# Imprints of air bubbles & crystal orientation fabric on RES signature ?

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## Introduction

Radio echo sounding (RES) enables mapping of bedrock topography and internal structure in large ice bodies. Via multi-frequency and multi-polarization sounding, internal reflections can be assigned to non-uniformities in density, conductivity and crystal orientation fabric (COF). This allows to deduce a multitude of glaciological parameters (e.g. accumulation, linking of ice cores). Similar as [1], [2], and [3], we analyse polarization dependent backscatter from ground based measurements in Antarctica and on an cold alpine glacier (Colle Gnifetti, Monte Rosa, Swiss-Italian Alps).

The Antarctic example displays anisotropic backscatter which changes its direction with increasing depth. We suspect that this is caused by changing COF or by anisotropic distribution of air bubbles in the ice matrix since the change in direction coincides with the clathrate transition observed in the nearby EPICA-DML ice core. We compare the results with a multi-polarization and multi-frequency experiment on the Colle Gniffetti. There, the anisotropic response is visible, but far less pronounced. Eventually, this study aims to link the observed anisotropy in the RES data to stress and strain rates in ice sheets.

## Observation

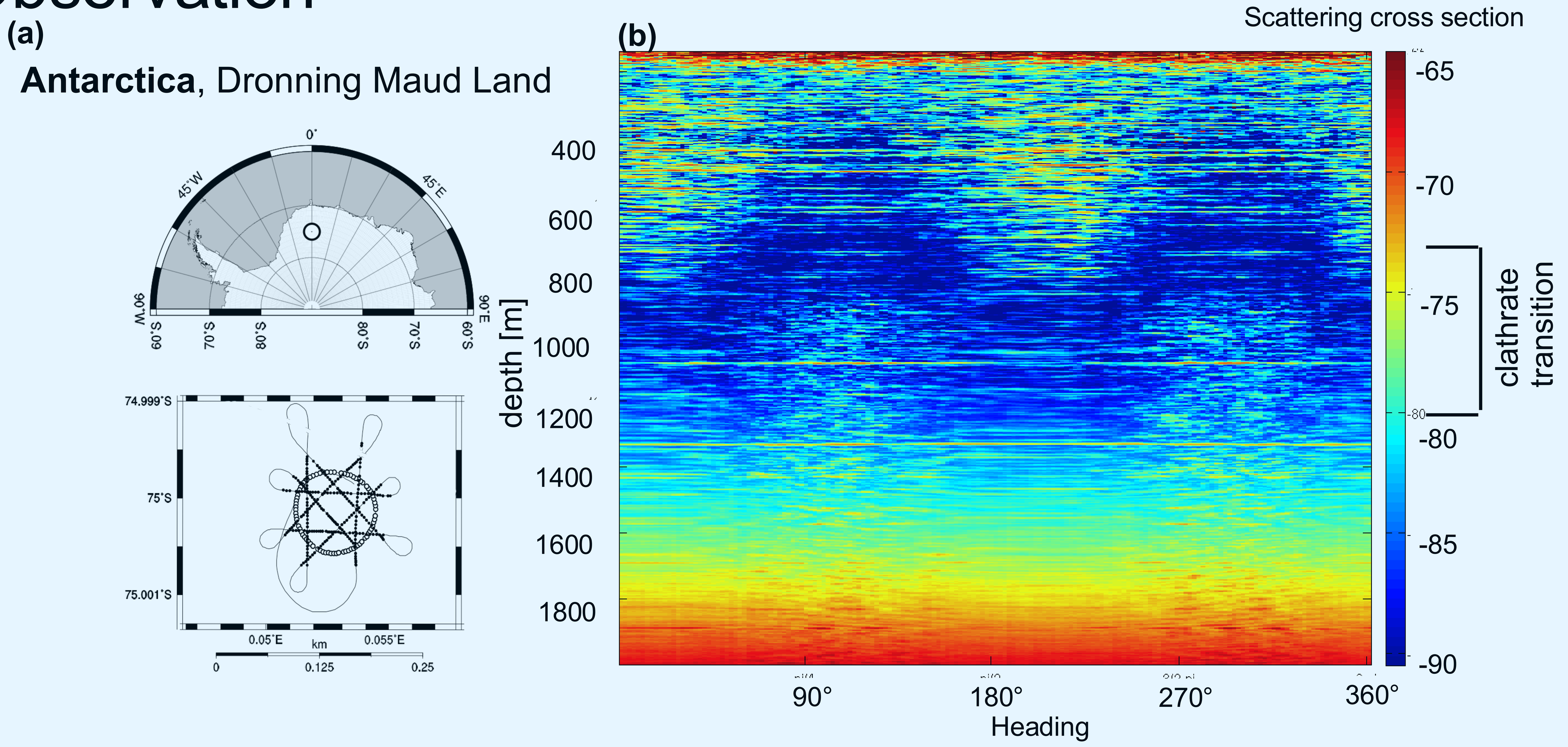


Fig. 1: **(a)** RES profile (60 ns pulse, center frequency 150 MHz) in Dronning Maud Land, Antarctica (see also [3]). The circular profile was taken with a plane moving on the ground. **(b)** Scattering cross section derived by inverting the radar equation including cable loss, spherical spreading and electromagnetic attenuation (calculated from dielectric profiling data of the nearby EPICA-DML ice core). Polarization dependent backscatter with a 180° symmetry is clearly visible in the depth range of 400 – 1200 m. Effects of birefringence (with a 90° symmetry) are visible to a lesser extent. The 90° shift of polarization dependence coincides with the clathrate transition observed in the EPICA-DML ice core. In the upper 900 m the maxima is perpendicular to the ice divide, between 900-1400 m it is parallel.

