Seismic Modeling, Migration and Velocity Inversion

Aliasing

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Outline

1. **Aliasing**
   - Quantifying Aliasing
2. **Review**
   - The Hierarchy
   - Economics and Practicalities

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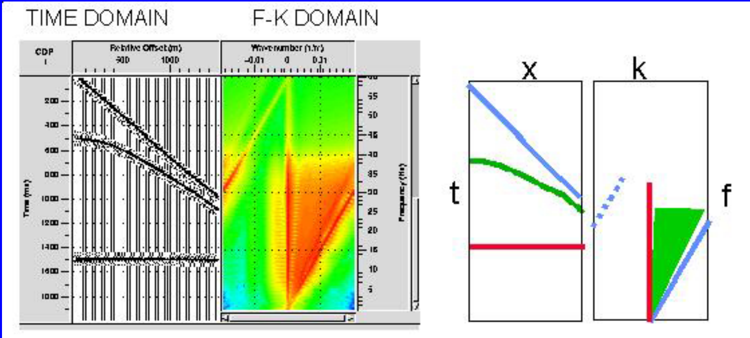
What is Aliasing

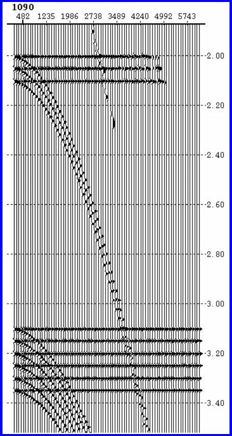


Aliasing is what happens when data are acquired with a sampling interval that is too large. The figure above demonstrates the effect in the wavenumber domain of an excessively large sampling increment in space. The image is an interpretation of where aliased events appear in the figure on the right.

What is Aliasing

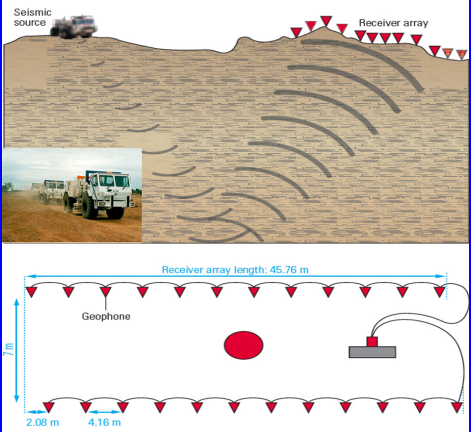
In modern day movies, images are usually sampled at 30 frames per second. When automobile or wagon wheels rotate faster then 30 revolutions per second they frequently revolve in reverse. If the wheels are spinning in the proper direction, the revolution is usually too slow..

Aliasing During Acquisition



Offset aliasing. Events can be aliased in offset even when all dips are perfectly sampled in space. This figure shows a synthetic (raytraced) CDP with multiples that are aliased in offset.

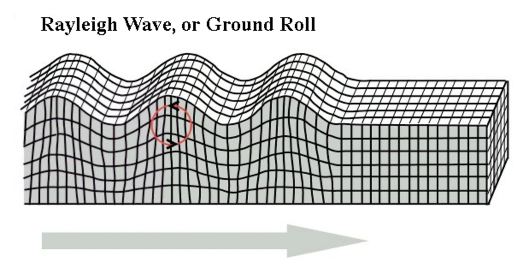
Aliasing During Acquisition



Schematic of a typical multi-fold, single-end seismic recording experiment. An array of land vibrators generates subsurface reflections to be recorded at surface receiver arrays. Both arrays can lead to aliased data

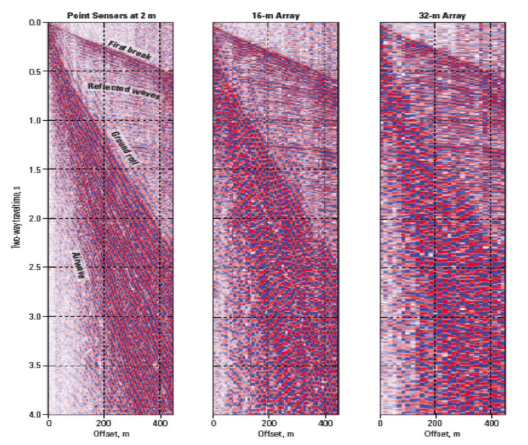
Ground Roll

Ground roll or Rayleigh waves (shear) are similar to Love wave (earthquakes) but have much slower apparent velocities.



