Radar Backscatter Measurements on FINO-2

SOPRAN III • Theme II • FINO-2

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Introduction

In order to help finding a direct link between the radar cross section (RCS) from the ocean surface and the ocean-atmosphere gas transfer velocity, Multi³Scat measurements were carried out on FINO-2 from September 2011 to November 2013. We measured the radar backscatter from the sea surface at five microwave frequencies (1.0 GHz, 2.3 GHz, 5.3 GHz, 10.0 GHz, and 15.0 GHz, corresponding to L, S, C, X, and Ku band, respectively), four polarization combinations (HH, HV, VH, VV – the first and second letter denoting the polarization of the transmitted and received signal, respectively) and three incidence angles (35°, 45°, 55°).

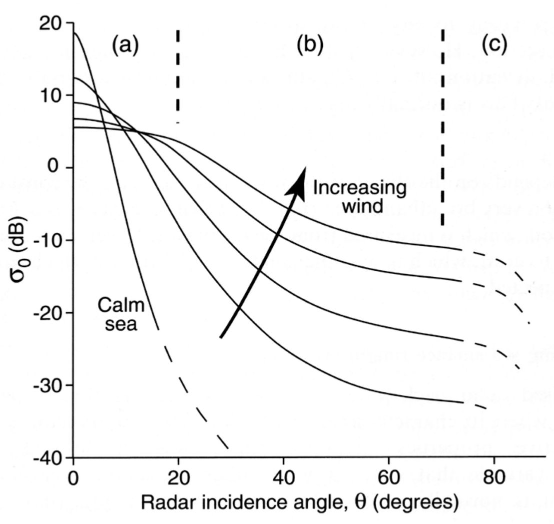
Here, we present first results of a quality assessment of all data of 2012, i.e. of 12 months of RCS measurements. The RCS increases with increasing wind speed for all radar bands/ polarizations / incidence angles. Furthermore, at moderate wind speed and steep incidence angles the radar backscatter depends only slightly on the azimuth direction. Our results are in good agreement with theories of radar backscattering from a slightly rough water surface, thus confirming the good quality of the backscatter data obtained on FINO-2.

Theory

Geophysical Model Functions (GMF) describe the relationship between the RCS and the wind vector. In its most simple form a GMF reads

$$\sigma = a \cdot U^b \cdot [A_0 + A_1 \cos(\varphi) + A_2 \cos(2\varphi)],$$

where φ is the azimuth direction and b is the wind speed exponent, which is a function of radar frequency, polarization and incidence angle and which reflects the sensitivity of the RCS to wind speed changes.

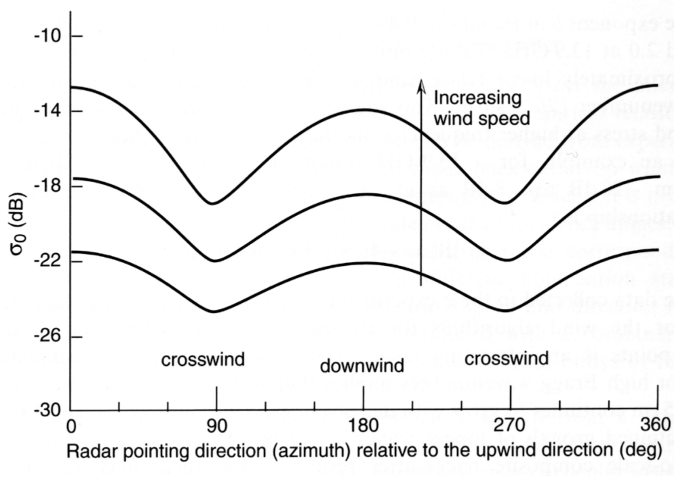


Normalized Radar Cross Section, σ_0, as a function of incidence angle, and its change with increasing wind speed (Robinson 2004). The regions (a), (b) and (c) indicate different dominant scattering mechanisms. Multi³Scat measurements were performed only in region (b) (Bragg scattering).

For oblique incidence angles (25° - 75°) the microwave backscattering from the sea surface is primarily dependent on small scale gravity/capillary waves (Bragg scattering). According to first order Bragg theory, the resonance water wavelength is related to the electromagnetic wavelength by:

$$\lambda_{\mathrm{radar}} = 2 \cdot \lambda_{\mathrm{water}} \cdot \sin\theta \ ,$$

where θ is the incidence angle.

