculated on grid point as time step increments

Sea surfaces are random rough surface generated by FFT of ocean wave spectra. Clean ocean surface wave spectra are modified with Jenkin's damping factor in contaminated ocean

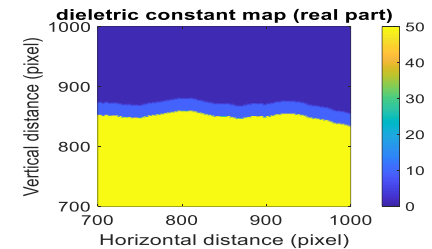
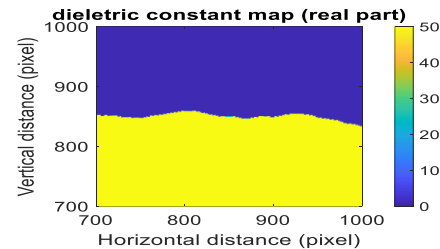


Validation of FDTD with UAVSAR
H and V pol Normalized Radar Cross Section (NRCS) from FDTD simulations are matched with observation from UAVSAR



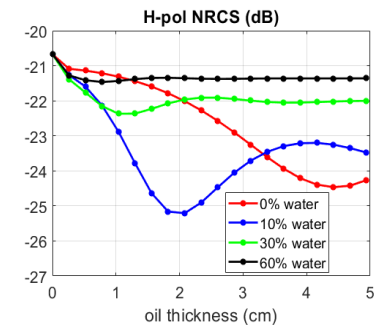
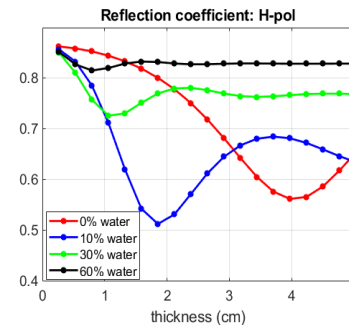
Study of contaminated ocean

- (1) Effect of oil contaminant on NRCS where oil properties vary
- (2) Effect of dielectric of oil and its thickness



Short conclusions:

- NRCS changes due to change in oil physical parameters are complicated functions
- Effect of change in surface elasticity, kinematic viscosity, and surface viscosity on NRCS are studied
- As oil layer thickness increases, it does not always reduce the NRCS. This is due to constructive interference. However, this happens when oil thickness is in the order of radar half wavelength inside the oil layer



This research was carried out at Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. The authors acknowledge the Texas Advanced Computing Center (TACC) at the University of Texas at Austin for providing HPC resources that have contributed to the research results reported within this paper.

Realistic Electromagnetic Modeling of SAR's Capability for Oil Spill Thickness Measurement

Sermsak Jaruwatanadilok, Xueyang Duan, Benjamin Holt, and Cathleen Jones
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

Overview

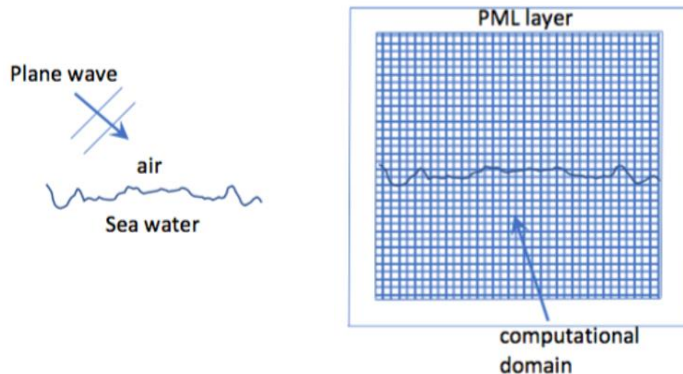
- Electromagnetic scattering model – Finite Difference Time Domain (FDTD)
 - Concept
 - Validation
- Ocean surface generation
 - Elfouhaily model
 - From spectrum to realization of surface
- Ocean surface damping – Jenkin's model
- Results
 - Sensitivity NRCS from change in the oil parameters
 - Dielectric effects

This research was carried out at Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. The authors acknowledge the Texas Advanced Computing Center (TACC) at the University of Texas at Austin for providing HPC resources that have contributed to the research results reported within this paper.

