The origin of the echo-free zone (EFZ)

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Introduction

Radio-echo sounding (RES) is a standard technique to resolve the geometry and the internal layering of large ice bodies. Internal reflection horizons (IRH) are caused by changes of dielectric properties e.g. trough variations of conductivity as well as density fluctuations and a preferred crystal orientation fabric (COF) ([1], [2]). The EFZ is characterised through the absence of internal layering in RES data in the lowest hundreds of meters above bedrock. It is observed in extensive parts of the Antarctic and Greenland ice sheets and often follows the bedrock topography. At the EPICA ice-core site in Dronning Maud Land, the upper onset of the EFZ occurs just below a change in crystal orientation fabric from a girdle to a single maximum distribution. To identify possible reasons for the suppression of radio echoes we link microphysical line-scan data from the EPICA ice core with radar profiles in the vicinity.

Microstructure from ice core analysis

(1) line-scans: cloudy bands

- similar to dark field microscopy [3]
- shows stratigraphy of zones with high scattering (dust, air bubbles ...)
- correlates well with chemical content [4]

⟶ **taken as proxy for conductivity stratigraphy**

(2) dielectric profiling: conductivity

- dielectric properties with focus on conductivity and correlation with RES

⟶ **Most internal layers originate from conductivity peaks of volcanic origin** [5]

(3) fabric analyser: crystal orientation

- microtome cuts -> c-axes orientation
- observed sequence: random, girdle, single-max.

⟶ **correlation of few (anisotropic) RES-peaks with COF** [6]

