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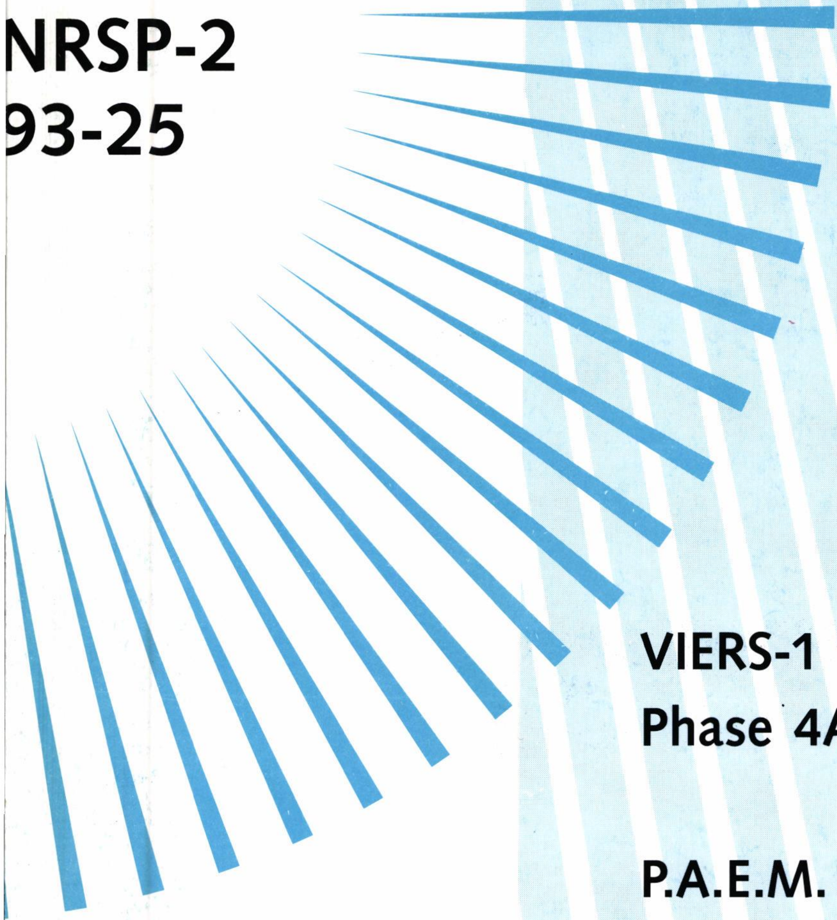

VIERS-1 Final Report
Phase 4A

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bcrs
BELEIDSCOMMISSIE REMOTE SENSING

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Phase 4A

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CONTENTS

ABSTRACT

The VIERS-1 group[1] has developed a scatterometer algorithm based on the present understanding of the radar backscatter process and the processes determining the spectral shape of the short surface waves. The algorithm has been tuned against laboratory data. Using ECMWF wave and wind fields we determined with the VIERS-1 algorithms the radar backscatter and a favourable agreement with observed backscatter from ERS-1 is found.

1. INTRODUCTION

Traditionally, the operational retrieval algorithms for scatterometer relating the radar backscatter measurements to surface wind vectors have been empirical. The assumption that the backscatter only depends on the local wind field may be questioned, however, since the backscatter reflects in some way the state of the high-frequency wind waves. The spectrum of gravity-capillary waves generated by wind not only depends on the local wind, but is determined by a number of physical processes, namely wind input, nonlinear three and four wave interactions, viscous dissipation and dissipation due to slicks (cf VIERS-1 report (1993)). Thus, for high winds when the waves are sufficiently steep, nonlinear processes may be dominant so that the state of the gravity-capillary waves is mainly determined by the longer gravity waves. In that event, the radar backscatter is likely to depend on the history of the wind field and not on the local wind field. On the other hand, for low wind speed, viscous dissipation and dissipation due to slicks may be relevant processes in determining the shape of the gravity-capillary spectrum, again suggesting that not only the local wind speed determines the backscatter.