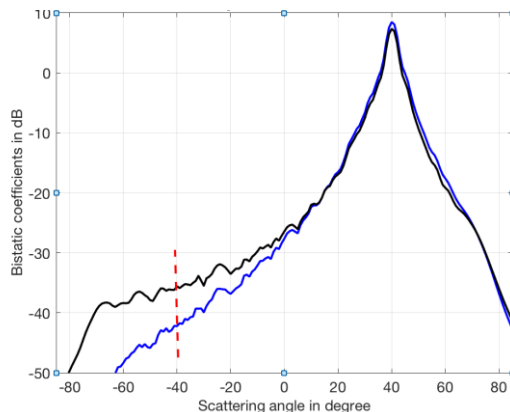
Electromagnetic scattering model – Finite Difference Time Domain (FDTD)

Concept of Finite Difference Time Domain (FDTD)

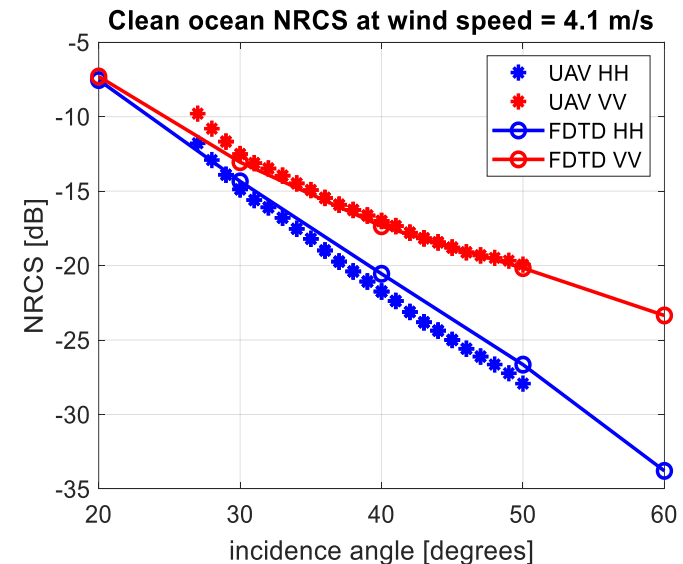
- Computational domain is discretized into small pixel, each should be fraction of wavelength of the center frequency of radar wavelength (Example is for L-band, wavelength is 24 cm. With 90 pixels per wavelength, each pixel is 2.6 mm)
- Perfect Match Layer (PML) acts as wave absorber. The idea here is to prevent reflection and scattering of out-going waves back into the computational domain which would interfere with the calculation of scattered wave
- Maxwell's equation of E and H fields are calculated on grid point as time step increments



