Comparison of 2-D and 3-D finite-difference simulations for infrasound propagation in heterogeneous atmospheres

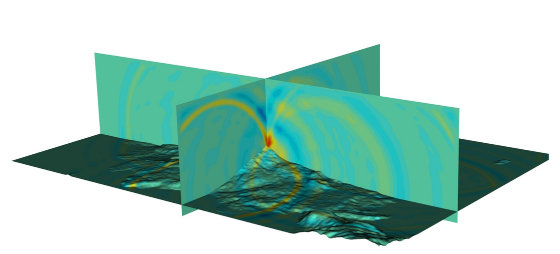
Keehoon Kim (kim84@llnl.gov)[1]

[1]Geophysical Monitoring Program, Lawrence Livermore National Laboratory, USA

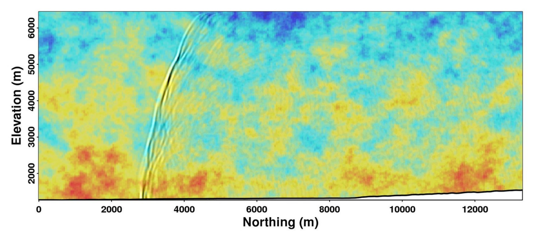
Lawrence Livermore National Laboratory

Motivation

- Full 3-D finite-difference modeling is widely used for infrasound propagation simulations including complex topography and atmospheric conditions

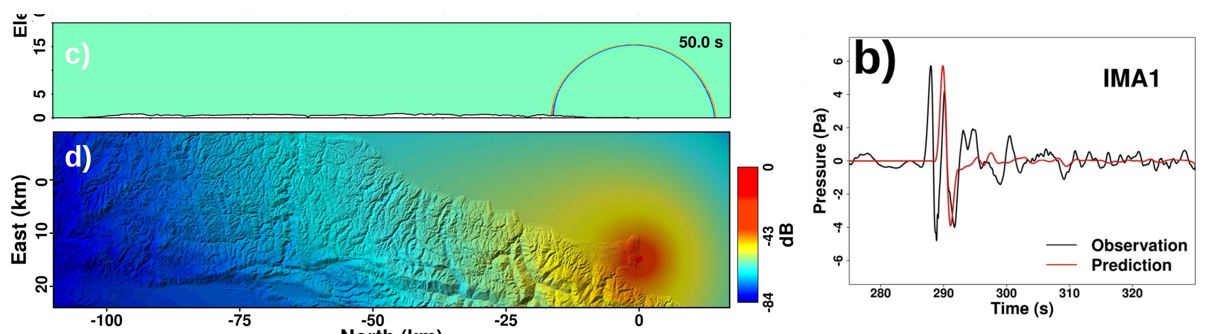


Sound propagation in 3-D medium



Sound propagation through turbulent atmosphere

- With appropriate weather models, 3-D simulations can provide accurate amplitude prediction for atmospheric infrasound, allowing for accurate source inversion (e.g. explosion yield estimation, Kim and Pasyanos, GRL 2022)

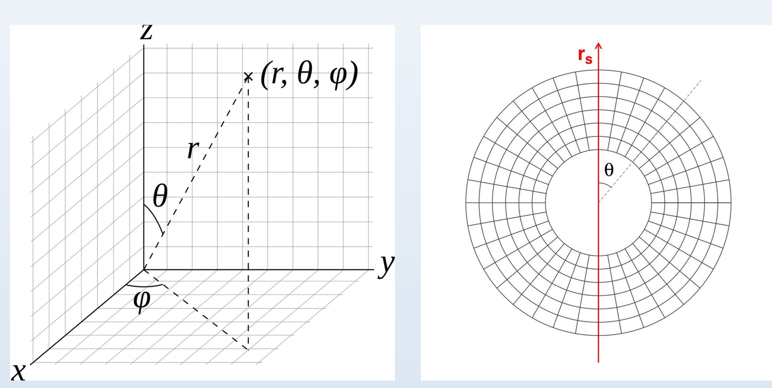


Full 3-D infrasound modeling for the 2020 Beirut explosion (Kim and Pasyanos, 2022)

