Modeling the phase variation with offset of seismic reflections

Bram Willemsen

5th year Ph.D student,
Department of Earth, Atmospheric and Planetary Sciences

In collaboration with Alison Malcolm

MIT Earth Resources Laboratory

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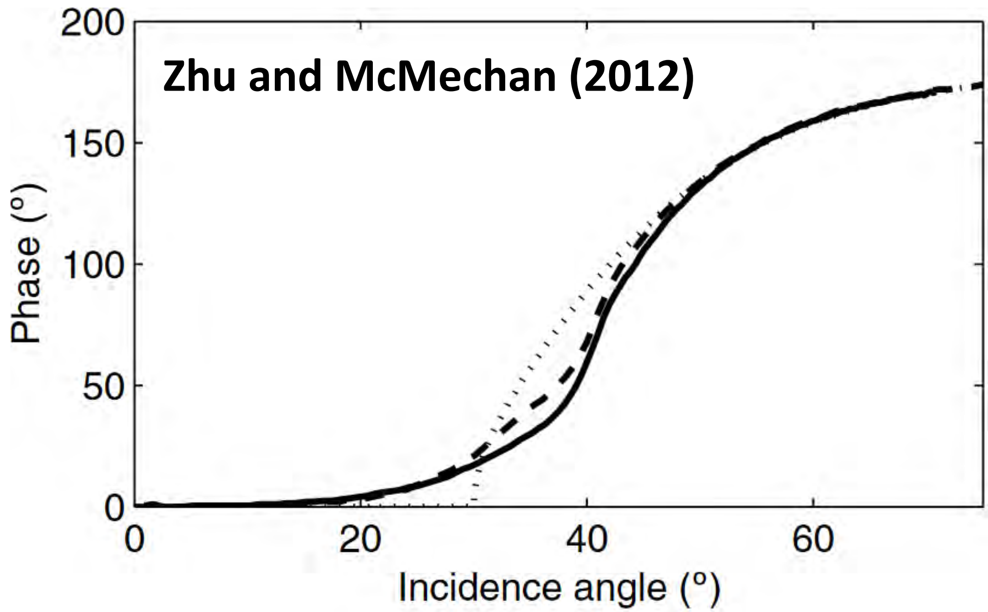
Massachusetts Institute of Technology

