Modeling Scattering from Rough Poroelastic Surfaces Using COMSOL Multiphysics

Anthony Bonomo, Marcia Isakson, and Nicholas Chotiros

Email: abonomo@arlut.utexas.edu

Work supported by
Office of Naval Research,
Ocean Acoustics

COMSOL CONFERENCE
BOSTON 2013

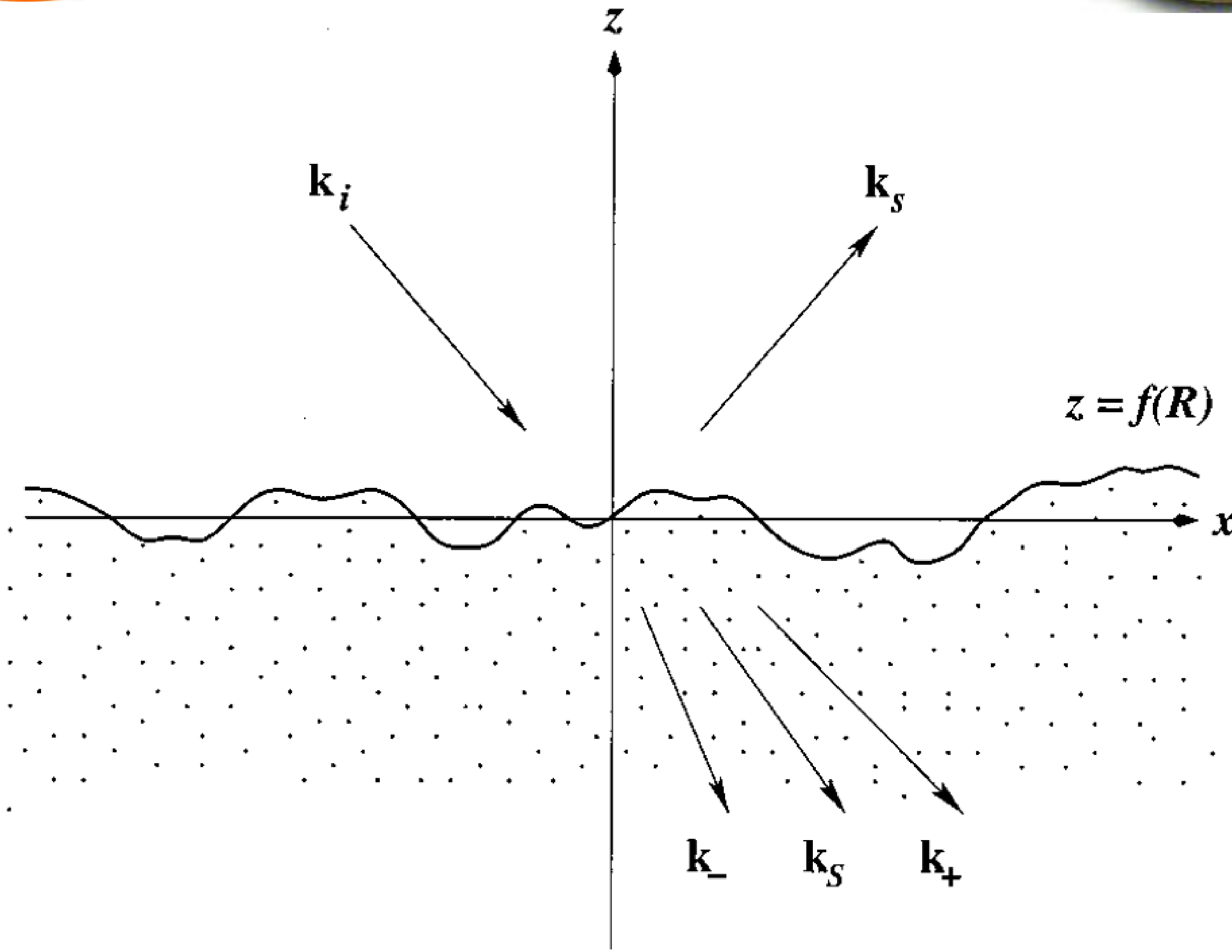
Outline

- Motivation
- Problem
- Implementation
- Scattering Strength Calculation
- Results
- Conclusions