The above consideration prompted an extensive investigation into the dependence of the radar backscatter on physical parameters such as wind speed, sea state, the presence of slicks and even parameters such as the

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[1] VIERS-1 is a Dutch acronym for Preparation and Interpretation of ERS-1 data. The project is a collaboration between the Royal Netherlands Meteorological Institute (KNMI), Delft Hydraulics, the Laboratory for Telecommunications and Remote Sensing Technology of Delft University of Technology, the University of Heidelberg, the Physics and Electronics Laboratory of TNO (FEL-TNO) and Rijkswaterstaat, Tidal Waters Division.

air-sea temperature difference. (The latter parameter becomes relevant when it is realised that the high-frequency wave spectrum depends on the surface stress and the relation between surface stress and wind speed at a certain height involves atmospheric stability (eg the air-sea temperature difference)). Thus, the VIERS-1 group emerged which started an experimental study in the laboratory and at sea to address the above issues. Parallel to the experimental work, the VIERS-1 group started the development of a scatterometer algorithm based on the present understanding of the radar backscatter process and of the relevant processes governing the shape of the gravity-capillary spectrum. The observed results on radar backscatter and the short wave spectrum were used to tune a number of unknown parameters in the scatterometer algorithm. As a result, a backscatter algorithm based on physics rather than empirical fitting was obtained.

The next question to ask is whether the VIERS-1 scatterometer algorithm produces reliable results when applied on a global scale. Assuming that the ECMWF wind and wave fields are accurate, we determined the radar backscatter with the VIERS-1 algorithm and compared the results with the backscatter as obtained from the ERS-1 satellite. The agreement between simulated and observed backscatter looks promising and will be described in full detail in a forthcoming VIERS-1 report. Here, we shall only present the main result briefly, concentrating on some results obtained during the tuning of the VIERS-1 scat algorithm and on the dependence of the backscatter on slicks.

2. TUNING THE VIERS-1 BACKSCATTER ALGORITHM

Using laboratory data for σ_o and the two dimensional wave number spectra, the performance of several backscatter models (*Fung*, 1987; *Holliday*, 1986; *Bahar*, 1981; two-scale approach (*Plant*, 1990)) was investigated. The two-scale model turned out to give satisfactory results in a reasonably short run time (VIERS-1 (1993)). Thus, the radar backscatter can be found by integrating the backscatter of the individual facets (which are tilted by the longer gravity waves) weighted with the probability that the water surface is tilted by a certain angle. For high wave numbers ($k>k_c$) the main scattering mechanism was assumed to be Bragg scattering, hence

$$\sigma_l \sim \Phi(k_b),\ k > k_c \tag{1}$$

while, for $k < k_c$, specular reflection was taken. Here, Φ is the wave number spectrum, k_R is the radar wave number, θ_l is the local incidence angle which depends on the tilt of the water surface by the long waves and k_c denotes the separation scale between Bragg and specular reflection. Finally, k_b follows from the Bragg resonance condition between the electromagnetic wave and the surface waves and is given by

$$k_b = 2k_R \sin\theta_l \tag{2}$$

A complete account of this algorithm, including the choice of separation scale k_c is given in the VIERS-1 report (1993) (but see also *Plant*, 1990). The comparison given in the VIERS-1 report showed, however, that for low incidence angles the backscatter was overestimated. Wallbrink and Janssen ascribed this discrepancy to a too high value of the standard reflection coefficient (see also *Valenzuela*, 1978). By reducing it somewhat, they obtained the results as given in Fig.1. Indeed, an impressive agreement between simulated and observed backscatter, both for horizontal and vertical polarisation, is obtained, giving confidence in the electromagnetic part of the VIERS-1 algorithm.

The geophysical part of the VIERS-1 scatterometer algorithms is determined by the modules for the short wave spectrum and the module that gives the relation between wind speed at 10 m height, the air-sea temperature difference and the surface stress. We will not discuss the latter module as it is fairly standard, except that the surface roughness is sea state dependent and is given by the empirical expression from *Smith et al* (1992).

