Rapid estimation of converted wave velocities using prestack migration

John C. Bancroft,

Thais Guirigay

Helen Isaac

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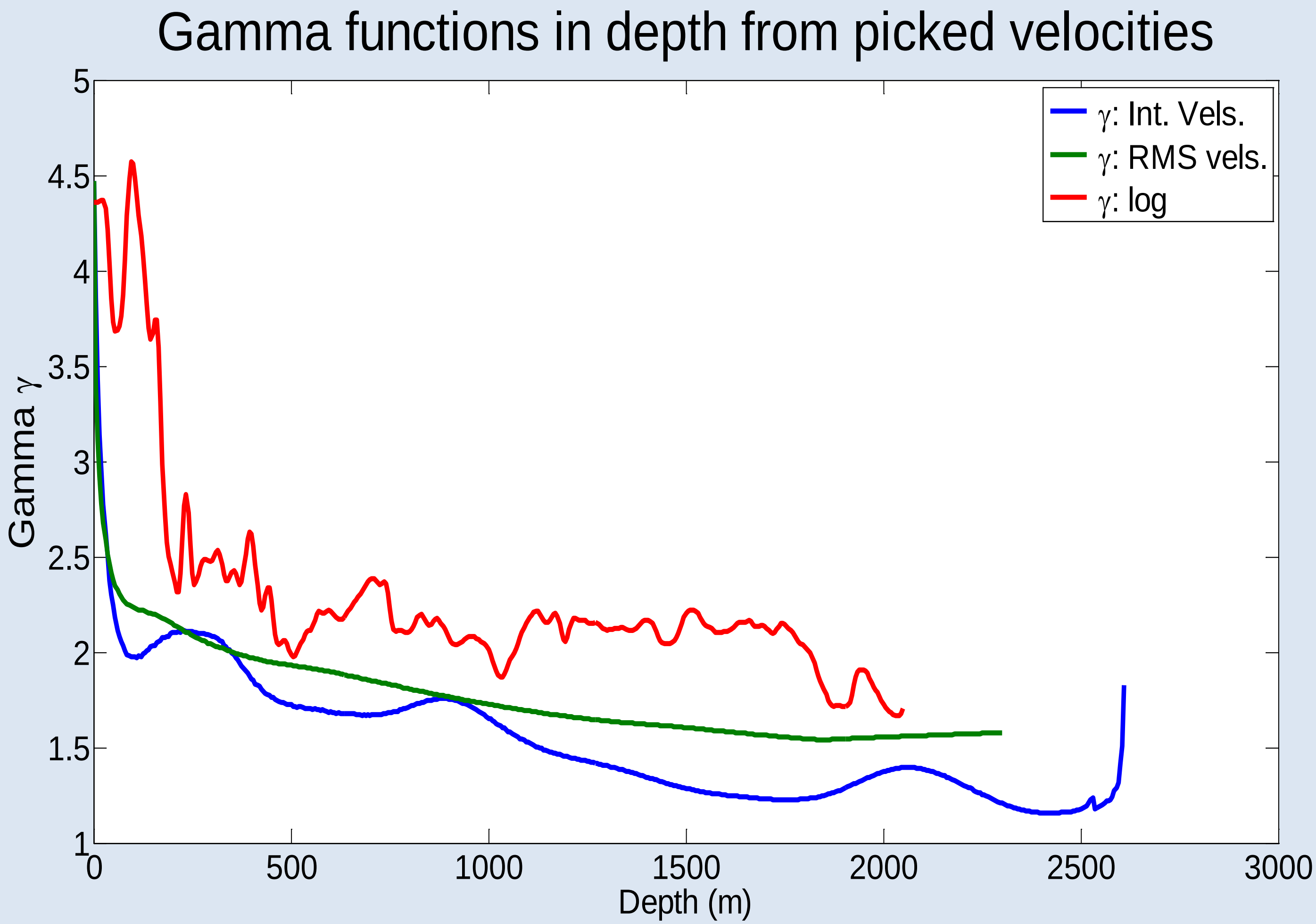
UNIVERSITY OF CALGARY

Motivation



Gamma functions in depth from picked velocities
γ: Int. Vels.
γ: RMS vels.
γ: log
Gamma γ
Depth (m)
5
4.5
4
3.5
3
2.5
2
1.5
1
0
500
1000
1500
2000
2500
3000