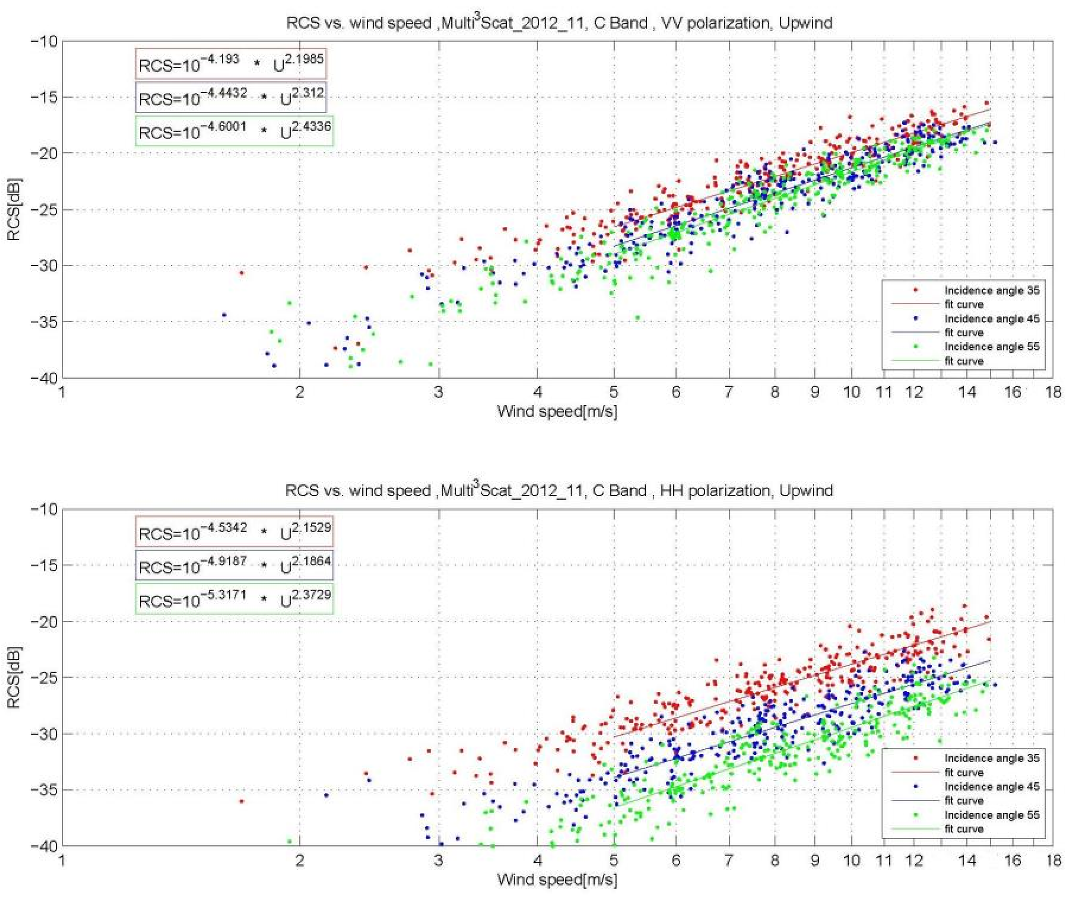


The effect of wind speed on the azimuthal dependence of the RCS for a radar frequency of 13.9 GHz and 40° incidence angle (Robinson 2004).