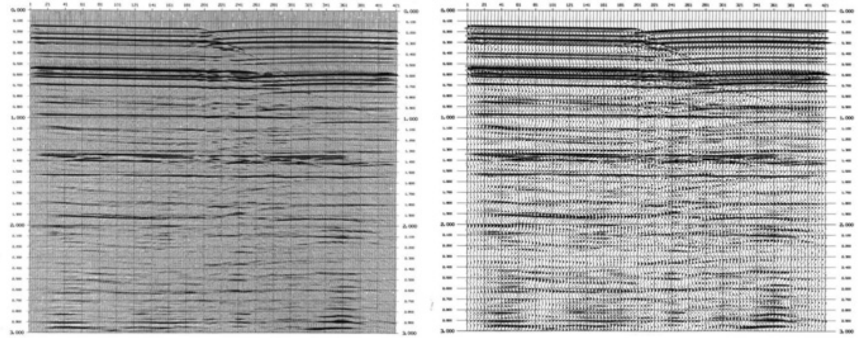
Aliasing During Acquisition

- Array effects
  - Left
    - Little
  - Middle
    - Strong
    - Mixed
    - Low frequency
  - Right
    - Severe
    - Severe mixing
    - Lower frequency
- Suppression
  - Left - Easy
  - Middle - Difficult
  - Right - Impossible



Ground roll here is traveling at approximately 160 m/s.

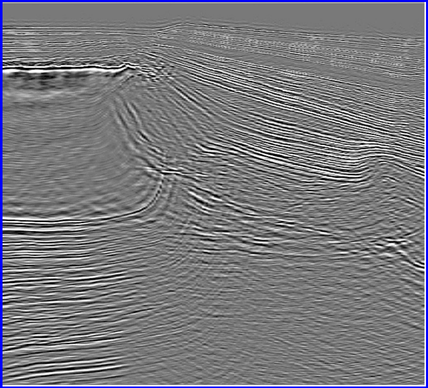
Aliasing in Flat Geology



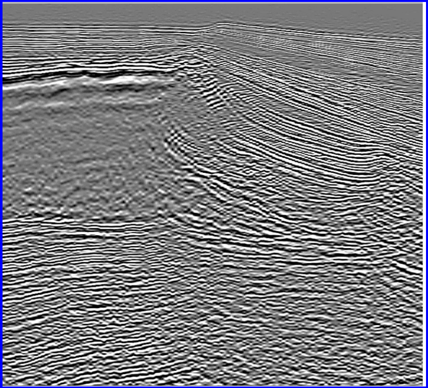
(a) Zero offset section. CDP spacing = 27.5’ (b) Zero offset section: CDP spacing = 110’

Aliasing when the data are flat.The figure on the left at 27.5 feet is clearly less aliased than the one on the right at 110 feet.

Algorithmic Aliasing of Steep Dips



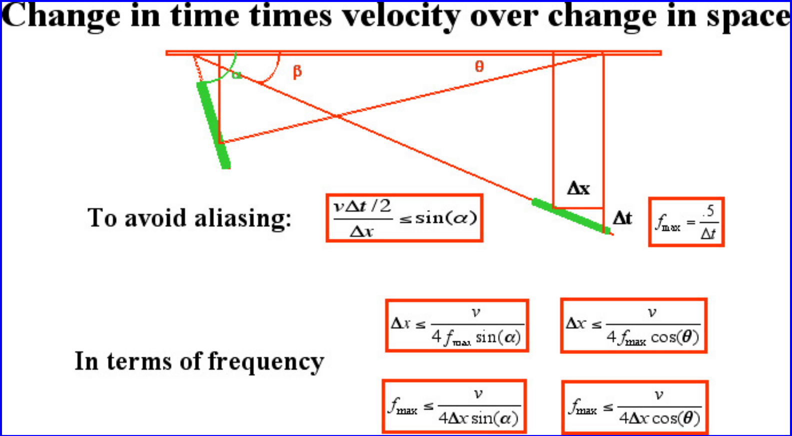
(a) Un-aliased Ray (Kirchhoff) Migration



