U.S. NAVAL
RESEARCH
LABORATORY

High-Fidelity Numerical Simulations of Range-Resolved, Time-Varying Radar Backscatter from a Sea Surface with Floating Targets

Jakov V. Toporkov and Mark A. Sletten
Remote Sensing Division, NRL
Washington, DC, USA

NATO SET-239 Specialists' Meeting,
Edinburgh, Scotland, UK
October 25-26, 2016

Introduction

“Numerical Experiment” Approach:

- use *first-principles solution* for backscatter from a given boundary
- the sea-like surface+target profile generated using physical models
- produce range-resolved, coherent time-varying echoes
- accumulate Monte Carlo ensembles

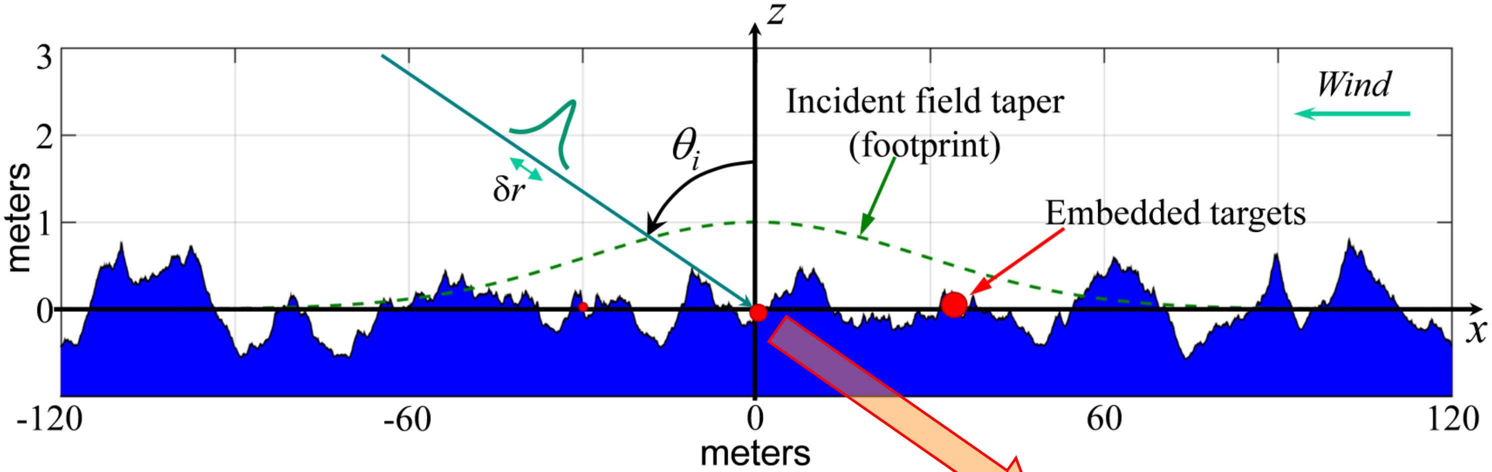
Limitations:

- 2-D space (care with interpretation, no cross-pol HV or VH)
- High computational cost of direct scattering solution

Benefits:

- Highly controlled conditions (e.g. can adjust wind speed at will)
- Flexibility
- Applicability at all incidence geometries, including low grazing angles
- Benchmark for approximate scattering models

Scattering simulations: Problem set-up



$f_0 = 10$ GHz

$\delta r \geq 0.34$ m

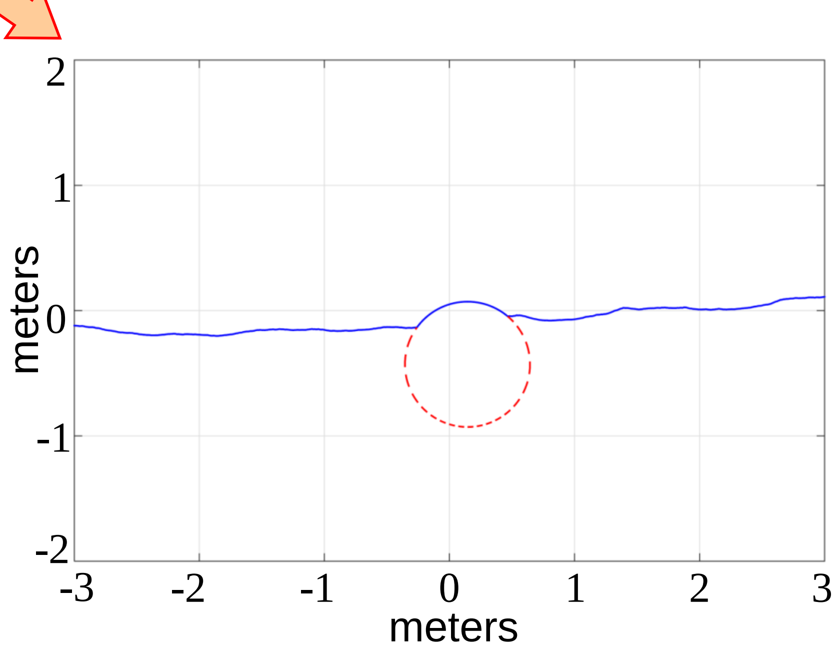
$\theta_{gr} = 90^{\circ} - \theta_i$:
$5^{\circ} .. 70^{\circ}$

Wind speed:
5, 7, 10 m/s

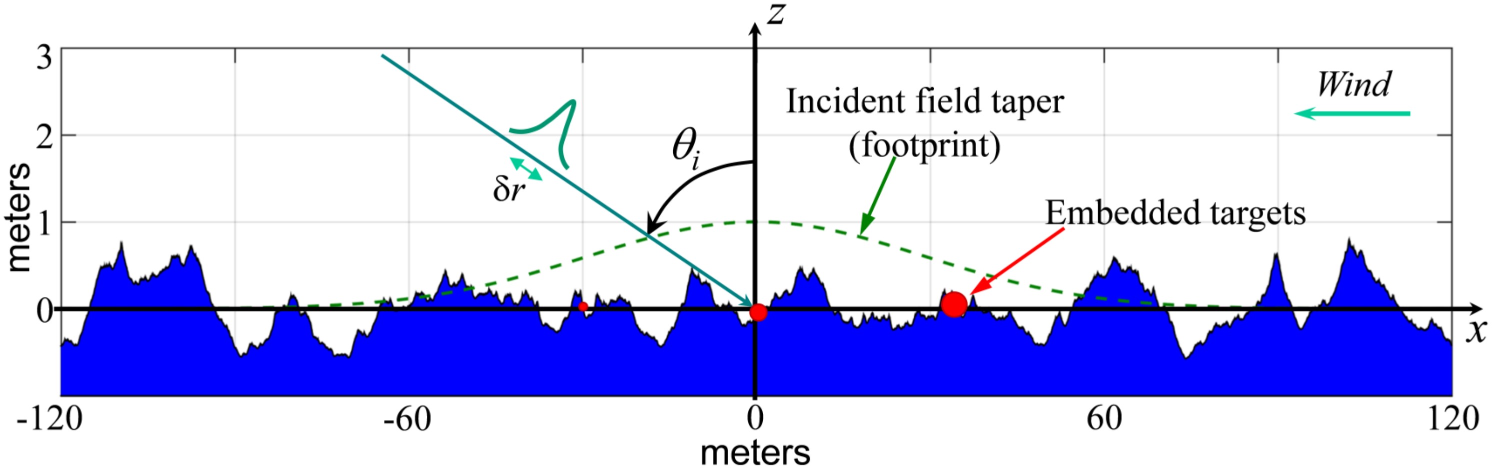
- Tapered plane wave incident field at θ_i
- Surface with wind-driven spectrum
- Conducting round floating targets
- Scene evolves with time (20 s)
- Simultaneous, coherent VV and HH