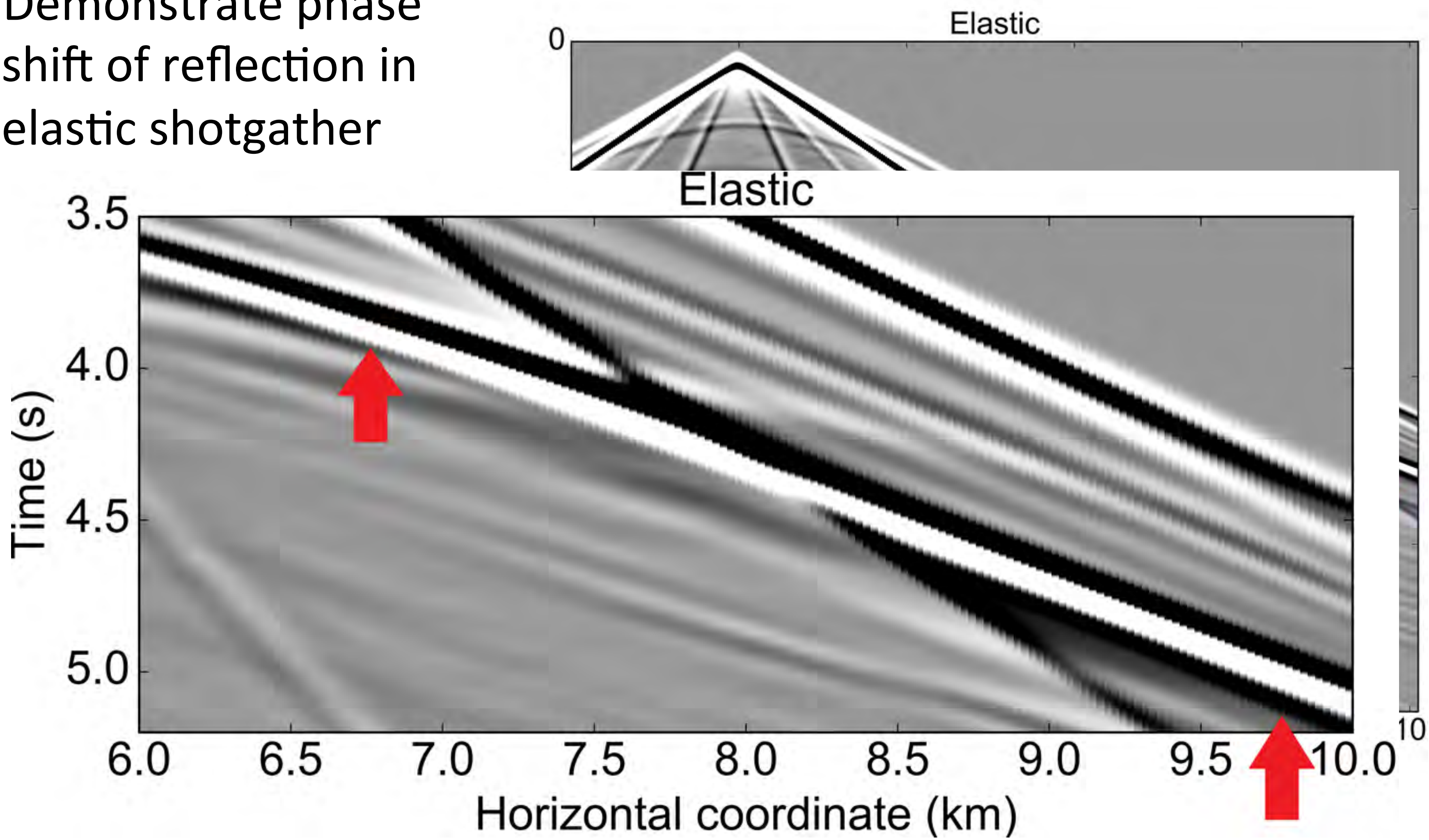
Phase shift of reflection

- Reflected waves acquire phase shift as function of incidence angle
    1. Phase shift depends on elastic material contrast at reflector
    2. Phase of wave mostly unaffected by transmission
- Therefore useful property to invert for reflector properties
    - Reservoir characterization
- For this we need efficient forward model
- Full domain elastic wavefield simulations are expensive
- Use local solver around reflector to reduce cost



