Field experiments on SAR detection of film slicks

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Motivation

Better understanding of possibilities to use SAR for detection and characterization of surface films (including oil spills) on the sea surface.

Previous experiments:

1. UoH: radar probing of film slicks with SAR (Gade, W. Alpers, Huehnerfuss et.al., JGR, 1 1998) and with L-C-X-Ku-scatterometer (Gade, Alpers, Huehnerfuss, Wismann, Lange, Rem. Sens. Env. 1998)
2. IAP RAS experiments on optical&radar probing of film slicks **simultaneous** with SAR : the Black Sea, Envisat ASAR 2008, the Gorky Water Reservoir, TerraSAR-X, 2009. Mostly low winds and very few scatterometer measurements.

New experiments:

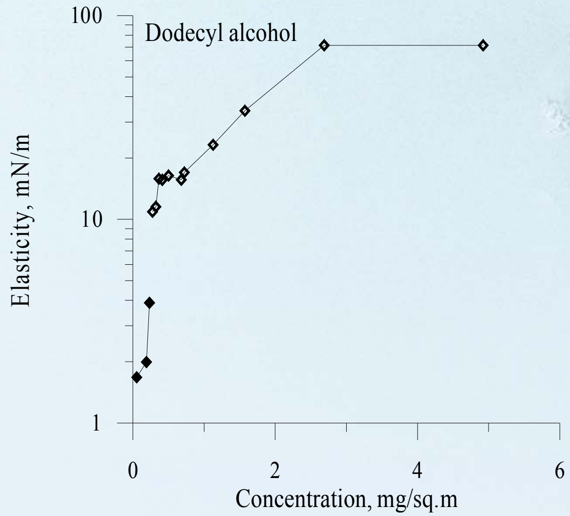
SAR contrasts in a wide range of wind velocities, comparison with simultaneous scatterometer measurements from a boat

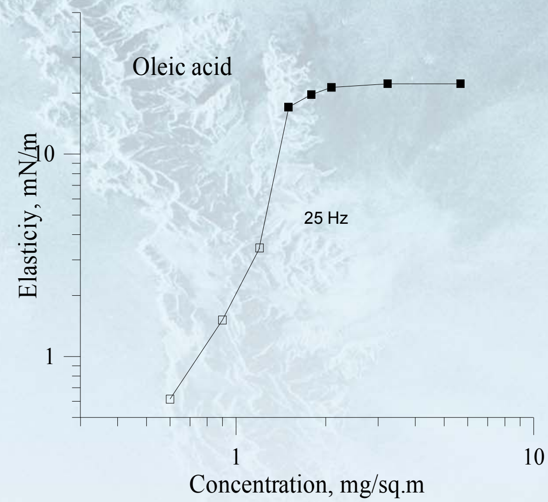
IAP RAS experiments on slick remote sensing. GWR, 2011

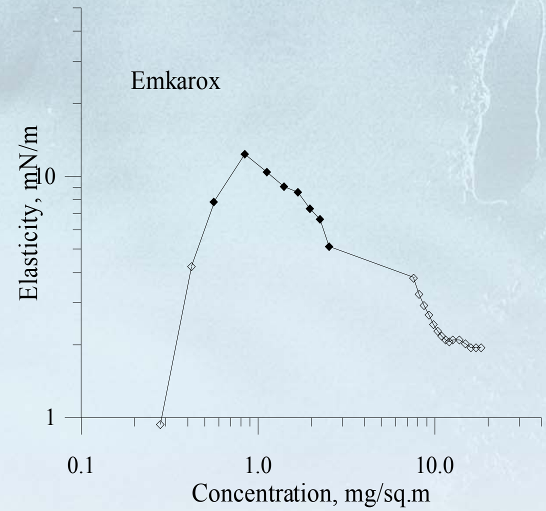
X-, Ka- band scatterometers on board a research vessel