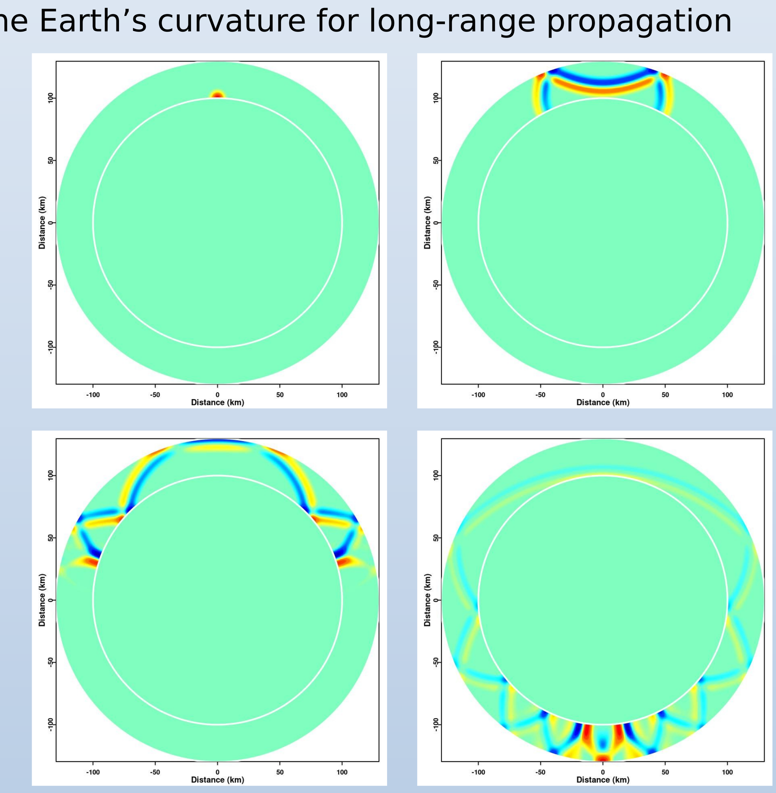
- However, 3-D modelings require large computational resources and computation time which limits its application to long-range infrasound propagation.

2-D Finite-Difference Simulations

- 2-D finite-difference code development for infrasound propagation in the atmosphere
- Linearlized Euler Equation for the governing equation
- A spherical coordinate with an axial symmetry: 3-d geometric spreading simulated by 2-D



- Includes the Earth's curvature for long-range propagation



Comparison of 2-D and 3-D Simulations

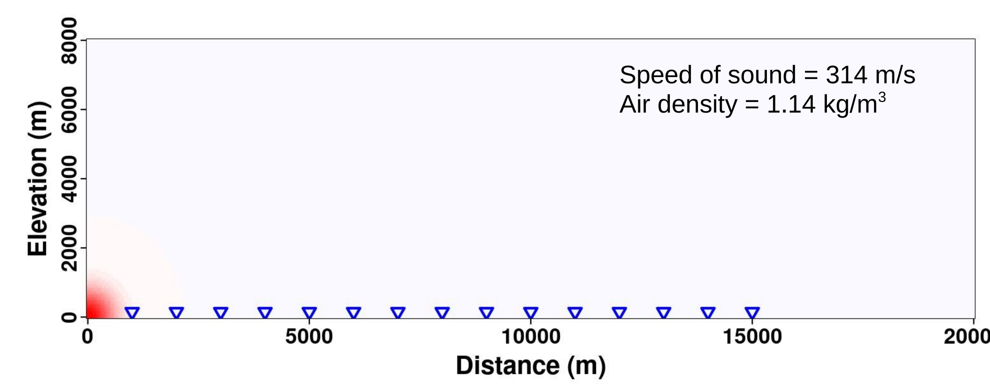
- The capability and limitation of 2-D modeling needs to be quantitatively evaluated by the comparison with a 3-D method (Petersson and Sjogreen, 2018).