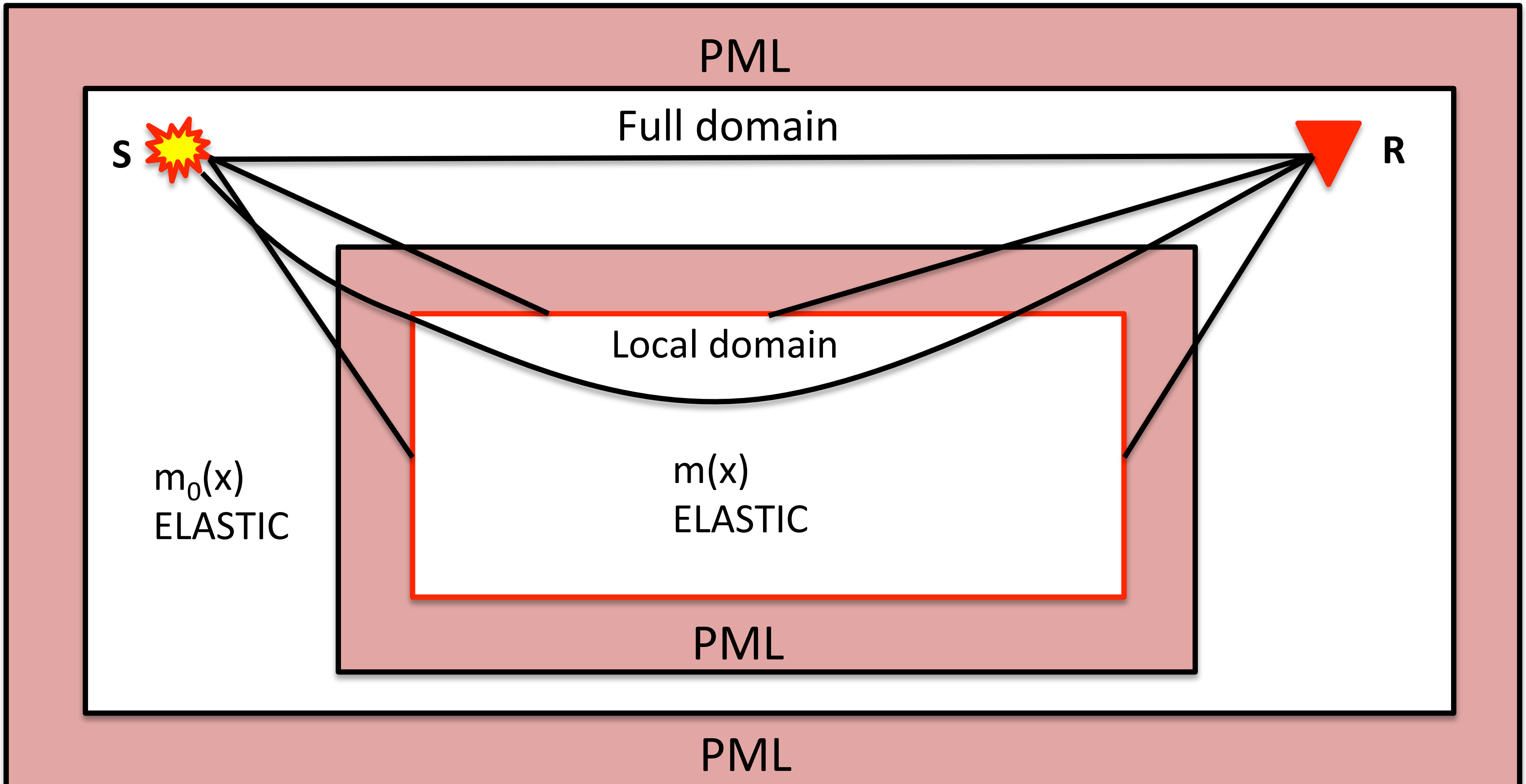
Phase shift example

- Demonstrate phase shift of reflection in elastic shotgather



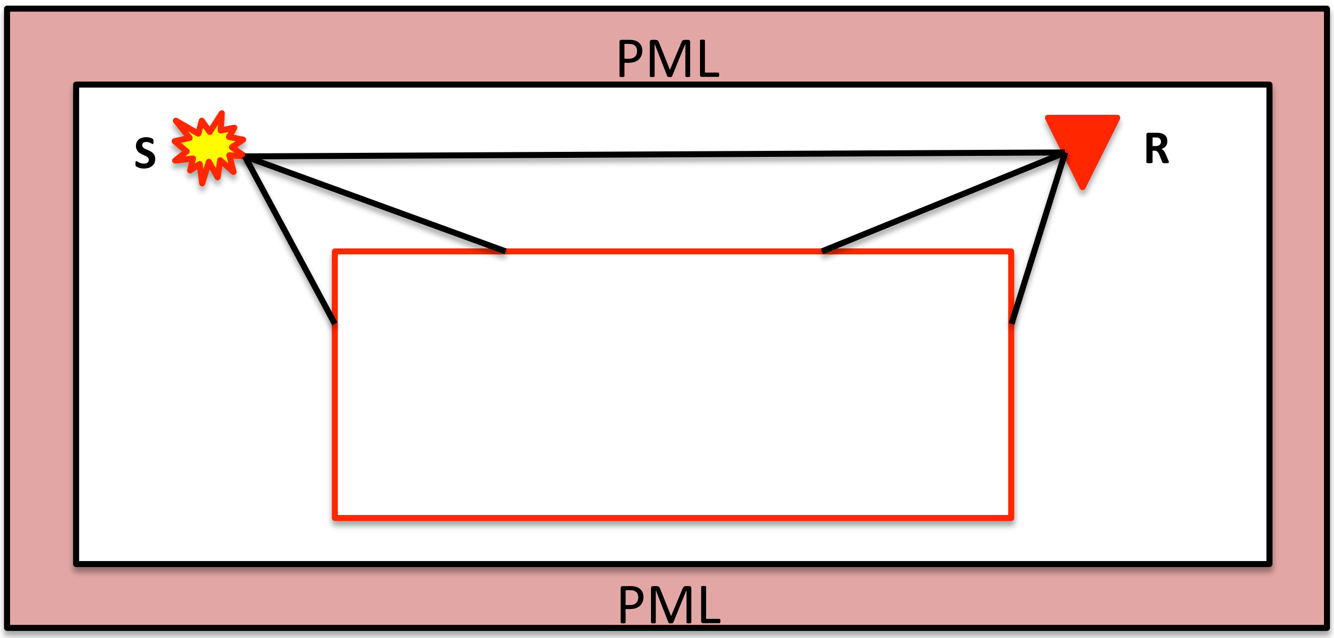
Local solver

- Model phase shift efficiently using local solver
- Use concepts from Robertsson and Chapman (2001)



Local solver continued

- Accurately models primary reflections on any model update inside local solver
- Smaller domain -> faster simulations
- Require many precomputations
  - Greens functions from source to receivers
  - Greens functions from source to local domain
  - Greens functions from receiver to local domain (boundary integral)
- These elastic full domain simulations are expensive!



