Radar imaging mechanism of underwater wrecks in coastal waters with strong tidal currents

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- Birkenfels wreck data
- Imaging theory
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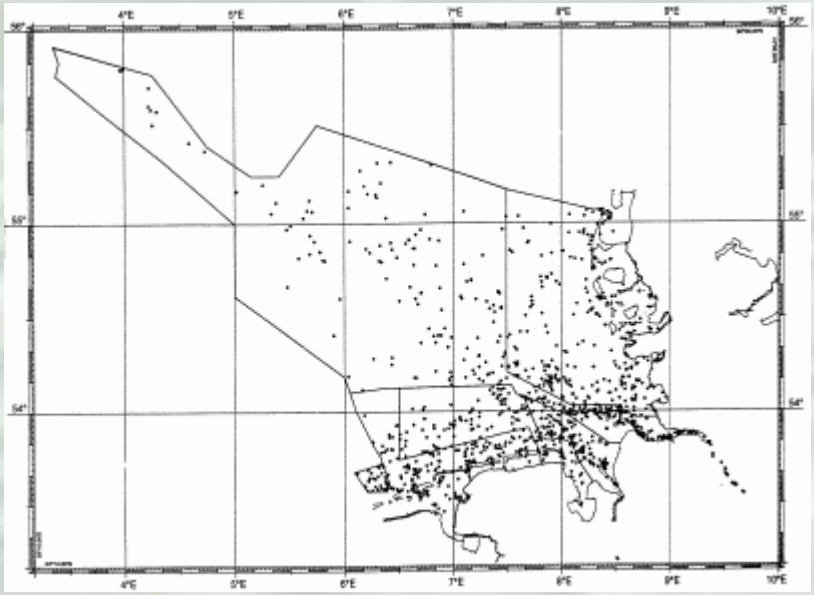
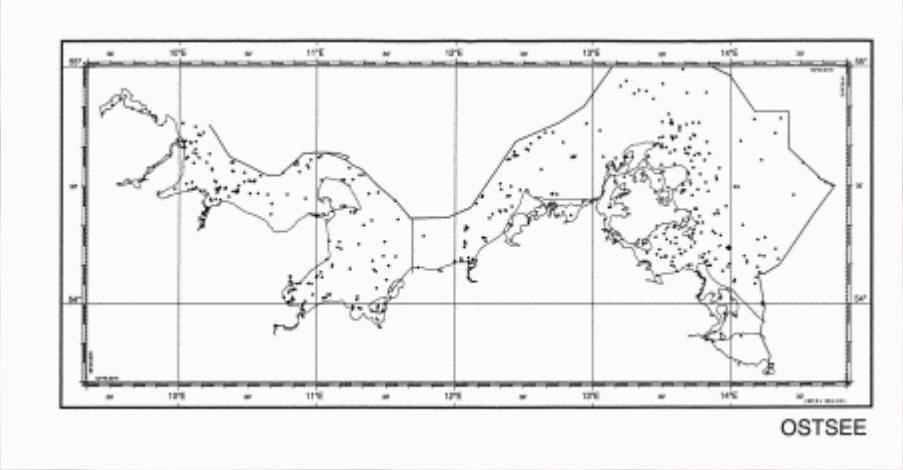
Wreck positions in the German sea areas

(more than 2000 underwater obstructions)