FDTD simulation of scattering from clean ocean

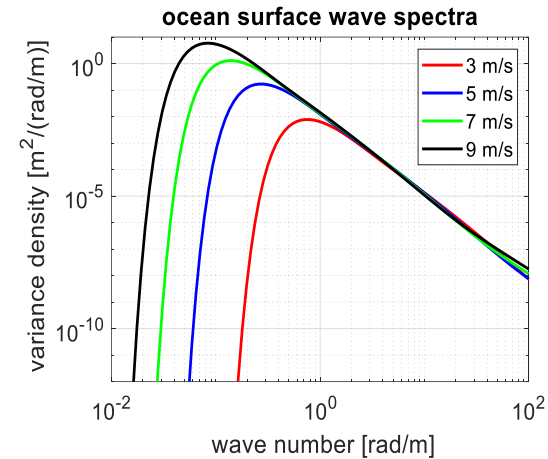


FDTD results vs UAR SAR data

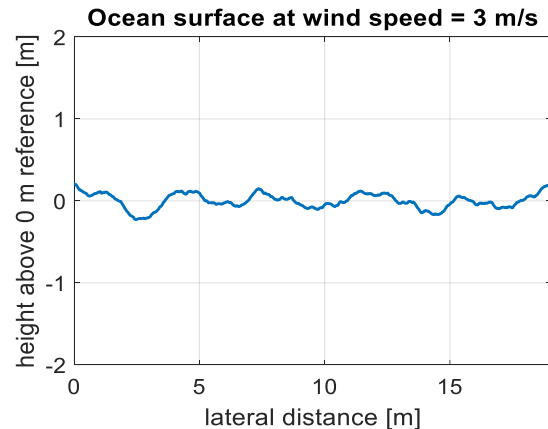
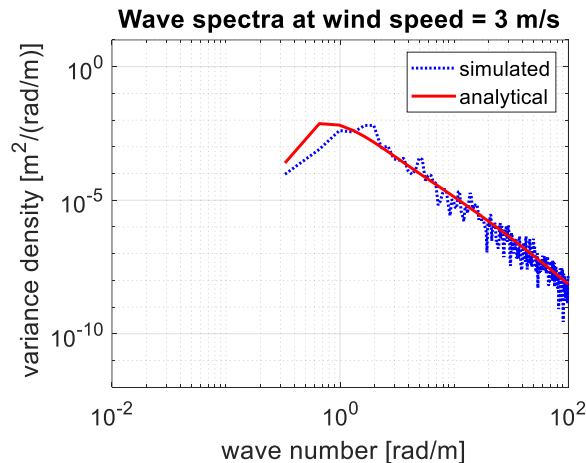


Ocean surface generation

- Elfouhaily model [1]: Analytical expression of ocean surface wave spectra that is a function of wind speed over the ocean
- Higher windspeed produce larger magnitude of longer wavelength



- Mobley [2] explains how ocean surface is constructed from spectra

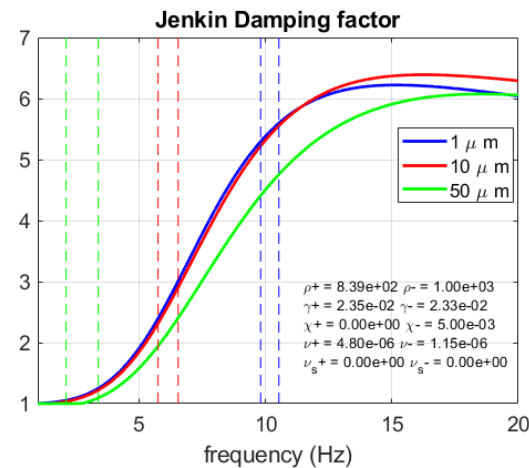
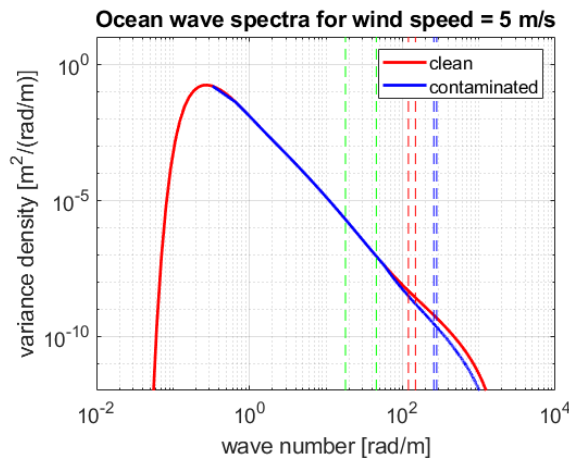


[1] Elfouhaily, T. et al, "A unified directional spectrum for long and short wind-driven waves," Journal of Geophysical Research, Vol. 102, No. C7, pp 15781-15796, July 1997.

[2] Mobley, Curtis D, "Modeling Sea Surface: A tutorial on Fourier transform techniques," Technical note Sequoia Scientific, Inc.

