Seismic Modeling, Migration and Velocity Inversion

Review and Summary

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Outline

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Why and Where

- Why model
  - For tying geology to measurements
  - For understanding wave propagation
  - For assessment and verification
- Three Earth Models
  - The most practical is probably anisotropic
  - The others simplify the problem
- What we Model
  - Particle motion and velocity
  - Propagation directions
  - Sources

Modeling Methods

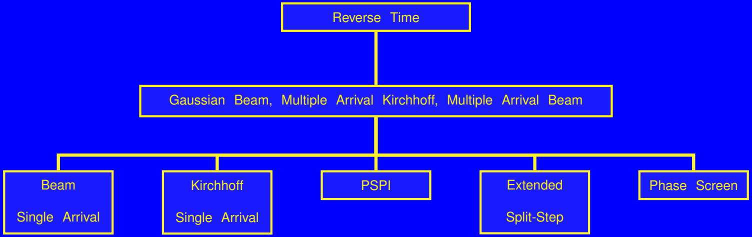
- Three Earth Types
  - Isotropic (Acoustic), Isotropic Elastic, Anisotropic
    - Up to nine volumes (Orthorhombic)
    - TTI currently most prevalent
- Methods
  - Raytrace based integral methods
  - Direct wave equation methods
- Point sources and receivers
  - Source - Receiver reciprocity
- Huygens Principle
  - Exploding Reflectors

Modeling Issues

- Model Construction
  - From Logs
  - From migrated data
- Acquisition
  - Arrays vs point sources and receivers
  - Aperture
  - Areal arrays finely sampled
- Computation
  - Acoustic and TTI realistic

Outline

A Hierarchy of Migration Options



Computational intensity tends to decrease from top to bottom
Everything below the horizontal line is a one-way method
Velocity sensitivity tends to increase from top to bottom
Basis for both poststack and prestack algorithms

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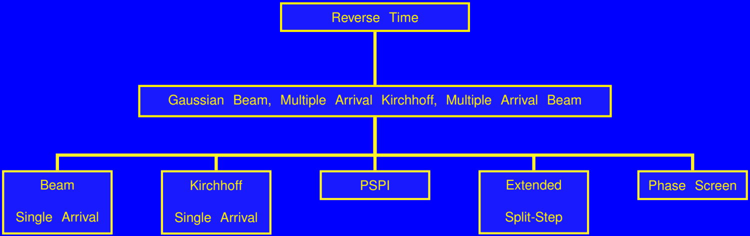

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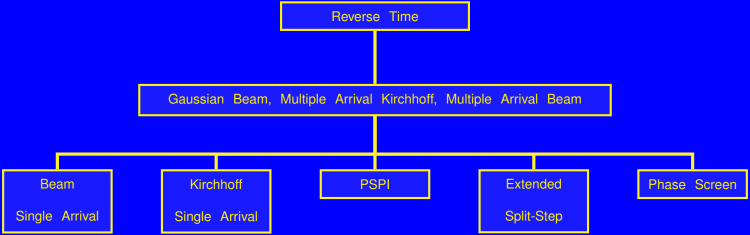

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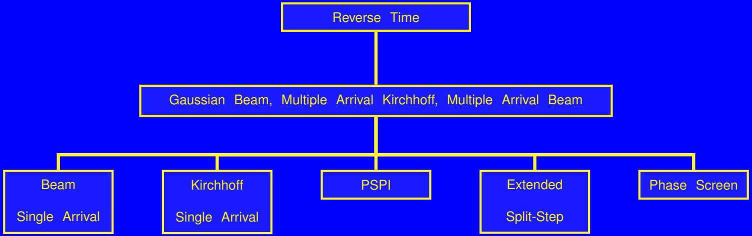

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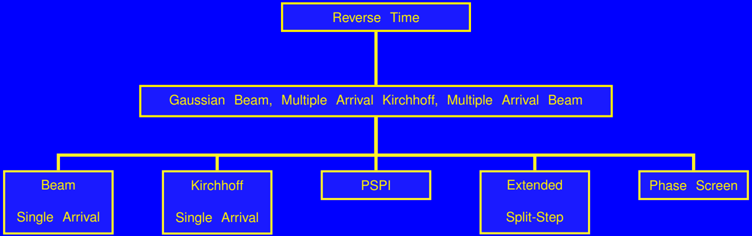