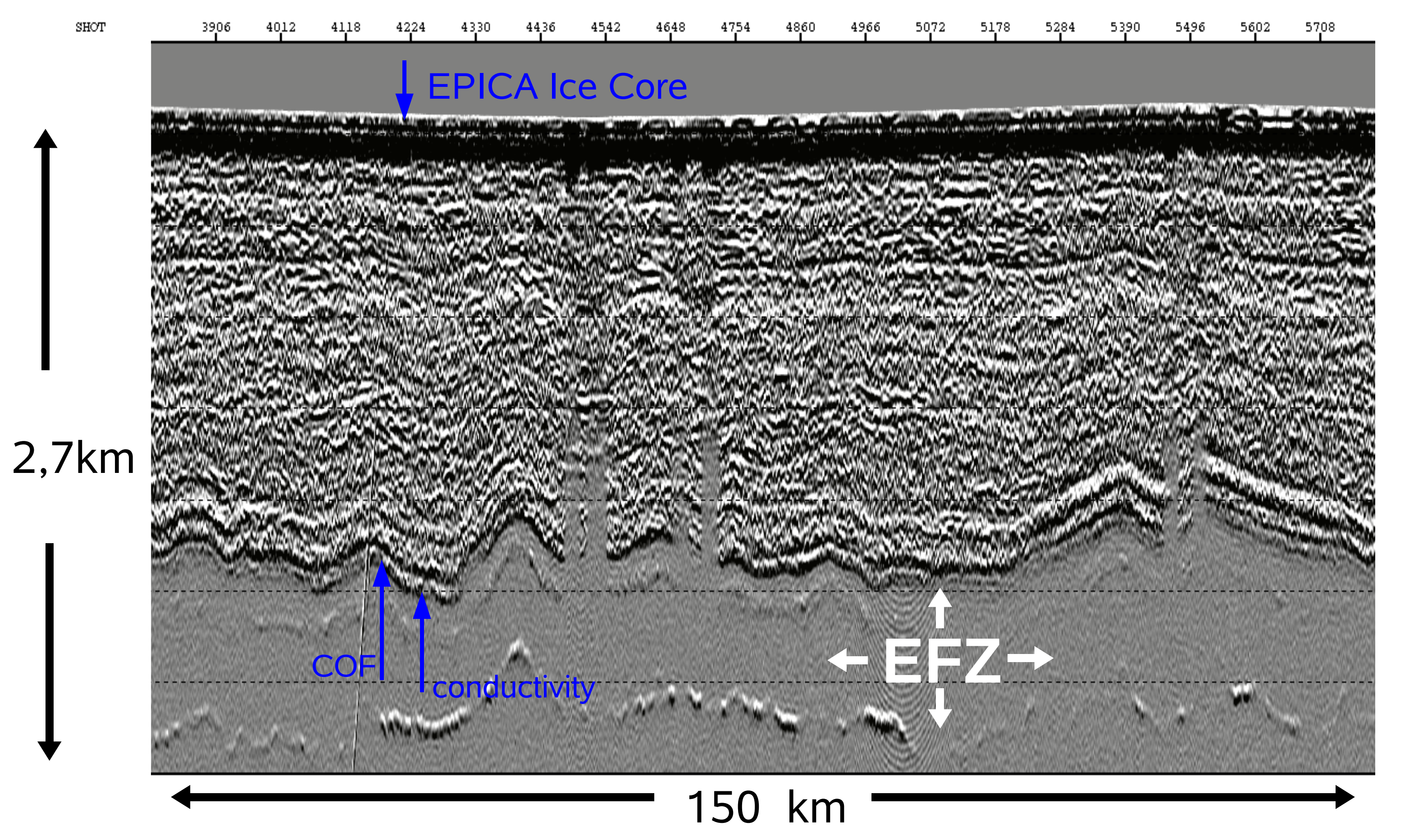

Fig.1 150 km radar profile with 600 ns pulse. Lateral onset of the EFZ is variable in depth and follows the bedrock topography. The transition is characterized by a COF and conductivity reflector (see arrows). The ice core drilling site is located close to trace 4224 (see arrow) and causes the nearby diffraction pattern.