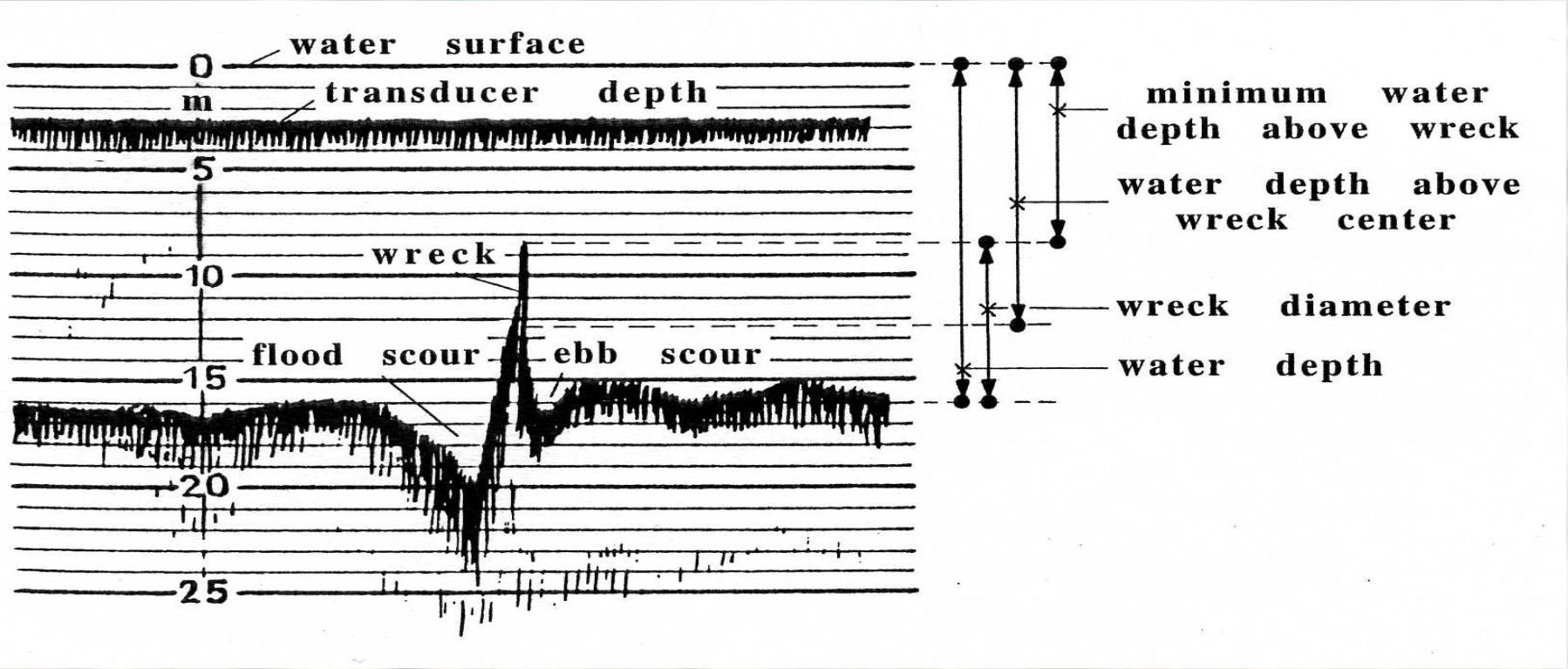
- of the North Sea



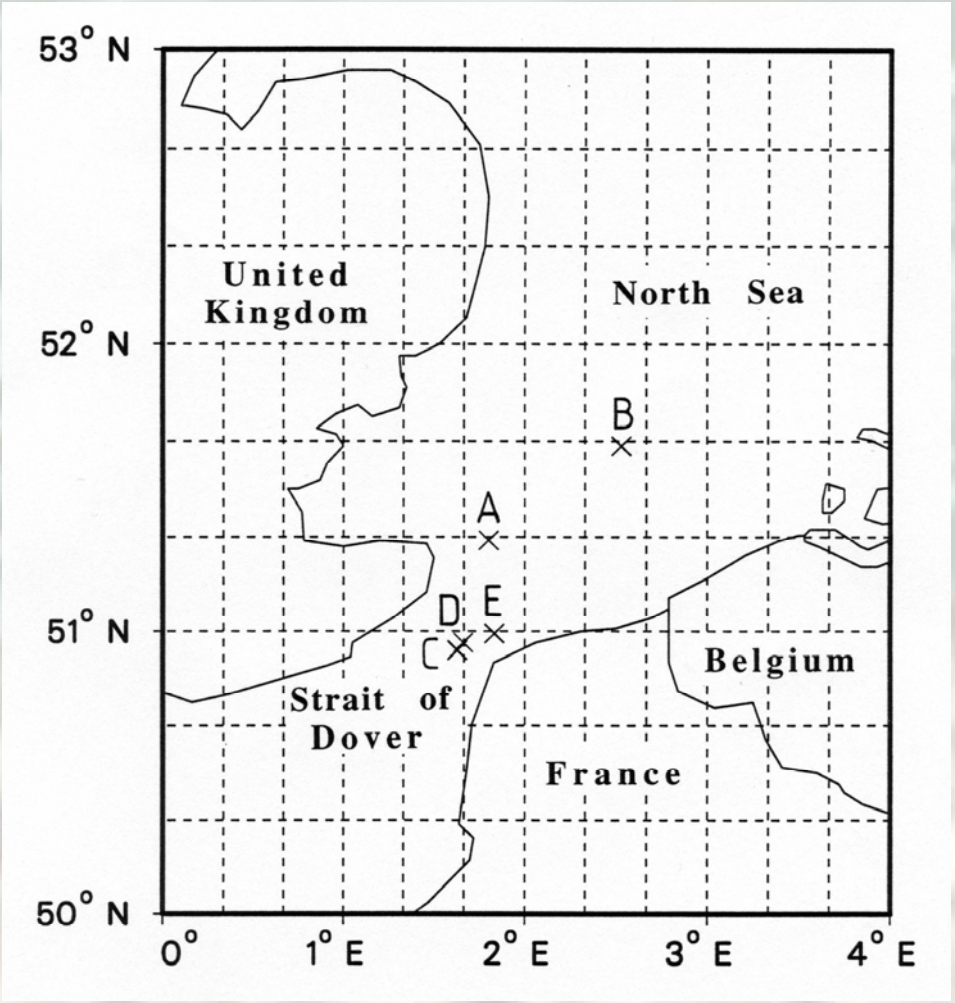
- of the Baltic Sea



Example of a section of an echogram showing a wreck in a water depth of 16 m with flood and ebb scours (modified after Nieder, 1964)



Analysed wrecks of the southern North Sea and Strait of Dover



wreck	A	B	C	D	E
position	51°19.3′N 1°48.1′E	51°39.0′N 2°31.9′E	50°56.0′N 1°37.8′E	50°57.6′N 1°39.8′E	50°59.5′N 1°50.0′E
water depth	37 m	36 m	20 m	22 m	15 m
minimum water depth above wreck	19.5 m	6.8 m	3.1 m	13.0 m	7.2 m
wreck diameter	17.5 m	29.0 m	16.9 m	9.0 m	7.8 m
water depth above wreck center	28.25 m	21.40 m	11.55 m	17.5 m	11.1 m
tidal current direction	214°	224°	52°	52°	68°
tidal current speed	0.7 m/s	0.7 m/s	1.0 m/s	1.0 m/s	1.1 m/s
wind direction from	140°	270°	326°	326°	326°
wind speed	2 m/s	8 m/s	10 m/s	10 m/s	10 m/s

Analysed radar signatures of wrecks in the southern North Sea and Strait of Dover