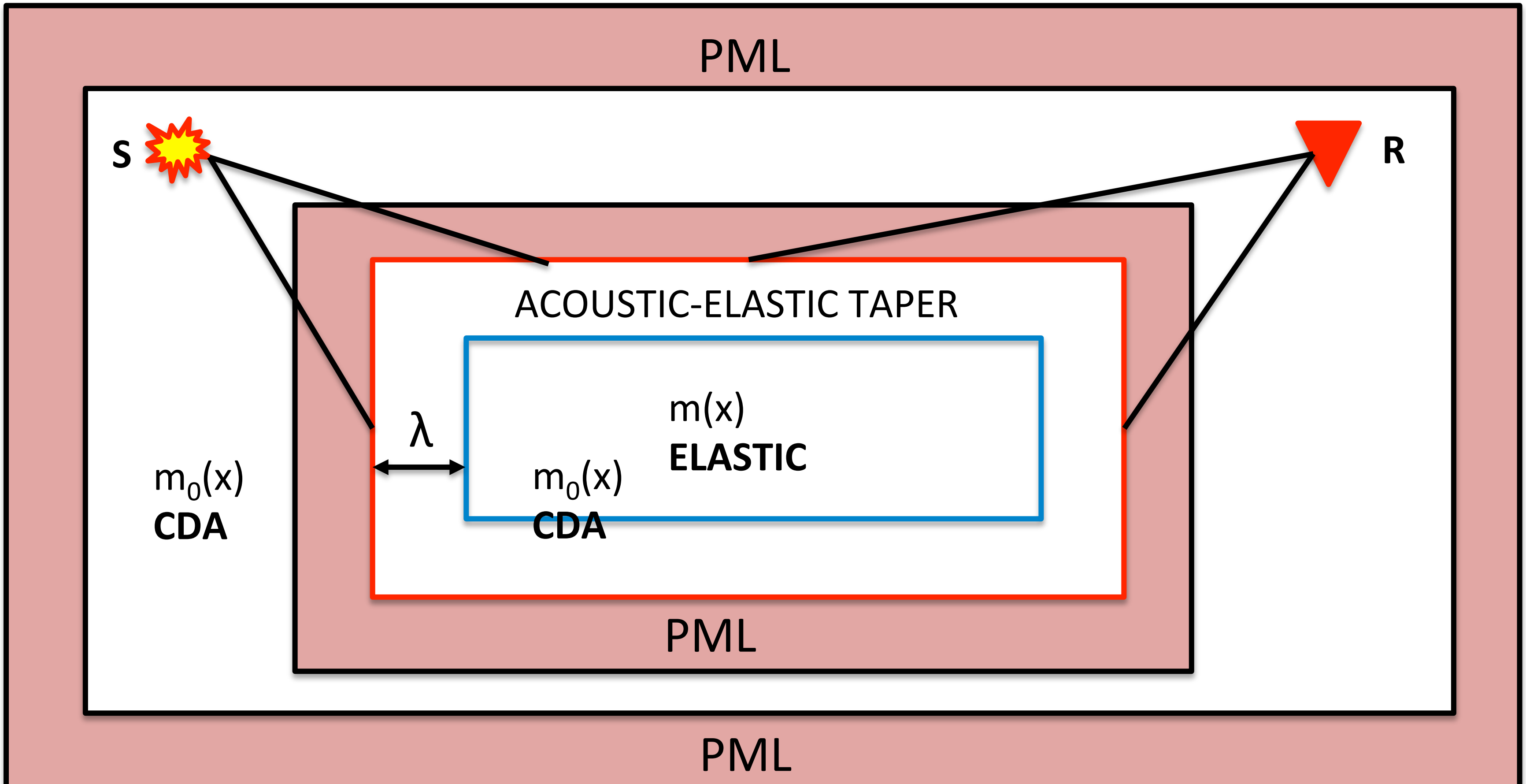
Local solver optimization

- Many expensive elastic full domain simulations
- **Recall observation:** Phase shift not affected by propagation through overburden
- **Idea:** Use <u>cheap</u> Constant Density Acoustic (CDA) simulation for Green's functions instead.
  - Fewer full domain simulations
  - Each simulation much cheaper
    - Fewer model parameters
    - Fewer field variables (scalar now)
    - Update equations simpler
    - Larger grid spacing, fewer nodes