Results

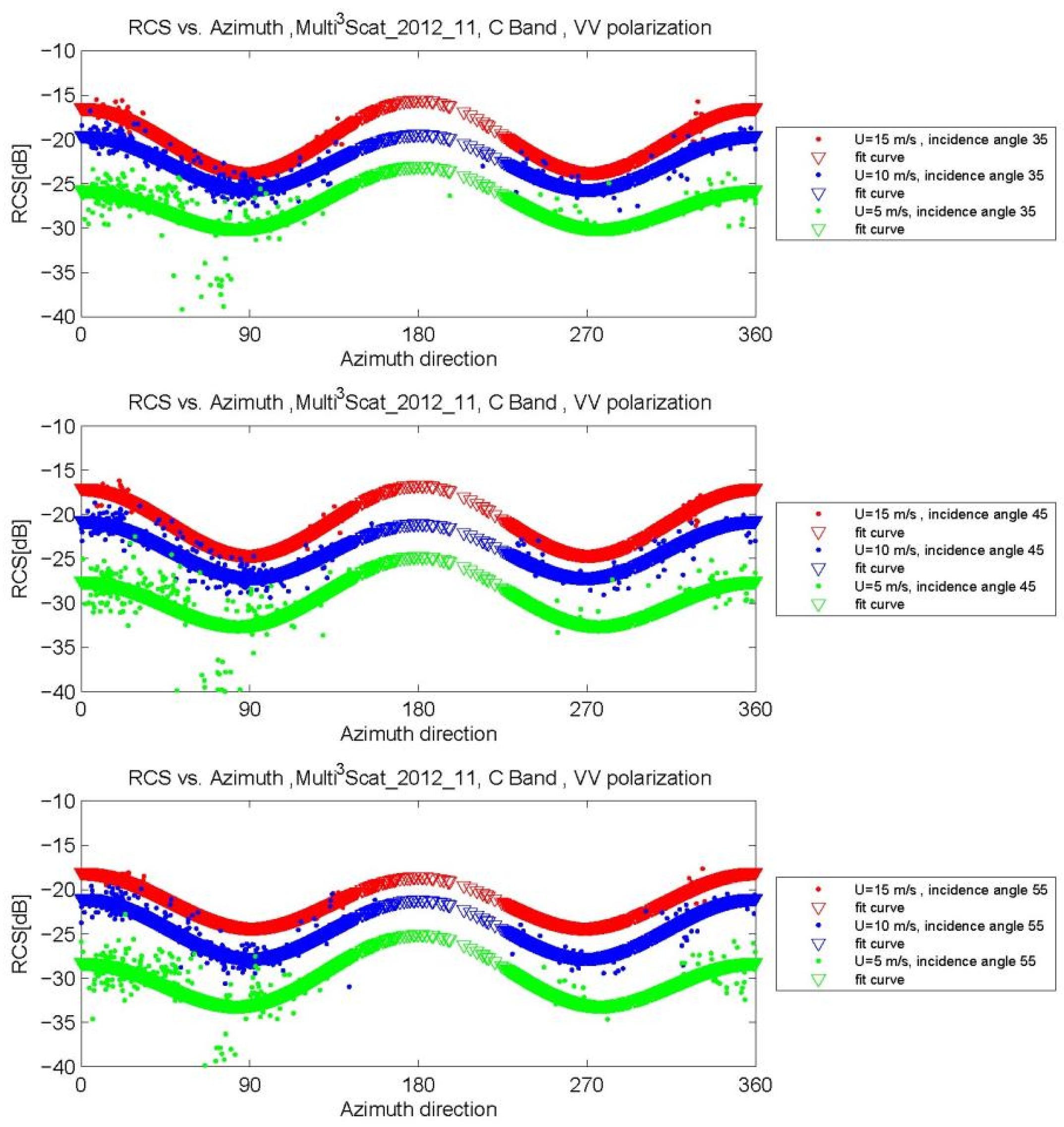
The RCS increases with increasing wind speed, and the wind speed exponent increases with increasing incidence angle. This indicates that more oblique viewing will sample shorter and smaller amplitude Bragg waves leading to lower radar backscatter.

Moreover, measurements at higher radar frequencies and steeper incidence angles (not shown herein) lead to an increased sensitivity of the RSC to wind speed.