Ocean surface damping – Jenkin’s model

Jenkin’s model [3] explains damping of ocean wave spectra from the oil contaminant. There is a list of input parameters to Jenkin’s model. Most are the physical properties of oil and ocean. Table below provide list of parameters used as a baseline for calculation of NRCS from ocean



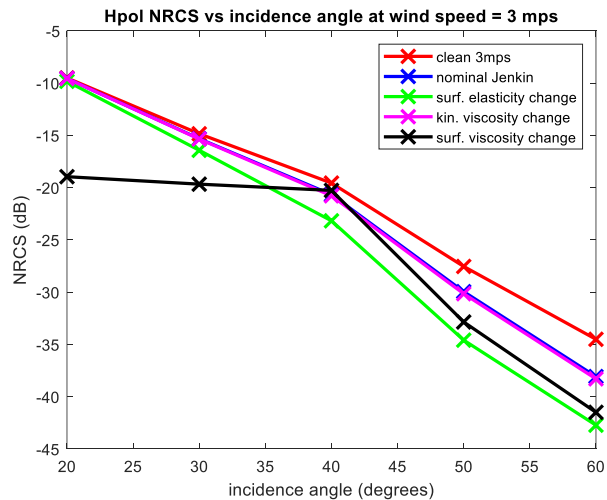
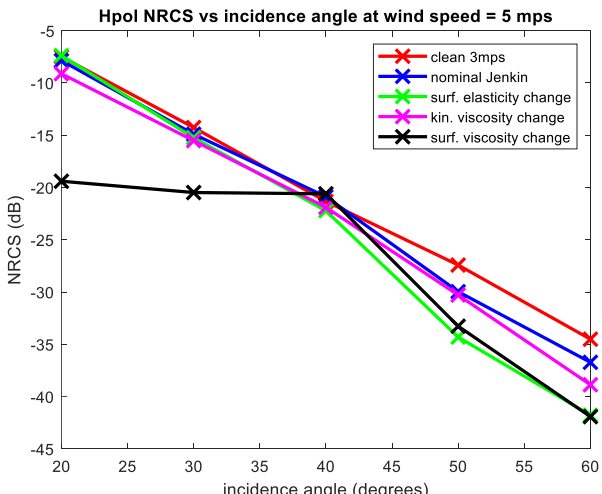
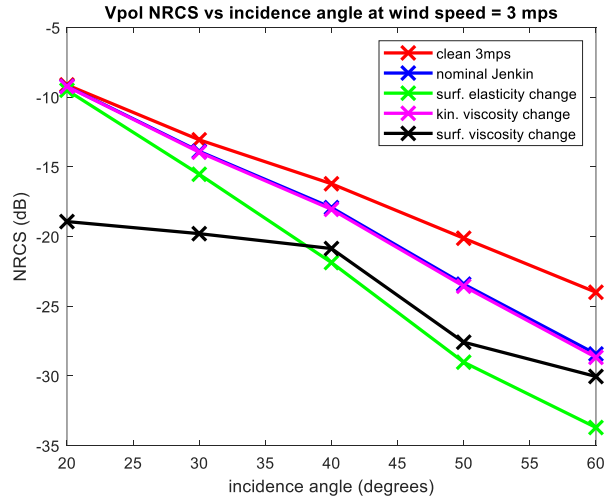
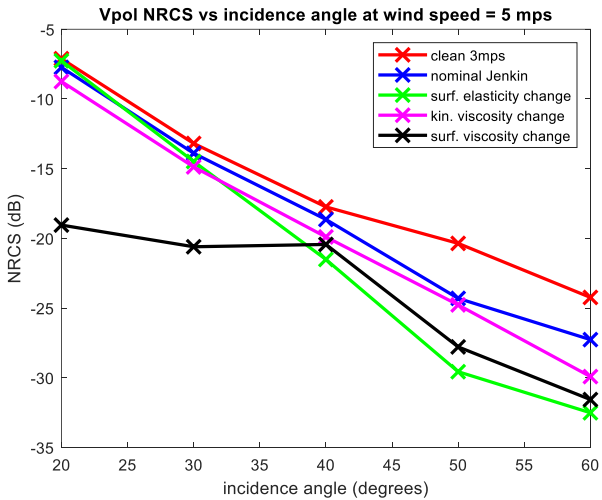
Vertical dash lines are Bragg’s scattering regime for L-band (in green), C-band (in read) and X-band (in blue)