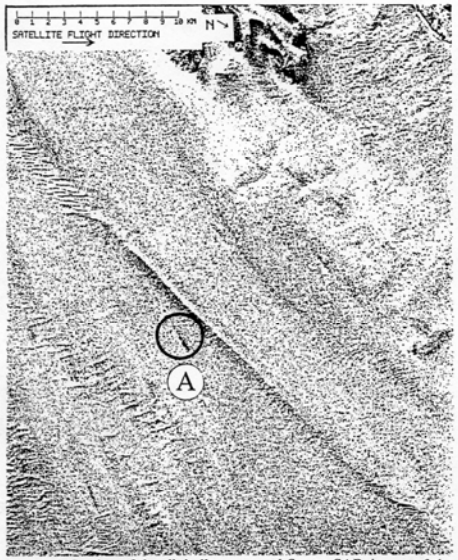


Figure 4. Section of the digitally processed Seasat SAR image of the Southern Bight of the North Sea from orbit 762 (August 19, 1978, 06.46 UTC) with frame center at $51^{0}19'26''$ N, $1^{0}52'51''$ E. The position of the radar wreck mark A is indicated. The land area in the upper right-hand corner is the English coast near Ramsgate. The feature near the wreck mark is the tidal current ridge South Falls.

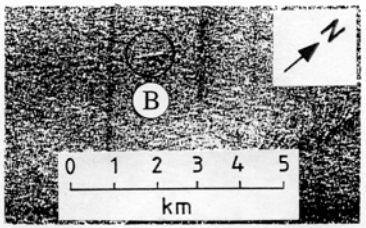


Figure 5. Airborne Ka-band real aperture radar (RAR) image from December 08, 1979, 11.30 UTC of the Hinder Banks in the southern North Sea. The position of the radar wreck mark B is indicated (courtesy of D.B. Ross).

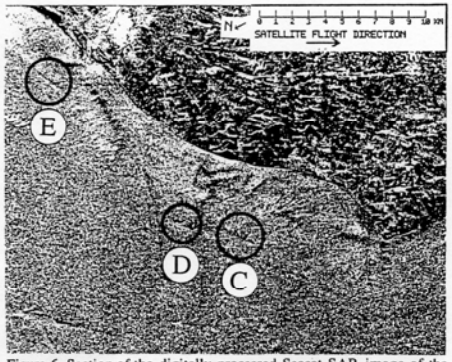


Figure 6. Section of the digitally processed Seasat SAR image of the Strait of Dover of the North Sea from orbit 957 (September 01, 1978, 22.15 UTC) with frame center at $51^{0}03'20''$ N, $1^{0}32'00''$ E. The positions of the radar wreck marks C-E are indicated. The land area on the upper side is the French coast with the port of Calais.

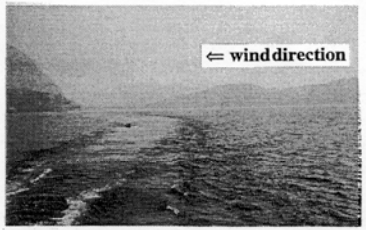
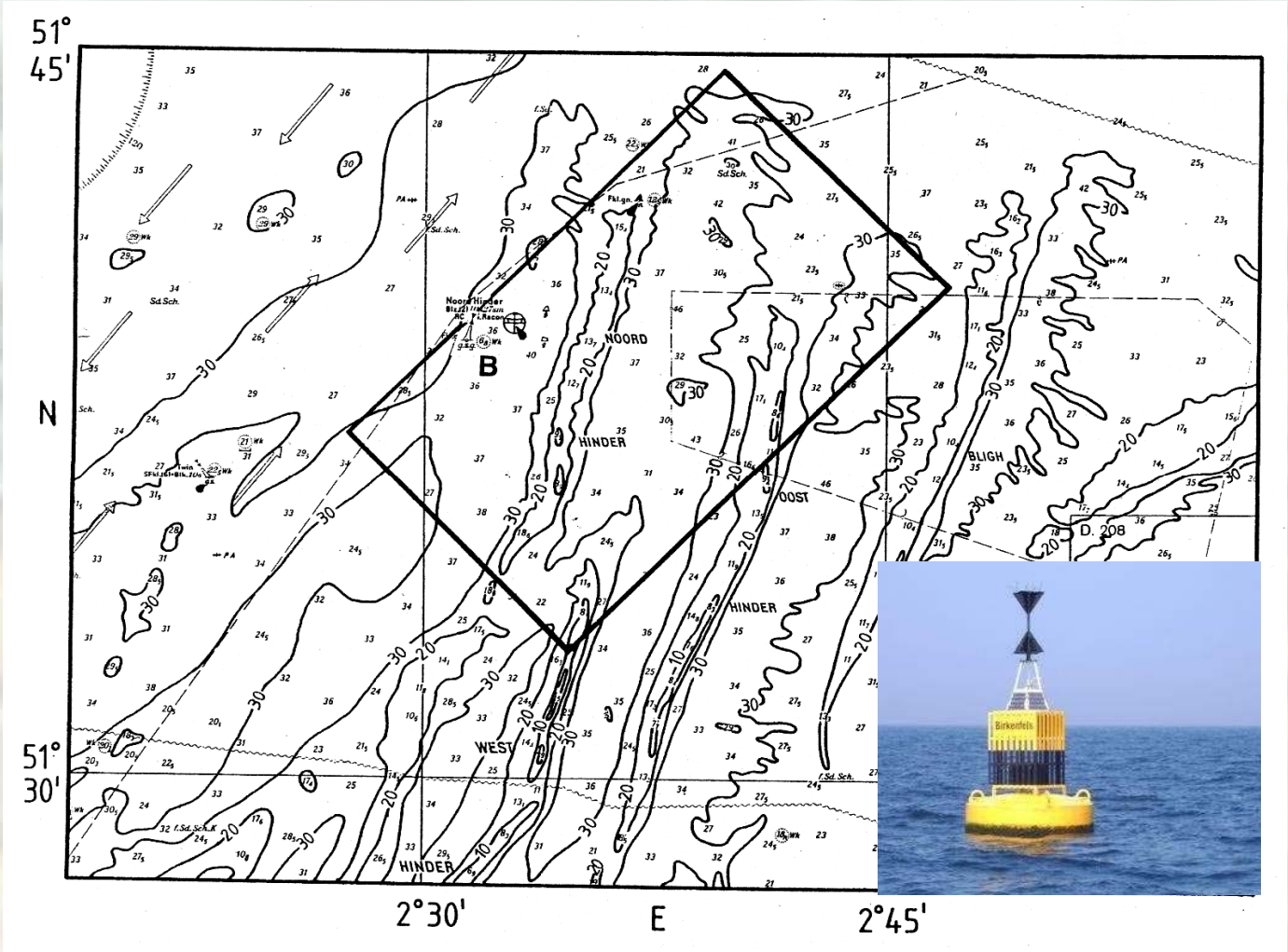