Methodology

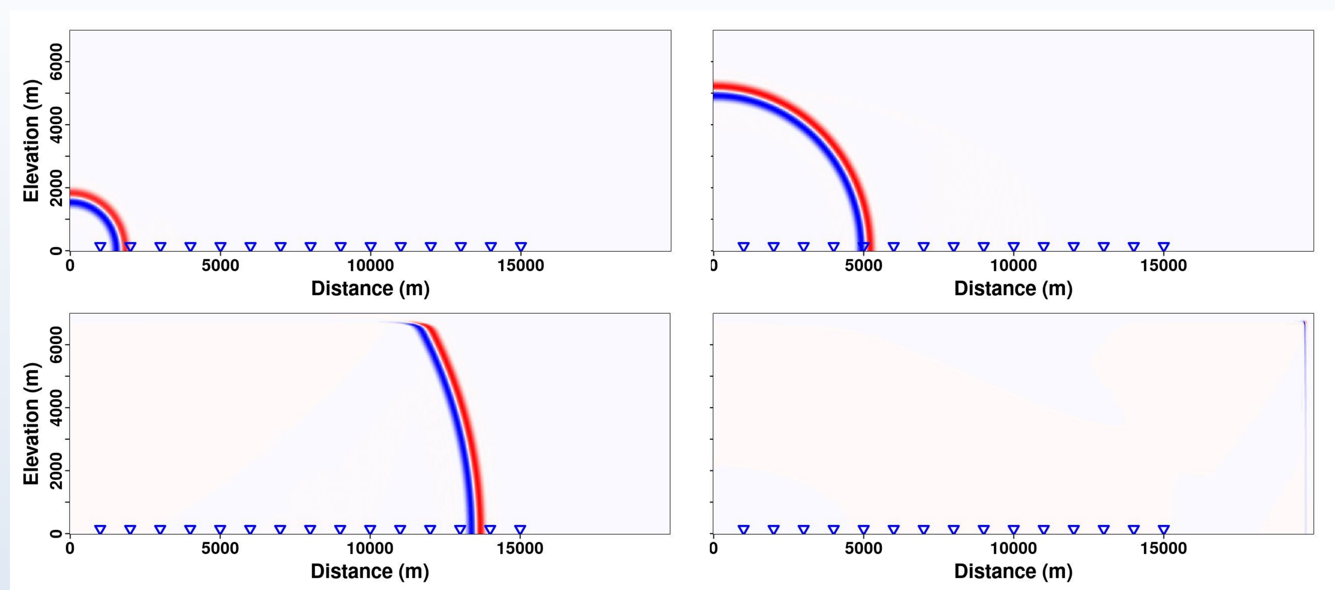
	3-D	2-D
Source Code	ElAc (Cartesian Coord.)	AC2Dr (Spherical Coord)
Spatial Discretinzation	6th order finite difference	6th order finite difference
Temporal Discretization	4th order Runge Kutta	4th order Runge Kutta
Absorbing Boundary	Super-grid	Super-grid