Objectives

Define a converted wave velocity Vc

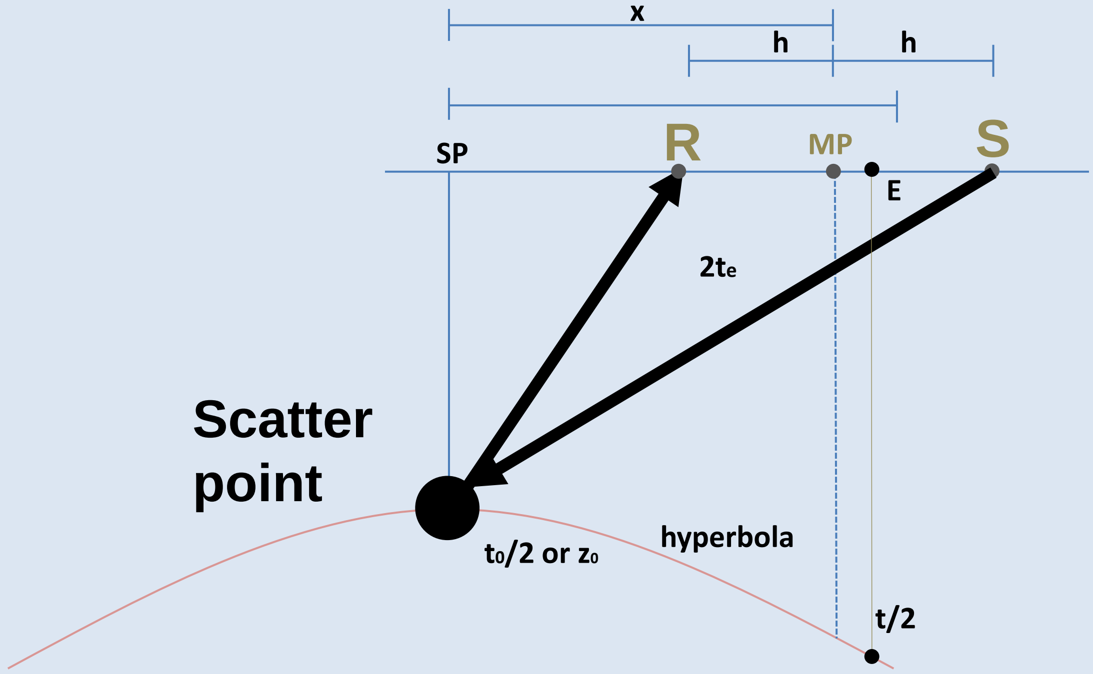
Use Vc to find Vs

Create CCSP gathers

Outline

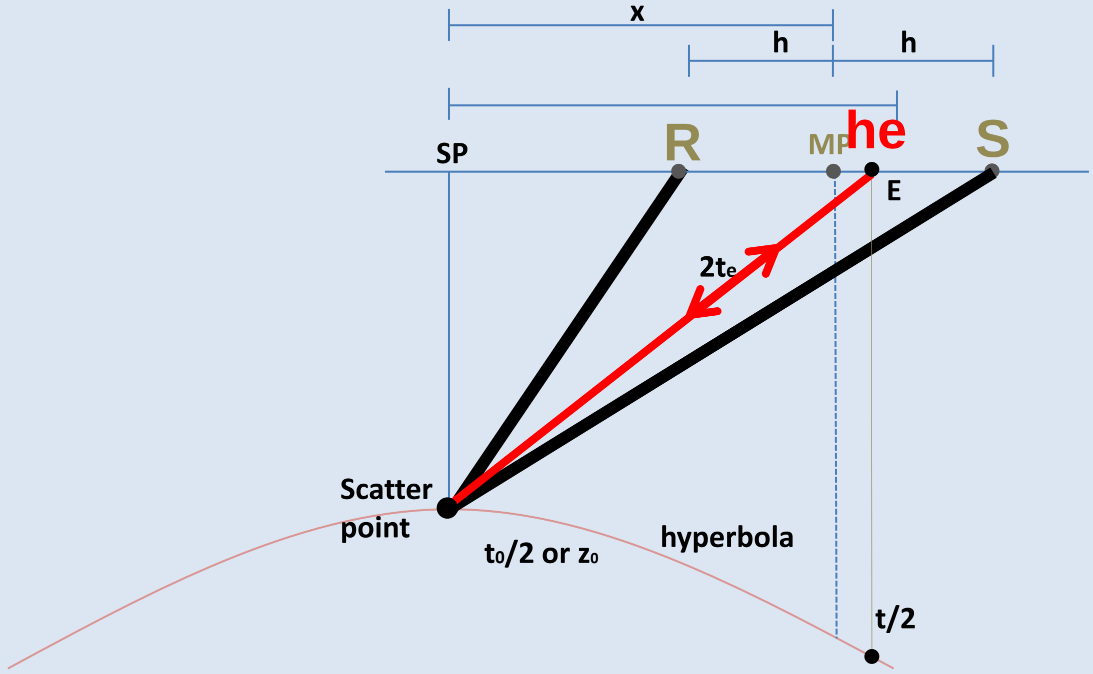
- Objectives
- Review EOM P-P and P-S, Vc
- Estimating Vc
- Estimation Vs
- Formation of Gathers
- Comments and Conclusion
- Results next talk

Kirchhoff Prestack Migration



$$t = \sqrt{\frac{t_0^2}{4} + \frac{(x+h)^2}{V^2}} + \sqrt{\frac{t_0^2}{4} + \frac{(x-h)^2}{V^2}}$$