GWR: width 15 km, length 70 km, mean depth 10 m

Physical characteristics of artificial surfactant films





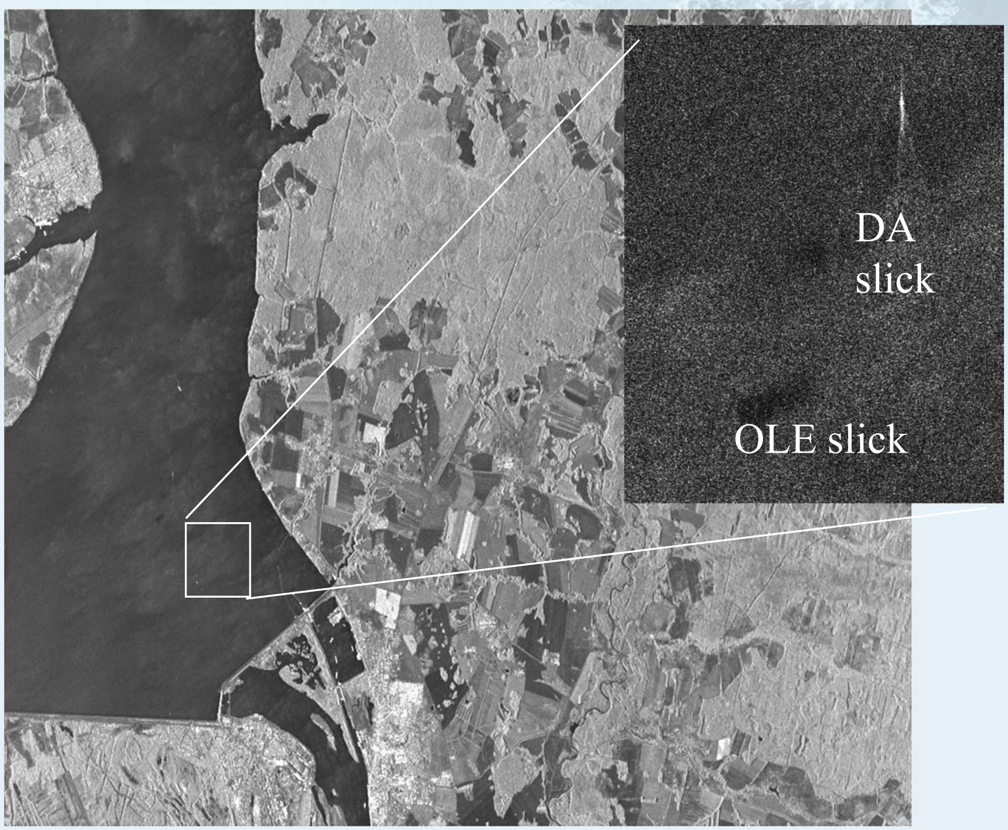


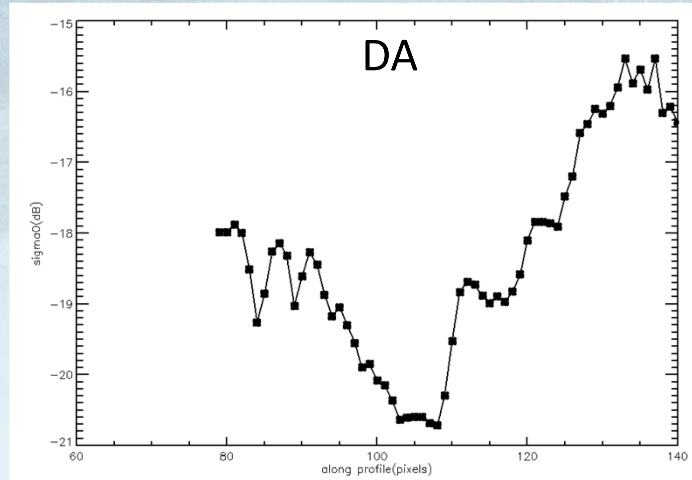
Substance	Emk	VO	OLA	OLE	DA
Surface tension, mN/m	39	40	36	32	22
Elasticity, mN/m	2-5	12	15	22	70

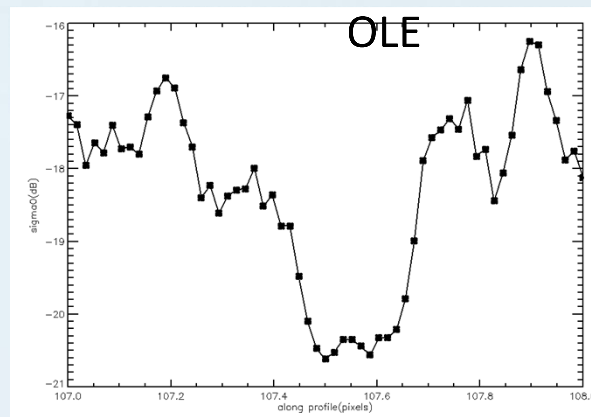
oleic acid (OLE), oleyl alcohol (OLA), Emkarox (Emk), vegetable oil (VO), dodecyl alcohol (DA)

Slick experiments of 26.06.2009. The Gorky Water Reservour.