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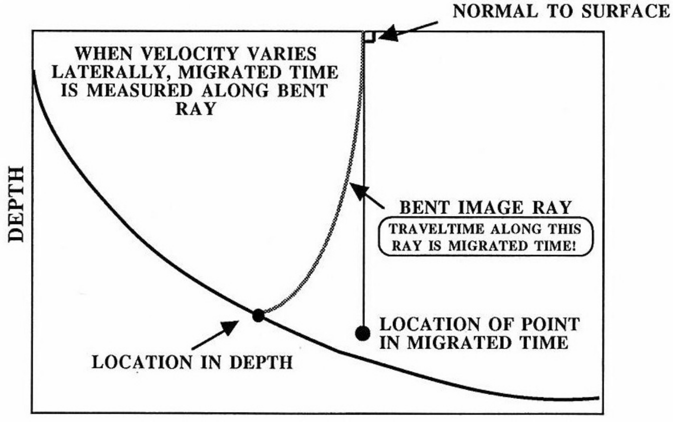
The Major Difference Between Time and Depth



The major difference between time and depth.

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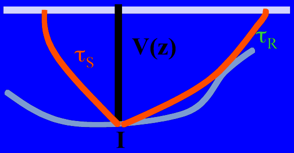
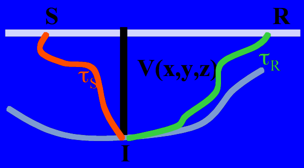
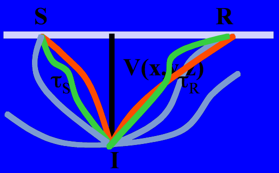


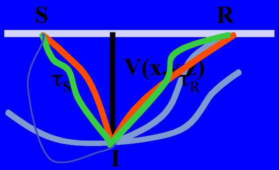
Curved ray or V(z)



Single Arrival Kirchhoff



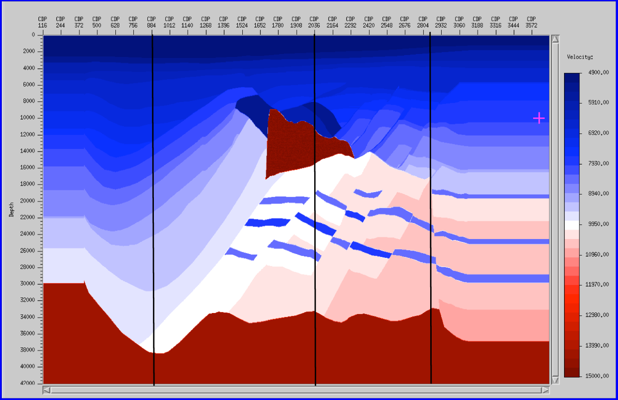
One way Wave Equation
Or
Angle limited single arrival Kirchhoff



Two way Wave Equation
Multiple Arrival Kirchhoff
Gaussian Beam

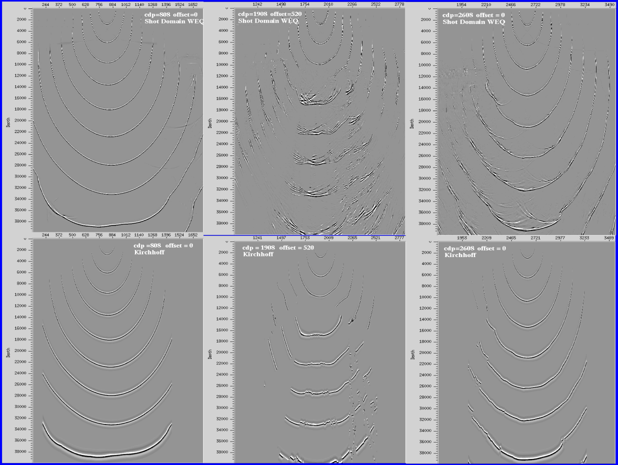
Prestack migration differences

A Complex Salt Model



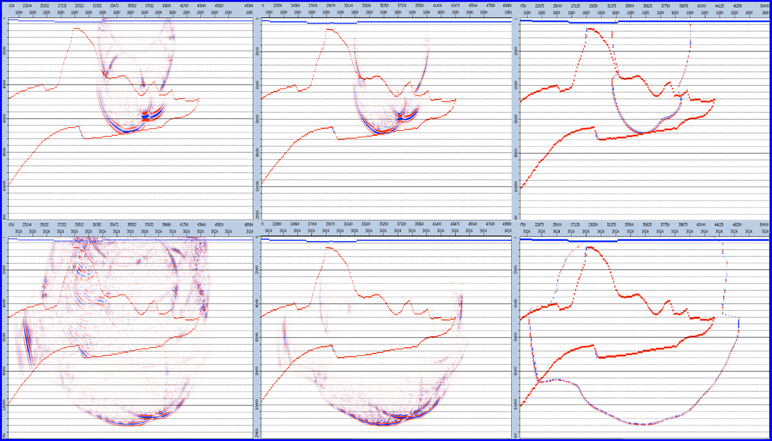
The KM velocity model and three surface shot locations.