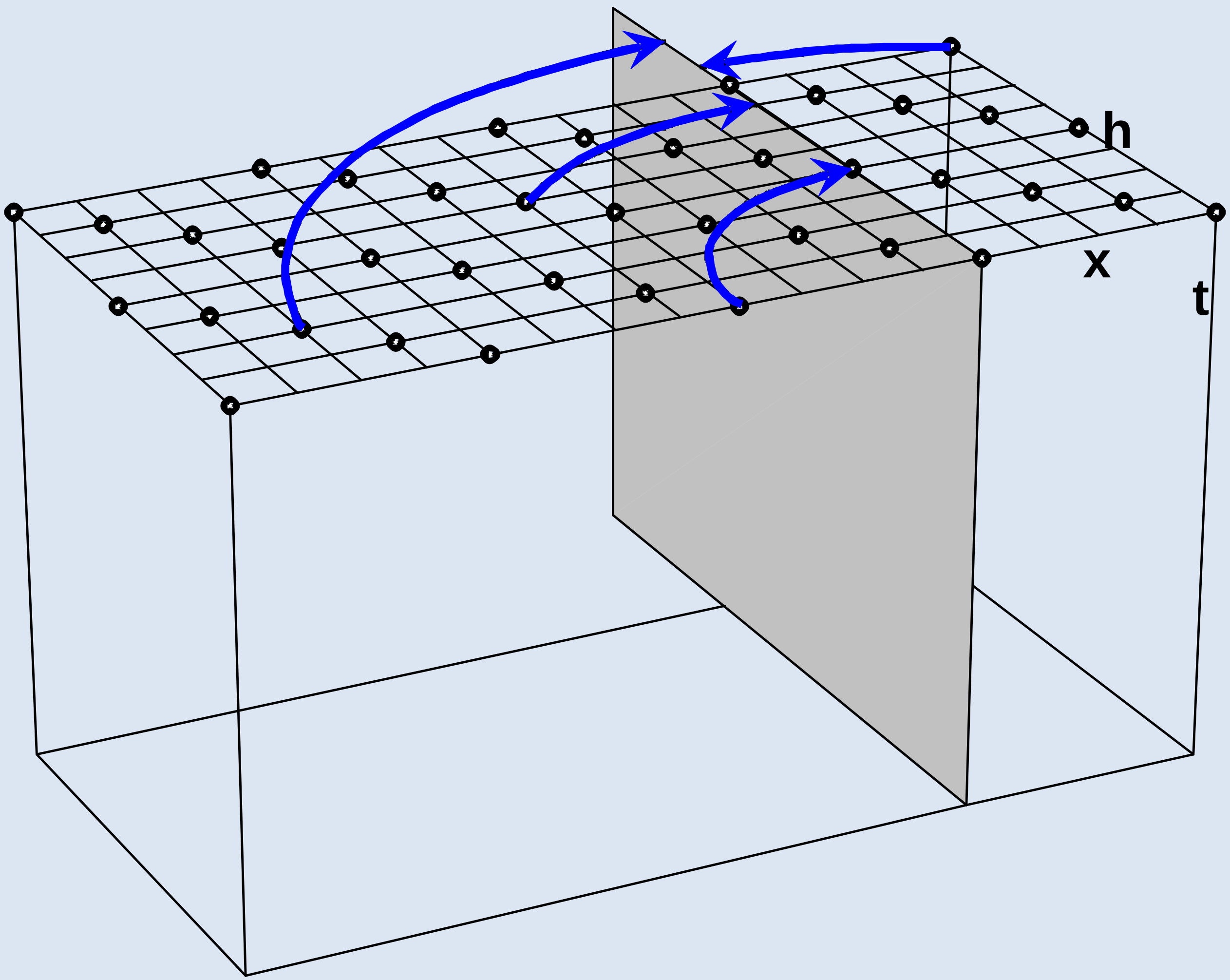
Equivalent Offset Migration



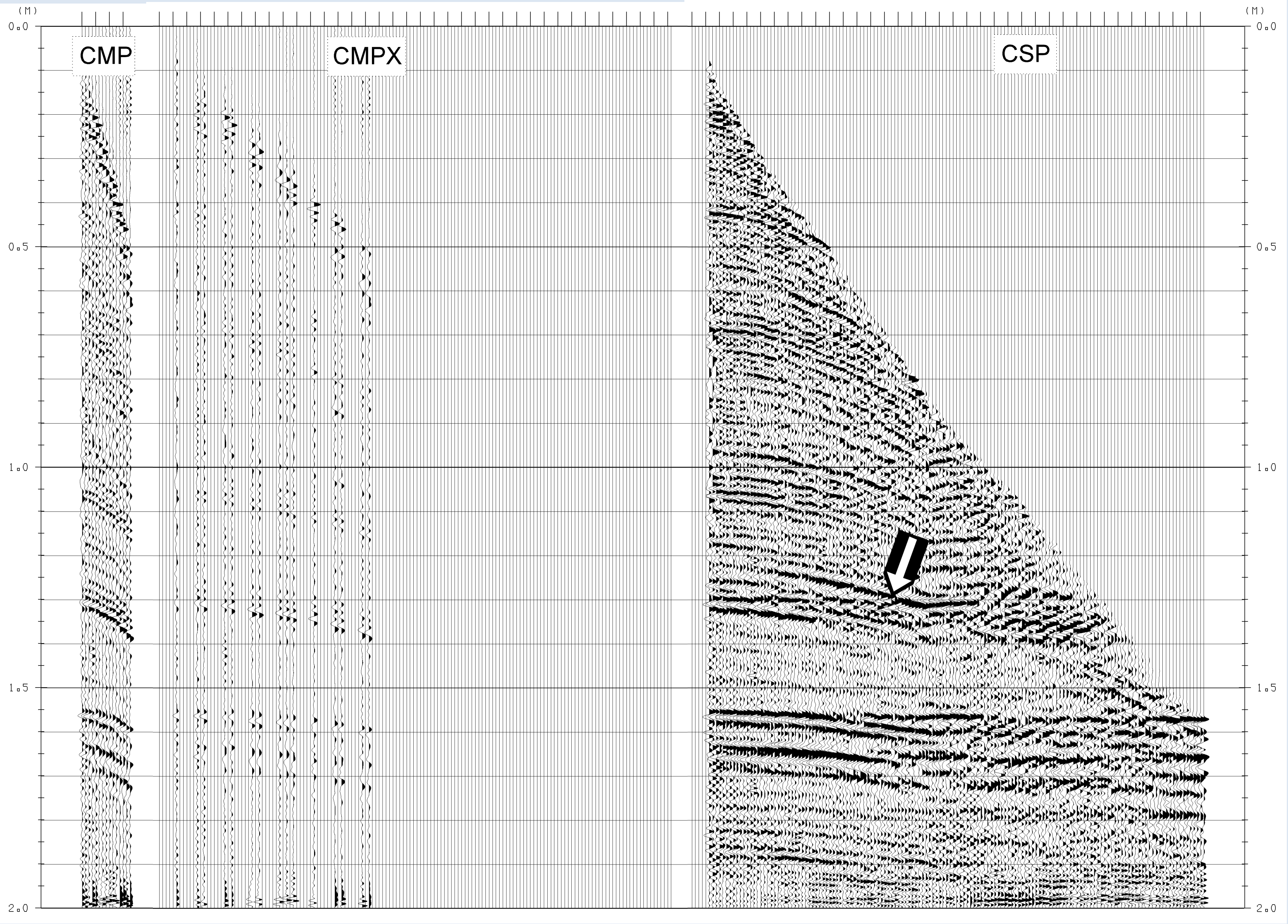
$$t = \sqrt{\frac{t_0^2}{4} + \frac{(x+h)^2}{V^2}} + \sqrt{\frac{t_0^2}{4} + \frac{(x-h)^2}{V^2}} = 2\sqrt{\frac{t_0^2}{4} + \frac{h_e^2}{V^2}}$$