Terra SAR-X,
26/06/2009

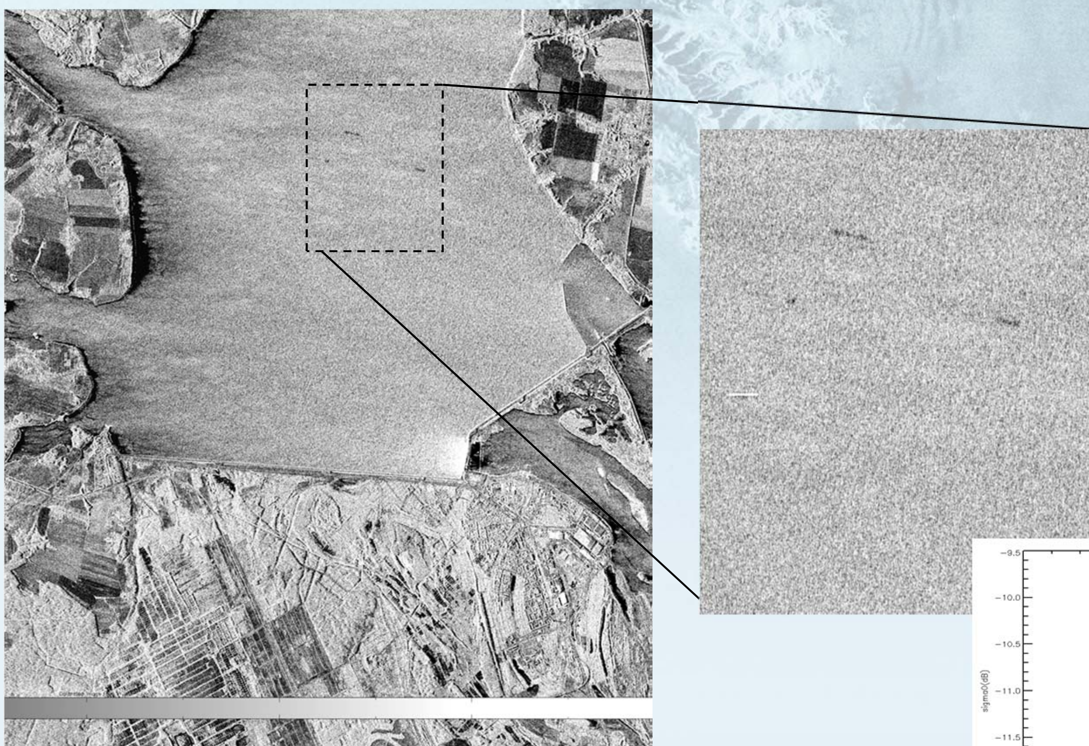


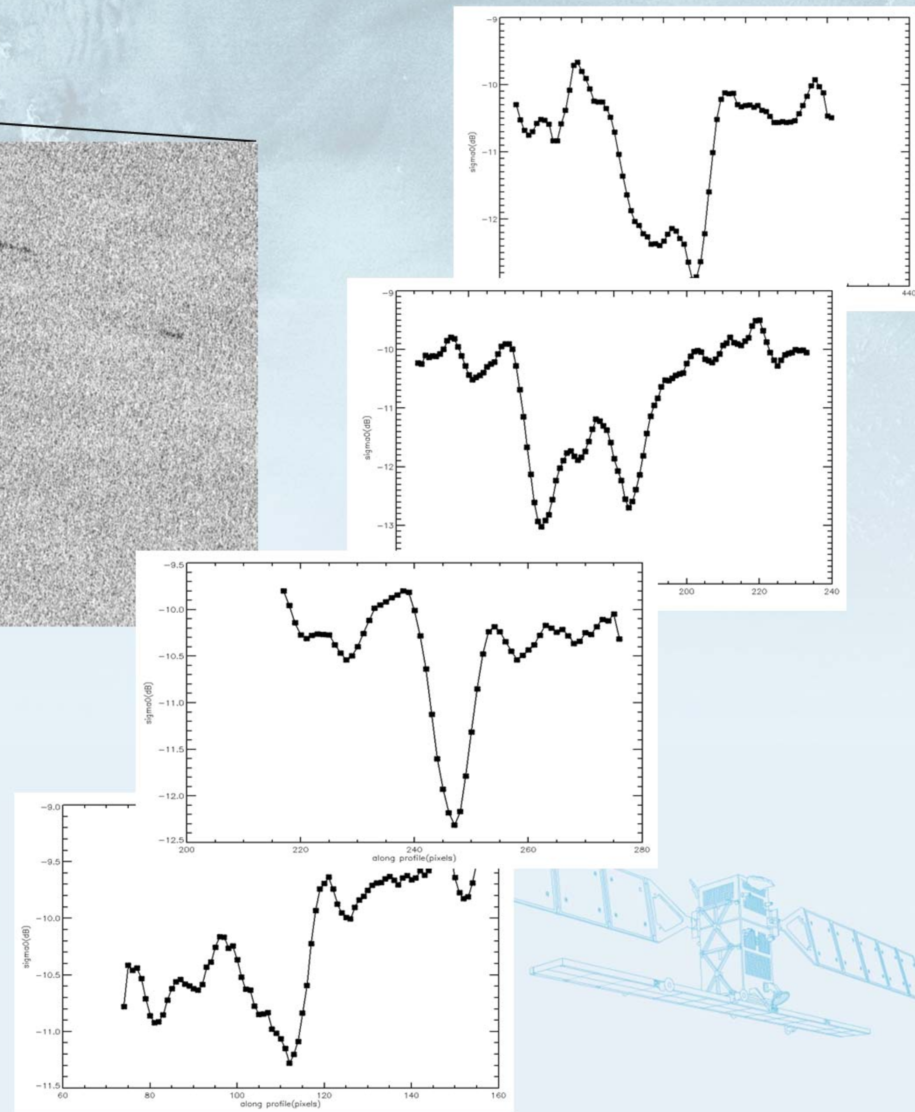




Slicks of OLE and DA. Inc. angle 36^0 . Wind velocity 3 m/s, N.(350 deg)