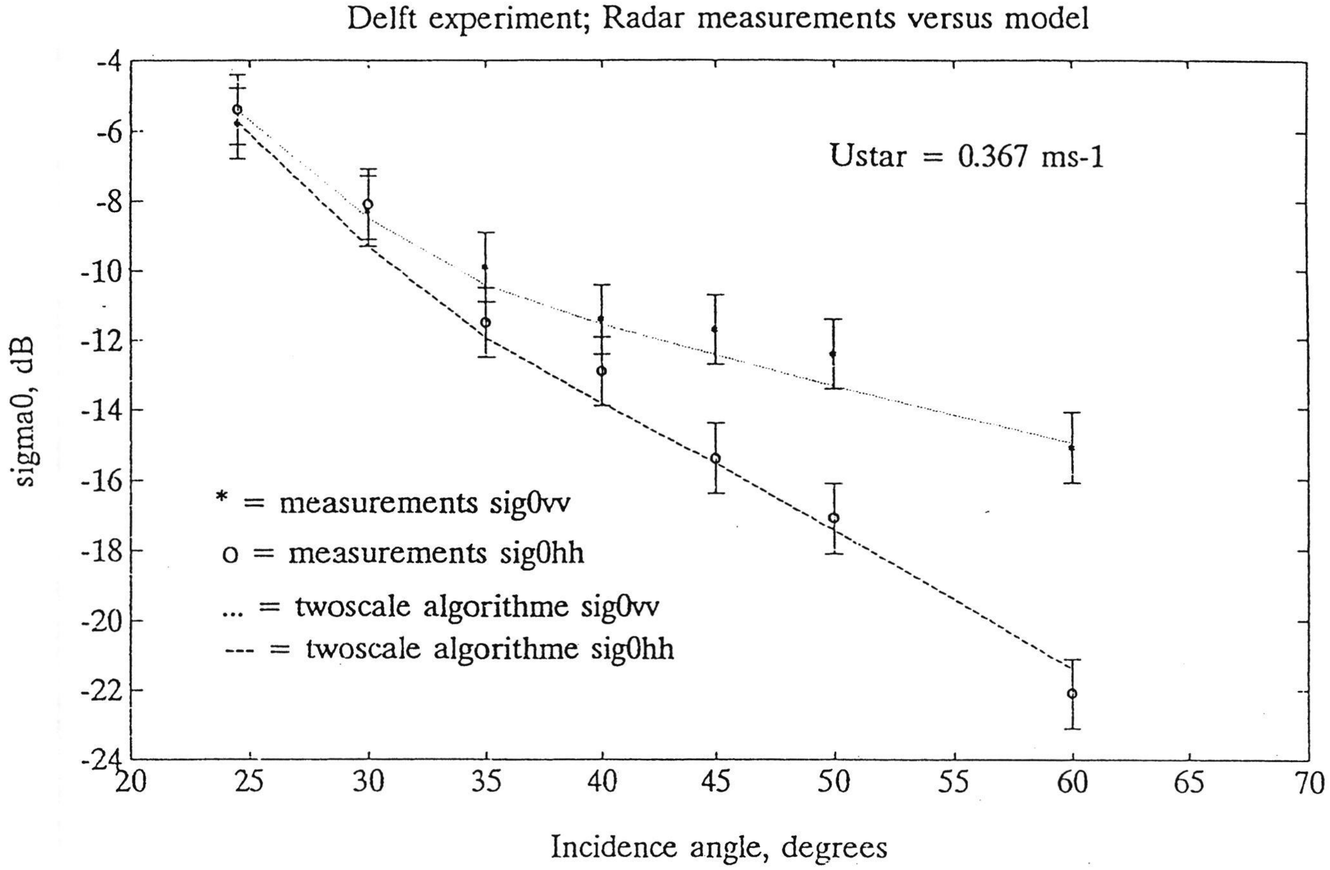

Fig.1 Comparison of simulated σ_0 and observed σ_0 as function of incidence angle.

The model for the short wave spectrum is based on the so-called energy balance equation, which is solved under steady state circumstances because the high-frequency waves have a very short response time scale. The energy balance equation for the short waves is therefore given by

$$\frac{\partial}{\partial t}\Phi = 0 = S_{in} + S_{nonl} + S_{visc} + S_{br} + S_{slicks} \tag{3}$$

where S_{in} represents the effect of wind, S_{nonl} describes the effect of 3 and 4 wave interactions, S_{visc} describes viscous dissipation, S_{br} describes dissipation due to white capping and S_{slicks} describes the resonant energy transfer between surface waves and slicks (Marengoni effect). The energy balance equation (3) is solved as a boundary value problem in wave number space by providing the energy flux from long to short waves at the boundary $k_{bou} = g/u_*^2$, corresponding to the condition $c/u_* = 1$ (where c is the phase speed of the waves and u_* the friction velocity). A pictorial view of the energy balance for short waves is given in Fig.2.