Two aspects of the problem:

- Hydro part: model surfaces and targets
- E/m part: evaluate scattered field



Scattering simulations: Problem set-up



$f_0 = 10$ GHz

$\delta r \geq 0.34$ m

$\theta_{gr} = 90^\circ - \theta_i$:
$5^\circ - 70^\circ$

Wind speed:
5, 7, 10 m/s

- Tapered plane wave incident field at θ_i
- Surface with wind-driven spectrum
- Conducting round floating targets
- Scene evolves with time (20 s)
- Simultaneous, coherent VV and HH

Two aspects of the problem:

- Hydro part: model surfaces and targets
- E/m part: evaluate scattered field

Embedded targets parameters:

#	Diameter *d*, m	Location *x*, m	Center depth
1	1.0	0	*d*/3
2	1.5	35	*d*/3
3	0.5	-30	*d*/3

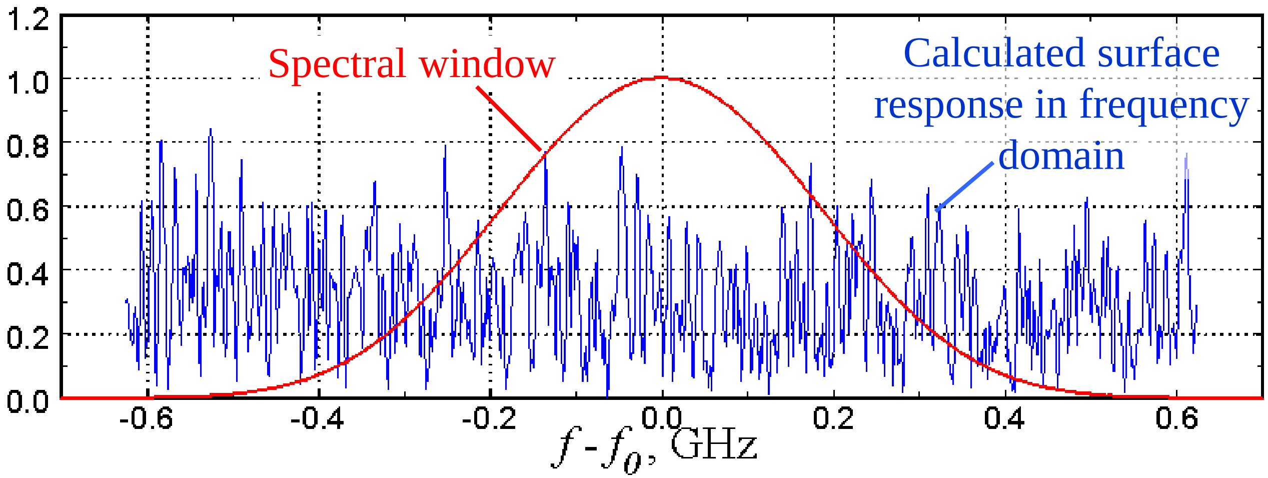
Scattering simulations: E/m calculations

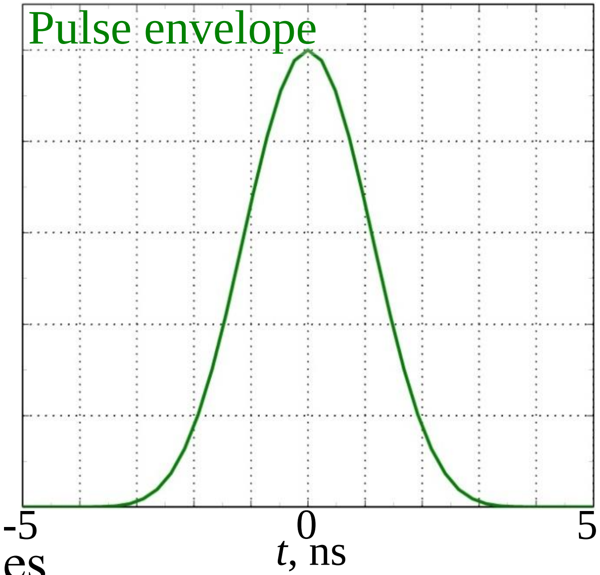
1. At <u>a given frequency</u>, surface electric current is found ***exactly*** by solving boundary integral equation (iterative “Forward-Backward” technique with accelerations)

⇨ Backscattered field is then found as the radiation effect of that current

2. Calculations repeated at 2048 frequencies covering a 1.25-GHz band ($f_0 = 10$ GHz)

3. Range-resolved surface radar response is synthesized in Fourier domain





$\tau = 2.2$ ns, $(c\,\tau)/2 = 0.34$ m

4. Procedure is repeated for 10,000 “frozen” surface profiles

*In (**1**), exact technique can be replaced by an approximate model (Small Slope Approximation, Bass-Fuks 2-scale, etc.)*

Scattering simulations: Surface model

1. Generate a realization of Gaussian random process with power spectral density given by Elfouhaily spectrum

2. Propagate each harmonic independently with the dispersion relation

$$\Omega(K) = \sqrt{gK\left[1 + (K/K_m)^2\right]},\quad K_m = 363\ \text{rad/m}$$

"Linear" surface

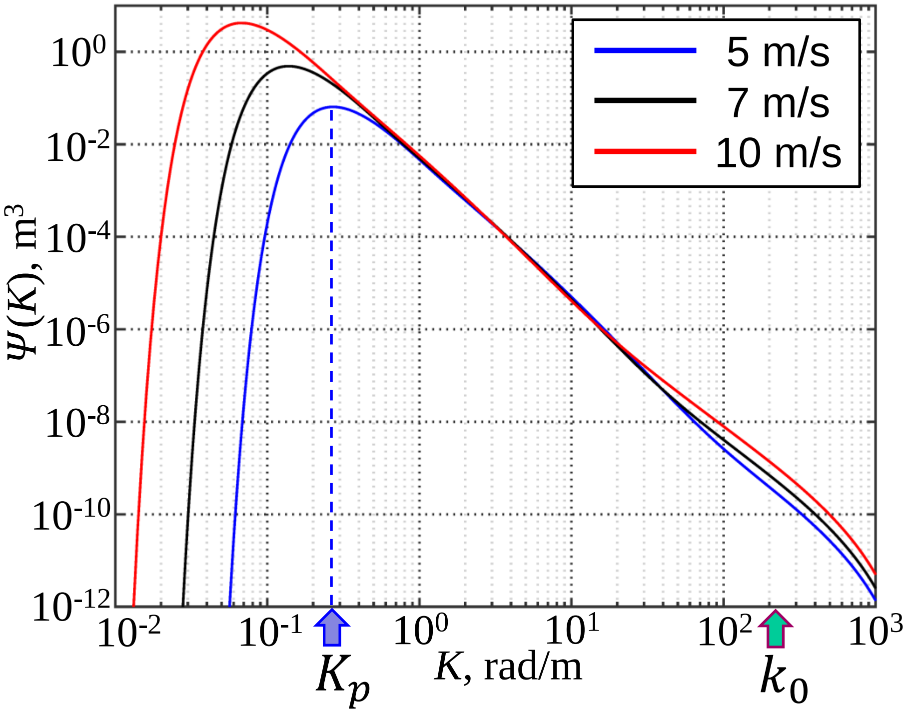
3. At each time step, apply Creamer transform → inter-harmonic interaction