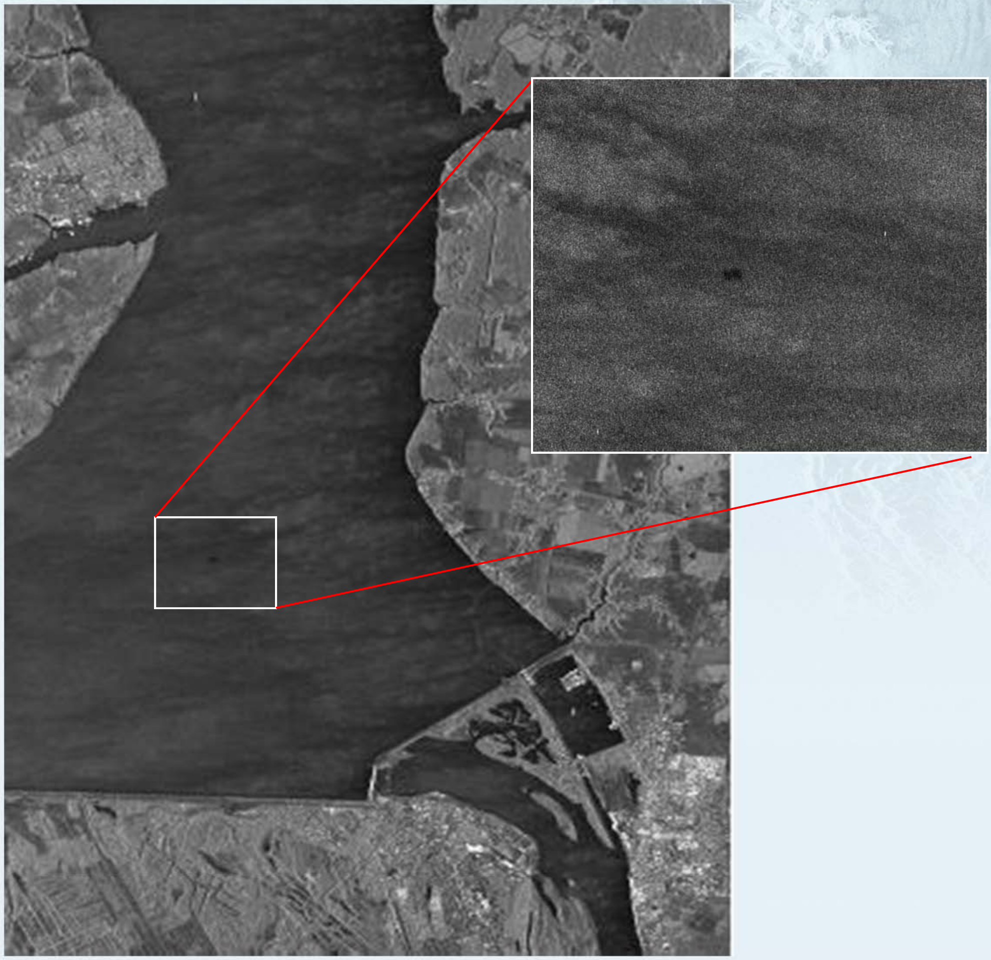
Experiment of 02/07/2009

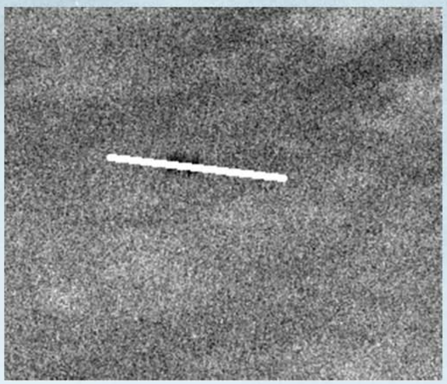


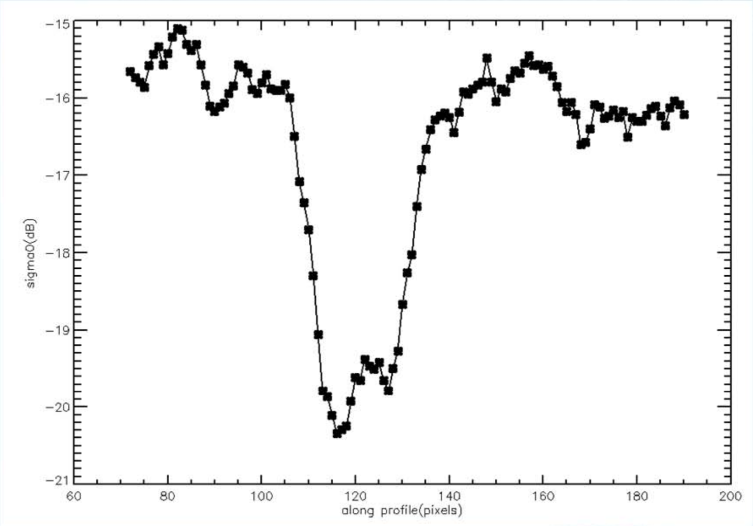


Incidence angle 22.5^0 . Wind 4.5m/s, 270^0

Experiments with slicks on the Gorky Water Reservoir, 2011

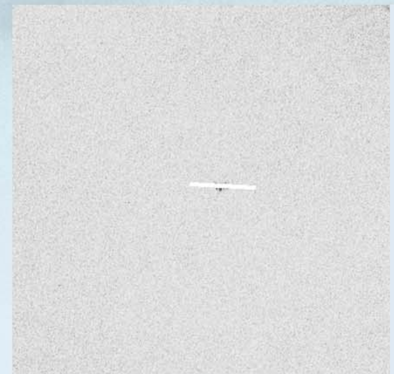


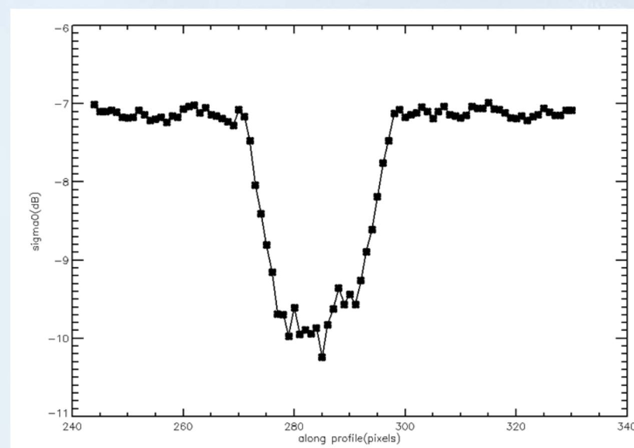




TS-X 16.08.2011. 14.44 UTC inc.angle 36-39^0 Bragg wavenumber k~2.5 rad/cm, Wind 5-6 m/s, East. Boat dir West-East, and East-West

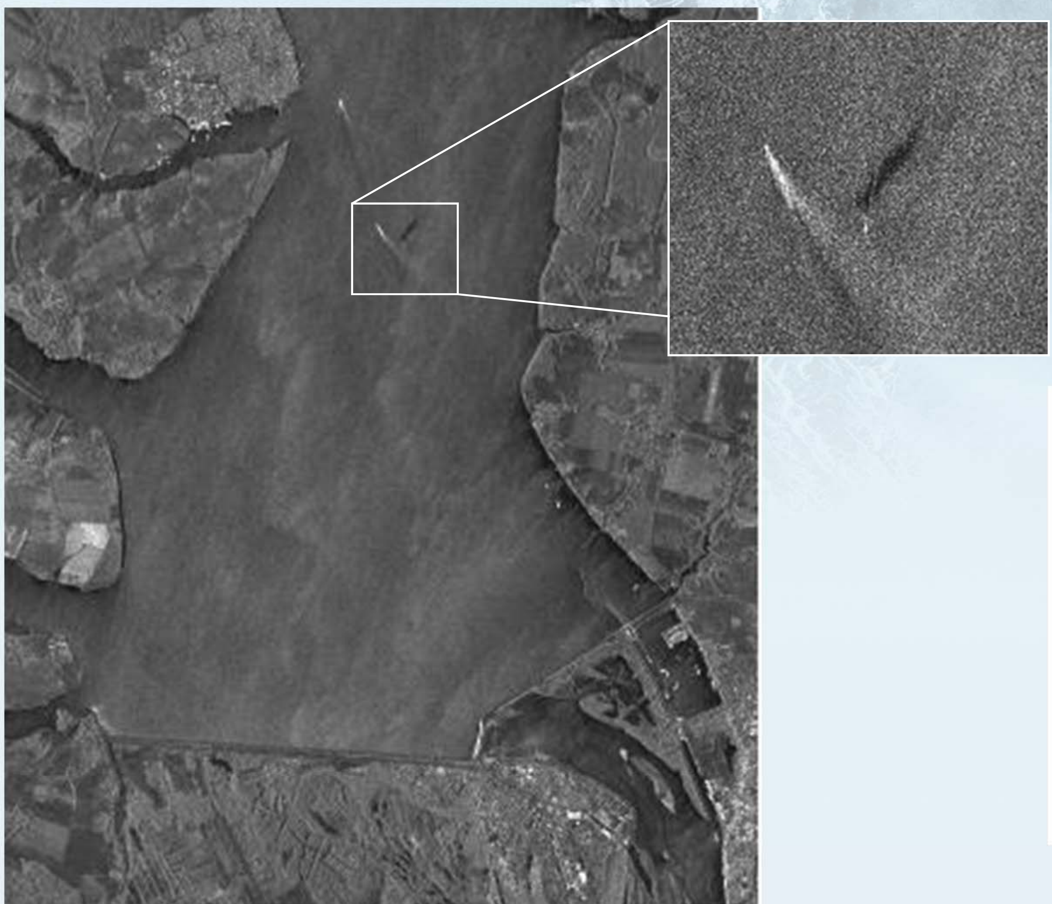
Experiments with slicks on the Gorky Water Reservoir, 2011

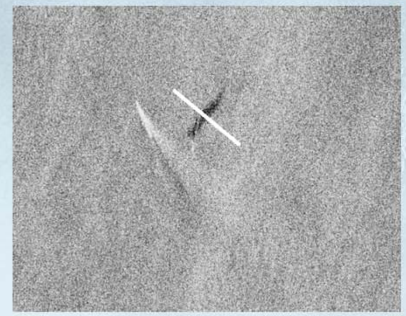


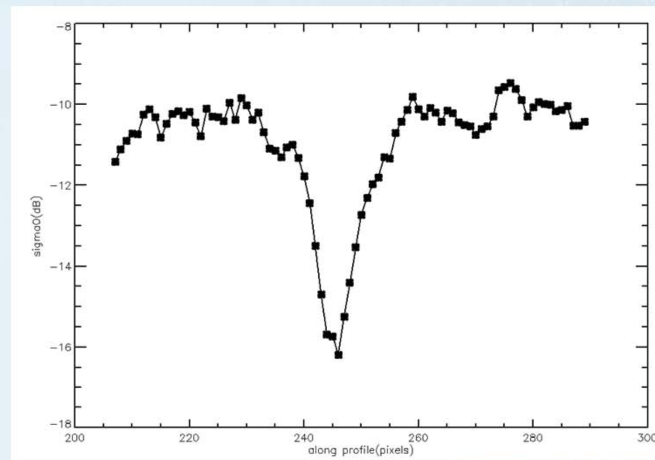


TS-X 17.08.2012, 03.40 UTC, inc. angle 20-23^0, Bragg wavelength ~4 cm, k~1.57 rad/cm

Experiments with slicks on the Gorky Water Reservoir, 2011







TS-X 22.08.2012, 14.35 UTC inc. angle 22-25^0, Bragg wavelength ~3.8 cm   k~1.63 rad/cm