Motivation

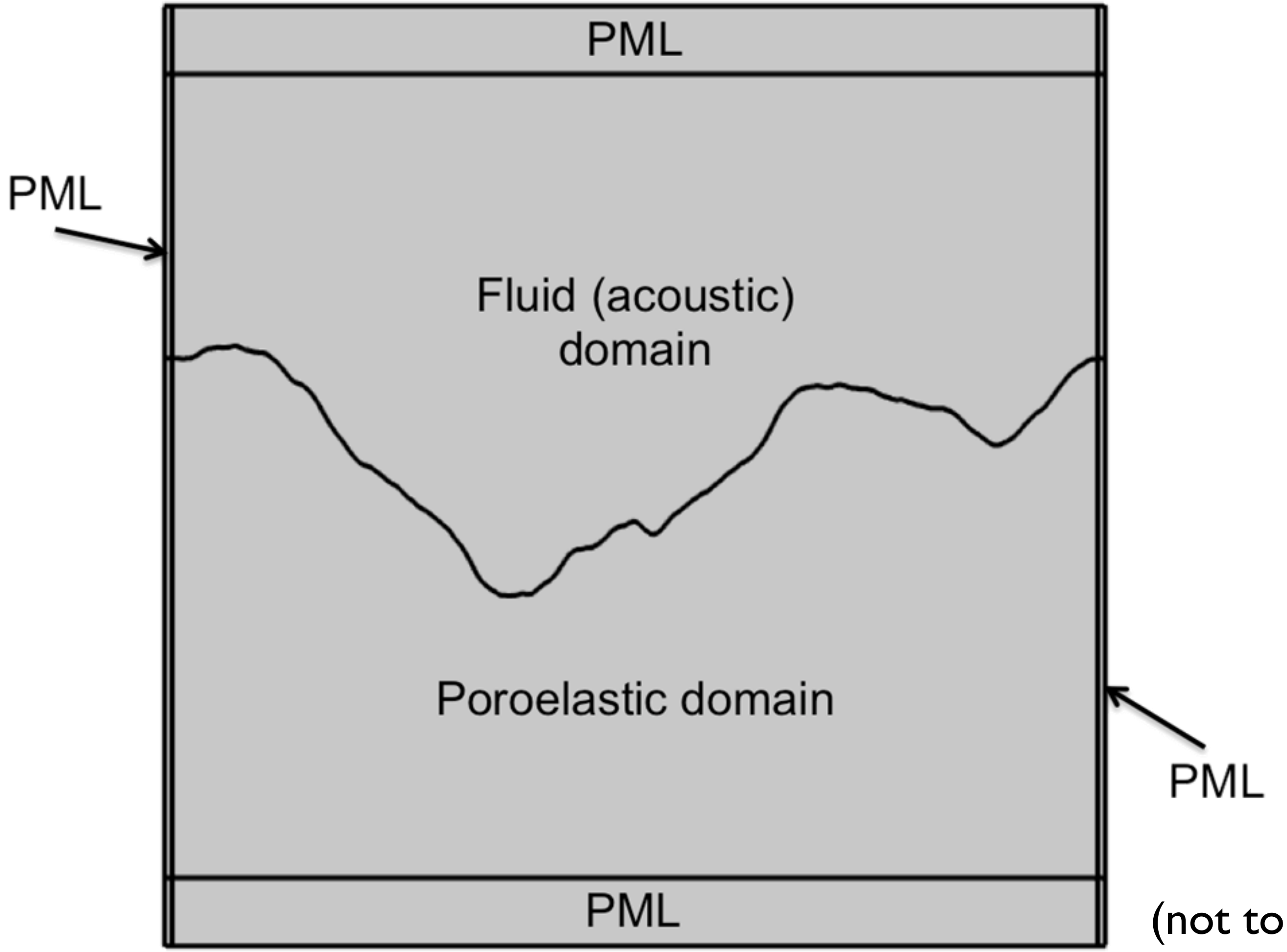
- Acoustic scattering from seafloor important source of interference with sonar systems.
- Necessary to accurately model physics of how sound interacts with the sea bottom.
  - Roughness effects
  - Physics of sediment (poroelasticity)

Problem



Reproduced from Yang et al., *IEEE Ocean Eng.*, **27**(3), 2002.