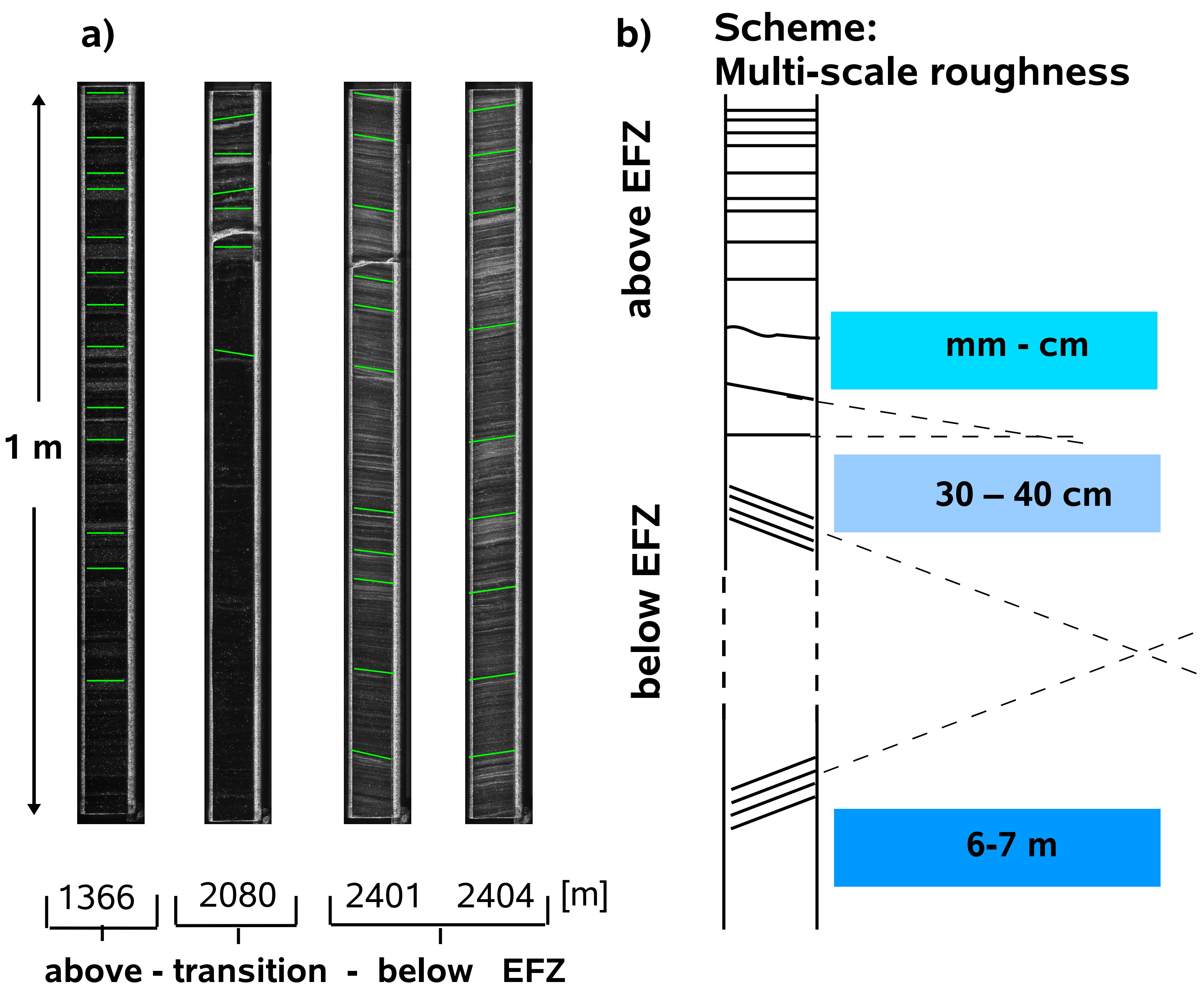

Fig. 2: a) Line-scans of samples above and below the EFZ. Above the EFZ the stratigraphy appears smooth and regularly, below the EFZ the stratigraphy is disturbed on various scales. **b)** As chronological order is maintained, single horizons do not intersect and the order of magnitude in surface roughness can be estimated.

Interpretation of multi-scale mechanisms

Multi-scale roughness leads to disturbances in RES layering:

(1) mm – cm:	broadening/flattening of peaks in DEP signal causes lack of prominent peaks in DEP profile below 2300 m.
(2) dm – m :	surface roughness attenuates coherent component (scattering on rough surface)
(3) m – 10 m:	mixing of physical properties within the first Fresnel zones lowers contrast for reflections

Implications

- Mapping upper onset of EFZ marks boundary to possible mixing in isochronous deposition
- EFZ indicates region of enhanced (anisotropic) ice-dynamical behaviour
- Interrelation of COF reflector to the beginning of the EFZ can give insight to ice-dynamical effects (stress&strain, recrystallisation...).

References

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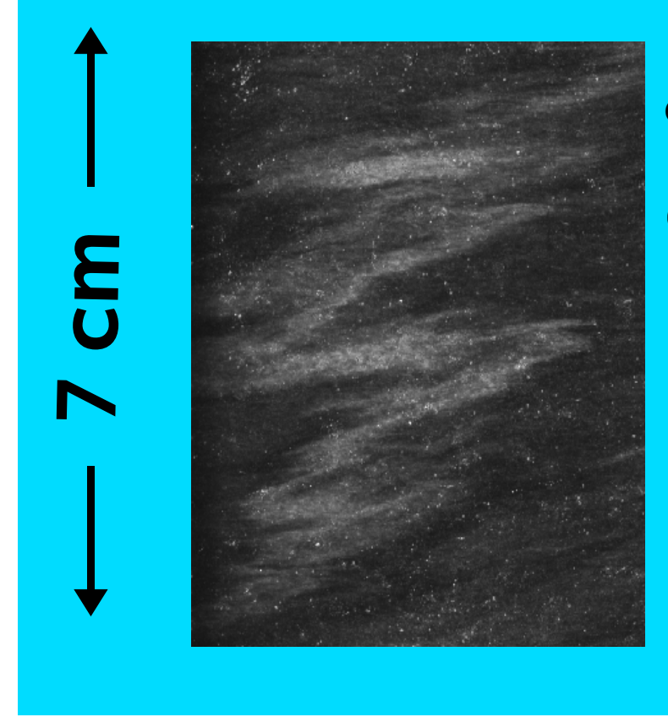
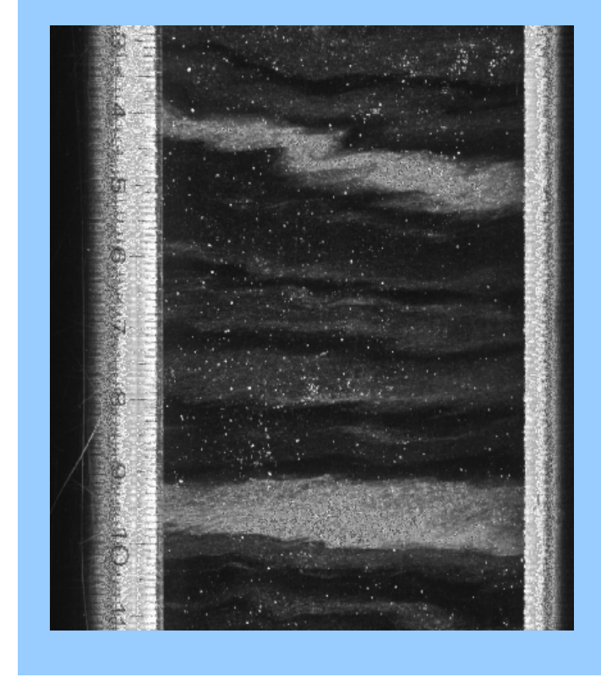
mm – cm scale