Parameter name	symbol	unit	Reference value
Thickness of oil	d	meter	1×10^{-6}
Density of oil	ρ_+	kg/m ³	839
Density of water	ρ_-	kg/m ³	1000
Surface tension	γ_+	N/m	23.5×10^{-3}
Interfacial tension	γ_-	N/m	23.3×10^{-3}
Surface elasticity	χ_+	N/m	0
Interfacial elasticity	χ_-	N/m	5×10^{-3}
Surface viscosity	ν_{s+}	m ² /s	0
Interfacial viscosity	ν_{s-}	m ² /s	0
Kinematic viscosity of oil	ν_+	m ² /s	4.8×10^{-6}
Kinematic viscosity of water	ν_-	m ² /s	1.15×10^{-6}

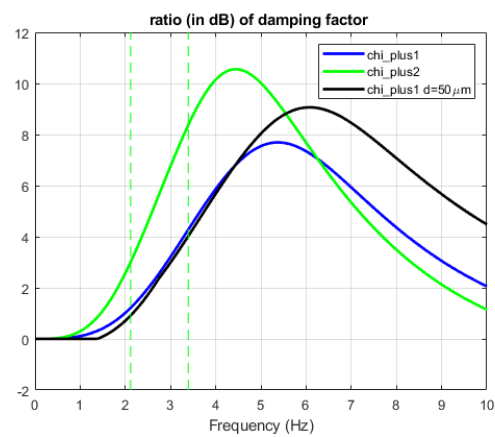
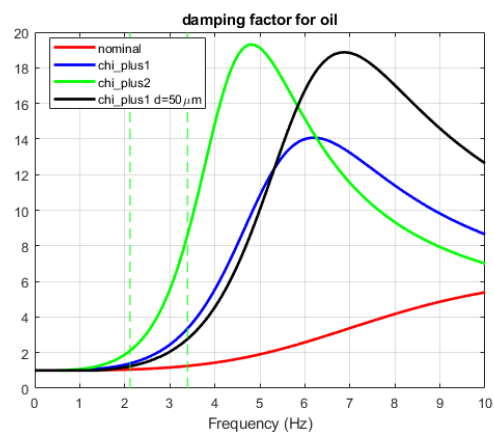
Results - Sensitivity NRCS from change in the oil parameters

We investigate 3 oil parameters that show to affect the NRCS from contaminated ocean. They are surface elasticity, kinematic viscosity, and surface viscosity

Oil parameters	unit	original value	new vlue
Surface elasticity	N/m	0	10^{-2} and 2×10^{-2}
Kinematic viscosity	m^2/s	4.8×10^{-6}	10^{-3} and 4.8×10^{-3}
Surface viscosity	m^2/s	0	10^{-3} and 10^{-2}

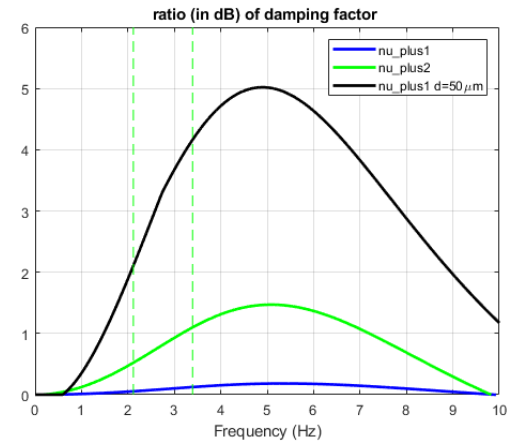
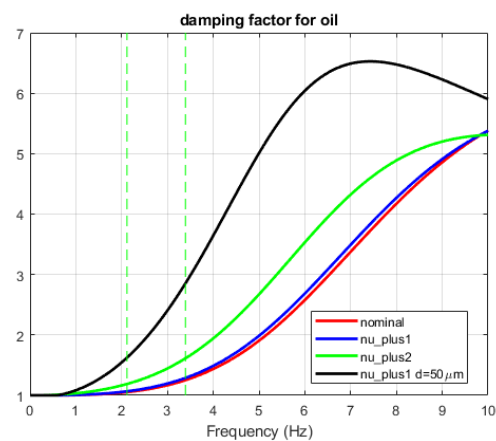