Implementation: Geometry



(not to scale)

Implementation: Physics

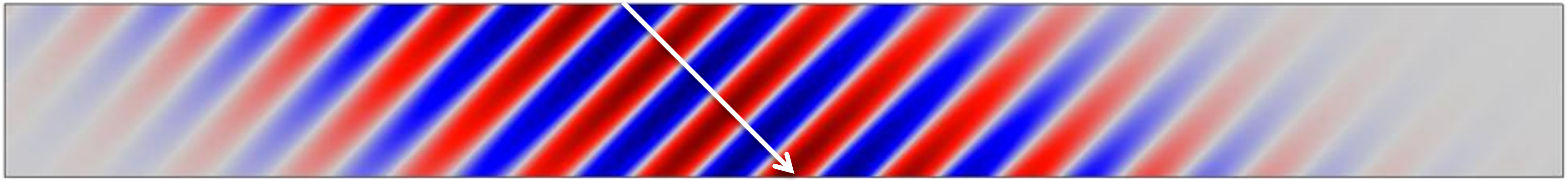
- Physics assignment
  - Fluid domain modeled with Pressure Acoustics, Frequency Domain Interface.
  - Poroelastic domain modeled with Poroelastic Waves Interface.
- Boundary conditions
  - Continuity of normal stress
  - Continuity of pressure
  - Continuity of normal displacement

Continuity of normal stress and continuity of pressure → Porous, Pressure Node

Continuity of normal displacement → Normal Acceleration Node

Implementation: Physics

- Modified Gaussian tapered plane wave used to guard against edge effects.
  - See Thorsos, *J. Acoust. Soc. Am.*, **83**(1), 1988.
  - Implemented as Background Pressure Field.



- Far-Field Calculation node used to find far-field scattered pressure.

Implementation: Mesh

- Rule of thumb: at least 6 elements per smallest wavelength supported by domain.
  - Poroelastic: minimum of slow/shear wavelength.
- Computationally demanding due to disparity between compressional and slow/shear speed.
- Slow and shear waves have high attenuation.
  - Sufficient to mesh finely on interface and based on compressional wave elsewhere.

Scattering Strength Calculation

- Many models with unique rough surface realizations run to obtain ensemble average of far-field scattered pressure.
- Average intensity used to calculate scattering cross section.

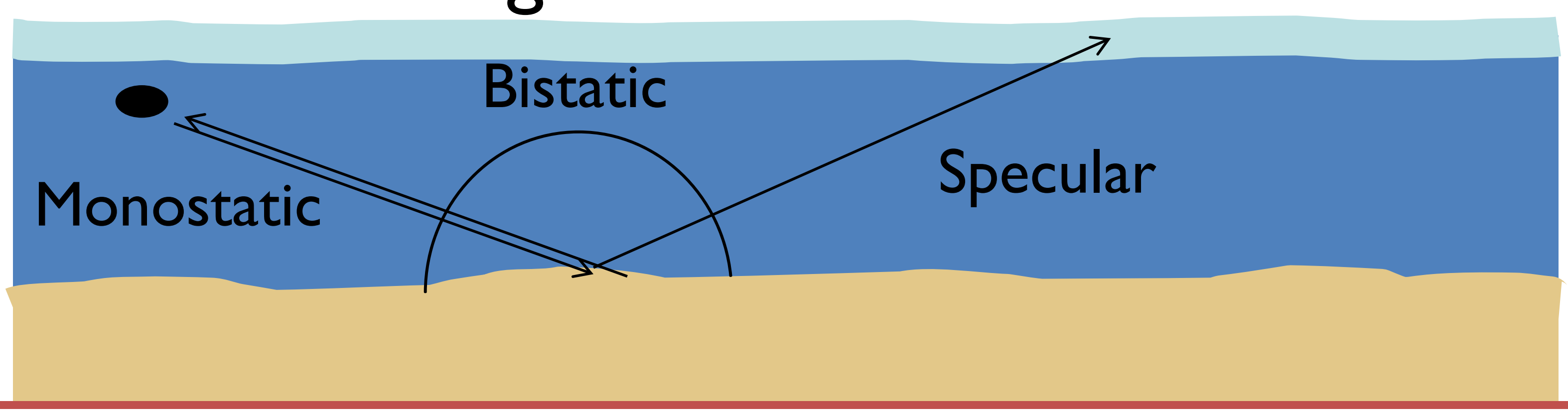
$$\sigma(\theta,\theta_s) = \frac{\langle I_s \rangle r \sin\theta}{E_f}$$

- Scattering strength: $10 \log_{10} \sigma(\theta,\theta_s)$

Thorsos, *J. Acoust. Soc. Am.*, **83**(1), 1988.