$$h_e^2 = x^2 + h^2 - \frac{4x^2h^2}{t^2V^2}$$

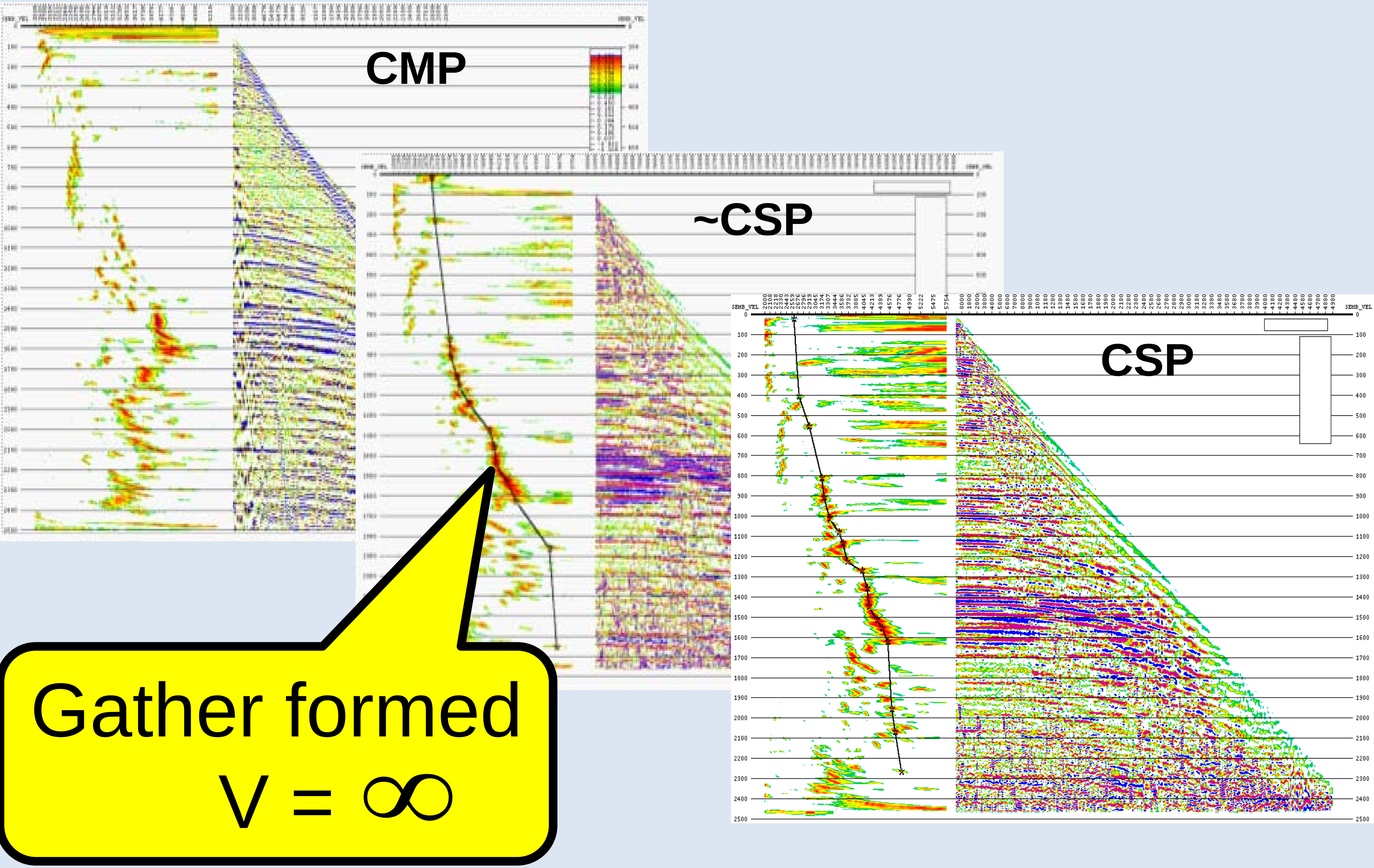
Forming a CSP gather



CMP Vs CSP gather



Gathers and semblance

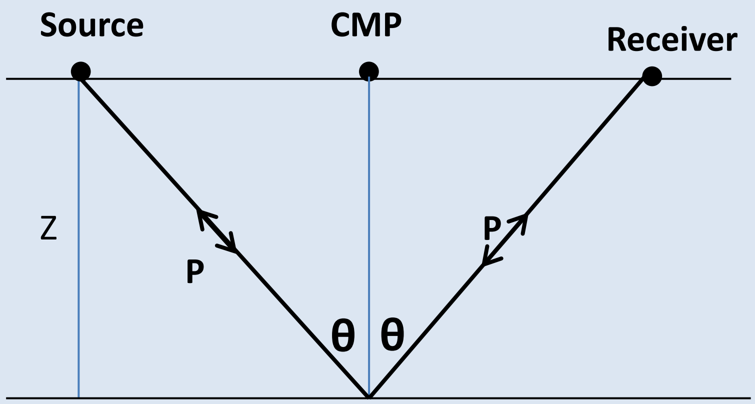


The point …

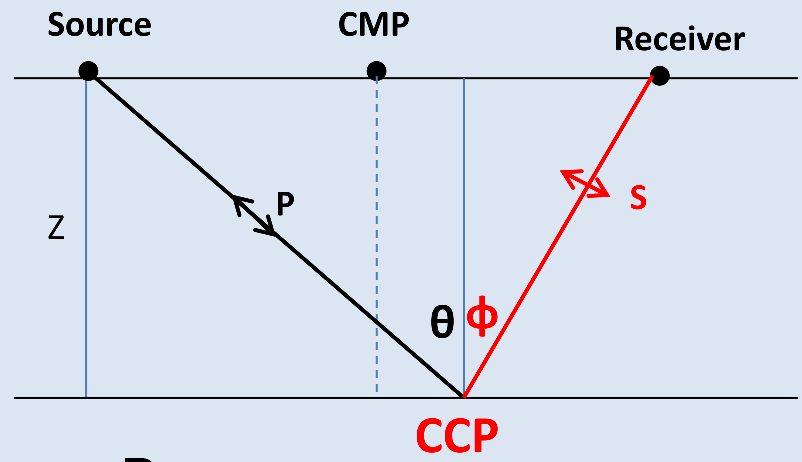
- Approximate Vp to form gathers
- More accurate Vp obtained from gathers
- For $Vp1 = \infty$ then $Vp2 = 3200$ m/s
- Not the case for converted wave data
- Need a more accurate starting velocity Vc