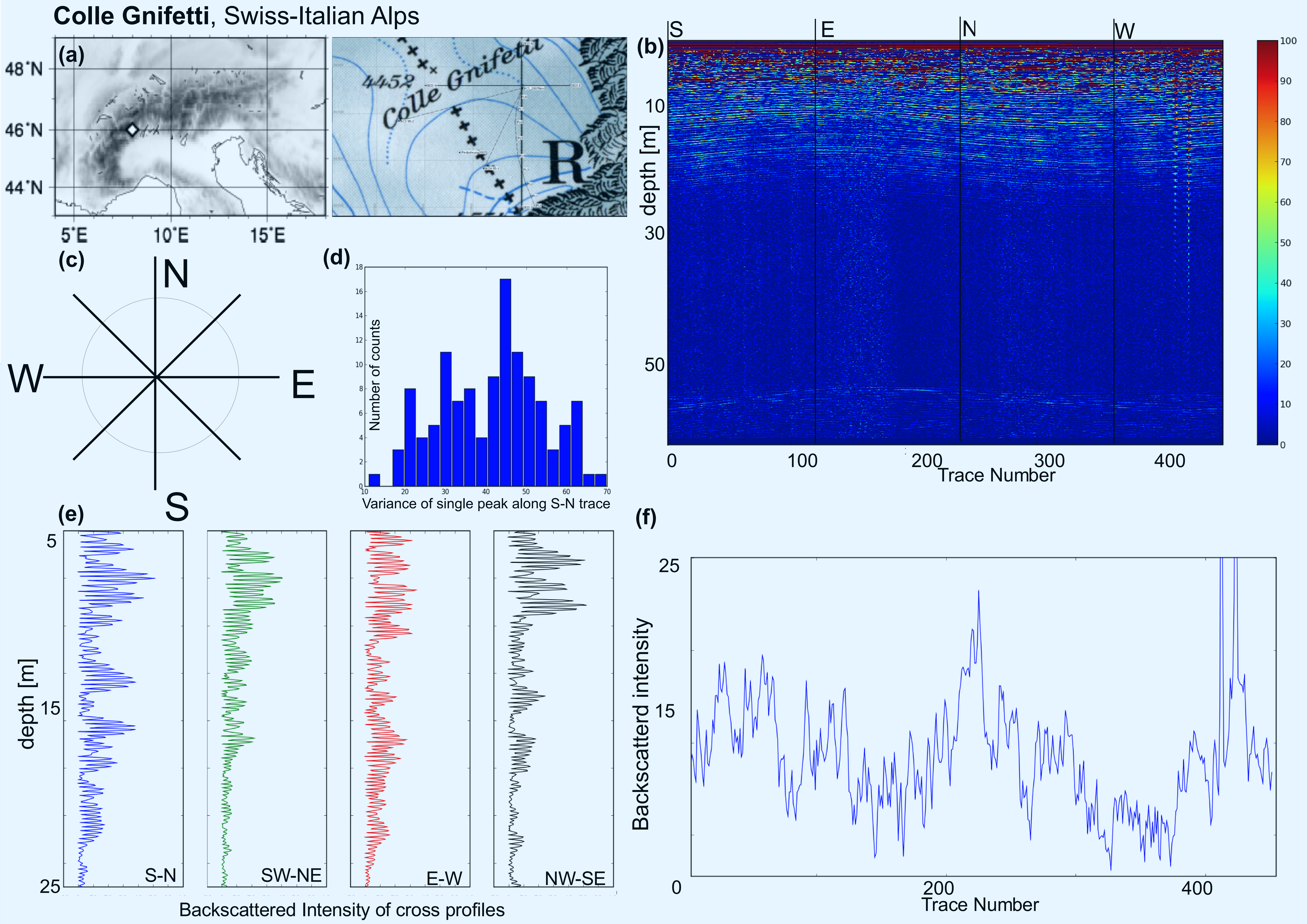


Fig. 2: Preliminary results of a survey on a cold alpine glacier in the swiss-italian alps (Colle Gnifetti, Monte Rosa **(a)**) . The displayed data is based on a circular profile intersected with cross profiles as displayed in **(c),** recorded with a RAMAC GPR system (250 MHz). Variations in backscattered intensity along a single horizon of a cross profile (S-N) with fixed polarization are illustrated in **(d).** Anisotropic backscatter with changing polarization is faintly visible in the plot of the entire circular profile in **(b)** and in the averaged traces of the intersecting cross profiles in **(e)**.The plot in **(f)** displays the circular profile at a fixed depth (~15 m) to visualize a somewhat similar behaviour as seen in Fig.1 (b). However, the effect is far less pronounced.