$$\underset{\uparrow}{\tilde{\zeta}}(K,t) = \frac{1}{|K|}\int e^{-jKx}\left[\exp\{jK\underset{\uparrow}{\zeta_{0H}}(x,t)\} - 1\right]dx$$

Surface Fourier components

Hilbert transform of "linear" surface

- ripple enhancement at crests
- modified dispersion relation
- no wave breaking

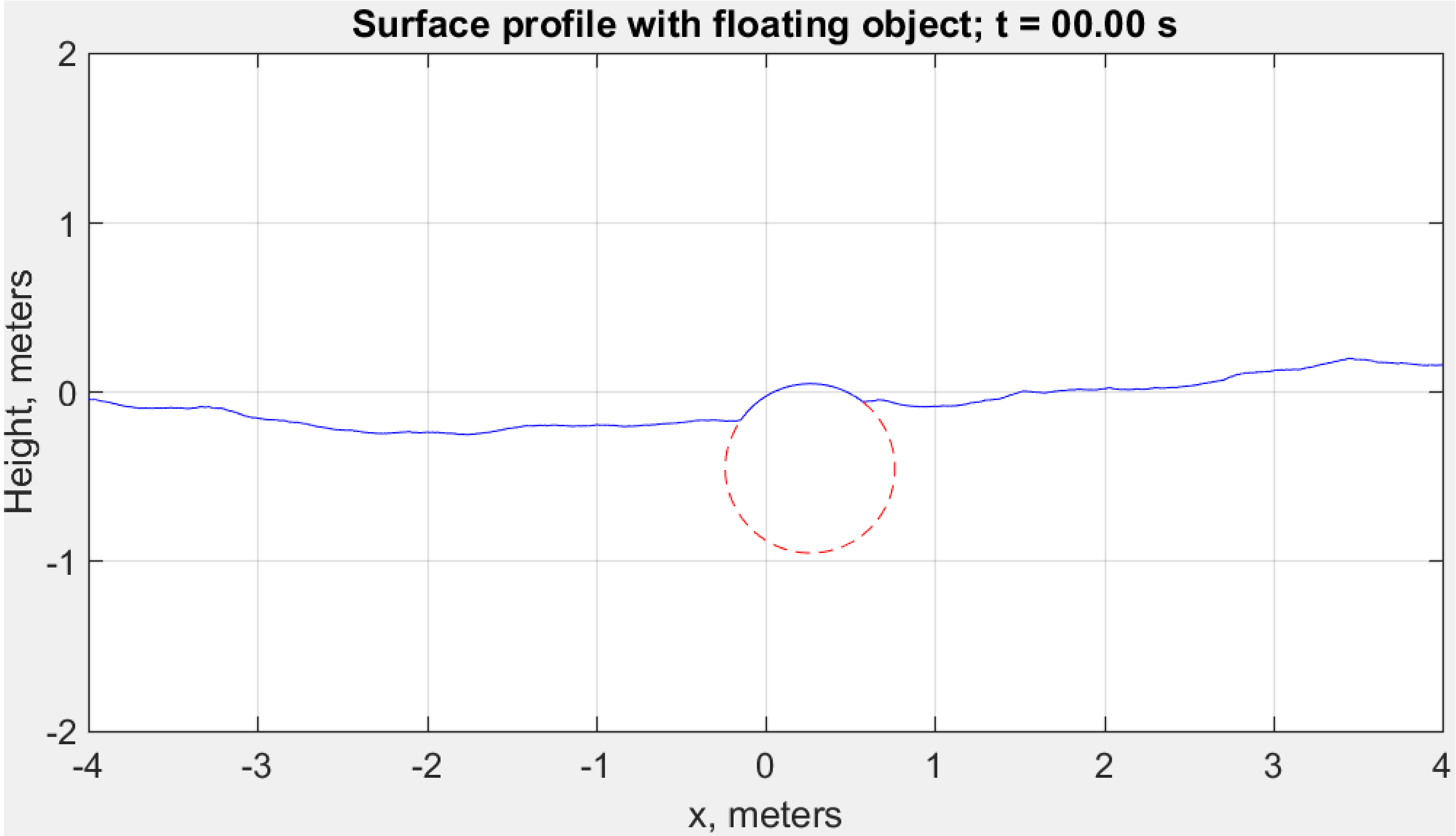


U_{10}, m/s	Rms height ζ_{rms}, m	Peak wave length Λ_p, m
5	0.16	23.3
7	0.32	45.5
10	0.65	92.4

Scattering simulations: Targets

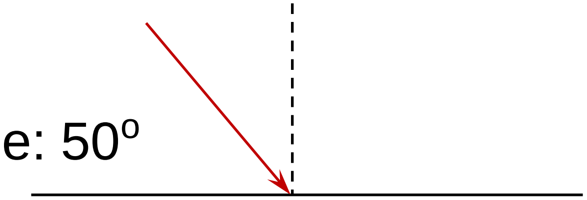
MODEL:

- a round body whose submerged center follows orbital current (no inertia)
- in the broached region surface roughness is replaced by the target contour
- otherwise, no disturbance of the ambient wave field