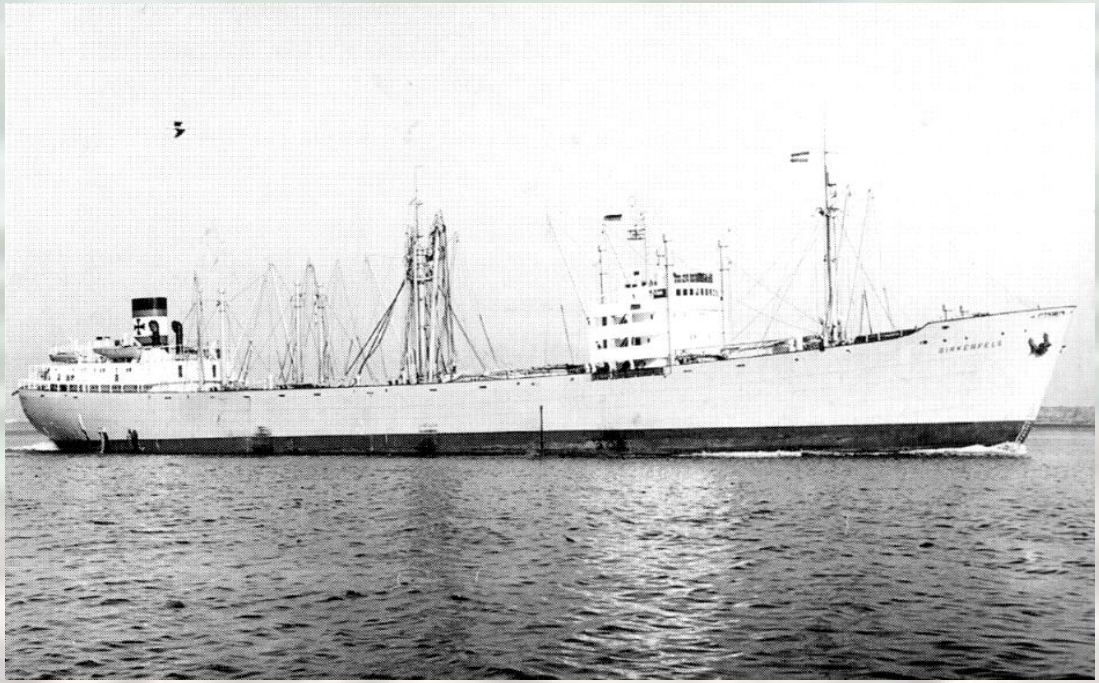
Figure 7. Image of a turbulent ship wake.

Bathymetric chart of the West-, Noord-, and Oost Hinder Banks in the southern North Sea with the position of the *Birkenfels* wreck marked by B