(b) Aliased WEQ Migration

Improper handling of aliasing can lead to inferior imaging.

Changes in time vs space



Apparent dip, β, is specified by velocity, v and a change in time, Δt, versus a change in space, Δx. The formula $tan\beta = sin\alpha$ relates the maximum unaliased frequency f_{max} to v, Δt, and true dip, α or θ.

The Impact of Aliasing in 3D

If Δs is the smallest of Δx, Δy, and Δz then

$$f_{max} \leq \frac{v}{4\Delta s \times sin\alpha} \qquad \text{or equivalently} \qquad \Delta s \leq \frac{v}{4 f_{max} \times sin\alpha} \tag{1}$$

implies that

- One should exclude frequencies larger than f_{max}
  - As a function of dip
- Otherwise
  - Highly dipping events will certainly be aliased
  - There may be significant uninterpretable artifacts
- Alternatively one could choose the output Δs to minimize aliasing
  - For $\alpha = 90^\circ$, $\Delta s \leq \frac{v}{4f_{max}}$

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Algorithmic Handling of Aliasing

- Kirchhoff and Beam
  - Band pass filtering as a function of dip
  - Triangular filtering
  - Both accomplish the same thing
- RTM
  - Filtering prior to migration
  - Higher the frequency the smaller Δx, Δy, and Δz.
  - Computational complexitin increases as frequency to fourth power
- WEM, and Gaussian Beam
  - Both handled in frequency domain
  - Similar to filtering as function of dip
  - Dip specfied in frequency domain

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Non Ray Based Methods

- Two-Way propagation
  - Finite Difference in Space-Time
  - Pseudo Spectral
    - Derivatives via Fourier Transform
  - No time domain version
- One-Way propagation
  - Finite Difference in Space-Time
    - Implicit method accurate but difficult to implement
  - PSPI
    - Phase-shift plus interpolation method
    - Wavefield interpolation is the issue
  - Phase Screen
    - No interpolation
    - More mathematical approach
    - Full 3D V(x,y,z) throughout

Alias Suppression

- RTM and XT one-way methods
  - Aliasing handled in XT
    - Choice of Δx, Δy, Δz
  - Proper choice of source frequency
- Frequency domain methods
  - Aliasing handled in FK or FX
    - Transformation of the basic equations
  - Aliasing handled in XT
    - Choice of Δx, Δy, Δz

$$f_{max} \leq \frac{v}{4\Delta s \times sin\alpha}$$

$$f_{max} \leq \frac{vk^2}{4\Delta s \times k_z^2}$$

$$k = \frac{2\pi f}{v}$$

Ray Based Methods

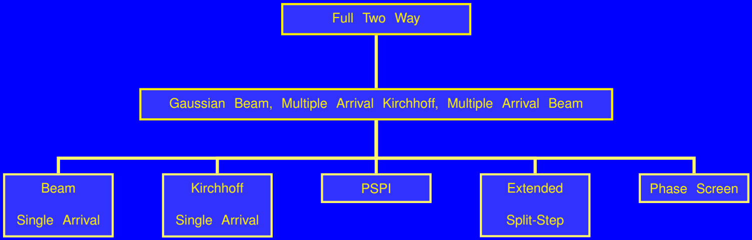
- Three Ray Based Methods
  - Classic Beam
  - Gaussian Beam
  - Kirchhoff
  - All easily handle TTI
- All have similar issues relative to traveltimes
  - Very sensitive to lateral velocity changes
  - Model must be smooth
  - High ray density for Kirchhoff and Beam
  - Rays below very fast structure in slow surroundings
    - Salt, Basalt, Granite, $\cdots$