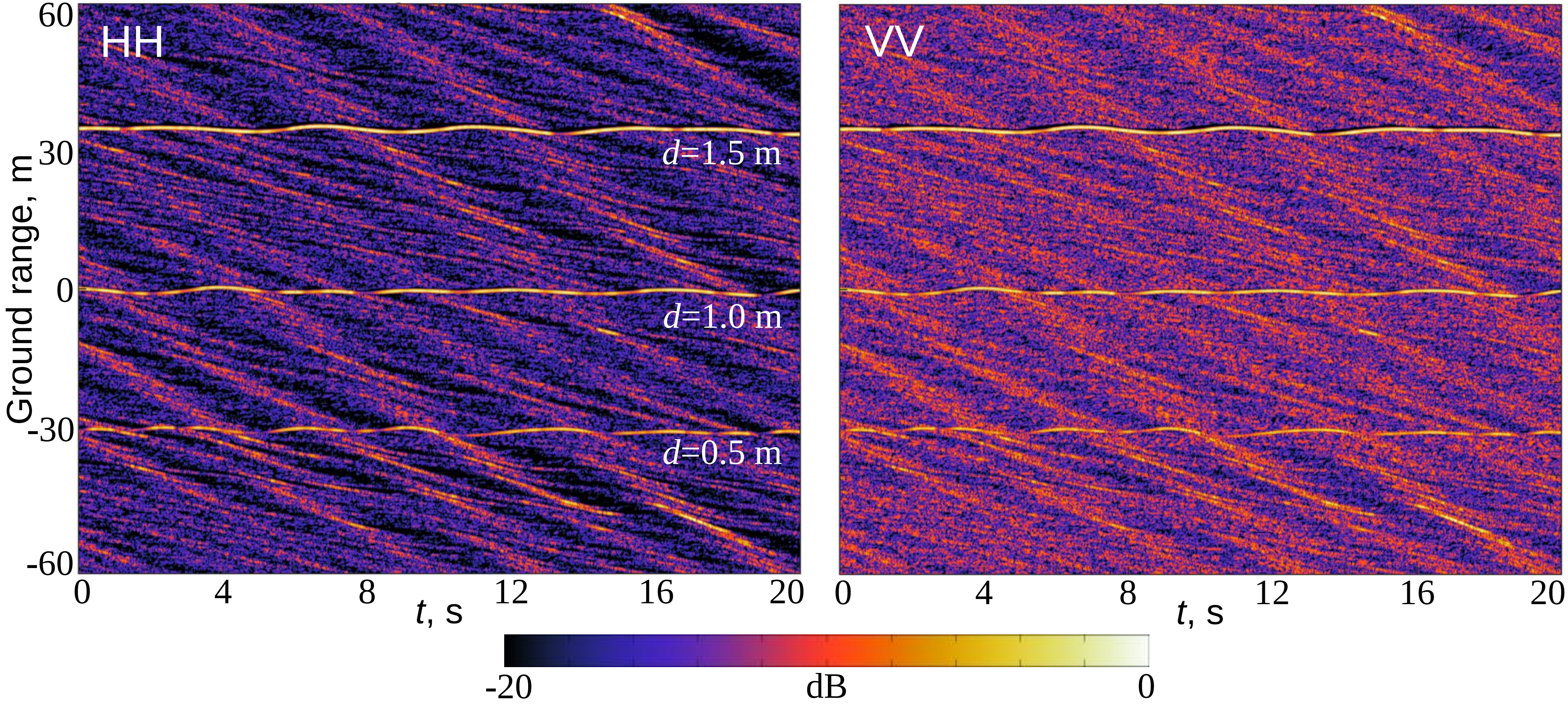


Results: Range-time records

Backscatter magnitude: range resolution 0.34 m, wind speed 7 m/s

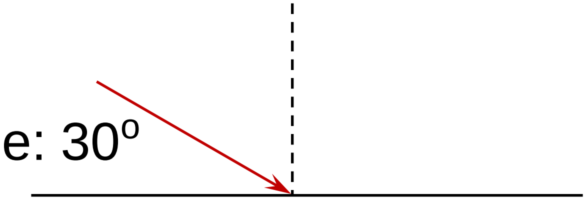


Grazing angle: 50^o

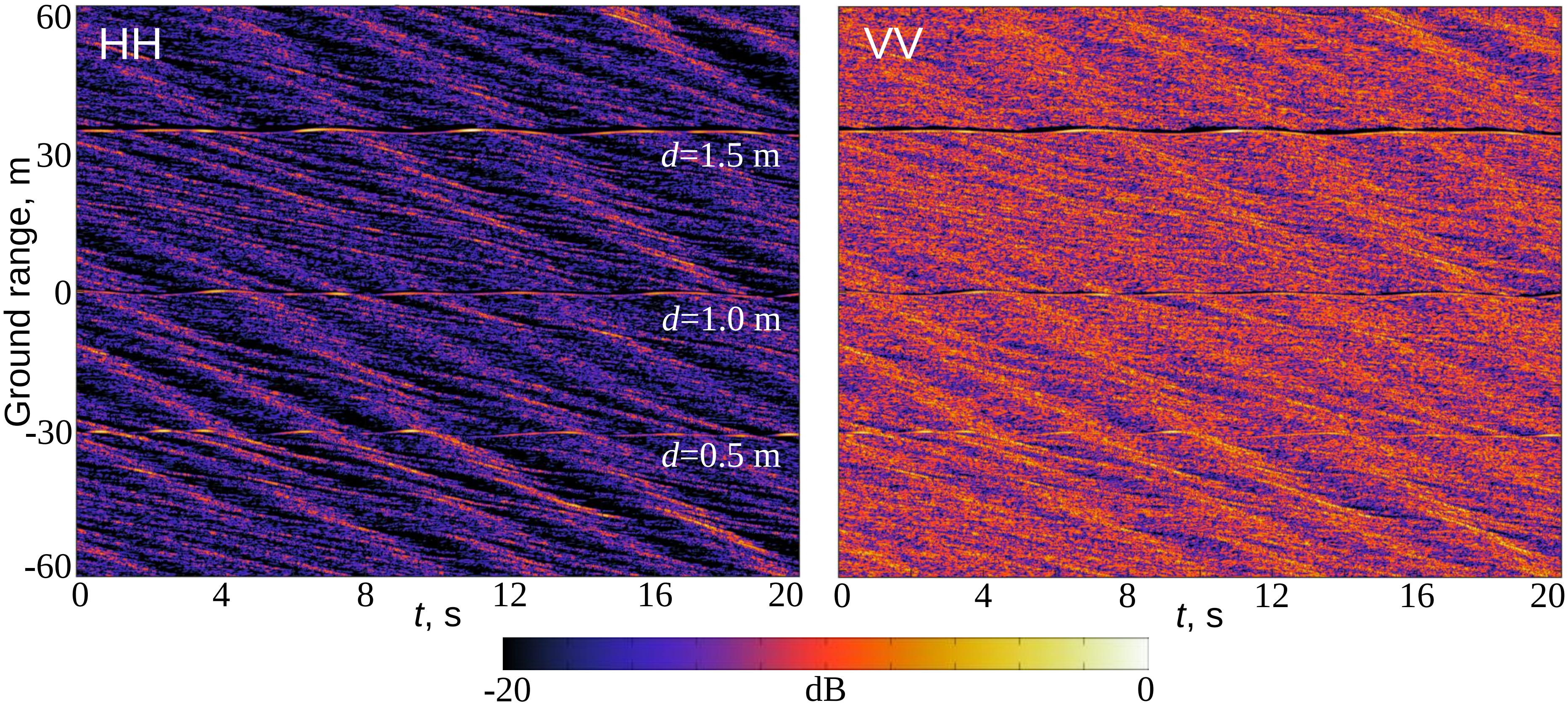


Results: Range-time records