1-D case

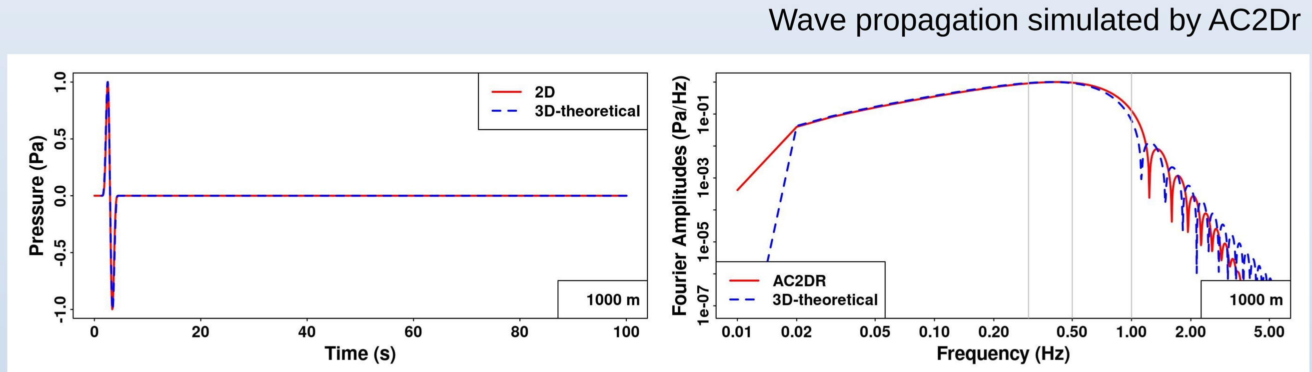
Homogeneous Medium without Wind



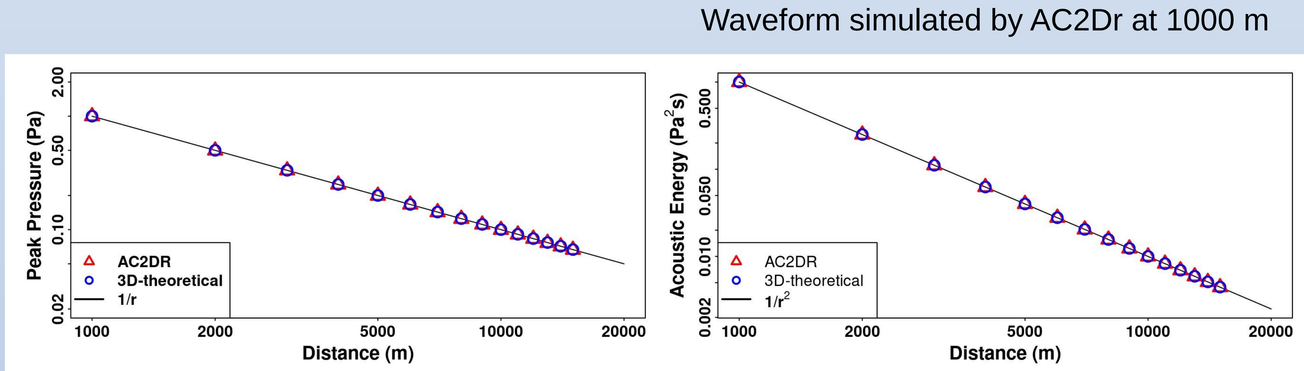
Source Characteristics	Shape	Peak Frequency	Corner Frequency
3-D (ElAc)	Gaussian (point)	0.5 Hz	1.0 Hz
2-D (AC2Dr)	Gaussian (initial field)	0.5 Hz	1.0 Hz