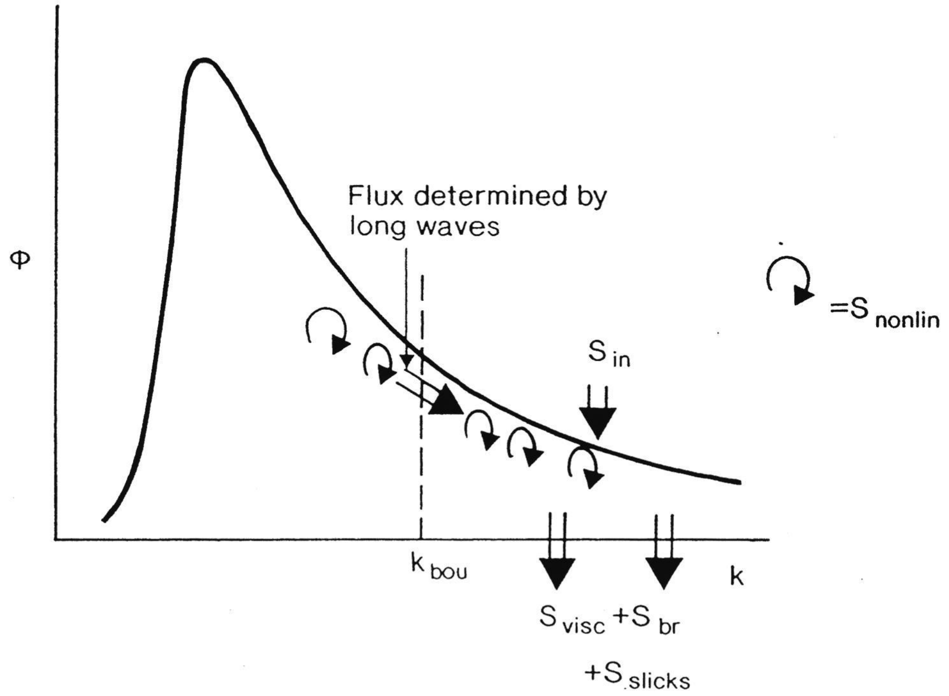

Fig.2 Pictorial view of the energy balance of short waves.

From this picture of the energy balance of short waves it is concluded that the gravity-capillary spectrum (and hence the backscatter) depends not only on the local friction velocity but also on parameters such as the stage of development of the long gravity waves. A complete account of the specific source terms used in the energy balance equation is given in VIERS-1 (1993). Here, we only present a comparison of simulated spectra and observed wind-wave tank spectra in Fig.3 to show that the present model is able to produce realistic spectra.