Mixed CDA-Elastic local solver

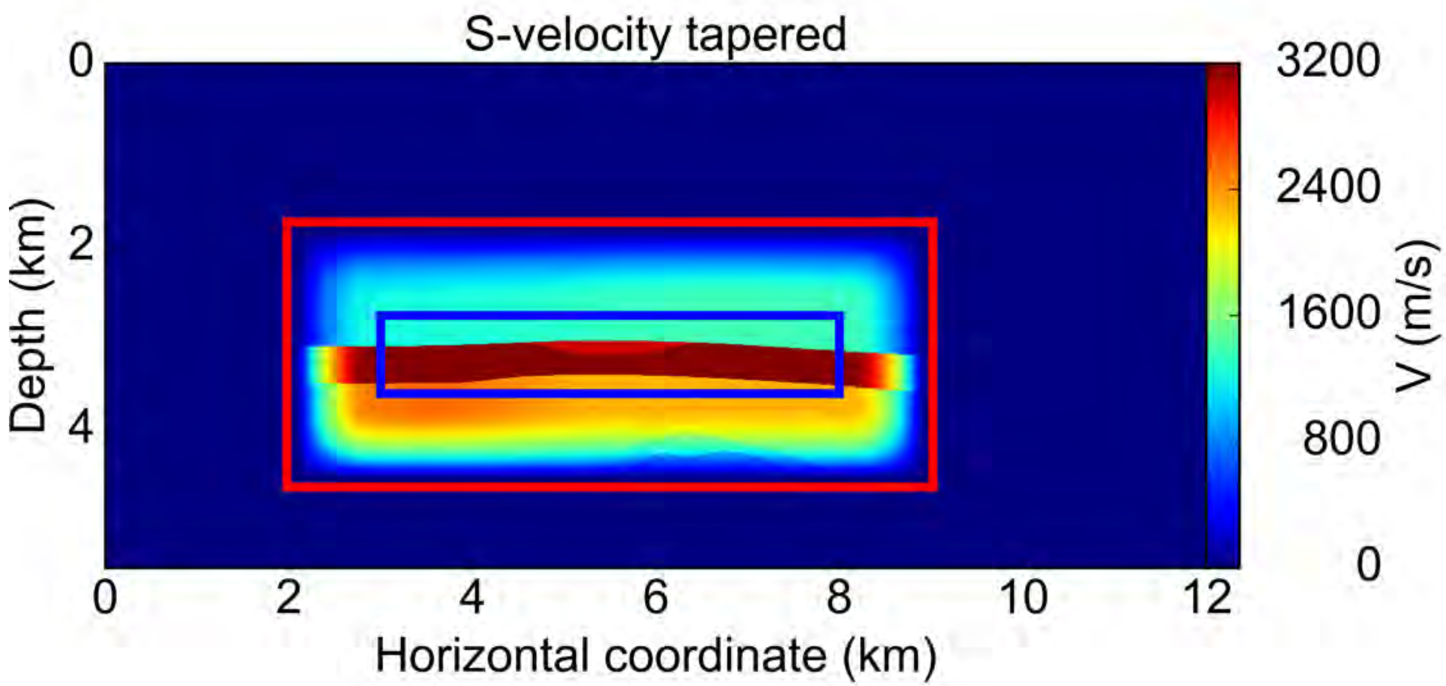
- Background model CDA
- Model update Elastic

$$p^{sc}(y,t) = \int_S \left[G_0(x,y,t) * \frac{\partial p(x,t)}{\partial x_n} - p(x,t) * \frac{G_0(x,y,t)}{\partial x_n} \right] dS_x$$



Synthetic Example

- Background model is CDA -> no longer need elastic full domain solves!
- Example: simplified synthetic North Sea model
  - Large contrast chalk layer, postcritical reflections
- Model update on top of Vp only background model
  - Tapered density model
  - Tapered Vs model