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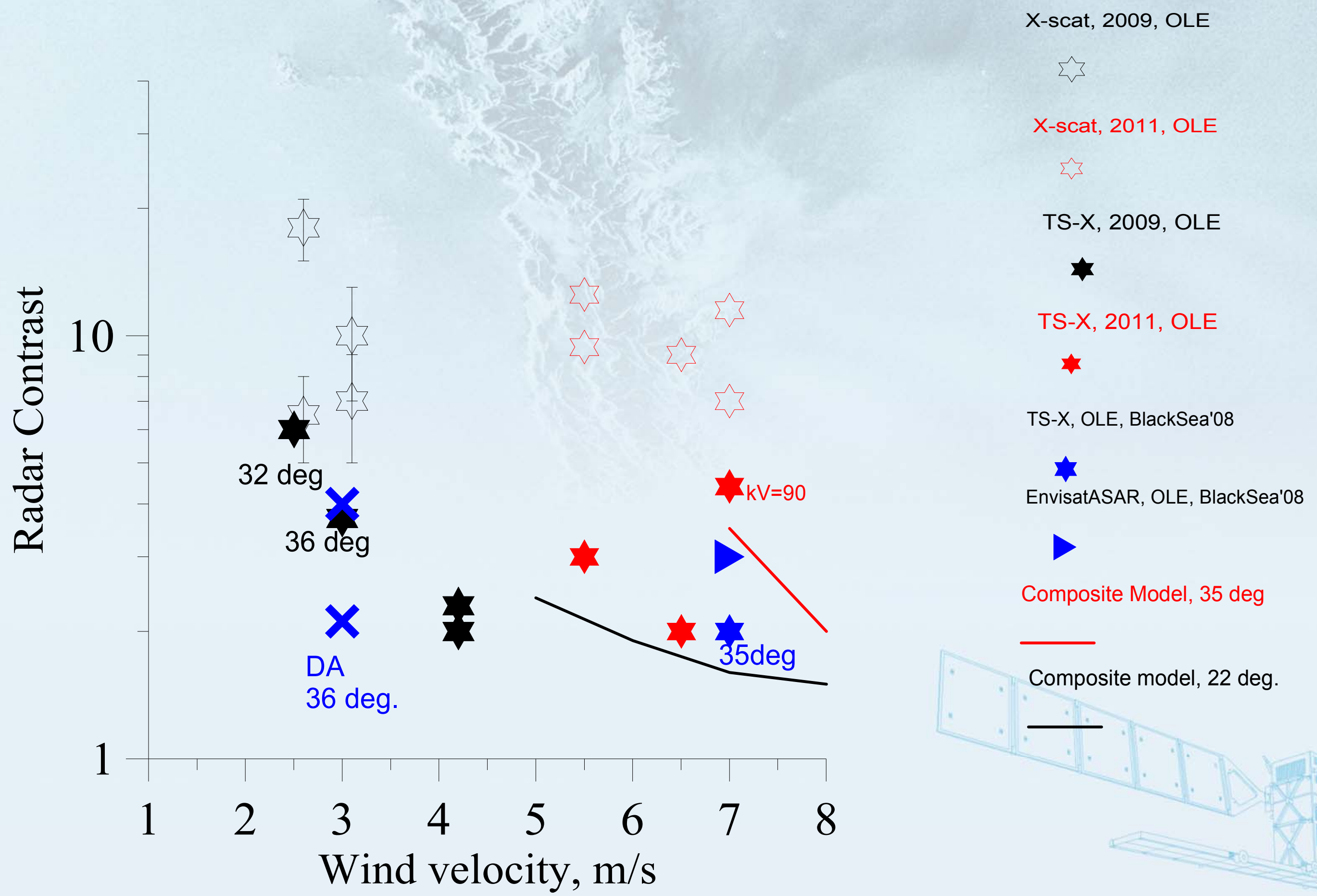
Contrasts in experiments of 2011 on GWR

Experiment	TS-X contrast	X-band scat contrast (inc. angle 60^0)	Ka-band scat contrast (inc. angle 60^0)
16/08/11, 14.44 UTC, Wind 5-6 m/s, East	**3** (k || V), inc. angle~37^0	12.5 (kV~165^0) 9.4 (kV~-115^0) 7.5 (kV~110^0)	19 (kV~165^0) 8.5 (kV~-115^0) 5.5 (kV~110^0)
17/08/11, 03.40 UTC, Wind 6-7 m/s, East	**2** (k||V) inc. angle~21^0	9 (kV~165^0) 2 (kV~ 25^0)	14.5 (kV~165^0) 8.2 (kV~25^0)
22/08/11, 14.35 UTC, Wind 6-8 m/s, North	**4** (k$\perp$V) inc. angle~23^0	7 (kV~-155^0) 6.2 (kV~ 155^0)	4.4 , 10.4 (kV~-115^0) 8.2 (kV~25^0)

Contrasts in slicks. Experiments of 2008-2011.



Models of wind wave damping and SAR contrast in slicks

Composite model of radar cross section (low-to-moderate inc. angles)

$$\sigma_0 = \sigma_{0Bragg} + \sigma_{0Specular}$$

$$\sigma_{0Bragg} = 16\pi k_{radar}^4 G(\theta) F(k_{Bragg} = 2k_{radar} \sin\theta, \varphi)$$

$$\sigma_{0specular} = \frac{\pi R^2}{s_u s_c \cos^4\theta} \exp\left(-\frac{\tan^2\theta}{2s_{sp}^2}\right)$$

$S_{u,c,sp}$ – mean square slopes of wind waves (with $k<1/4\ k_{bragg}$)

$$K_{radar} = \frac{\sigma_{0Bragg} + \sigma_{0Specular}}{\sigma_{0BraggSlick} + \sigma_{0SpecularSlick}}$$

Models of wind wave damping and SAR contrast in slicks

$$\frac{dN(k,x,t)}{dt} = \Pi_a + \beta(u_*,k)N - \gamma(E,\sigma,k)N + I_{nl}(N)$$

$N(\mathbf{k},\mathbf{x},t) = \rho F(\mathbf{k},\mathbf{x},t)\omega(\mathbf{k})/|\mathbf{k}|$ F – the wavenumber spectrum of wind waves

β - wind wave growth rate, γ - wave damping coefficient, σ - surface tension, E - film elasticity, u_* - friction velocity

A local balance model for the spectrum of wind waves **(**Pelinovsky, Donelan&Pierson, Ermakov et.al..)