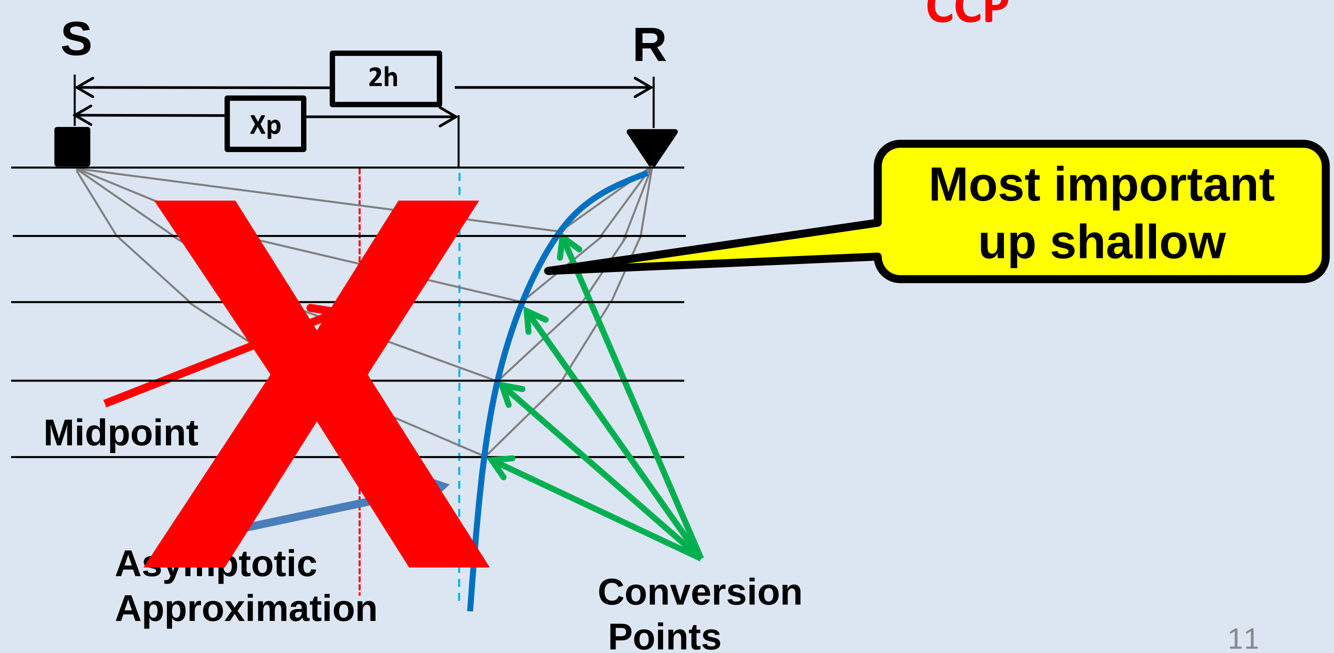
Converted waves

P-P

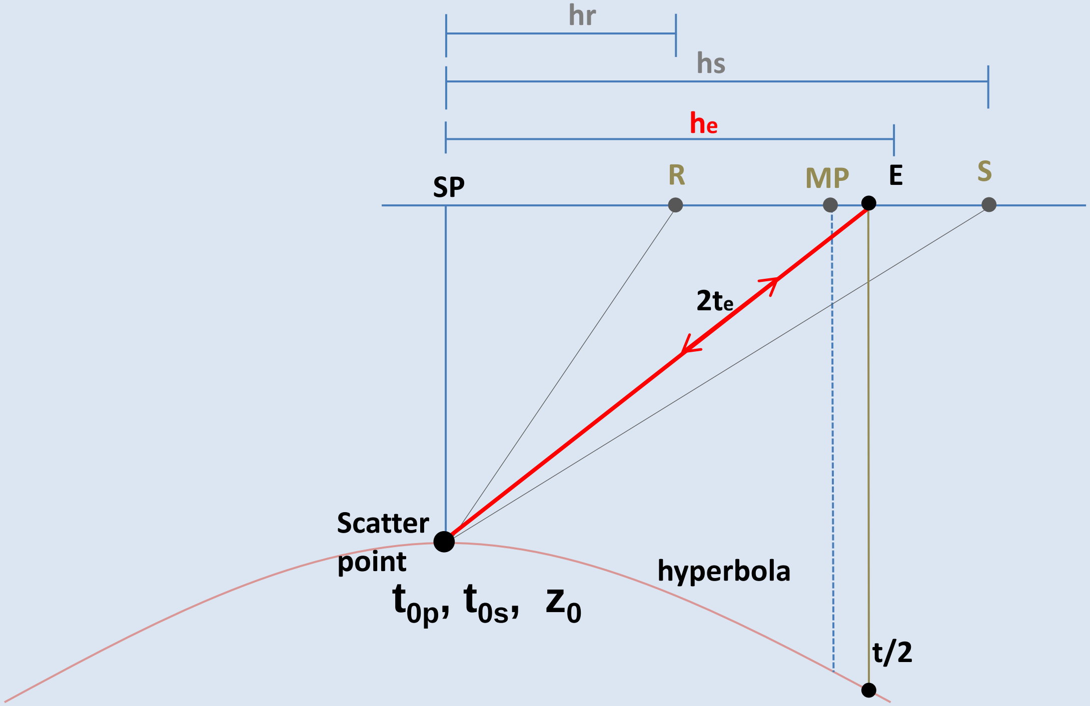


P-S



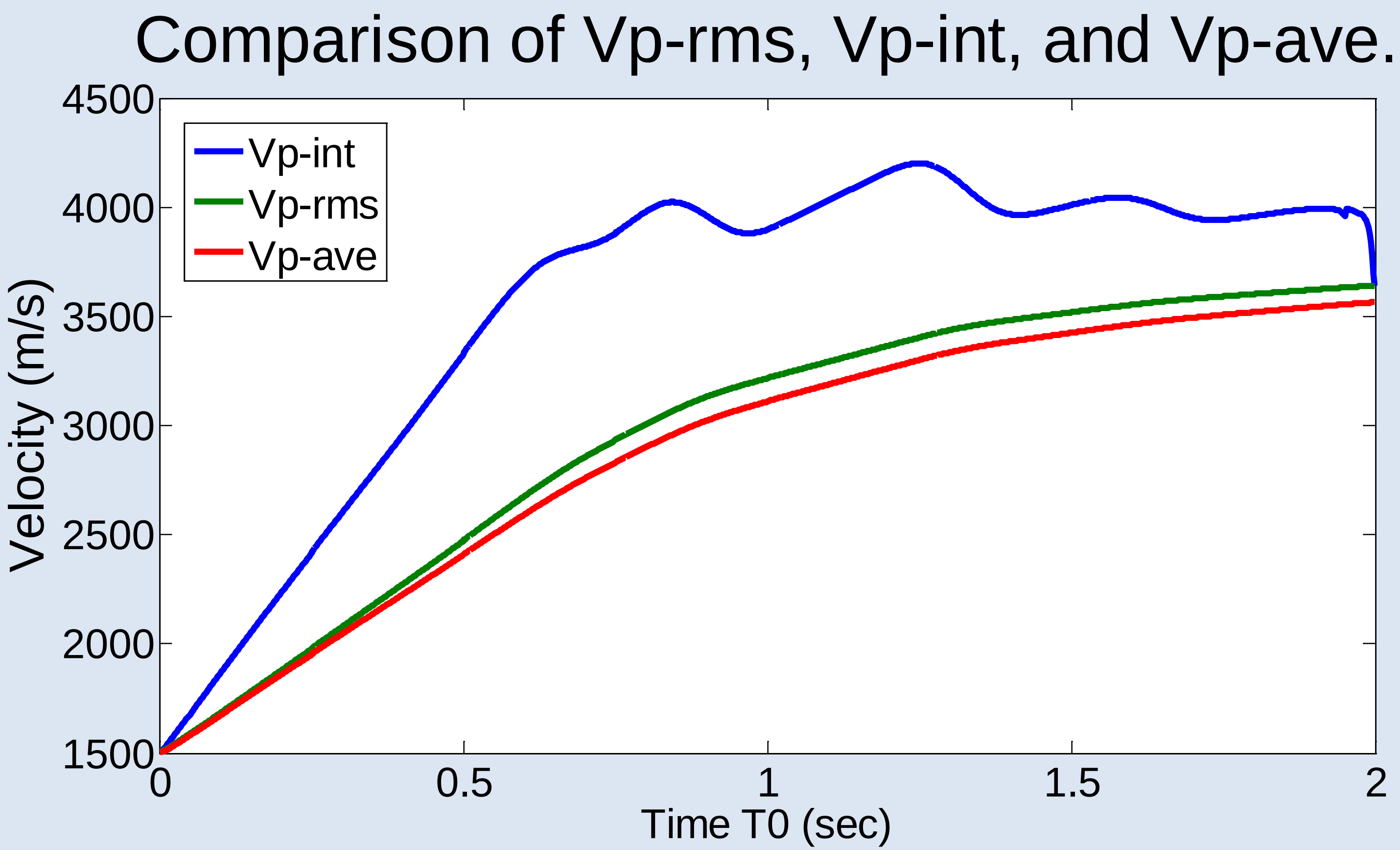


Equivalent offsets: converted waves



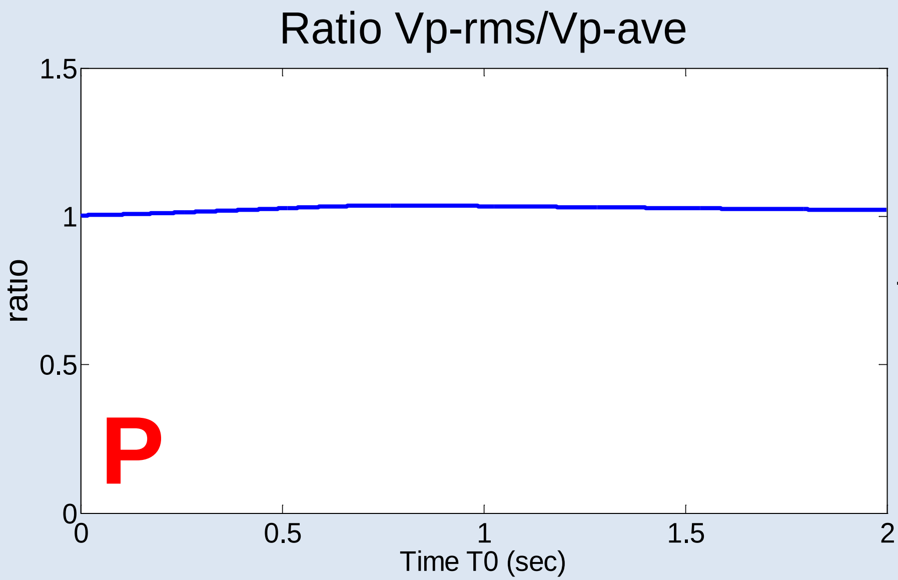
$$t=\sqrt{\frac{t_{0-p}^2}{4}+\frac{h_s^2}{V_{rms-P}^2}}+\sqrt{\frac{t_{0-s}^2}{4}+\frac{h_r^2}{V_{rms-S}^2}}=\sqrt{\frac{t_{0-p}^2}{4}+\frac{h_e^2}{V_{rms-P}^2}}+\sqrt{\frac{t_{0-s}^2}{4}+\frac{h_e^2}{V_{rms-S}^2}}$$