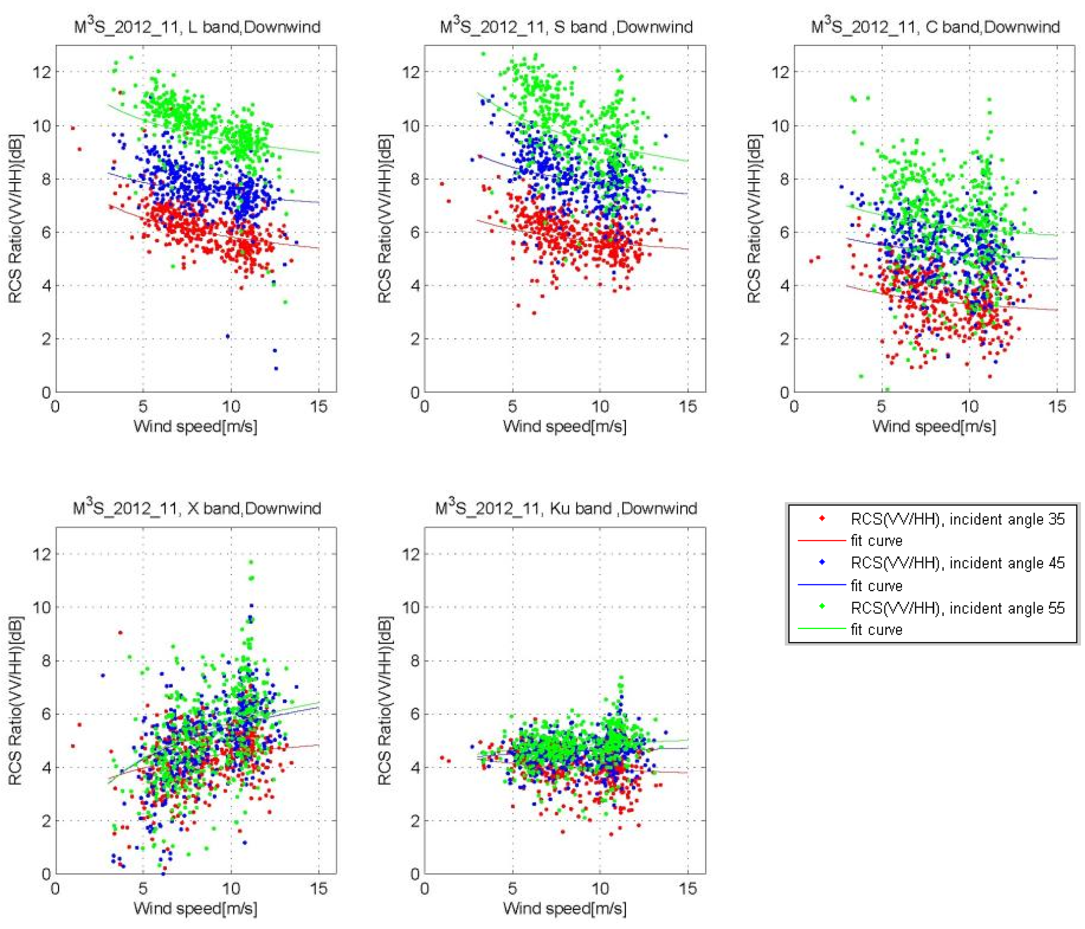
Wind-dependent RCS at C band, vertical (VV, upper panel) and horizontal (HH, lower panel) polarization, for incidence angles 35° (red), 45° (blue) and 55° (green). Shown are all upwind measurements in November 2012.

At moderate wind the azimuthal dependence of the RCS is smaller than at high wind speeds. For upwind and downwind measurements the backscattered power is higher than for crosswind measurements, which is related to orientation and tilt of the Bragg waves with respect to the radar. Data gaps in downwind direction are due to wind shadowing by the platform.