$I_{nl} = -\delta N^m$ **m=2**

Contrast $K(k)=F_{nsl}(k)/F_{sl}(k)$ in the wavenumber spectrum of wind waves

$$K(k) = \left[\frac{\beta(u_{*nsl},k) - \gamma(0,\sigma,k)}{\beta(u_{*sl},k) - \gamma(E,\sigma,k)}\right]^n$$

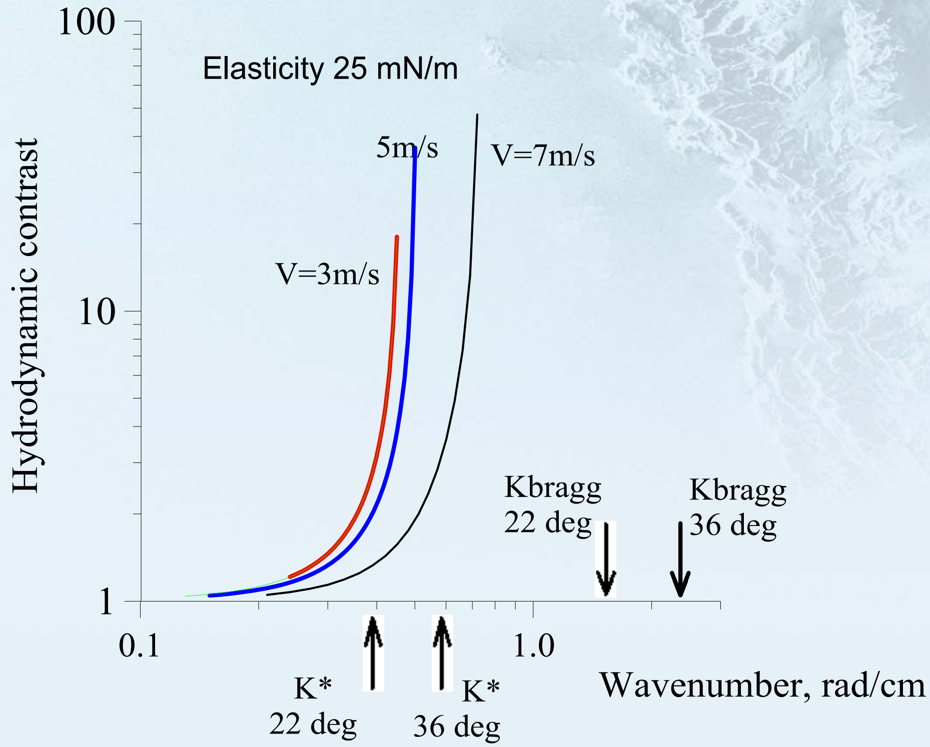
$\beta>\gamma$ n=1; $\beta<\gamma$ n=-1

A non local model (Kudrjavtsev et.al)

$$I_{nl} = -\delta N^m + I_{nl}^{sw}(k)$$

$$I_{nl}^{sw}(k) = \frac{\omega}{k^5} c_b \iint_{k'<k_{mb}} \beta(k',\varphi)k'^4 \cdot N(k')/\omega(k') \cdot dk'd\varphi$$

Damping of wind waves due to films



Wind wave damping=Radar Bragg Contrast vs. wavenumber of wind waves. K* - max wavenumber for specular model.

OLE films (E= 25 mN/m) strongly (>10 times) depresses the Bragg component, and weakly affects the specular component

$$\sigma_{0\,BraggSlick} << \sigma_{0\,BraggNonslick}$$

$$\sigma_{0\,specularSlick} \approx \sigma_{0\,specularNonslick}$$

On possibilities of film characterization

$$K_{radar} = \frac{\sigma_{0Bragg} + \sigma_{0Specular}}{\sigma_{0BraggSlick} + \sigma_{0SpecularSlick}}$$

1. Low inc. angles (<20^0): Specular>>Bragg

Contrast is almost insensitive to film elasticity
(at moderate wind >5 m/s)

$$K_{radar} = \frac{\sigma_{0SpecularNonslick}}{\sigma_{0SpecularSlick}} \approx 1$$

2. Inc. angles ~ 25^0: Specular≈Bragg

Contrast weakly depends on film elasticity

$$K_{radar} = \frac{\sigma_{0Bragg} + \sigma_{0Specular}}{\sigma_{0SpecularSlick}} \geq 2$$

3. Inc. angles >25-30^0: Specular<Bragg
- Bragg(Slick)<<Specular(Slick): contrast weakly depends on film elasticity
- BraggSlick>>SpecularSlick: contrast K=K(E), and E varied *in some limited range* can be estimated

$$K_{radar} = \frac{\sigma_{0Bragg}}{\max\{\sigma_{0BraggSlick}, \sigma_{0SpecularSlck}\}} >> 1$$

Summary

- SAR contrasts (inc. angles ~22-36 deg.) are smaller than scat-contrasts (inc. angles ~ 60 deg.)
- SAR contrasts for films with strongly different elasticity values (OLE, E≈22 mN/m and DA, E≈70 mN/m) are close to each other.
- Rough estimates using a composite radar model (Bragg + Specular) at low-to-moderate angles are consistent with experimental SAR contrasts