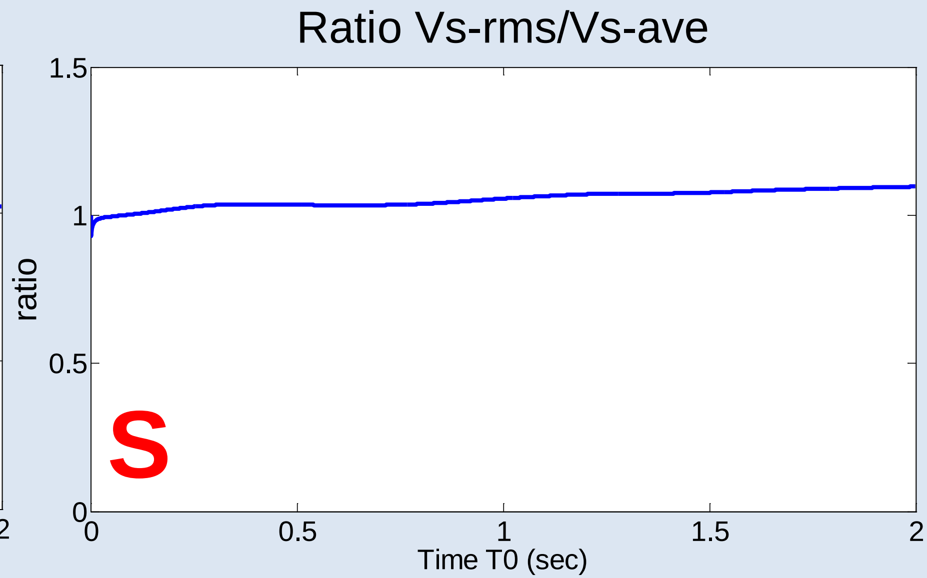
V_{rms} and V_{ave}

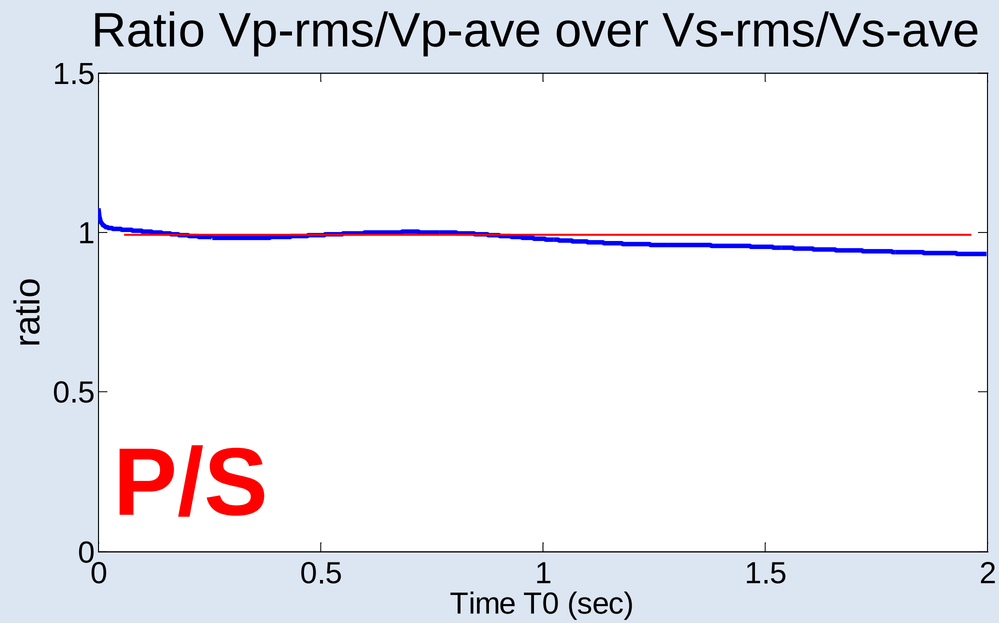


RMS velocity slightly higher than average velocity.

V_{rms} / V_{ave}


Ratio Vp-rms/Vp-ave
1.5
1
0.5
0
ratio
P
0
0.5
1
1.5
2
Time T0 (sec)


Ratio Vs-rms/Vs-ave
1.5
1
0.5
0
ratio
S
0
0.5
1
1.5
2
Time T0 (sec)


Ratio Vp-rms/Vp-ave over Vs-rms/Vs-ave
1.5
1
0.5
0
ratio
P/S
0
0.5
1
1.5
2
Time T0 (sec)

Assume $$k \approx \frac{V_{rms-p}}{V_{ave-p}} \approx \frac{V_{rms-s}}{V_{ave-s}}$$

Define $$\hat{z}_0 = z_0 \frac{V_{rms}}{V_{ave}}$$

$$t = \frac{1}{V_{rms-p}}\sqrt{\hat{z}_0^2 + h_s^2} + \frac{1}{V_{rms-s}}\sqrt{\hat{z}_0^2 + h_r^2} = \frac{1}{V_{rms-p}}\sqrt{\hat{z}_0^2 + h_e^2} + \frac{1}{V_{rms-s}}\sqrt{\hat{z}_0^2 + h_e^2}$$

$$t = \frac{2}{V_c}\sqrt{\hat{z}_0^2 + h_e^2}$$

$$V_c = \frac{2V_{rms-p}V_{rms-s}}{V_{rms-p} + V_{rms-s}}$$

$$h_e^2 = \frac{t^2 V_c}{4} - \hat{z}_0^2$$

Converted wave velocity V_c

- Initial V_{c1} with V_p and γ
- Limited range EO gathers
- Pick new V_{c2}
- Estimate V_s
- Full EO gathers with V_p and V_s
- Pick new V_{c3}
- Moveout correction with V_{c3}
- Stack to complete the prestack migration

$$V_c = \frac{2V_{rms-p}V_{rms-s}}{V_{rms-p} + V_{rms-s}}$$

Estimating of *Vc*1

Initial *Vc* can be formed

1. **Using** $\gamma = \frac{V_p}{V_s}, \quad \gamma = 2 \qquad V_{c1} = \frac{2V_{rms-P}}{(1+\gamma)}$