- Faulting possibly causes attenuation of DEP signal in the lowermost region (Fig. 4, turquoise box)

cm - m scale



- dm - scale surface roughness [λ radar ~ 1.1 m]

m – 10 m scale

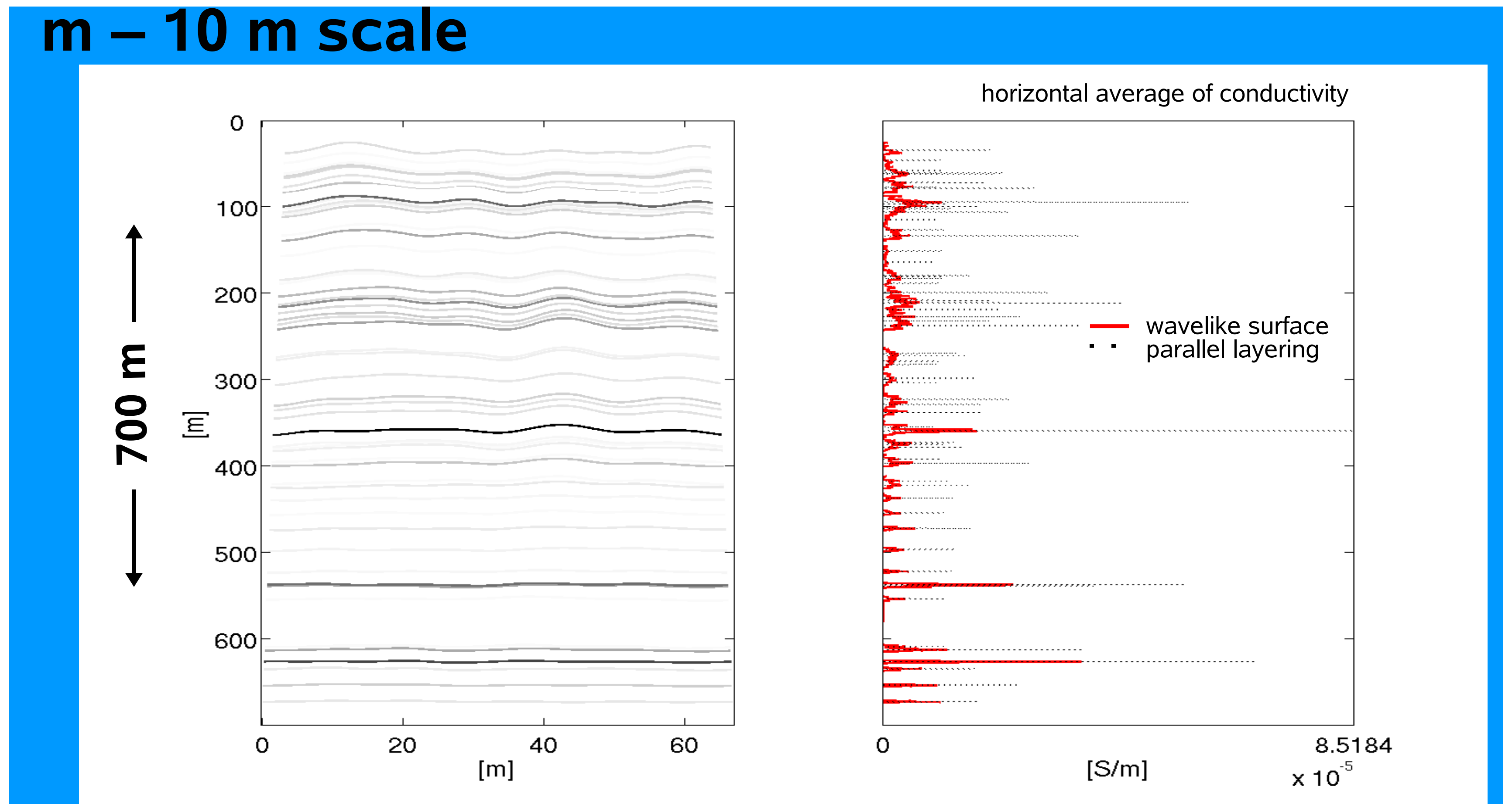


Fig. 3: (top) Zoom of line-scans. **(bottom)** Synthesized layers with conductivity characteristic from 1000 – 1600 meters of Fig. 4 (layer thickness = 0.7 m). Wavelike patterns (corr. length= 2 m, rms = 0.7 m) are added to the individual layers to illustrate the broadening of conductivity peaks inside the first Fresnel zone.