Picture of M.V. *Birkenfels*

and general data of the ship

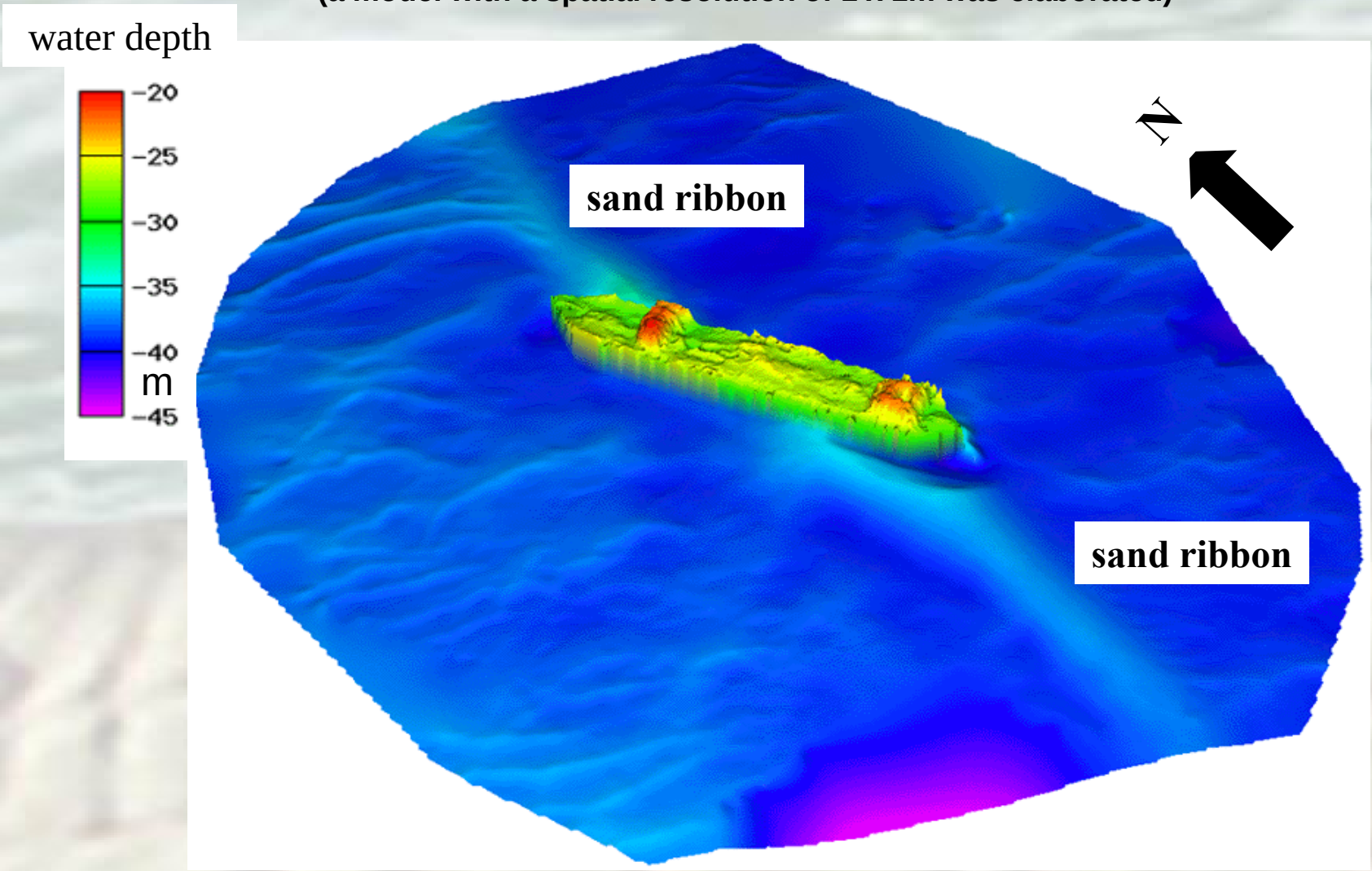


nationality	German
owner	Deutsche Dampfschifffahrtsgesellschaft (DDG) Hansa, Bremen
type of ship	cargo ship
propulsion	motor vessel
deadweight carrying capacity (tdw)	10869
gross register tons (GRT)	6974
net register tons (NRT)	3982
length over all (LOA)	156.1 m
length between perpendiculars	146.0 m
length according register and measurement certificate	140.3 m
beam	18.68 m
draught	8.06 m
moulded depth (shelter decker)	9.20 m
horse power (HP)	3820
engine	MAN
speed	12.0 kn
crew	43
passengers	6
building year	1951
building yard	A.G. Weser Seebeck, Bremerhaven
yard number	696
heavy cargo gear	165 t
cause lost	collision
date lost	07.04.1966
position of wreck	51°39.0' N, 2°31.9' E
water depth	36 m

Multibeam echo sounding image of the M.V. *Birkenfels* wreck

Kongsberg EM1002 multibeam echo sounding data collected during a survey with the *Belgica* in May 2001

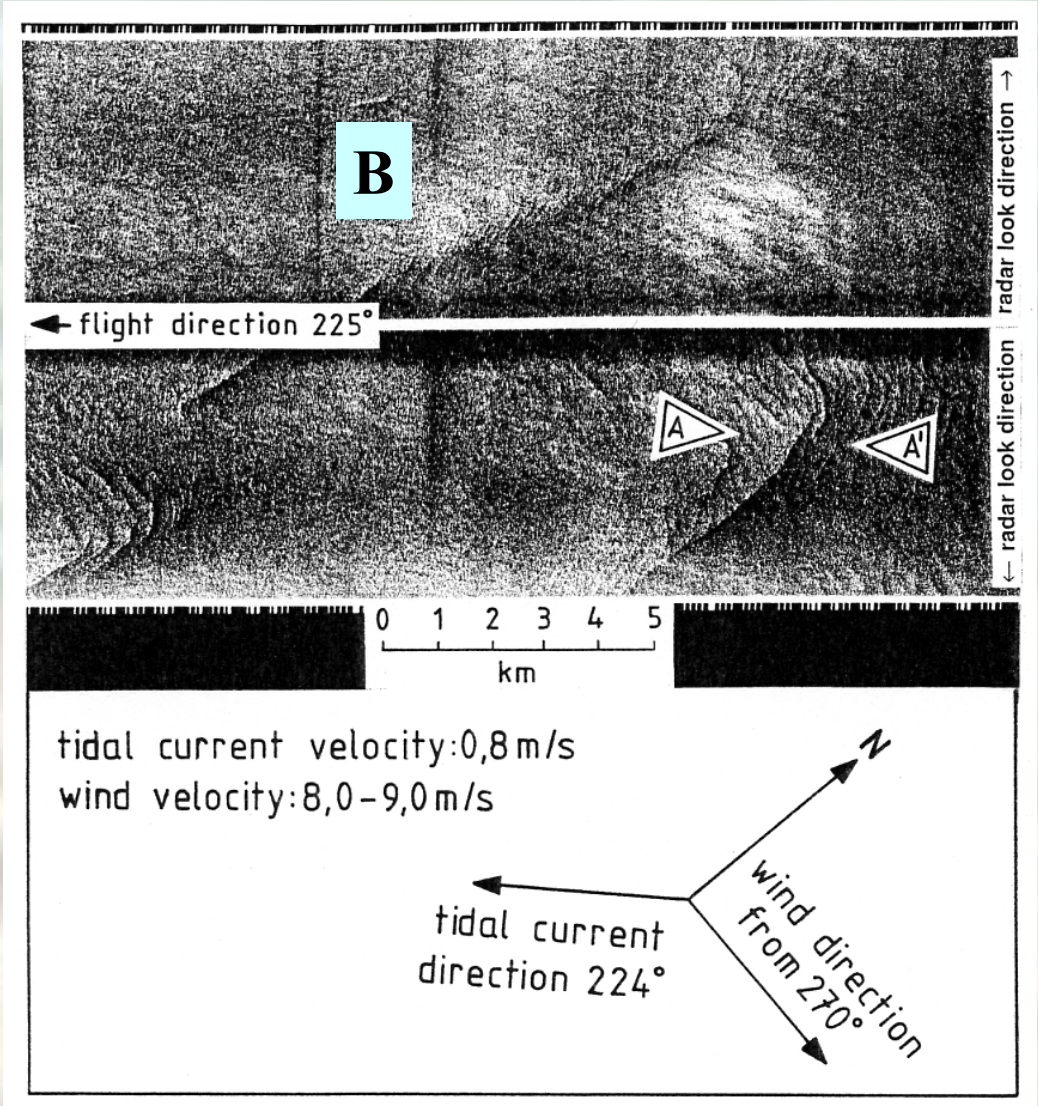
(a model with a spatial resolution of 1 x 1m was elaborated)