Backscatter magnitude: range resolution 0.34 m, wind speed 7 m/s



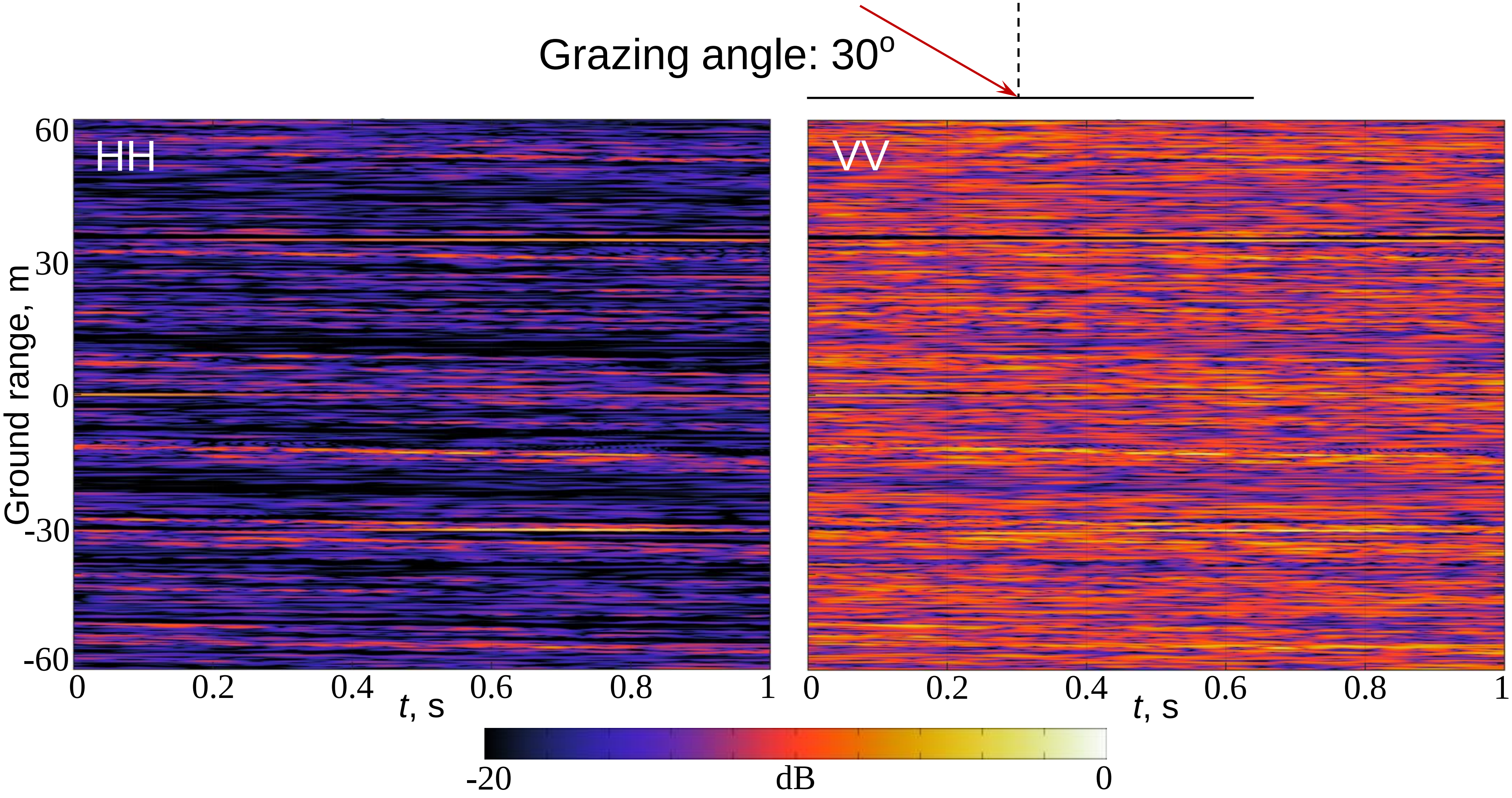
Grazing angle: 30°



Results: Range-time records

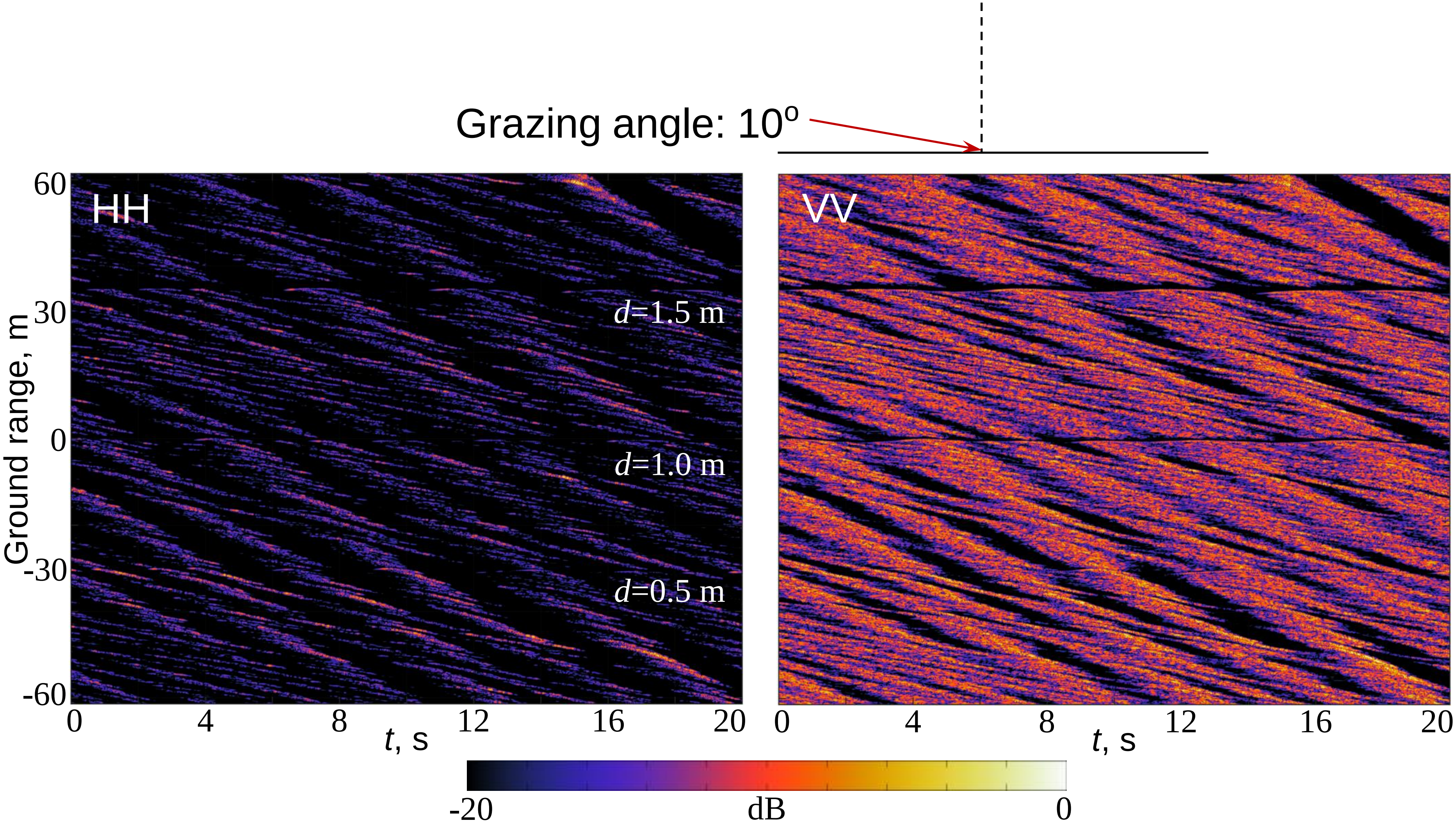
Backscatter magnitude: range resolution 0.34 m, wind speed 7 m/s