Wave propagation simulated by AC2Dr



Waveform simulated by AC2Dr at 1000 m

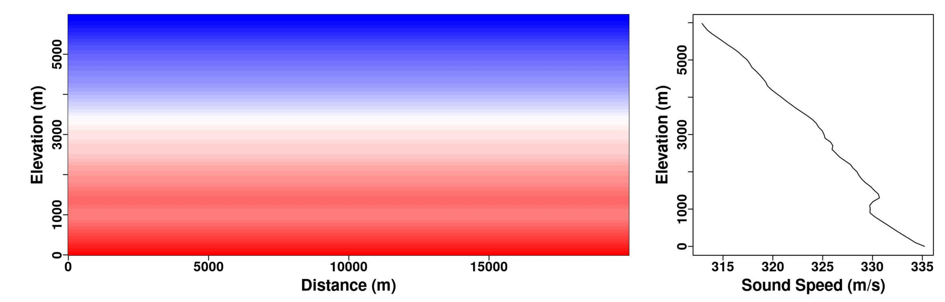


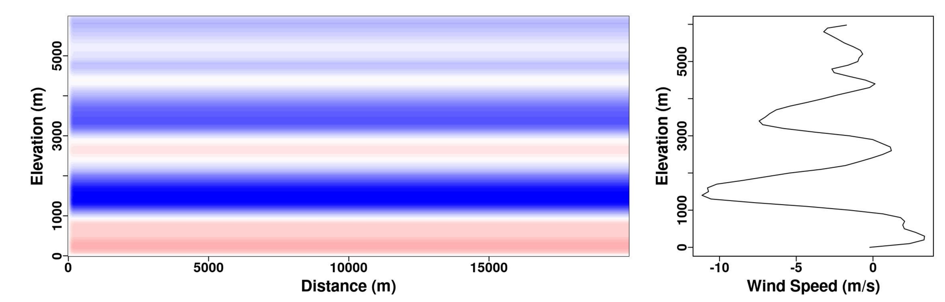
Peak amplitude and acoustic energy attenuation simulated by AC2Dr

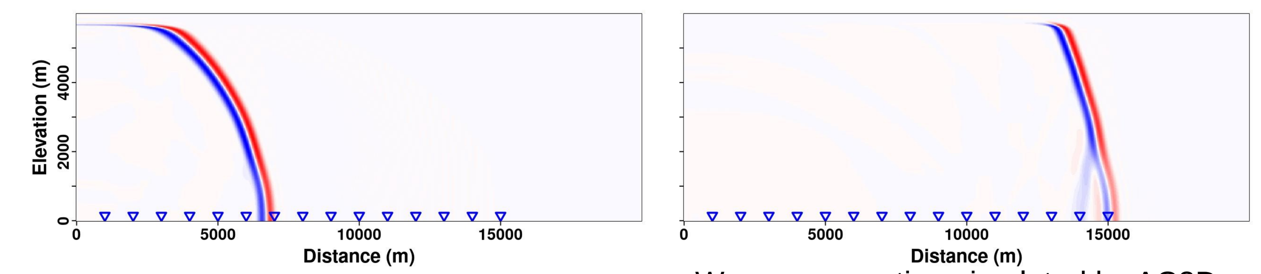
1-D Case (contd.)

Range Independent

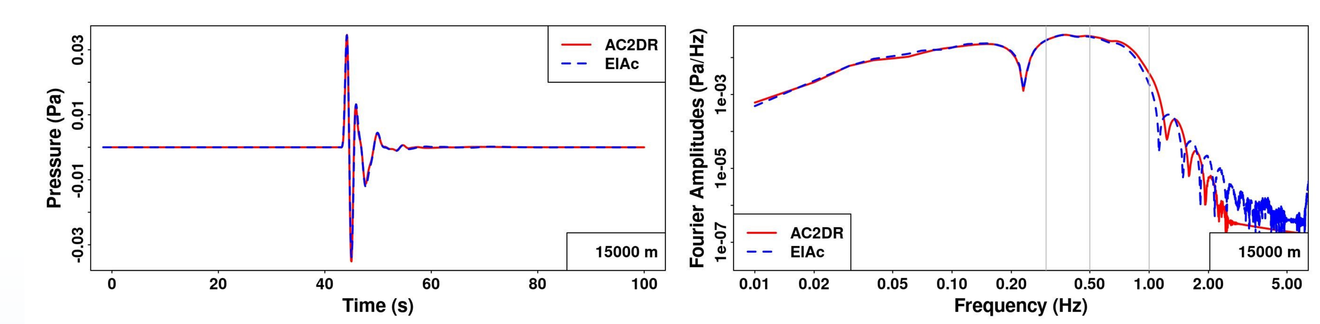
- Define range-independent sound speeds and horizontal winds for ElAc (3D) and AC2Dr (2D)