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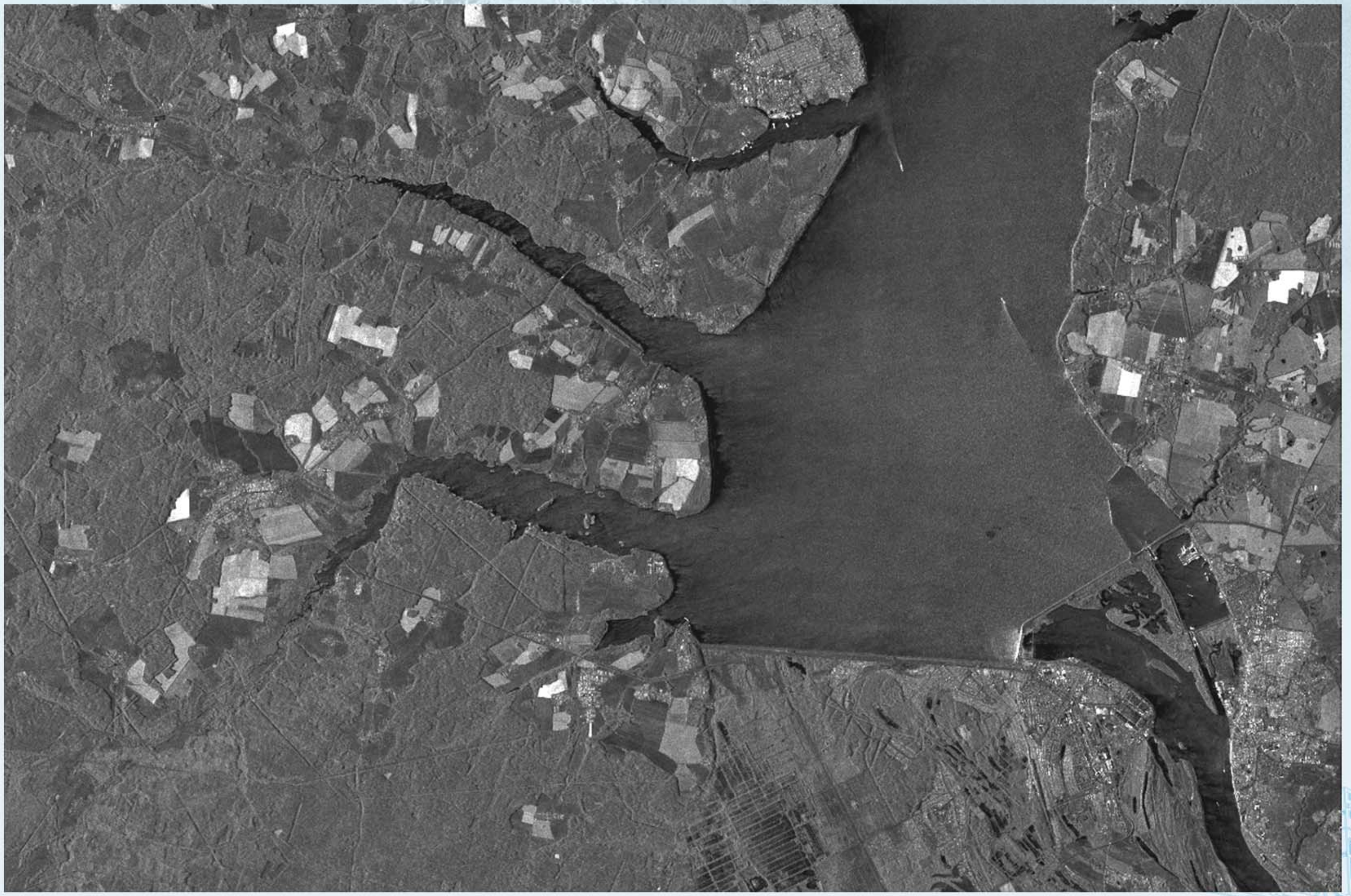
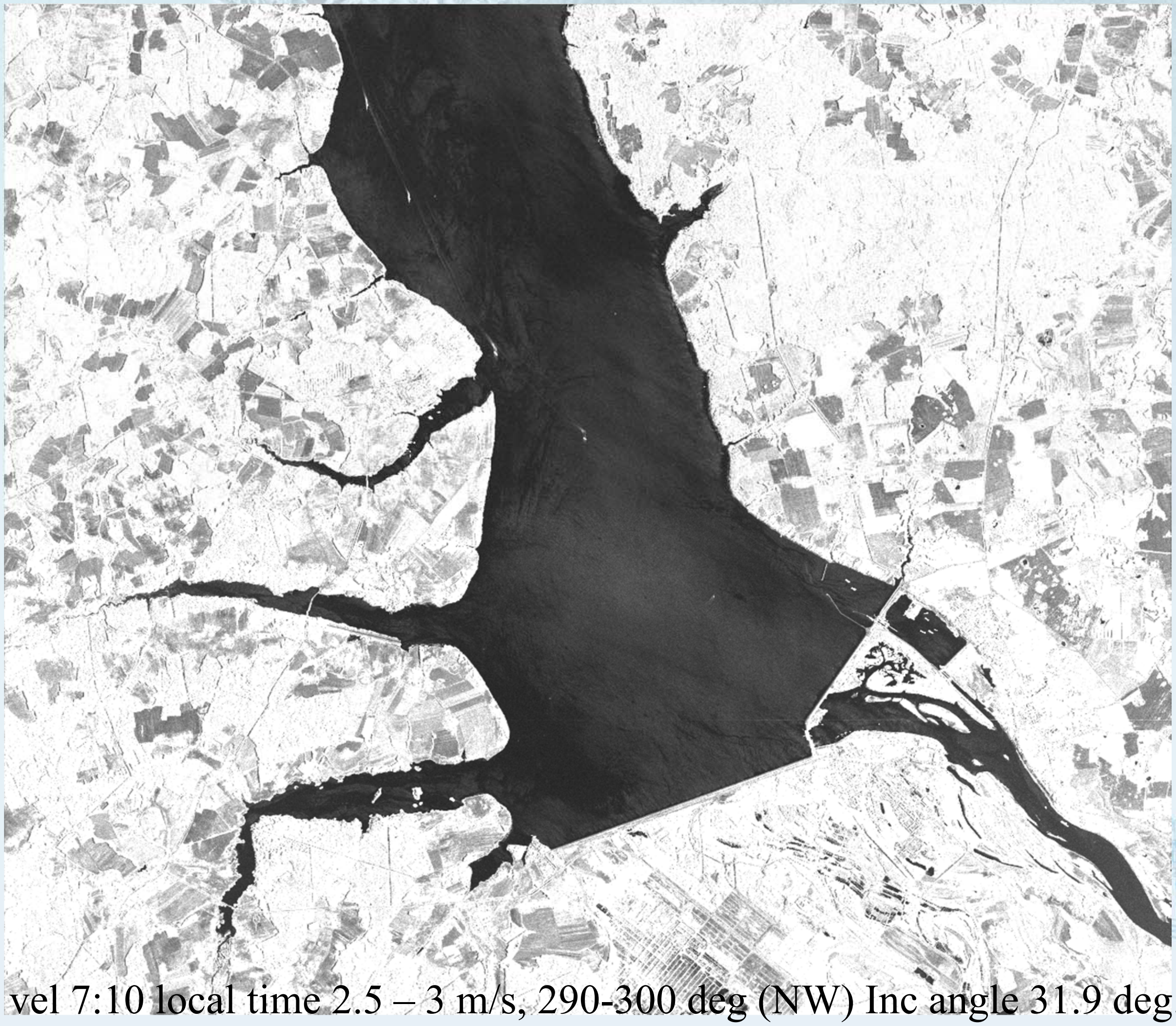
- SAR (at low-to-moderate inc. angles) can be used to detect slicks, but probably is not very effective for film characterization, since the contrasts weakly depend on film elasticity
- More experiments&data analysis are needed, however.