Numerical Results

- COMSOL calculations compared with more conventional scattering formulations.
  - Perturbation theory
  - Kirchhoff approximation
  - Small-slope approximation
- Monostatic and bistatic results shown for least and most rough cases studied.



Numerical Results

Roughness Parameters

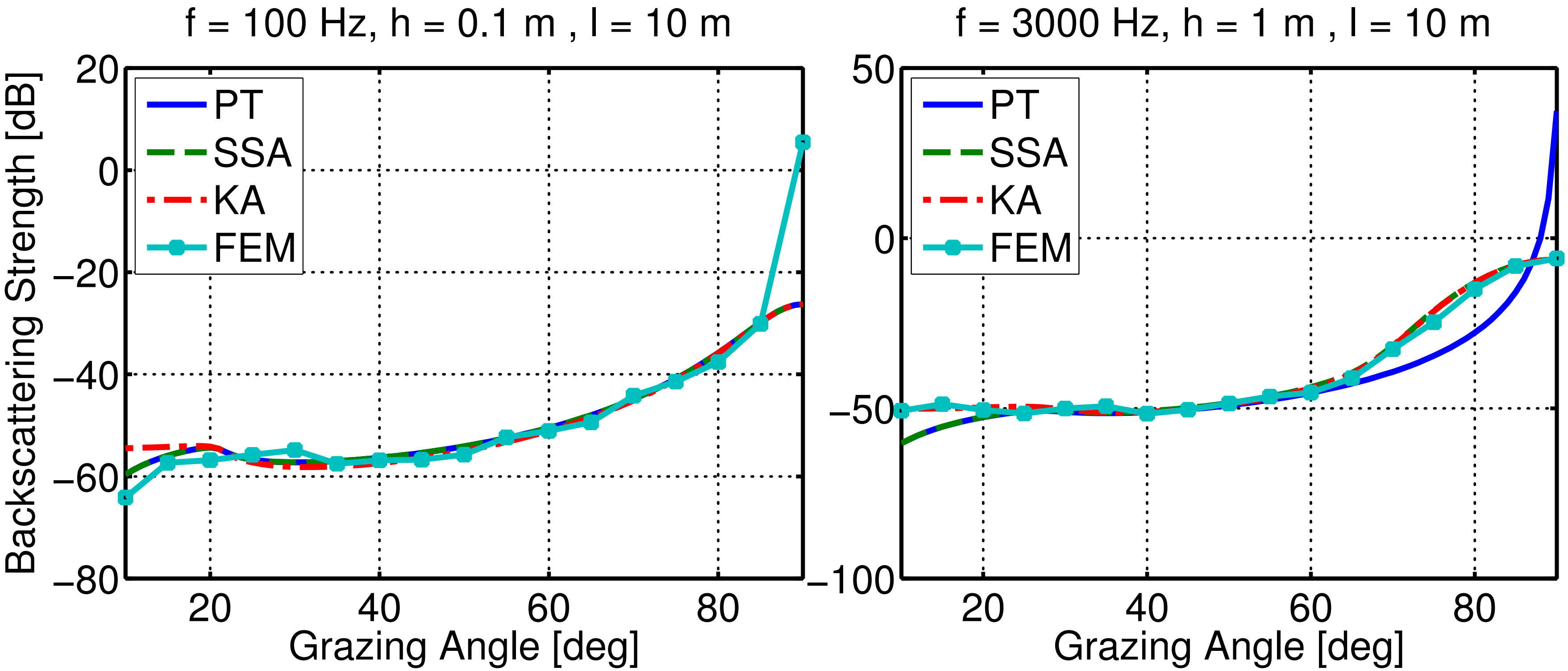
Parameter	Values
Frequency (f)	100 Hz and 3 kHz
rms surface height (h)	0.1 and 1 m
Surface cutoff length (l)	10 m
Bistatic grazing angle (θ)	45 degrees