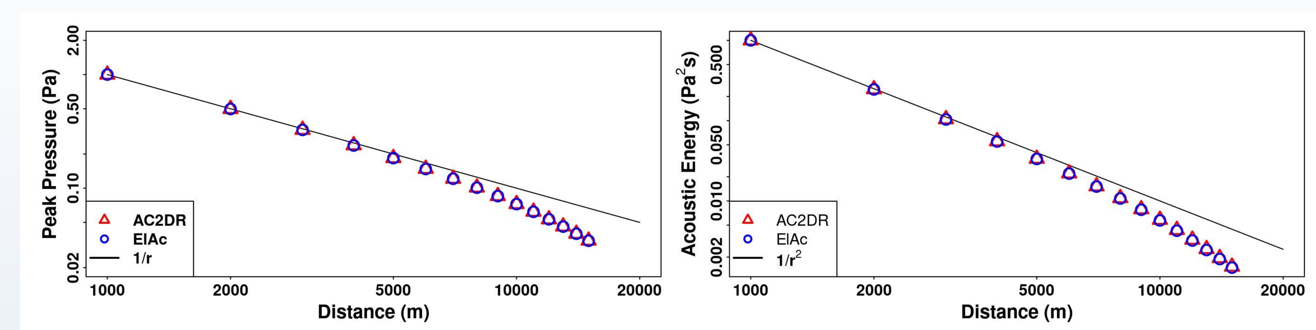




Wave propagation simulated by AC2Dr



Waveform simulated by AC2dr and ElAc

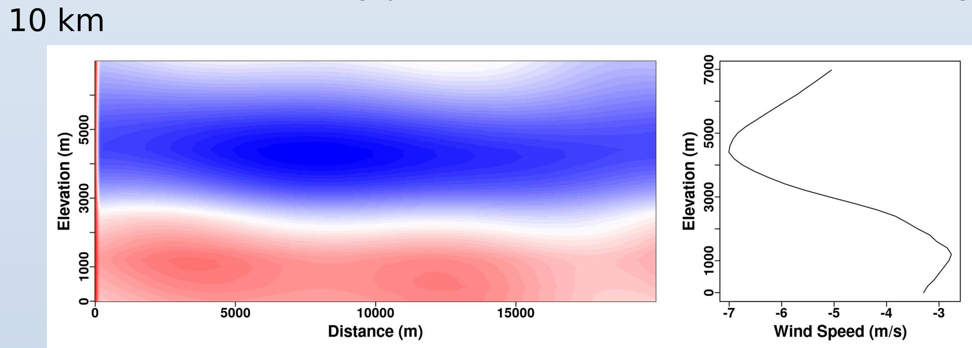


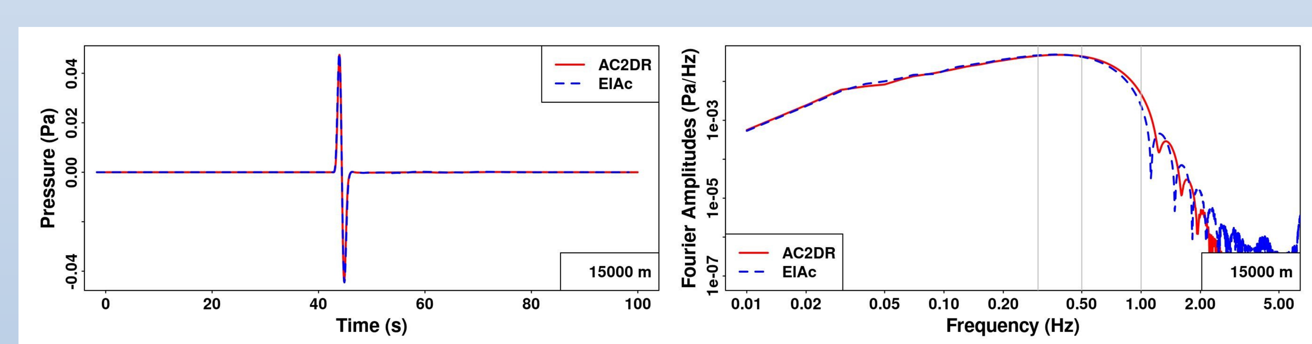
Amplitude and energy attenuation simulated by AC2dr and ElAc