Results - Sensitivity NRCS from change in the oil parameters – SURFACE ELASTICITY



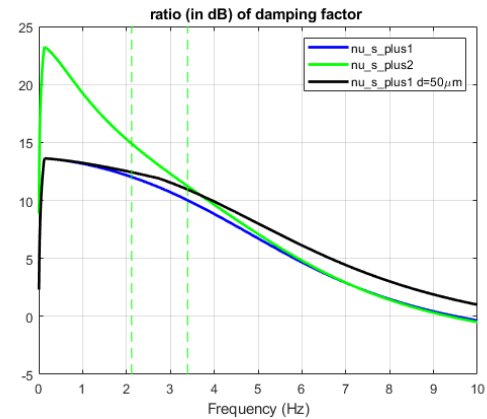
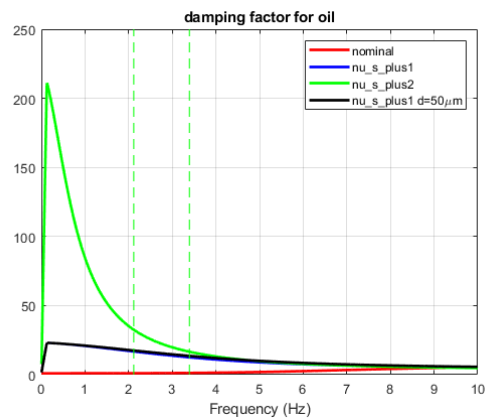
chi_plus1	H-pol - surface elasticity = 10 x 10 ⁻³ N/m					V-pol - surface elasticity = 10 x 10 ⁻³ N/m			
	3 m/s	5 m/s	7 m/s	9 m/s		3 m/s	5 m/s	7 m/s	9 m/s
20	0.27	-0.48	0.34	-0.02		0.28	-0.47	0.35	0.07
30	1.11	0.34	1.59	-0.29		1.65	0.59	2.05	0.13
40	2.51	1.35	2.50	1.38		3.94	2.87	3.32	2.99
50	4.64	4.34	4.66	3.32		5.60	5.26	5.90	4.57
60	4.65	5.06	4.69	5.32		5.28	5.25	5.53	5.96
chi_plus2	H-pol - surface elasticity = 20 x 10 ⁻³ N/m					V-pol - surface elasticity = 20 x 10 ⁻³ N/m			
	3 m/s	5 m/s	7 m/s	9 m/s		3 m/s	5 m/s	7 m/s	9 m/s
20	0.73	0.75	0.98	0.07		0.75	0.61	0.69	0.30
30	2.53	1.28	0.90	1.77		3.15	1.71	1.18	2.66
40	3.66	4.34	3.09	4.33		5.76	5.67	4.13	6.22
50	5.70	6.15	5.43	5.39		6.85	6.54	6.19	6.47
60	4.73	6.51	4.96	4.14		3.99	6.01	4.71	4.28

Results - Sensitivity NRCS from change in the oil parameters – KINEMATIC VISCOSITY



chi_plus1	H-pol - kinematic viscosity = 1 x 10 ⁻³ m ² /s					V-pol - kinematic viscosity = 1 x 10 ⁻³ m ² /s			
	3 m/s	5 m/s	7 m/s	9 m/s		3 m/s	5 m/s	7 m/s	9 m/s
20	0.00	1.26	2.36	2.82		0.02	1.02	2.08	2.98
30	0.03	0.62	0.44	2.73		0.06	0.98	0.41	2.95
40	0.12	1.02	1.16	1.92		0.13	1.25	1.17	2.55
50	0.20	0.32	1.56	2.34		0.15	0.47	1.11	3.10
60	0.22	2.15	1.96	0.82		0.24	2.65	1.10	0.38
chi_plus2	H-pol - kinematic viscosity = 4.8 x 10 ⁻³ m ² /s					V-pol - kinematic viscosity = 4.8 x 10 ⁻³ m ² /s			
	3 m/s	5 m/s	7 m/s	9 m/s		3 m/s	5 m/s	7 m/s	9 m/s
20	-0.13	0.41	0.66	0.44		-0.11	0.23	0.29	0.64
30	0.24	0.27	-0.79	0.84		0.26	0.42	-0.73	1.16
40	0.61	1.72	0.48	1.10		0.60	1.62	0.57	0.93
50	0.79	0.65	0.81	1.82		0.61	0.87	0.61	2.43
60	0.47	1.82	1.39	-0.43		0.66	2.09	0.36	0.24