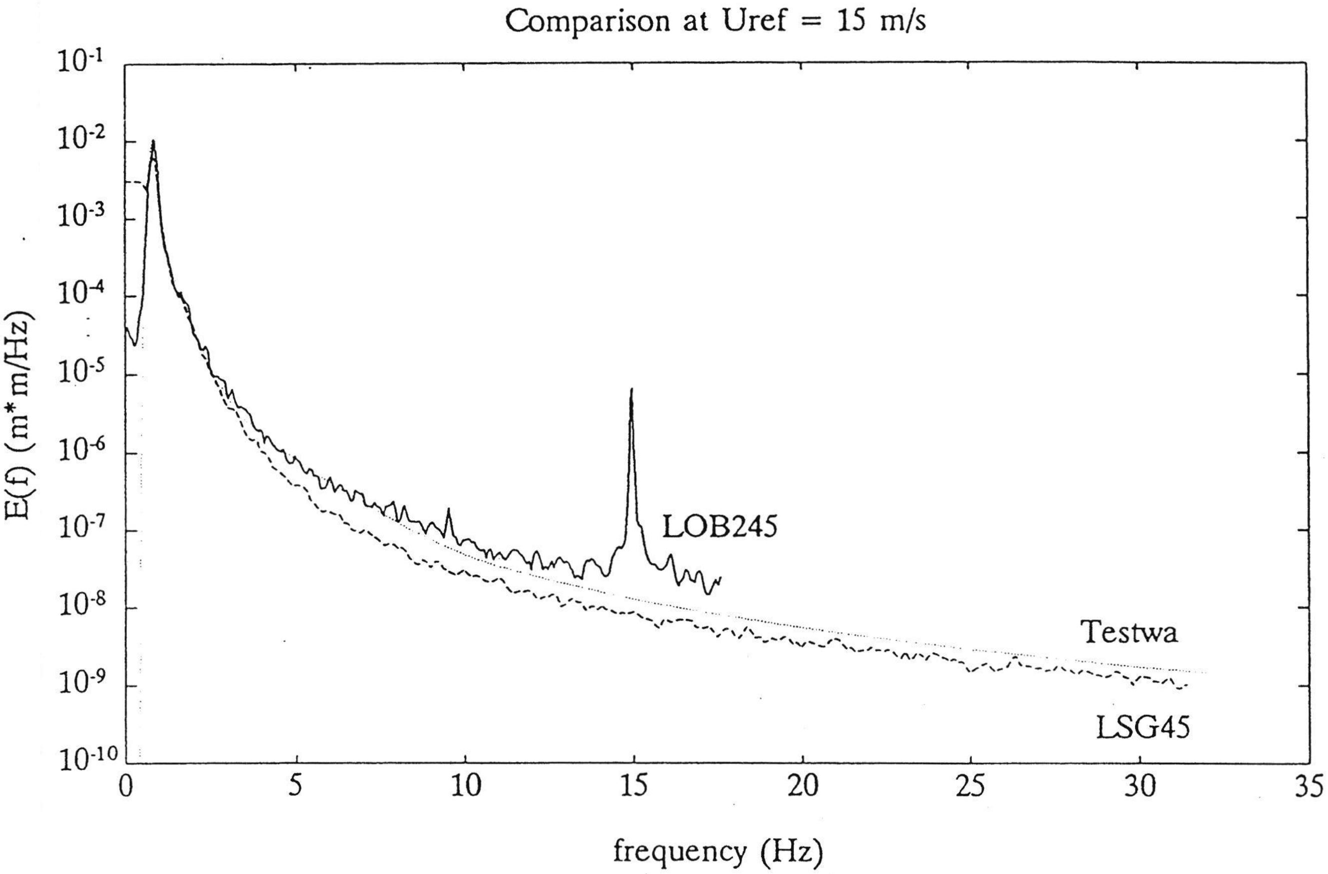

Fig.3 Comparison of simulated and observed short-wave frequency spectre for a fetch of 90 m.

3. VALIDATION OF VIERS-1 SCATTEROMETER ALGORITHM AGAINST ERS-1 DATA

After our discussion of the tuning of our algorithm against laboratory data we would like to return now to the question of the application to the simulation of the backscatter σ_o under realistic circumstances.

It is emphasised that this question is a valid one because so far the VIERS-1 scat algorithm has only been validated under the limited conditions of the laboratory. In addition, the Radar in the laboratory was X-band, while the Radar on board of ERS-1 is C-band.

Using the collocation files containing both ECMWF wind and wave fields we determined with the VIERS-1 scatterometer the radar backscatter σ_o (vertical polarisation). The air-sea temperature difference was set to zero since neutral stability is the most common situation that occurs over the oceans. In Fig.4 we compare the simulated backscatter with the observed one, while as a bench mark we have also shown results of the present operational scatterometer algorithm CMOD4. The contour lines in this figure denote lines of constant number of collocations of observed and simulated backscatter. Our impression is that the VIERS-1 algorithm shows an overall good agreement, with a bias of 0.3 dB and a standard deviation of 2 dB while CMOD4's standard deviation has the higher value of 2.9 dB. The large scatter with CMOD4 is entirely due to the bad performance of this algorithm at low winds (U10 ≤ 5 m/s). Realizing that these low winds comprise about 25% of the cases and that these low winds occur mainly in the tropics (an area which is of vital importance for climate simulations), it is concluded that the VIERS-1 algorithm has a definite advantage over CMOD4.

Finally, to illustrate that the backscatter not only depends on the wind speed but also on other geophysical parameters, we show in the right panel of Fig.4 the considerable effects that slicks of natural origin have on backscatter results.

4. CONCLUSION

We conclude from this comparison that the VIERS-1 scatterometer algorithm, based on our present knowledge of air-sea interaction, is performing well, even compared to CMOD4 which is tuned on the data set we have considered in this comparison. The advantage of the VIERS-1 algorithm over CMOD4 is, however, that it is based on physics so that dependencies on sea state, slicks, etc are automatically included in the algorithm. One would therefore expect that this algorithm is performing better in rapidly varying circumstances, such as the passage of frontal systems. In order to substantiate this claim, the VIERS group is presently working on the inversion of the VIERS-1 scatterometer algorithm so that a retrieval of wind speed and wind direction from observed back scatter returns becomes feasible.