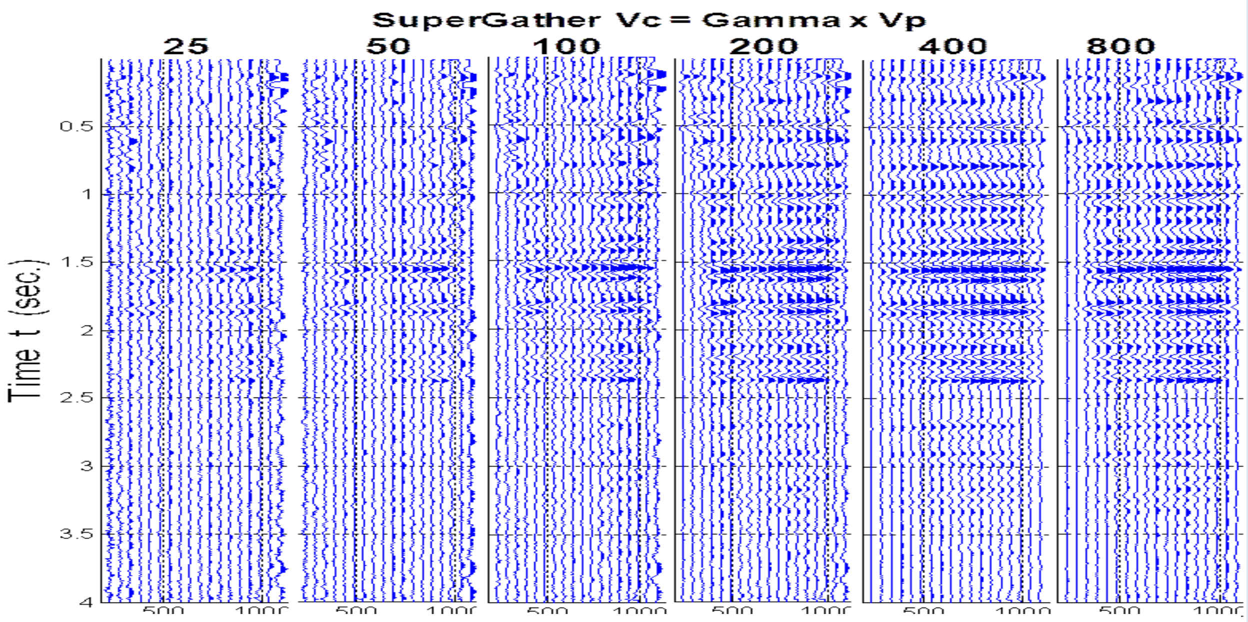
2. **Narrow range gather** $|x| \ll x_{\max}$

$$t = \frac{1}{V_{rms-P}}\sqrt{\hat{z}_0^2 + (x+h)^2} + \frac{1}{V_{rms-S}}\sqrt{\hat{z}_0^2 + (x-h)^2}$$

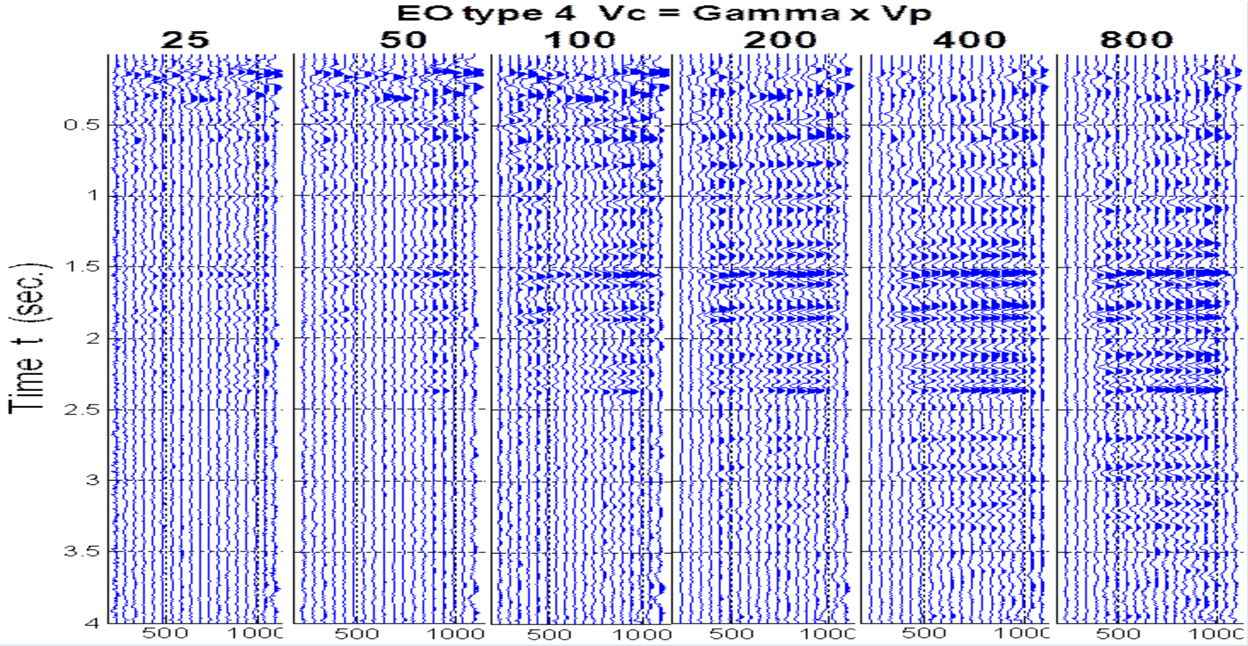
$$t_{x\to 0} \approx \frac{1}{V_{rms-C}}\sqrt{\hat{z}_0^2 + (x+h)^2} + \frac{1}{V_{rms-C}}\sqrt{\hat{z}_0^2 + (x-h)^2}$$