2-D Case: Range Dependent

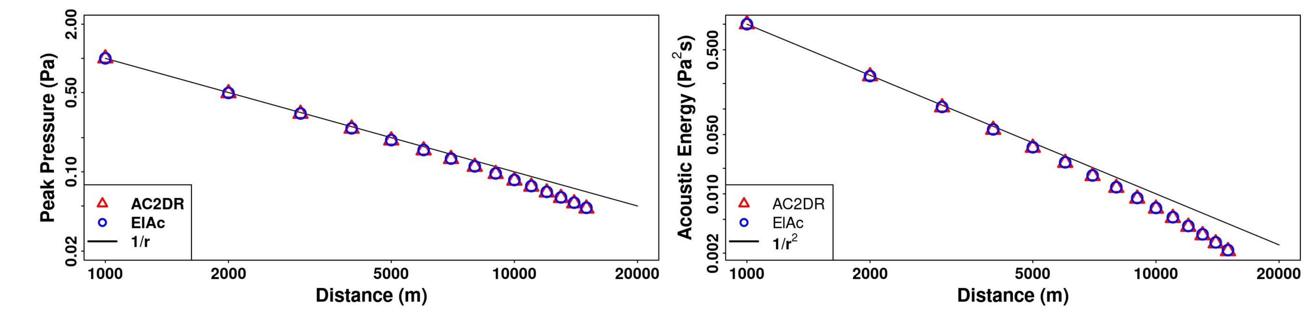
Slowly Varying Field

- Use 1-D sound speed profile and 2-D range-dependent wind field for simulations
- The wind field is randomly perturbed with the characteristic length scale of 10 km



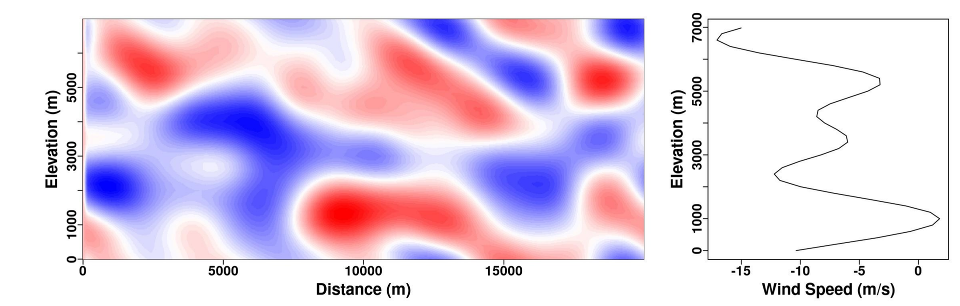


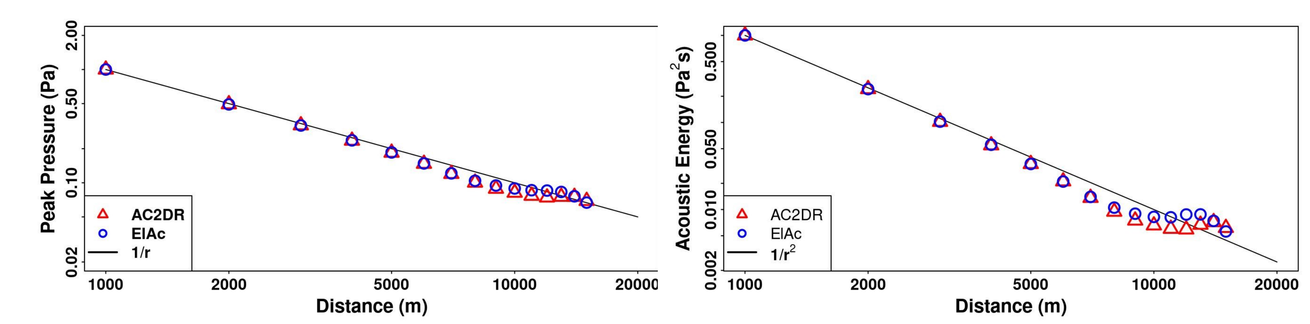
2-D Case (contd.)