Synthetic Example continued

- Compare phase
  1. Full domain elastic solver: True Vp(x), True rho(x), True Vs(x)
  2. Full domai … Vs(x)
  3. CDA Gree … pered Vs(x)
  4. Full doma … ero Vs
- Red and blue l…
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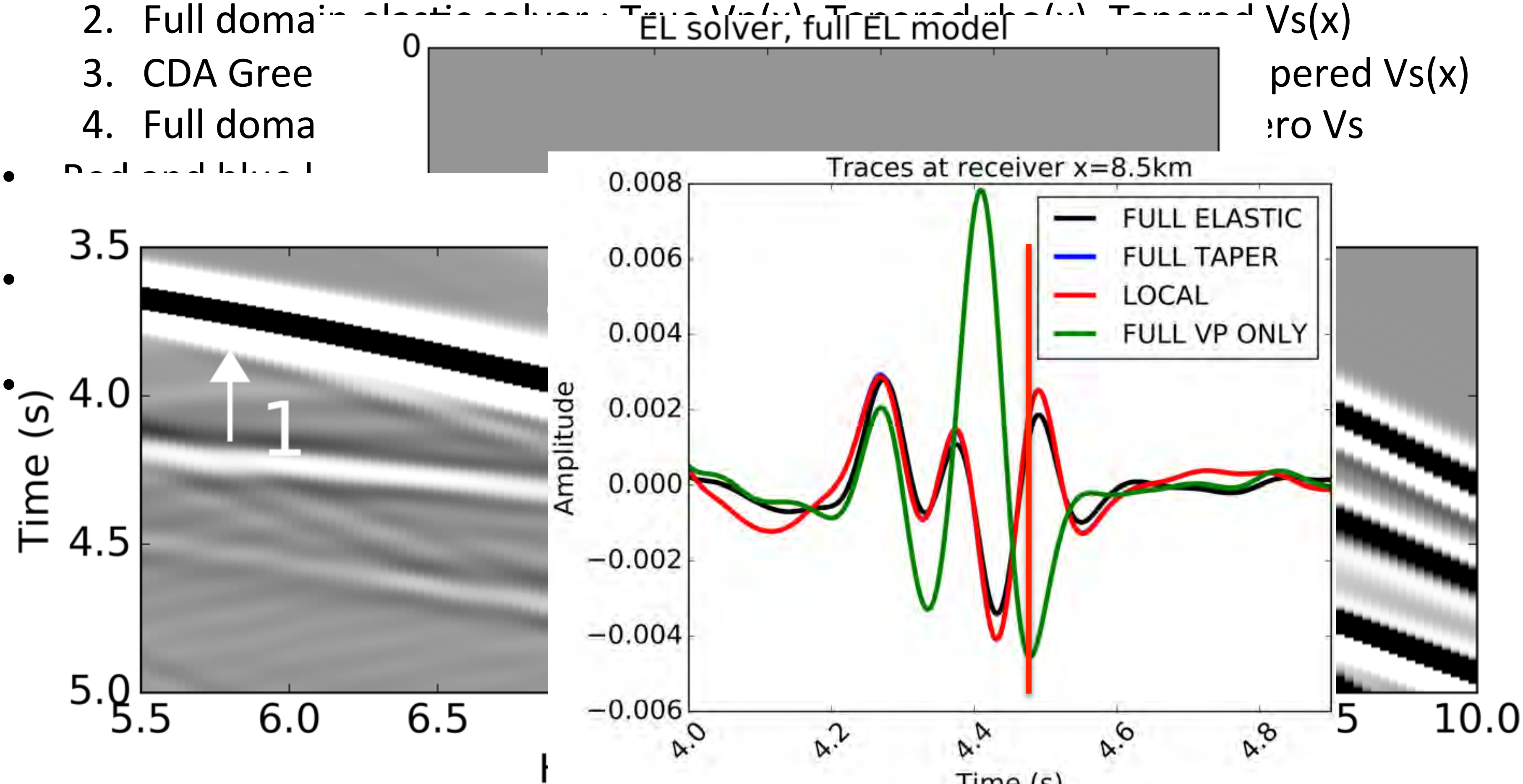
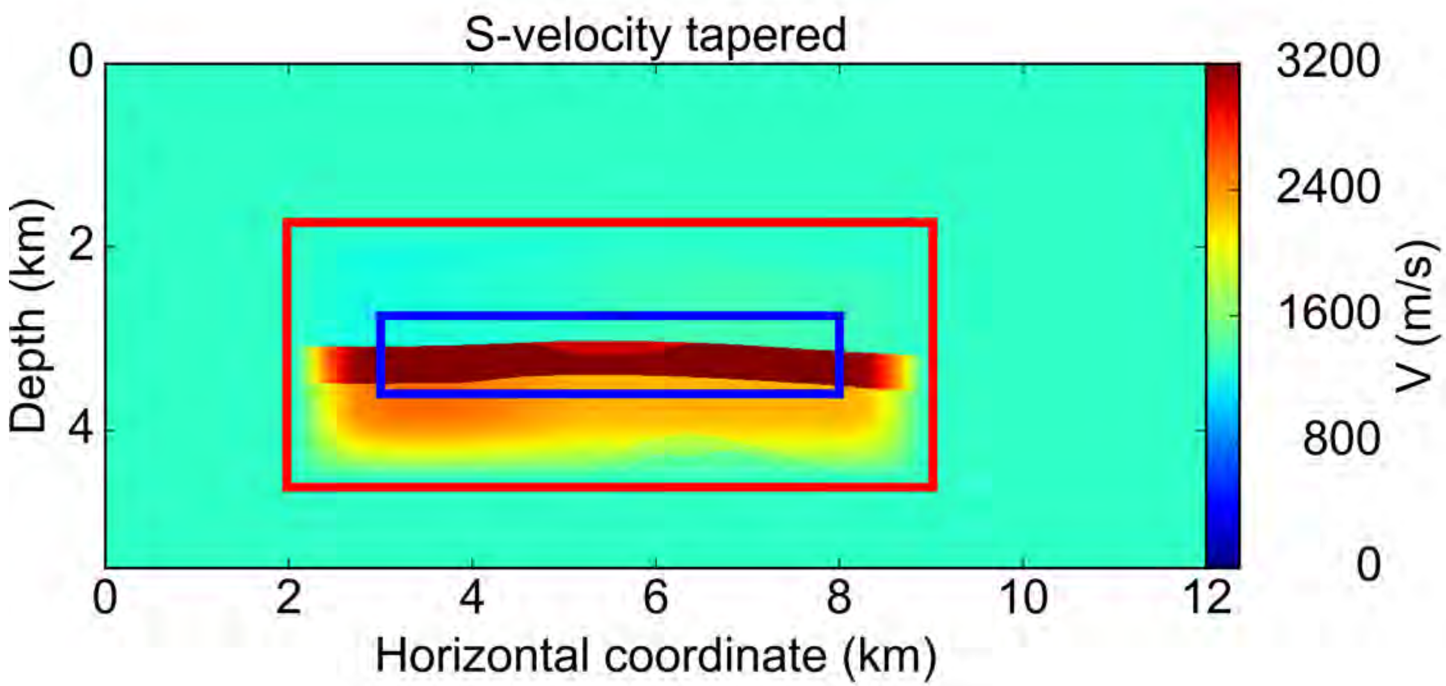