TerraSAR-X. 03.06.2012, inc. angle 22-25^0 ,wind 8 m/s, VO-slick

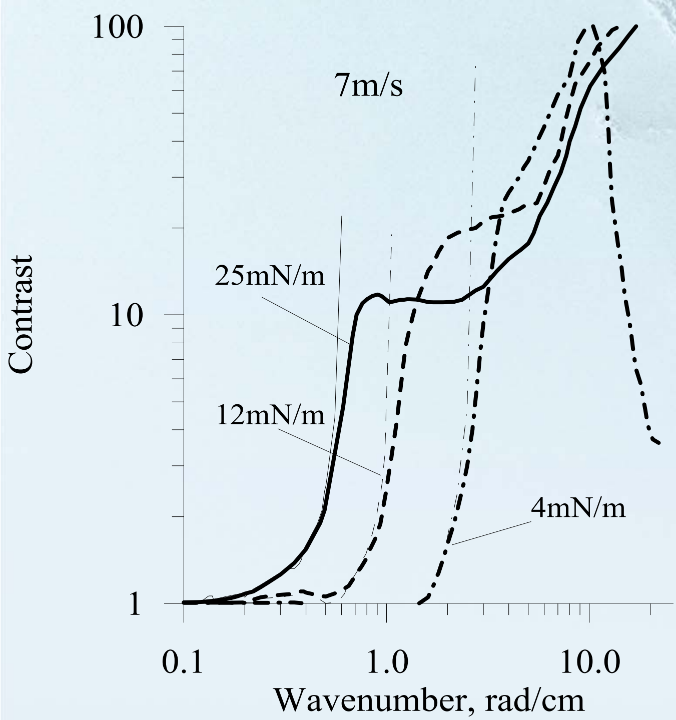
Thank you

TerraSAR slick experiment of July,14, 2009

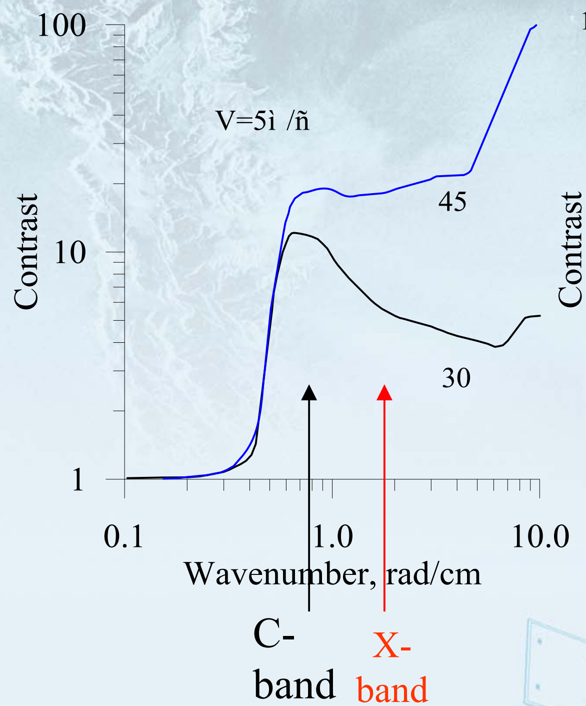


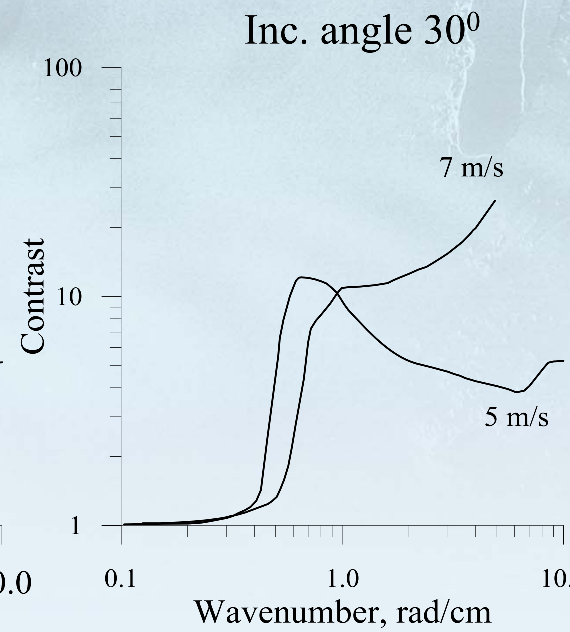
Wind vel 7:10 local time 2.5 – 3 m/s, 290-300 deg (NW) Inc angle 31.9 deg.

Model of wave damping in slicks



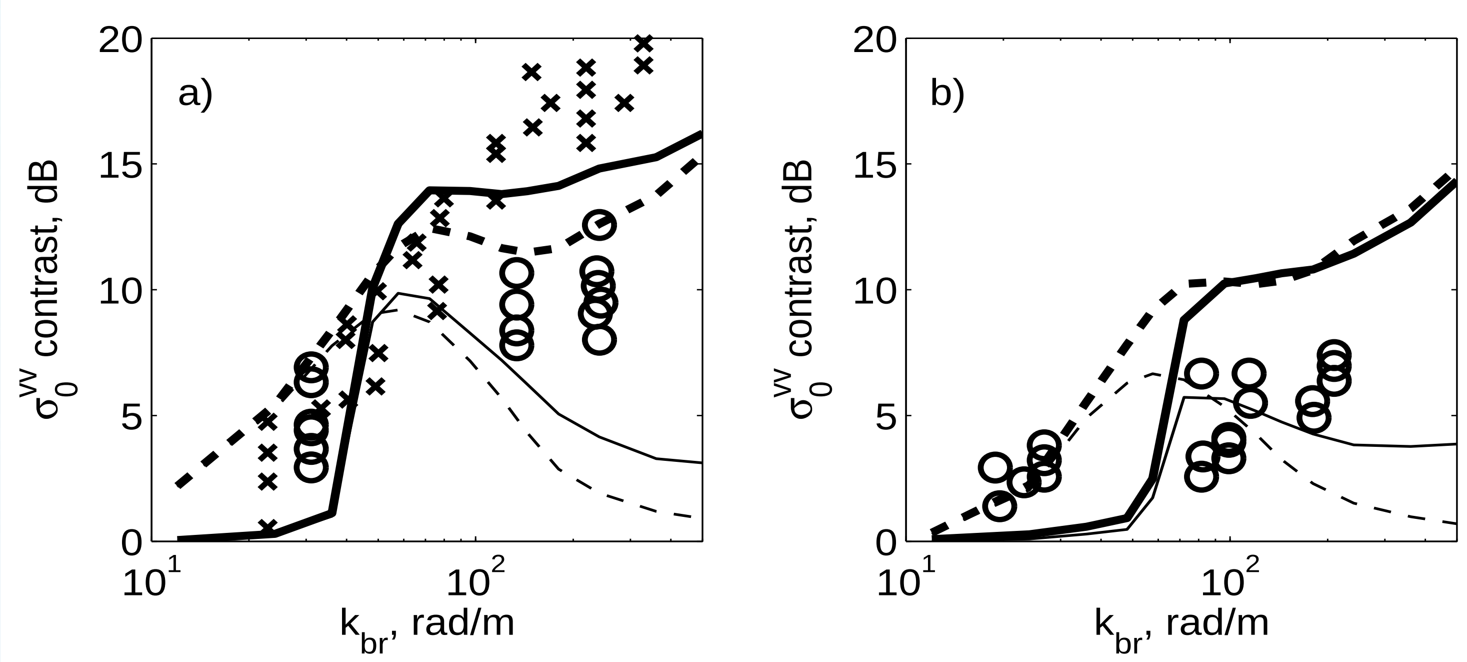
Hydrodynamic contrasts in the spectrum of wind waves. Local (thin curves) and non local (solid curves) models. Film elasticities 25, 12, 4 mN/m.





Radar contrasts in slicks – composite model. Film elasticity 25 mN/m

Radar contrasts in slicks. Experiments by Gade et.al.



Radar contrasts for OLA artificial slicks

a) wind 5m/s, θ=35^0, *b) wind 7 m/s,* θ=31^0.

«o»– SAR L-C-X-band (Gade et.al., 1998),

«x» - L-S-C-X-Ku-band scatterometer simultaneous with SAR *(Gade et.al., 1998)*