Material Properties

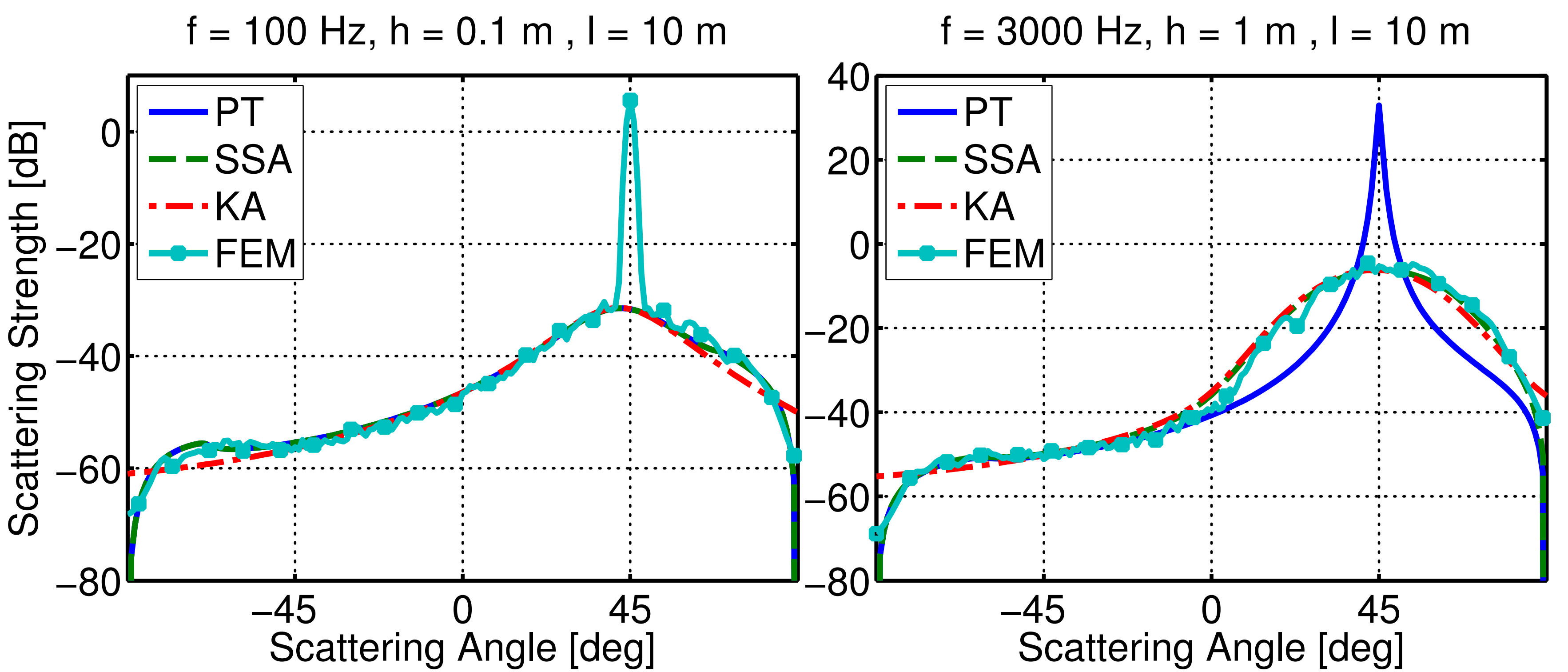
Parameter	Values
Fluid sound speed (c_f)	1530 m/s
Fluid density (ρ_f)	1023 kg/m^3
Fluid compressibility (χ_f)	4.176×10^{-10} Pa^{-1}
Fluid viscosity (μ_f)	10^{-3} Pa·s
Drained density (ρ_d)	1404.5 kg/m^3
Drained bulk modulus (K)	43.6 + *i*2.08 MPa
Drained shear modulus (G)	29.2 + *i*3.86 MPa
Biot-Willis coefficient (α_B)	$0.998 - i8.15\times10^{-5}$
Permeability (κ_p)	3×10^{-11} m^2
Tortuosity (τ)	1.2
Porosity (ϵ_p)	0.38
Reference frequency (f_c)	410.4 Hz

Taken from Yang et al., *IEEE Ocean Eng.*, **27**(3), 2002.

Results: Monostatic



Results: Bistatic



Conclusions

- Scattering from rough poroelastic surface successfully modeled using COMSOL Multiphysics.
- COMSOL Multiphysics robust tool for evaluating conventional scattering models.
- Good agreement between FEM and small-slope approximation.
- FEM monostatic results at shallow grazing angles warrant further study.