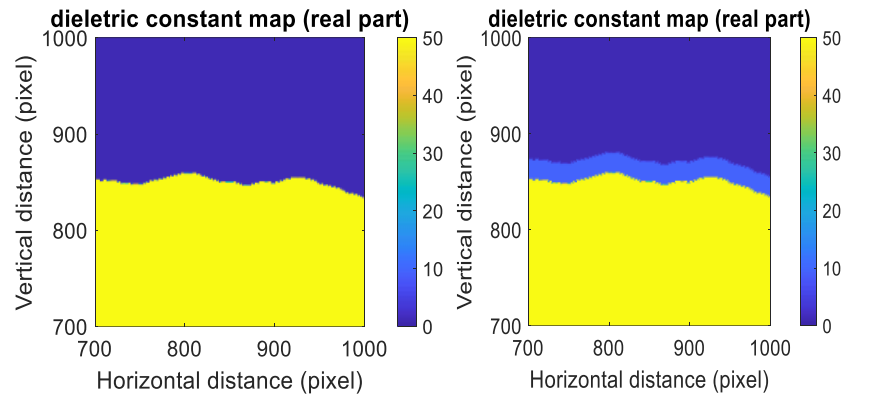
Results - Sensitivity NRCS from change in the oil parameters – SURFACE VISCOSITY



chi_plus1	H-pol - surface viscosity = $1 \times 10^{-3} \text{ m}^2/\text{s}$					V-pol - surface viscosity = $1 \times 10^{-3} \text{ m}^2/\text{s}$			
	3 m/s	5 m/s	7 m/s	9 m/s		3 m/s	5 m/s	7 m/s	9 m/s
20	9.39	11.54	12.58	11.40		9.71	11.32	12.30	11.59
30	4.35	5.58	5.95	6.09		5.91	6.71	7.21	7.05
40	-0.40	-0.29	1.51	0.84		2.94	1.79	3.49	3.34
50	2.90	3.31	4.08	3.47		4.17	3.48	5.43	4.91
60	3.42	5.20	5.29	4.84		1.62	4.30	3.20	1.98
chi_plus2	H-pol - sruface viscosity = $10 \times 10^{-3} \text{ m}^2/\text{s}$					V-pol - surface viscosity = $10 \times 10^{-3} \text{ m}^2/\text{s}$			
	3 m/s	5 m/s	7 m/s	9 m/s		3 m/s	5 m/s	7 m/s	9 m/s
20	9.44	11.46	12.29	10.88		9.63	11.48	12.29	11.42
30	3.67	4.19	4.40	4.79		5.37	5.44	5.62	5.59
40	-1.50	-1.48	-0.32	-1.05		1.46	1.38	1.71	1.87
50	2.08	2.42	4.04	2.83		3.33	3.03	5.18	3.96
60	2.27	3.95	4.04	5.26		0.86	2.84	1.52	2.97

Results – Dielectric effect

We study the NRCS change due to dielectric effect by placing a layer of oil without changing the surface spectra. Oil layer has different dielectric due to the degree of water/oil mixing



Percentage of salt water	Complex dielectric constant
0 (pure oil)	
10	$9.75 + 6.126 i$
30	$24.25 + 18.32 i$
60	$46 + 36.61 i$
100 (pure ocean)	$75 + 61 i$

As oil layer thickness increases, it does not always reduces the NRCS. This is due to constructive interference. However, this happens when oil thickness is in the order of radar half wavelength inside the oil layer