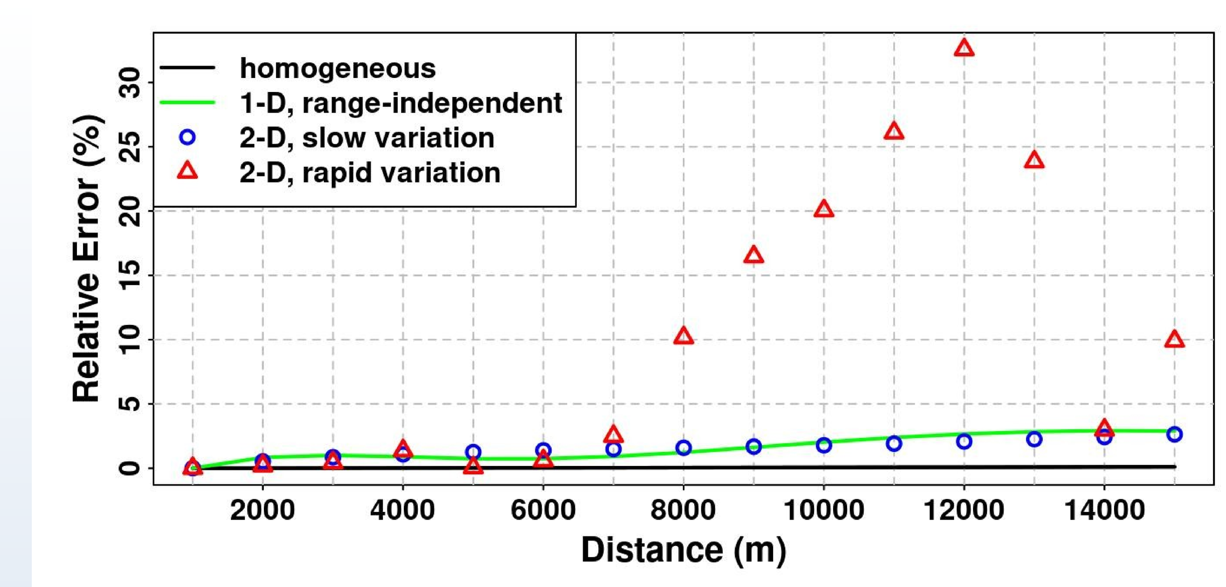
Rapidly Varying Field

- The wind field is randomly perturbed with the characteristic length scale of 2 km





Summary



- Relative errors between the acoustic energies calculated by ElAc and AC2dr are calculated with respect to the ElAc's results (3-D).
- 2-D simulation results show good agreement with the 3-D simulation (errors less than 5%) for the homogeneous, 1-D, and slowly varying 2-D materials.
- For the rapidly varying 2-D material, the 2-D simulation had an error up to 40% of the 3-D results. In this case, caution must be taken for quantitative approximation by 2-D.

References

Kim, K., & Pasyanos, M. E. Yield Estimation of the August 2020 Beirut Explosion by Using Physics-Based Propagation Simulations of Regional Infrasound. Geophysical Research Letters, e2022GL101118.

Petersson, N. A., & Sjögreen, B. (2018). High order accurate finite difference modeling of seismo-acoustic wave propagation in a moving atmosphere and a heterogeneous earth model coupled across a realistic topography. Journal of Scientific Computing, 74(1), 290-323.

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