Furthermore, the scatterometer algorithm will be validated against field data obtained during the ESA field campaign in the Norwegian Sea.

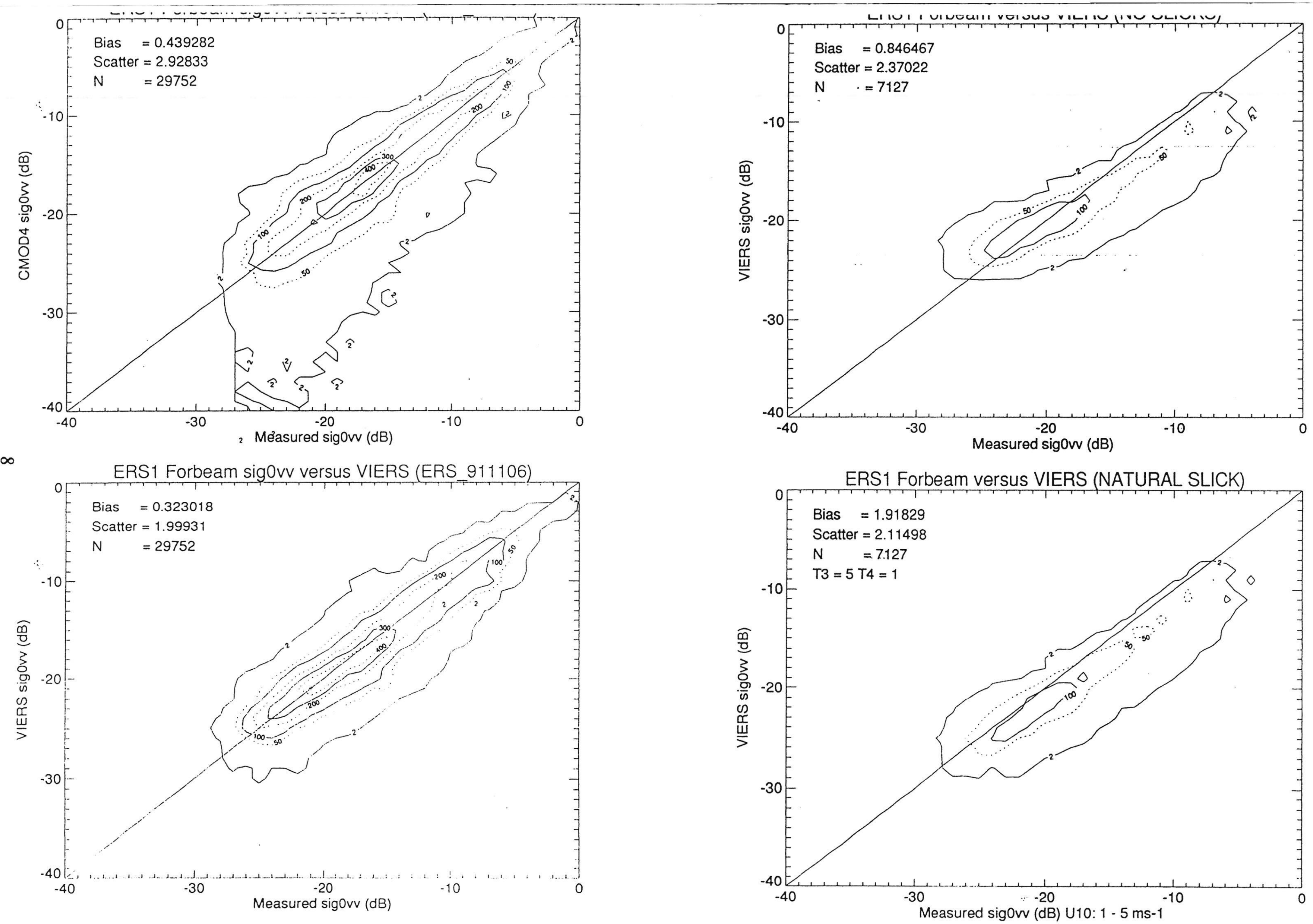

Fig.4 Left panel shows simulated and observed σ for CMOD4 and VIERS, while the right panel shows the impact of slicks on backscatter for wind speed below 5 m/s.

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