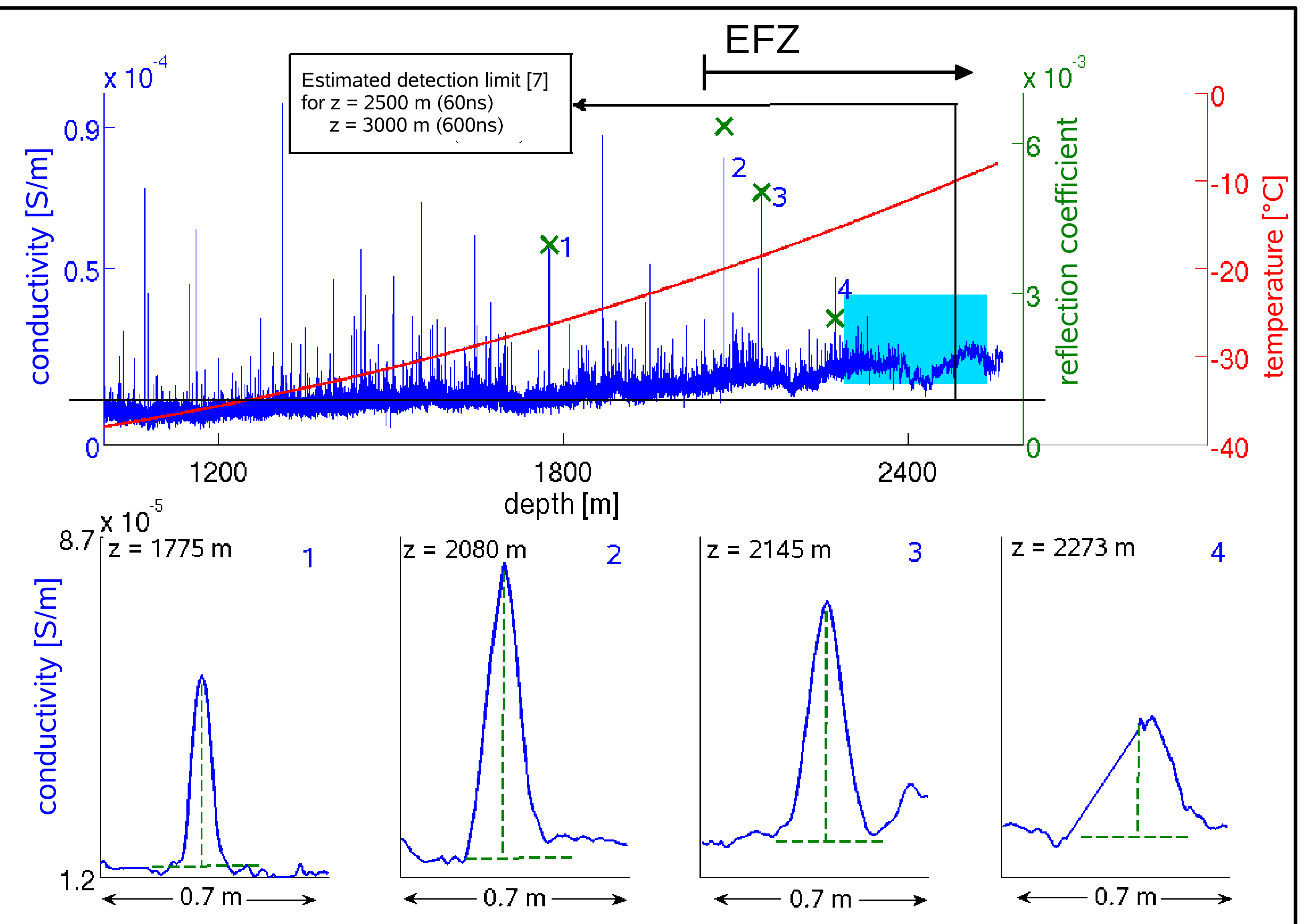


Fig. 4: Conductivity profile and estimated reflection coefficients (green x) for sample peaks (1,2,3,4): 2 marks transition to EFZ, 3 possibly causes a faint reflector within the EFZ (Fig.1), 4 is not visible as a reflector despite sufficient conductivity contrast [5]. In lowest area (turquoise box) the conductivity shows no prominent peaks (Fig. 3, top). Temperature difference between 4 and 2 is 4 K.