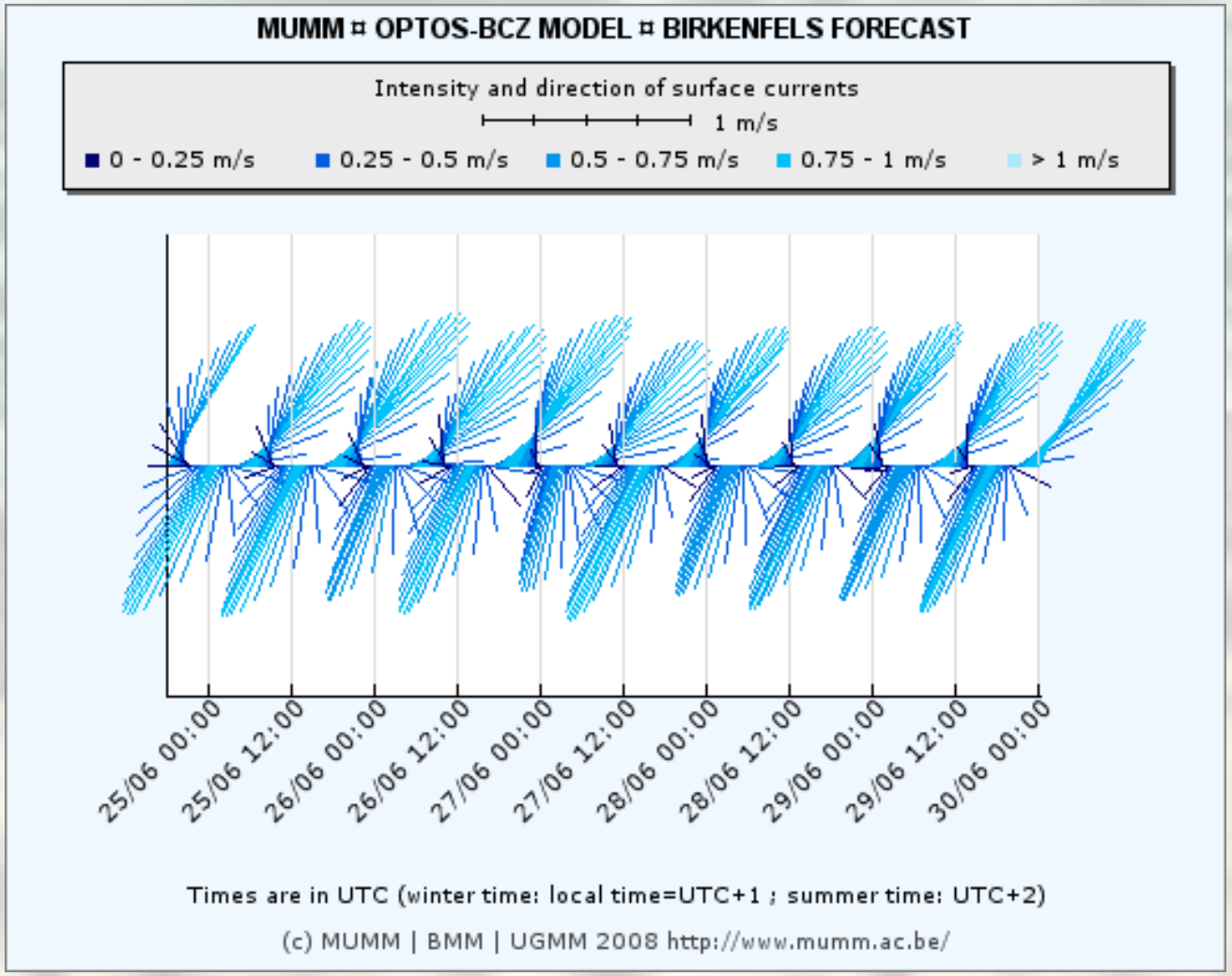
Authors : M. Roche, P. Schotte, K. Degrendele

Many thanks to the crew of the research vessel Belgica for their contribution in the collection of the necessary data.