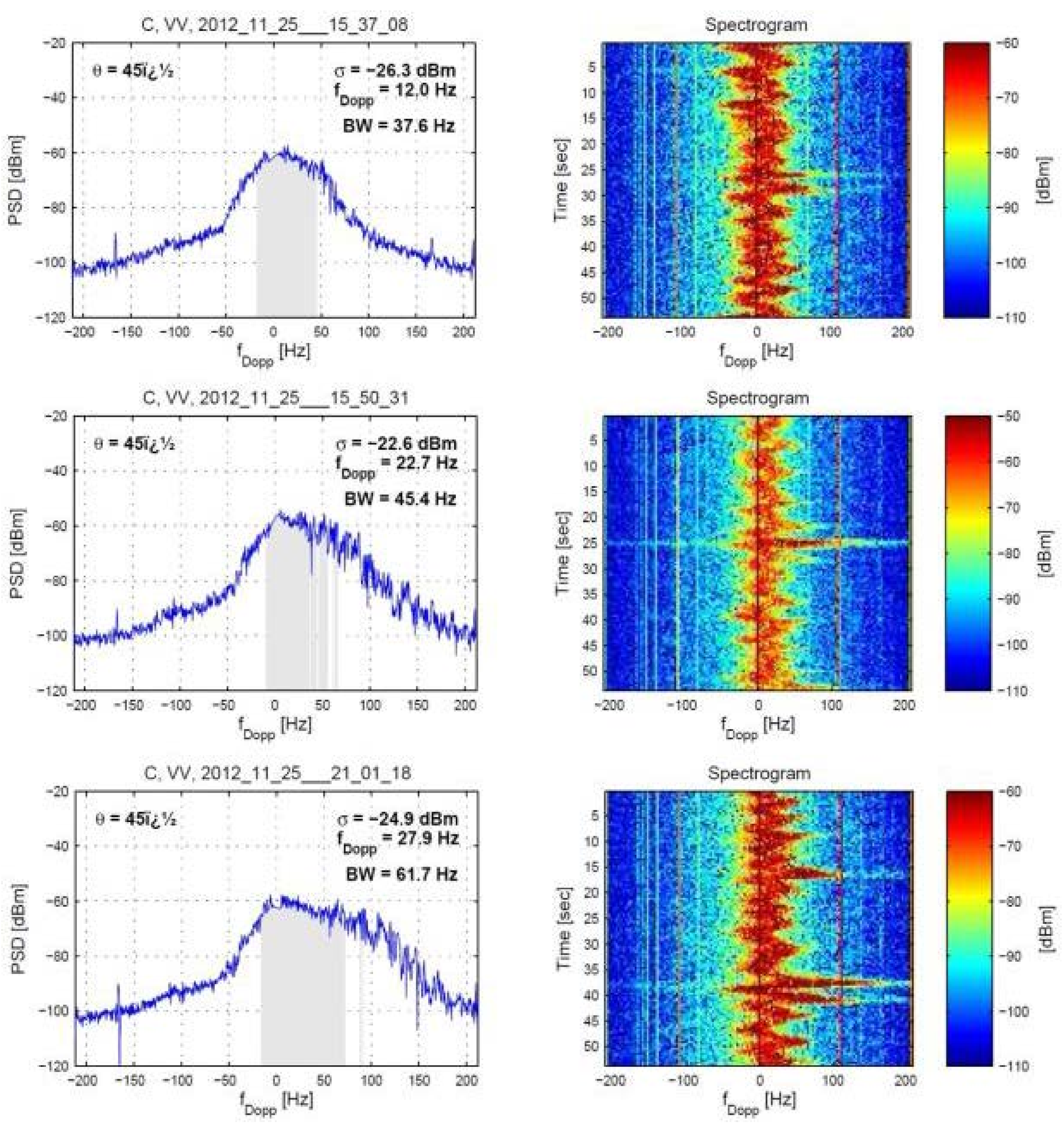
RCS versus azimuth angle for C band, vertical (VV) polarization, and wind speeds of 5 m/s (green),10 m/s (blue) and 15 m/s (red) at incidence angles 35°, 45°, 55° (top to bottom). Added are fits to the data according to the GMF presented above.

The polarization ratio, i.e. the ratio of the RCS at vertical (VV) and horizontal (HH) polarization, is independent of the system calibration and therefore provides further information on the data quality. It decreases with increasing radar frequency, which indicates that higher radar frequencies are better suited for ocean surface scatterometry.



Polarization ratio, i.e., the ratio of the RCS at VV and HH polarization) based on the Multi³Scat measurements for all radar bands, downwind look direction, and three incidence angles.

In general, the Multi³Scat data show a strong scatter. Here, we demonstrate that the frequency of strong wave breaking can explain some temporal variability of the RCS, which in turn may manifest in the measured scatter of the data.



Power spectral density (PSD, left column) and spectrograms (right column) measured at C band, VV polarization and 45° incidence angle, and at wind speeds between 10 m/s and 12 m/s. The different number of wave breakers manifests in both different Doppler bandwidth and RCS.

At approximately the same wind speed (11.6 m/s, 11.3 m/s and 10.2 m/s, from top to bottom) and under the same scattering conditions (vertical polarization, C band, 45° incidence angle) a higher density of wave breakers results in a broader Doppler spectrum, with greater Doppler bandwidth, and in a stronger radar backscatter (RCS – see the shaded areas, which indicate the spectral range used for ther computation of the backscattered power).

In general, the analyses performed so far indicate that the overall quality of the Multi³Scat data obtained on FINO-2 is sufficient for the anticipated correlation with existing gas flux data.

References

Robinson, I. S., Measuring the Ocean from Space , the principle and methods of satellite oceanography, Chapter 10, 2004.