Importance of time dimension



Results: Range-time records

Backscatter magnitude: range resolution 0.34 m, wind speed 7 m/s

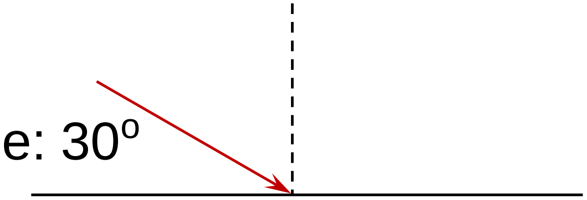


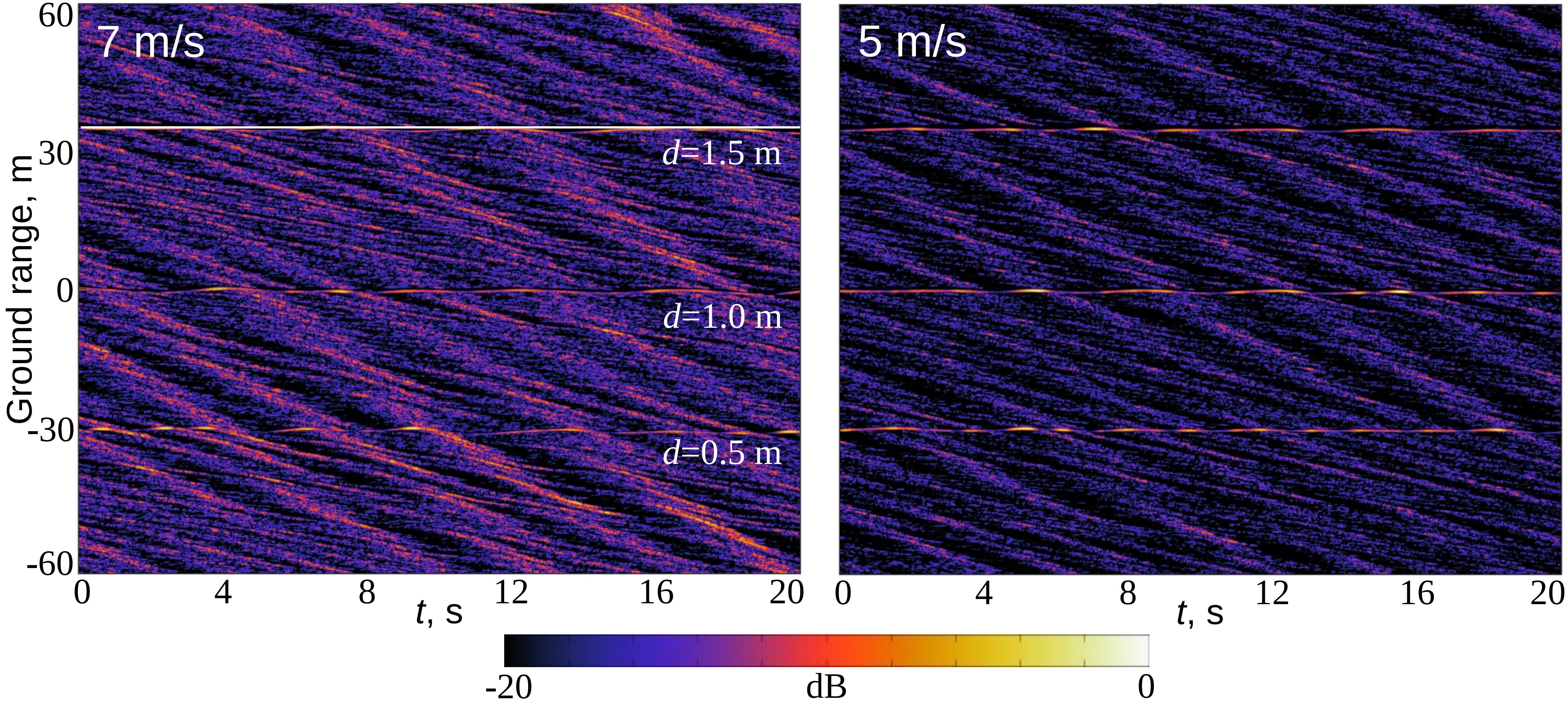
Results: Range-time records

Backscatter magnitude: range resolution 0.34 m, HH

Impact of wind speed

Grazing angle: 30°

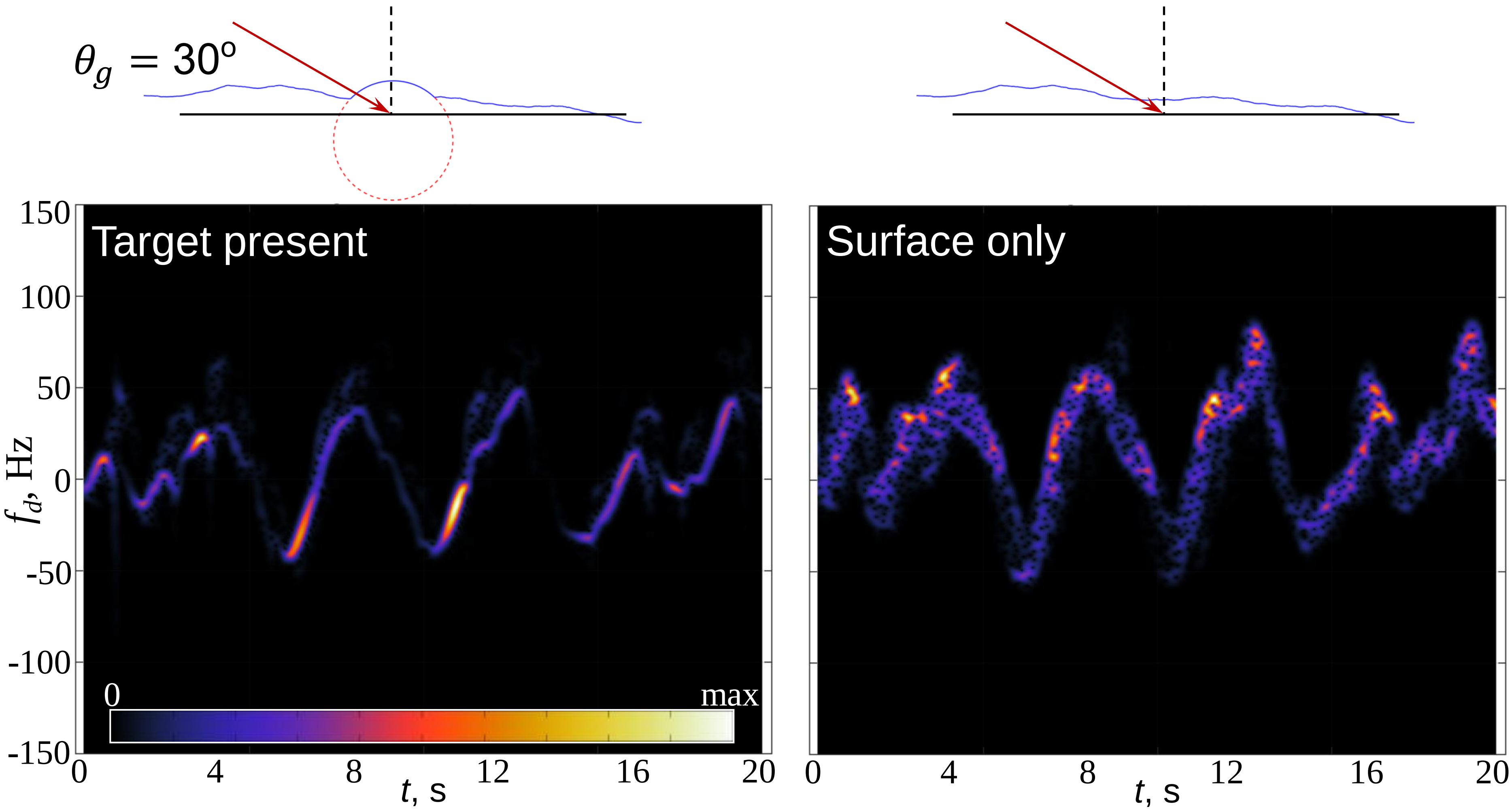




Results: Doppler spectra

Doppler spectrogram at x_g=34.5 m: 7 m/s, range resolution 1 m, HH

(sliding 0.5-s Hann window)