Remarks

- Acoustic state requires tapering Vs to 0.0 m/s
- Very large transition
- Adapted methodology to taper to nonzero Vs
- Gives slightly more accurate phases still



Summary

- Introduced mixed acoustic-elastic local solver
- Avoids large cost of full domain elastic simulations
- Reproduces elastic phase shifts accurately
- Future work:
  - Reduce size of tapers for faster simulations
  - Don't compute full time range
  - Use in inversion

Acknowledgements

- Filippo Broggini (ETH Zurich) for insightful discussions
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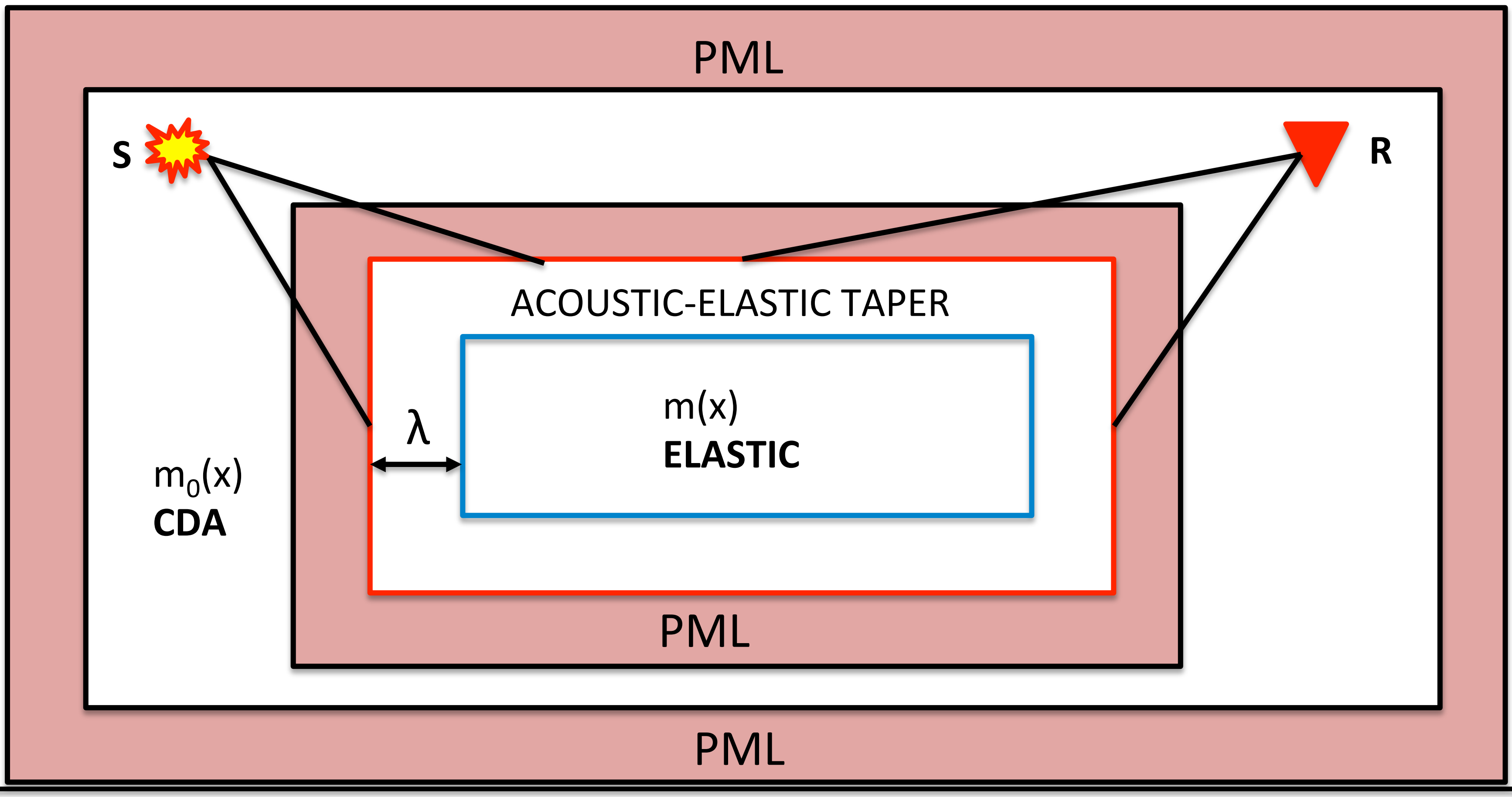
Thank you for your attention