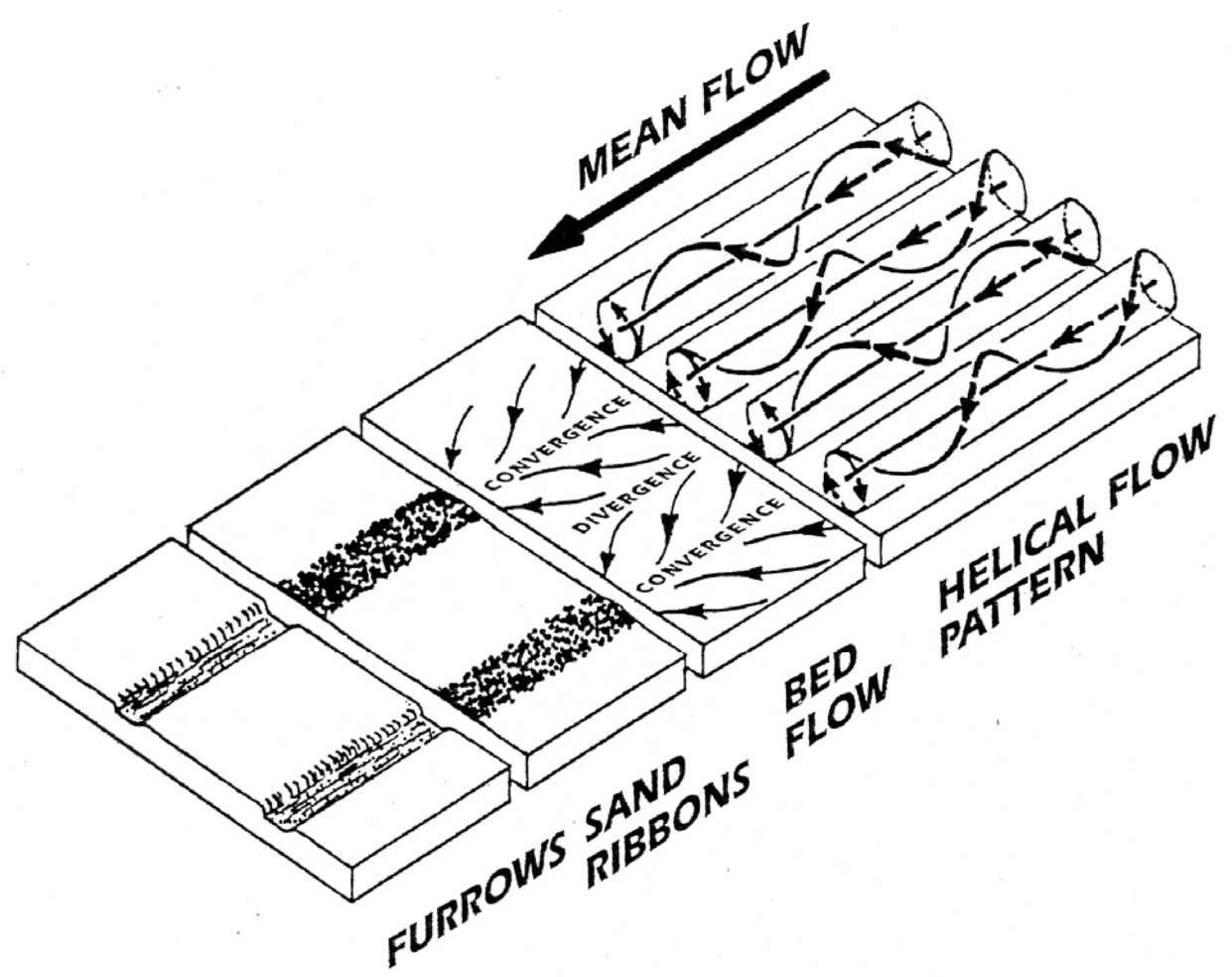
Airborne K_a-band real aperture radar (RAR) image with the radar signature of the M.V. *Birkenfels* wreck indicated by B



Surface current intensities and –directions at the M.V. *Birkenfels* wreck position in the southern North Sea,
calculated for the period of 24-30 June 2008



Schematic representation of the relationship between secondary circulations of the boundary layer, zones of convergence and divergence on the sea bed, sand ribbons, and sedimentary furrows (Viekman et al., 1992)



Theory

Disturbed normalized radar cross section (NRCS) due to quasi-specular scattering

$$\delta\sigma_{dis} = \sigma - \sigma_0 = \frac{|R(0)|^2}{\left(s_0^2 + \delta s^2\right)} \frac{1}{\cos^4\left(\theta_0 + \delta\theta\right)} \exp\left(-\frac{\tan^2\left(\theta_0 + \delta\theta\right)}{s_0^2 + \delta s^2}\right) - \sigma_0$$

with the disturbed square slope

$$\delta s^2 = \int_{k_r}^{k_c} \mathbf{k}^2(\mathbf{x}) \delta\psi(\mathbf{x}, \mathbf{k}) \mathrm{d}\mathbf{k}$$

and the relationship between ψ(k), F(k),

and N(k)

$$F(\mathbf{k}) = \omega'(k) N(\mathbf{k}) = \frac{\omega'(k)^2}{k} \psi(\mathbf{k})$$

modulation of the first order wave-energy density spectrum

$$\frac{\delta F}{F_0} = -(4+\gamma)\frac{\partial u_{perp}}{\partial x_{perp}}\left(\left(\mathbf{c_g}+\mathbf{u_0}\right)\frac{1}{L}+\mu\right)^{-1}$$

the divergence of a vector **v** is defined in cylinder coordinates by

$$\nabla\cdot\mathbf{v} = \frac{1}{\rho_{zyl}}\frac{\partial}{\partial\rho_{zyl}}\left(\rho_{zyl}\nu_{zyl}\right)+\frac{1}{\rho_{zyl}}\frac{\partial u_{\varphi_{zyl}}}{\partial\varphi_{zyl}}+\frac{\partial w}{\partial z_{zyl}}$$

with the components of a tangential current of a spherical gyre

$$u_{\varphi_{zyl}} = U_0\left(\frac{r}{h_0}\right)\exp-\left(\frac{r}{h_0}\right)^2$$

$$\nu_{\rho_{zyl}} = -\frac{U_0}{a}\left(\frac{r}{h_0}\right)\exp-\left(\frac{r}{h_0}\right)^2$$