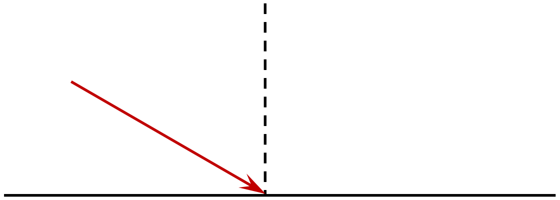


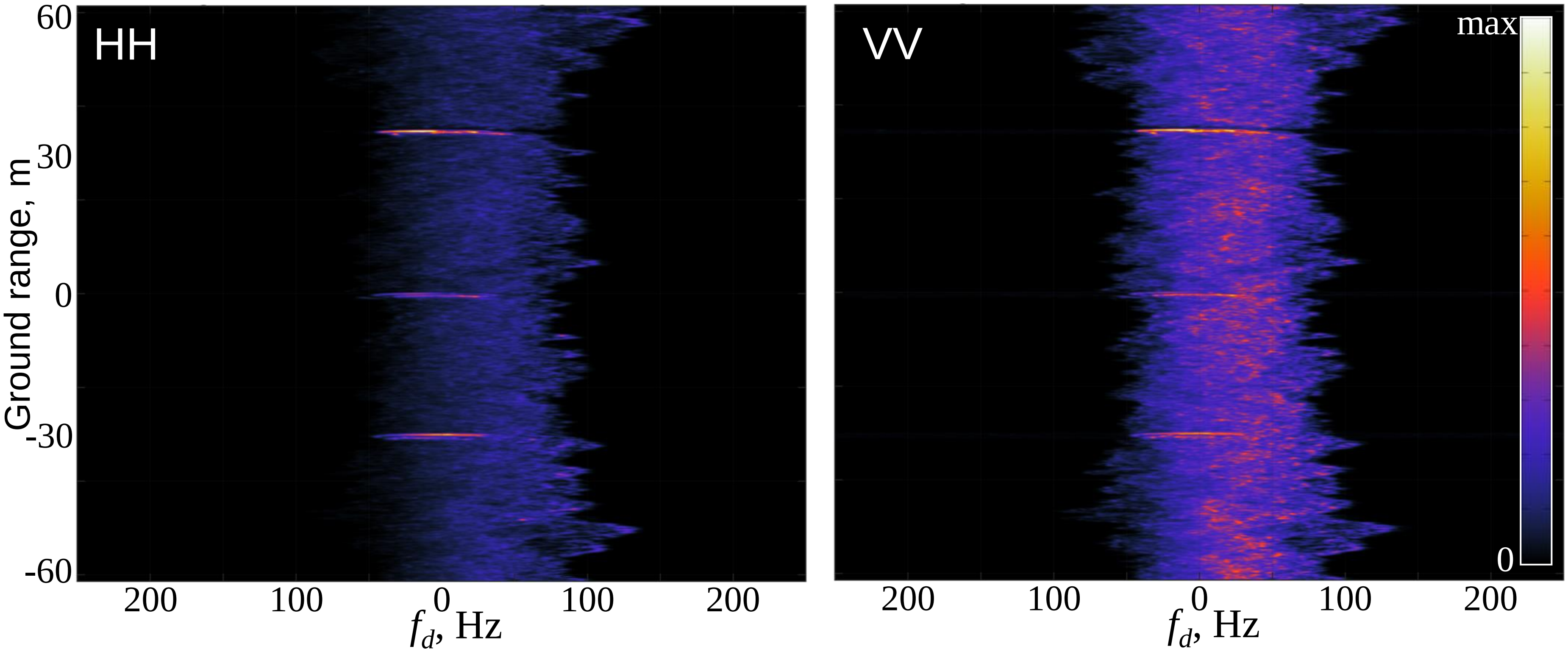
Results: Doppler spectra

Average Doppler Spectrum vs range: 7 m/s, range resolution 0.34 m

Spectrograms averaged over 20 s

Grazing angle: 30°

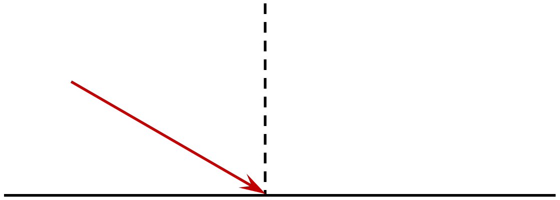


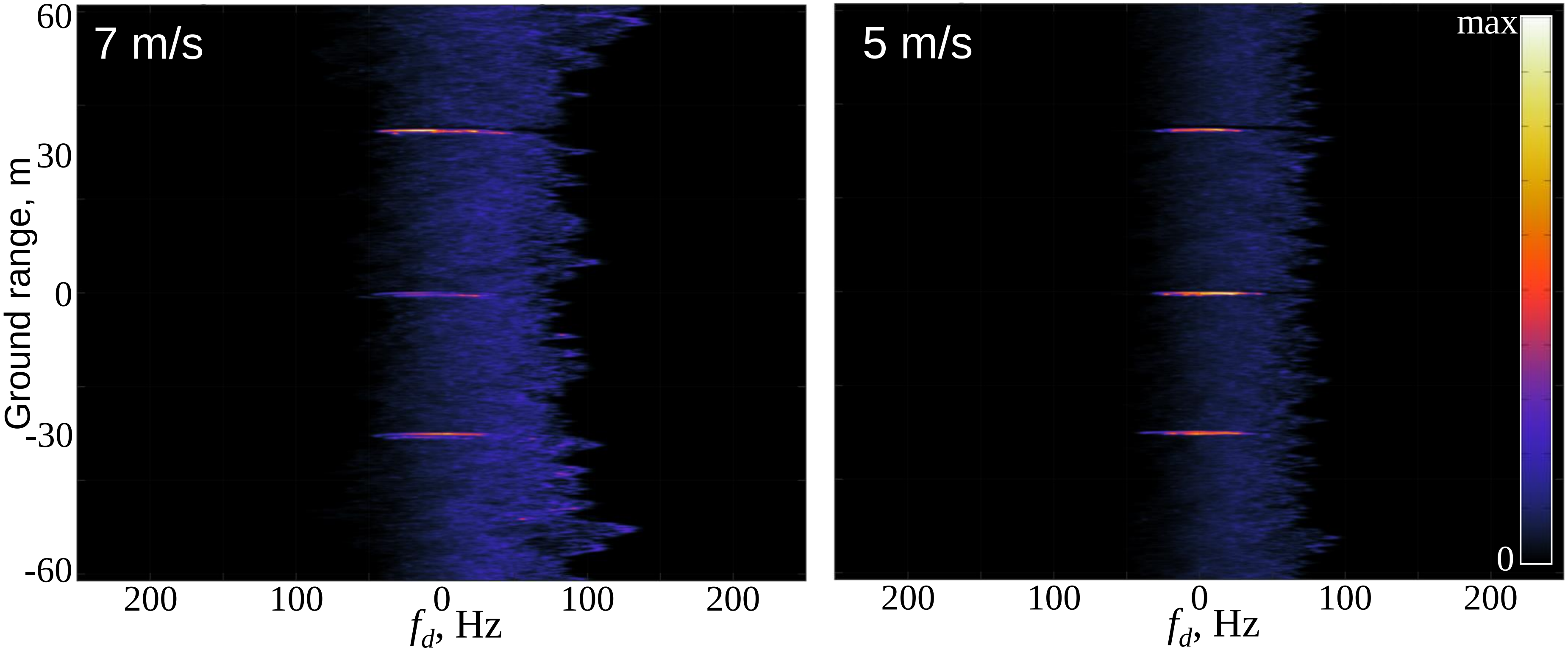


Results: Doppler spectra

Average Doppler Spectrum vs range: range resolution 0.34 m, HH

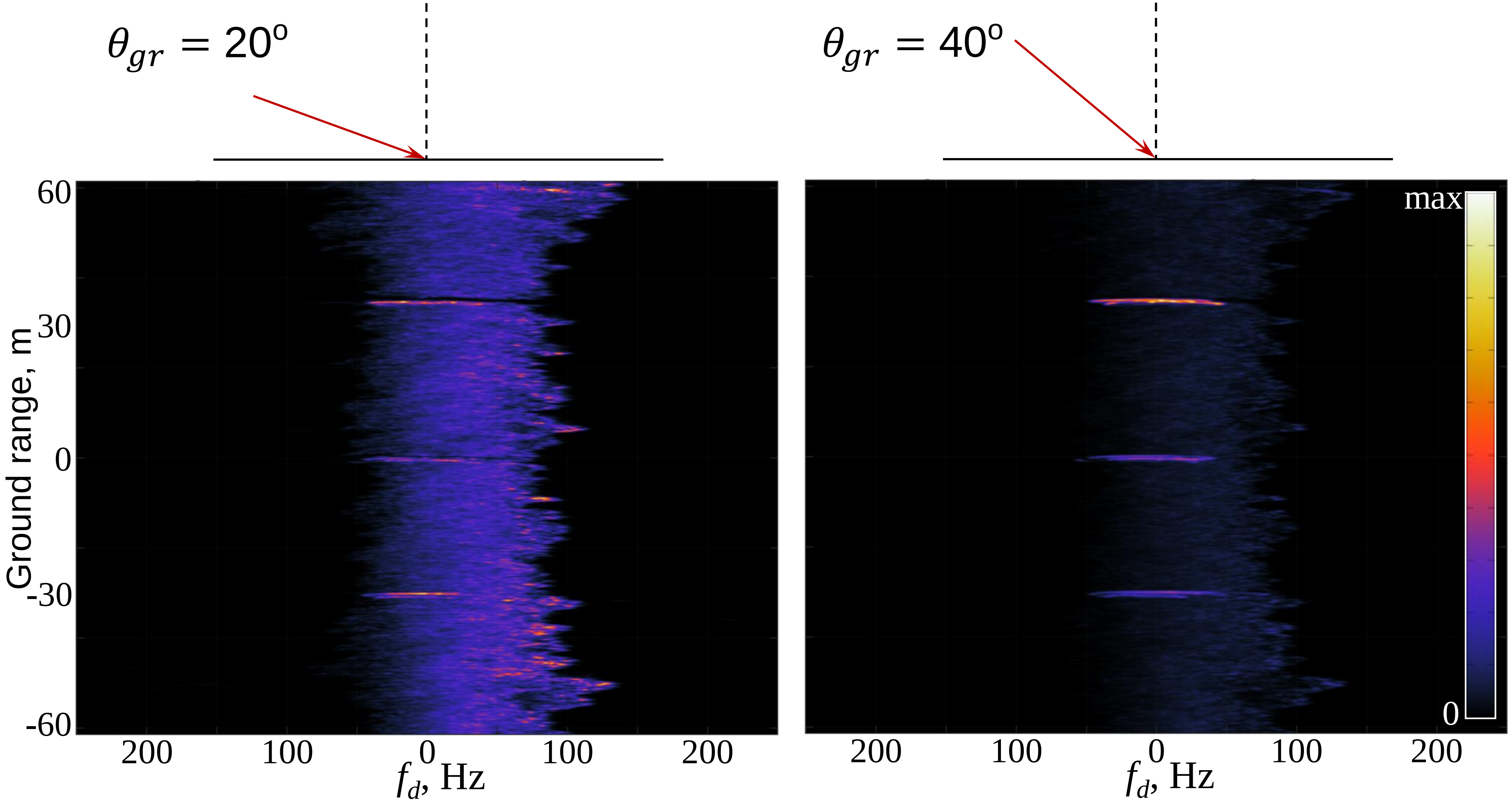
Grazing angle: 30^o





Results: Doppler spectra

Average Doppler Spectrum vs range: range resolution 0.34 m, HH, 7 m/s



Summary

- Modelled round targets visible at moderate grazing angles
- Time dimension is important for detection
- Differences of Doppler spectra of targets and background: similar orbital motions but different scattering mechanisms
- More elaborate model for floating bodies desired
- Numerical experiment: control and flexibility
- Integral-equation scattering solution – may be overkill at medium and high grazing angles, but always works
- Simulated data - benchmark for detection algorithms