Alias Suppression

- Ray methods handle aliasing on the fly
- They filter as a function of dip
- There are two popular methods
  - Direct application of a low pass filter
  - So called triangular filters
  - Both accomplish the same result

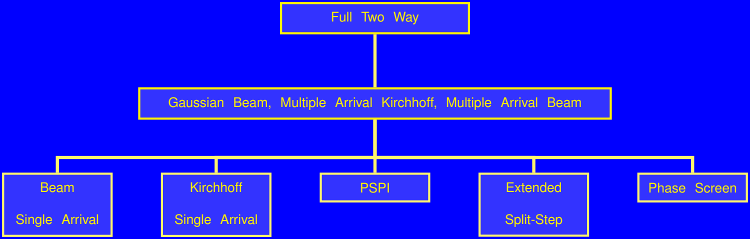
$$f_{max} \leq \frac{v}{4\Delta s \times sin\alpha}$$

Prestack Migration/deMigration Algorithms



Accuracy (Amplitudes and Wavefront) increases from bottom to top
Sensitivity to velocity errors tends to decrease from bottom to top
Computational costs tends to increase from bottom to top
Everything below the horizontal line is a one-way method

Prestack Migration/deMigration Algorithms



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Prestack Migration/deMigration Algorithms

Full Two Way

Gaussian Beam, Multiple Arrival Kirchhoff, Multiple Arrival Beam

Beam Single Arrival	Kirchhoff Single Arrival	PSPI	Extended Split-Step	Phase Screen

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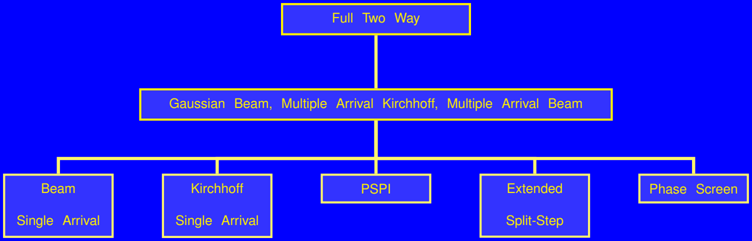

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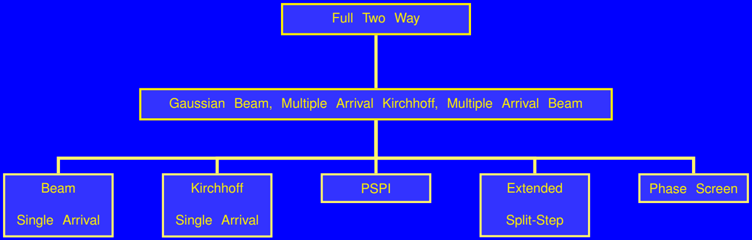

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Beam

- Fabulous for velocity estimation
  - When coupled with automatic picking algorithms
  - Multiple migrations with different Earth models
- Can bring out events not visible in other methods
- Poor amplitude response in some implementations
- Excellent for initial interpretations
- Excellent for hypothesis testing
  - Restricted dip imaging
  - Flat water bottom multiple suppression
- Best in areas with weak lateral velocity variation
- Economic

Kirchhoff

- Velocity workhorse
- Understood by everyone
- Excellent implementations
- Improved resolution
- Reasonable amplitude response
- Less Economic then Beam
- Better in areas with weak lateral velocity variation

One-way methods

- Much higher resolution
- Improved amplitude response
- Some loss of dip
- Much less economic then Beam and Kirchhoff
- Excellent imaging in areas with strong lateral velocity variation

RTM and Gaussian Beam

- Much higher resolution
- Most expensive approaches
- Least velocity sensitivity
- Best amplitude response
- All dips maintained
- Excellent imaging in areas with strong lateral velocity variation

Questions?