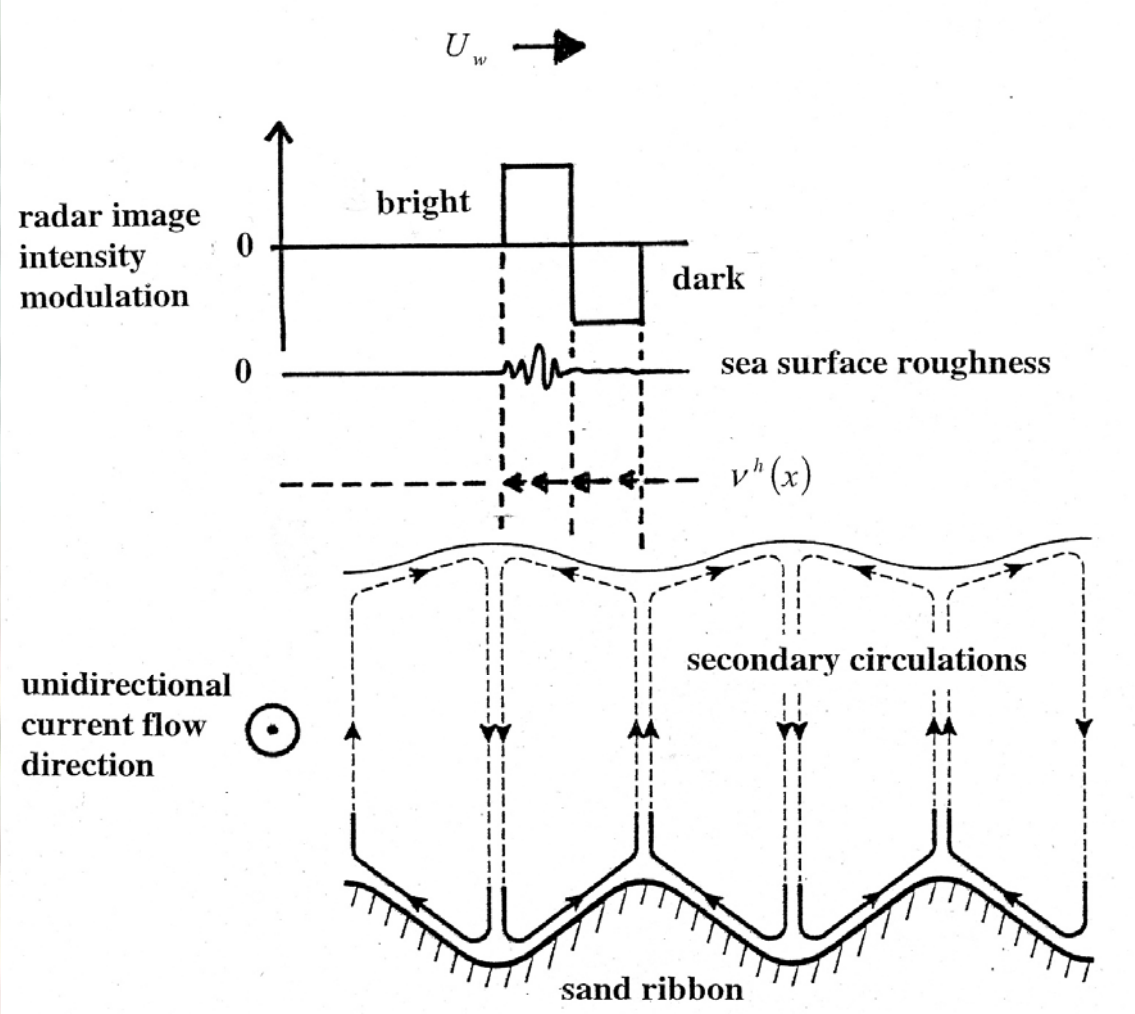
the vortex current gradient is then given by

$$\nabla \cdot \mathbf{v} = -\frac{2U_0}{ah_0} \exp -\left(\frac{r}{h_0}\right)^2 \cdot \left(1 - \frac{r^2}{h_0^2}\right)$$

this second order circulation cell due to tidal current flowing over a submarine wreck can then be approximated by the horizontal component of the tangential current gradient

$$\nabla \cdot \mathbf{v} = \frac{\partial \nu^h_{\rho_{zyl}}}{\partial x} = \cos\theta \frac{\partial \nu_{\rho_{zyl}}}{\partial \rho_{zyl}}$$

Schematic sketch of the unidirectional current flow, cross structure residual flow above sand ribbons, horizontal component of the tangential current of the secondary circulation cell at the sea surface, associated sea surface roughness, and radar image intensity modulation



Conclusions (1)

- In general, the detection of radar signatures of wrecks can support rapid wreck search of hydrographic agencies of shallow sea areas to ensure the safety of shipping.

- Wreck marks or sand ribbons as well as radar signatures of wrecks are indicators of the local dominant (tidal) current direction.

- Radar signatures of wrecks are indicators of helical flow cells in the water column triggered by unidirectional (tidal) current flow caused by the wreck lying on the sea bed.

Conclusions (2)

- The bright edge of an imaged radar wreck signature correlates with the windward direction.
- Radar signatures of underwater wrecks look like comet marks as imaged on side scan sonar records.
- Radar signatures of underwater wrecks depend on radar parameters, size, orientation and shape of the wreck, surrounding water depth, water depth above the wreck, and local wind and current conditions.