## Discussion

- **Dronning Maud Land**
- A strong anisotropy is observed and likely caused by an anisotropic reflection coefficients and to a lesser extent by birefringence
- The effect of COF can be estimated for a simple two-layer approximation (Fig. 3). Next step is a volume scattering model
- High resolution (~1-2 m) COF measurements are missing, but it is likely, that COF variations are responsible for anisotropy in deeper ice. In shallow ice, COF is not as well developed.
- Effect of anisotropic air bubble shape is small, what about an anisotropic distribution of air bubbles?

- **Colle Gniffetti**
- For the alpine example an anisotropic response is harder to evaluate and still work in progress
- Birefringence overlays an anisotropic reflection?
- In a nearby snow pit several layers which are laterally not continuous and variable in height are visible. This increases clutter and increases in backscattered power along a single polarization profile.

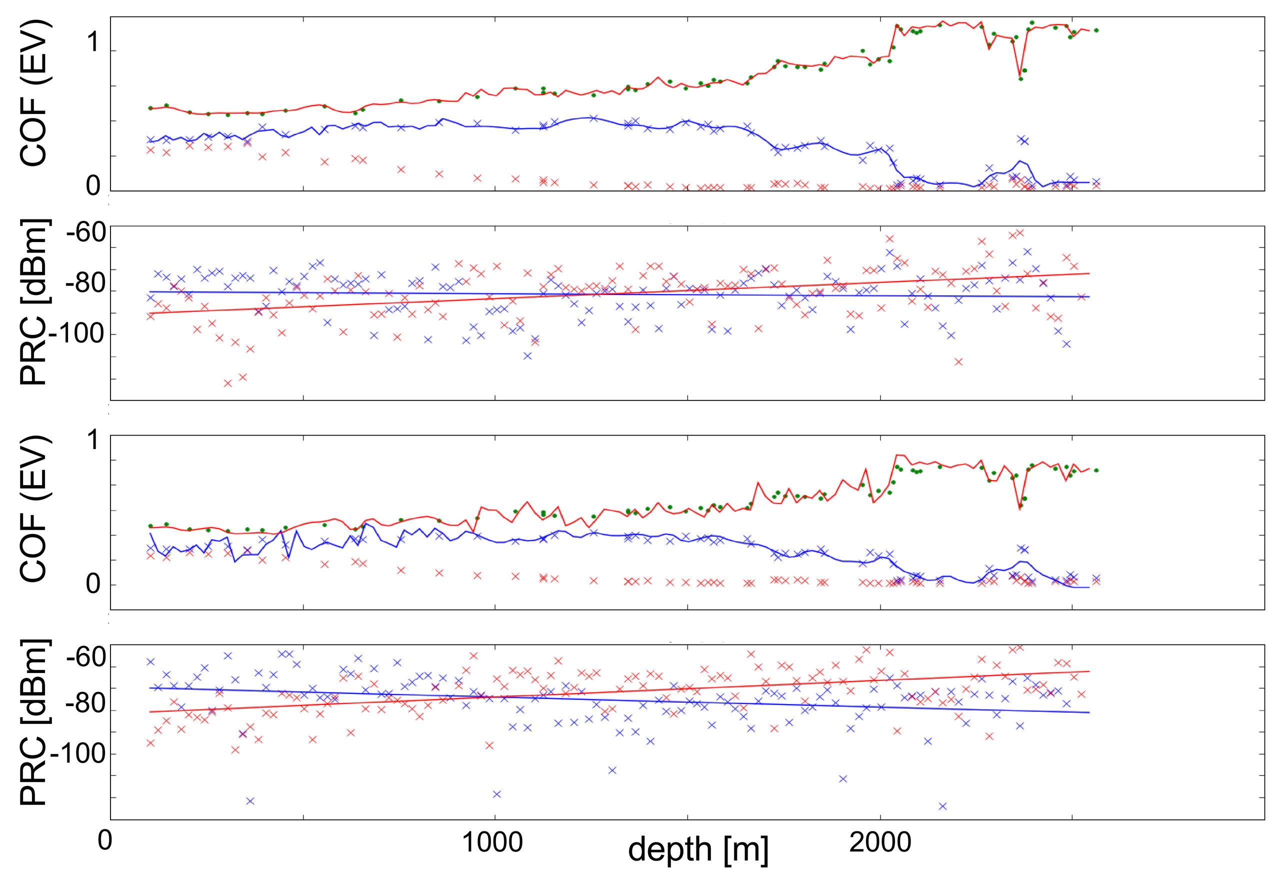


Fig. 3: Estimation on how short-scale variations in COF result in anisotropic power reflection coefficients (PRC) for a two-layer approximation. An artificial "COF roughness" by interpolation and addition of Gaussian white noise. The upper boundary of COF roughness has been defined by the standard deviation of the measured values.

## References

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