Impulse Responses from a Complex Salt Model



A comparison of impulse responses from the KM model of the previous slide.

Impulse Responses from the SEG AA' model



A simple comparison of Kirchhoff, one-way and two-way impulse responses over the SEG/EAGE AA' data set.

Outline

Migration Velocity Analysis

- Migration sends sources and receivers offsets to zero
  - Any gather we build should take this into account
  - Offset-shift and time-shift gathers do
  - The others don't
- Gathers
  - Common offset, Common Angle, Common Image Point, Offset-shift, Time-shift
- Tomography
  - Not Dix
- Short-spread vs Long-spread velocity analysis
  - Anisotropy
  - Probably requires log information
- Horizon vs no horizon based
- Full waveform inversion (FWI)
  - Somewhat in its infancy

Outline

Styles

- Two basic algorithm styles
  - Raytrace (Integral) based
    - Beam, Beam Stack, Kirchhoff, Gaussian Beam
    - So called high frequency approximation
  - Partial Differential Equation Based
    - Finite Difference, Finite Element, Dual Domain (FKX)
- Multiple Combinations
  - Raytrace with PDE in shot-profile
  - Delayed shot beam using PDE's

Anisotropy

- Kirchhoff, Beam, and Gaussian Beam
  - Function only of raytracer
- One-way
  - Limited by approximation
- Two-way
  - All versions of anisotropy

Velocity Sensitivity

- Kirchhoff
  - Single Arrival very sensitive
  - Multiple Arrival should not be so sensitive
- Beam
  - Smearing tends to reduce sensitivity somewhat
- One-way
  - Approximations make it sensitive to large changes
    - Not as severe as Kirchhoff
    - Unusual subsurface positioning
- Gaussian Beam
  - Almost none
- Two-way
  - None

True Amplitude Accuracy

- Kirchhoff
  - Single arrival limits accuracy
- Beam
  - Single arrival limits accuracy
- One-way
  - Approximations
    - Not as severe as Kirchhoff
    - Loss mostly due to one-way approach
    - That darn square root
- Gaussian Beam
  - Almost as good as you can get
- Two-way
  - As good as you can get

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Which one should I use?

- Dependent on exploration stage
  - Earth model estimation
    - Velocity analysis
    - Anisotropic analysis
  - Geological declination
    - Stratigraphic detail
    - Structural style
  - Interpretation
    - Initial trap delineation
    - True depth
    - Reservoir size
    - Well placement
  - Reservoir Characterization
- Each algorithm has its use
  - Be prepared to use them all if necessary

Algorithmic Issues

- Beam
  - Potential loss of stratigraphy
  - Cannot be beaten
    - For initial Earth model estimation
    - Hypothesis testing with various parameters
    - For mapping large structural traps
  - Suspect amplitudes
- Kirchhoff
  - Velocity estimation workhorse for many years
  - Better than beam at revealing stratigraphy
  - Excellent for target line imaging
  - Suspect amplitudes
  - Initial reservoir characterization
    - Particularly in time

Algorithmic Issues

- One-way — PSPI, Extended Split-step, Phase Screen
  - Can be faster than full two-way
  - Not good for velocity analysis
    - Exception is common azimuth implementations
  - Very good at stratigraphic imaging
  - Very good amplitudes
  - Loss of dip limits structural accuracy
- Gaussian Beam
  - Good for velocity analysis
    - But slow
  - Excellent stratigraphic imaging
  - Excellent amplitudes
  - Excellent structural accuracy
  - Reservoir characterization

Algorithmic Issues

- Two-way — RTM, Pseudo Spectral
  - By far the most accurate mathematically
  - Excellent for Earth model refinement
    - Only method accurate enough for full waveform inversion
    - Turnaround speed is issue
    - GPU versions and new computer systems will change this
    - Becoming very cheap and available to even small contractors
  - Excellent stratigraphic imaging
  - Excellent amplitudes
  - Excellent structural accuracy
    - Faults imaged from both sides
    - Absolutely no dip limits
  - Final image

Conclusions

- Algorithm choice
  - Function of basin, play, economics, objective
  - Oil found with all of them
  - In your exploration career you will see them all
  - — and hear a lot of BS from your favorite contractor
- RTM most accurate
- Beam least accurate
- Rest fall in between

Questions?