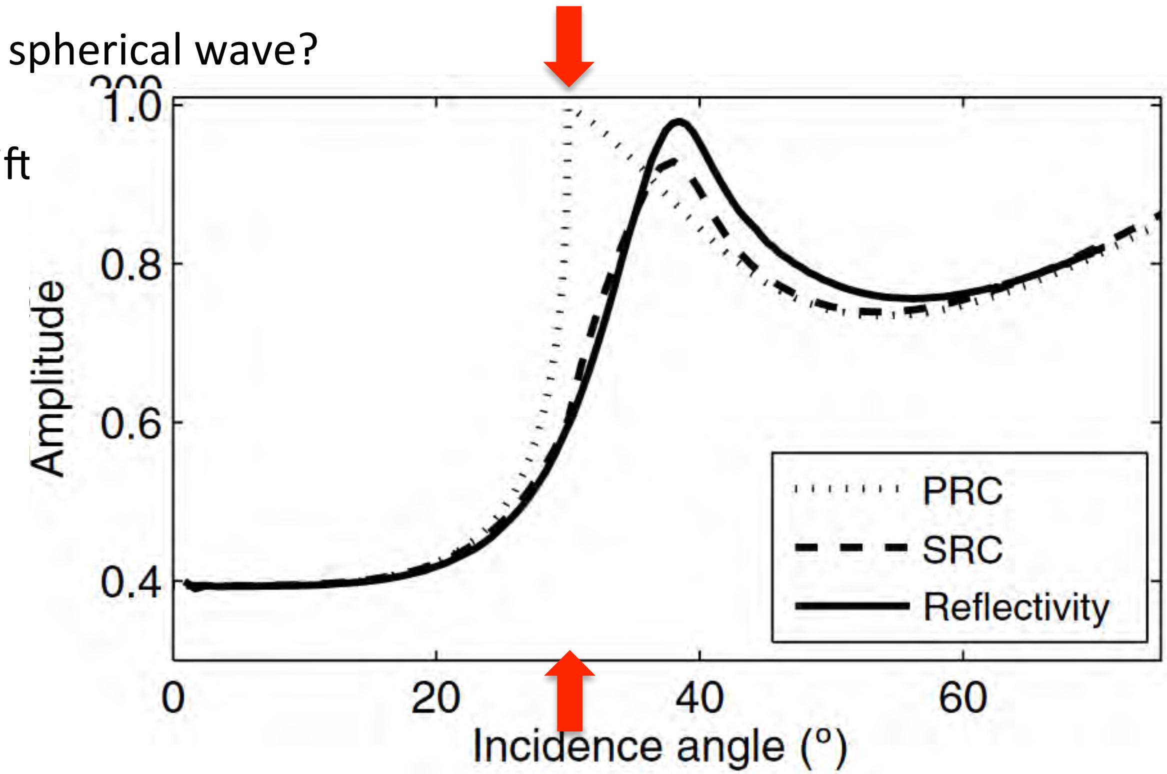
- I'm happy to take questions



ADDITIONAL SLIDES

Phase variation in reflected wave?

- Today's topic: efficiently model phase of reflected wave
- Relate to a familiar concept
- Reflection amplitude, function of angle
- Zoeppritz equations
- Assumes plane wave, how about spherical wave?
  - 'Smoothing' over angles
- Postcritical waves have phase shift



Zhu and McMechan (2012)