Initial estimate of Vc

Supergather



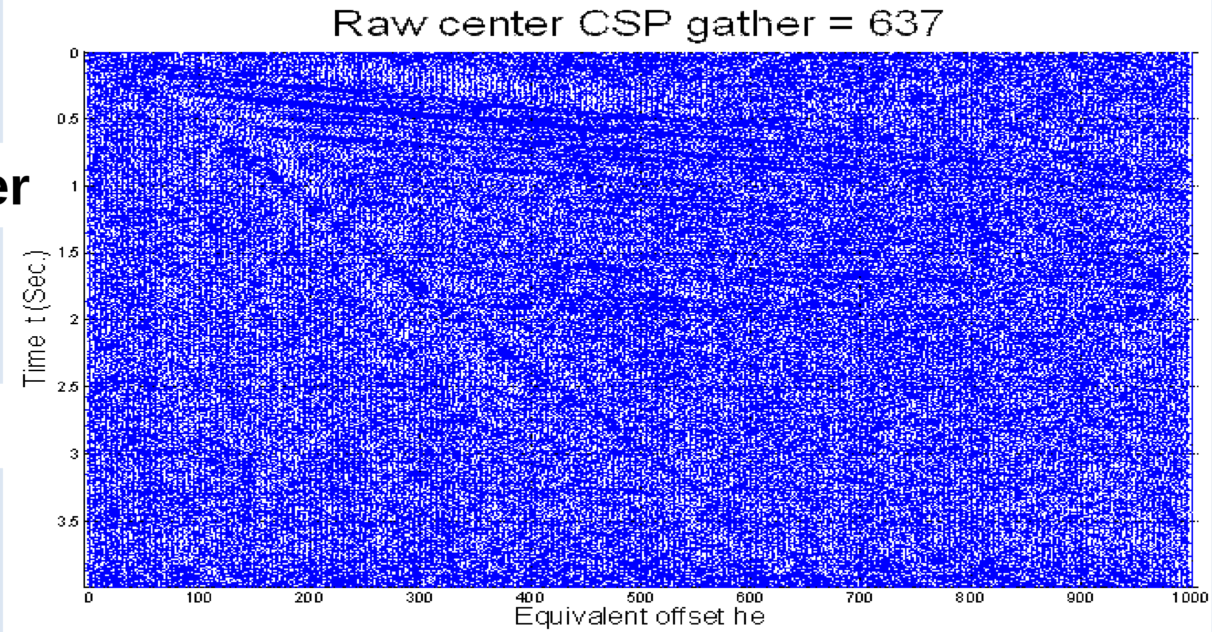
A full EO meth

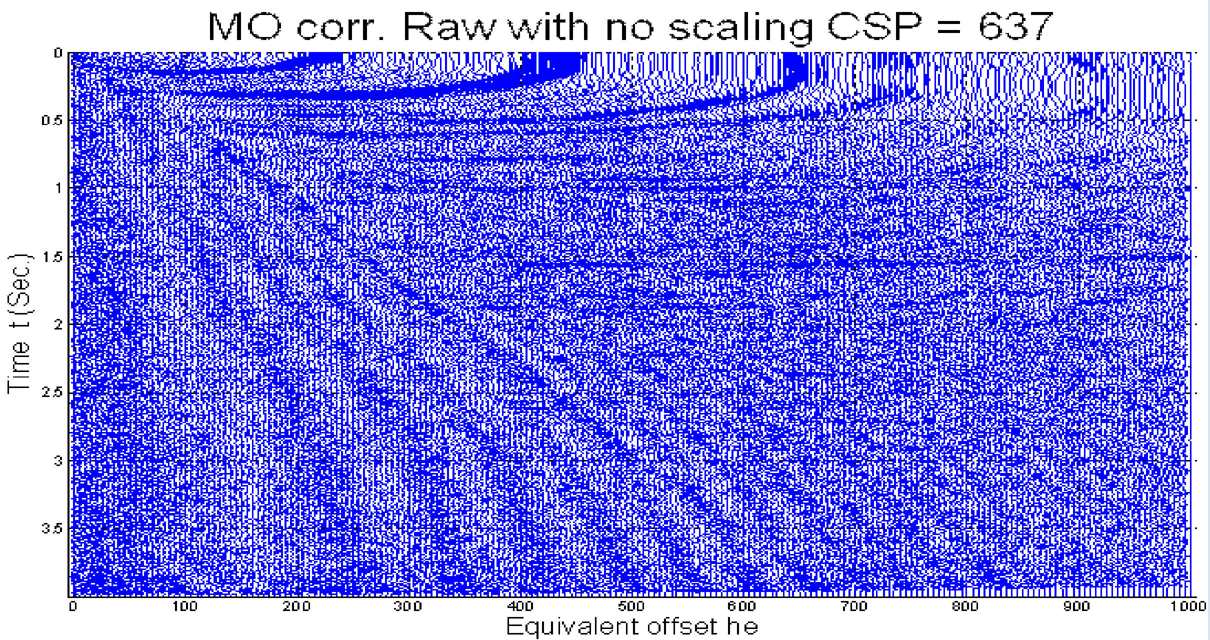


LCCSP gather

Initial gather

Pick Vc2





Estimating Vs from *Vc*2

Form few gathers using one velocity *Vc*1

Velocity analysis to find *Vc*2

Now find Vs

$$V_{rms-C} = \frac{2V_{rms-P}V_{rms-S}}{V_{rms-P} + V_{rms-S}}$$

$$V_{rms-S} = \frac{V_{rms-C}V_{rms-P}}{2V_{rms-P} - V_{rms-C}}$$

Full CCSP gathers

$$t_{p-s} = \frac{1}{V_{rms-P}}\sqrt{\hat{z}_0^2 + (x+h)^2} + \frac{1}{V_{rms-S}}\sqrt{\hat{z}_0^2 + (x-h)^2}$$

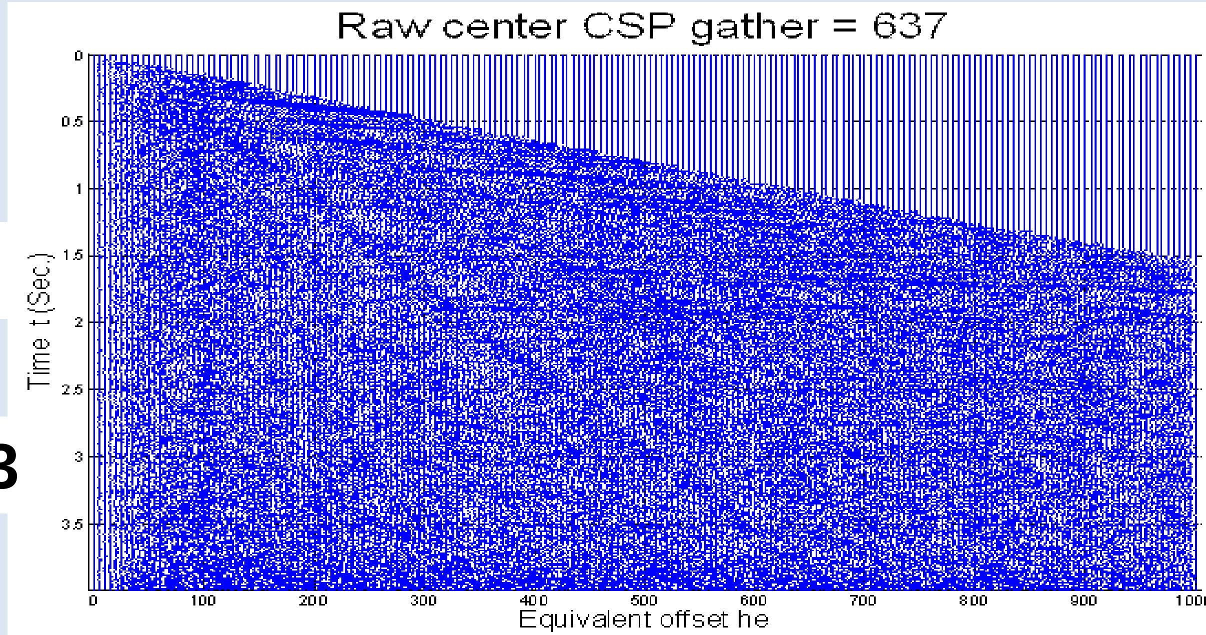
$$t_{p-s} = \frac{2}{V_{rms-C}}\sqrt{\hat{z}_0^2 + h_e^2}$$

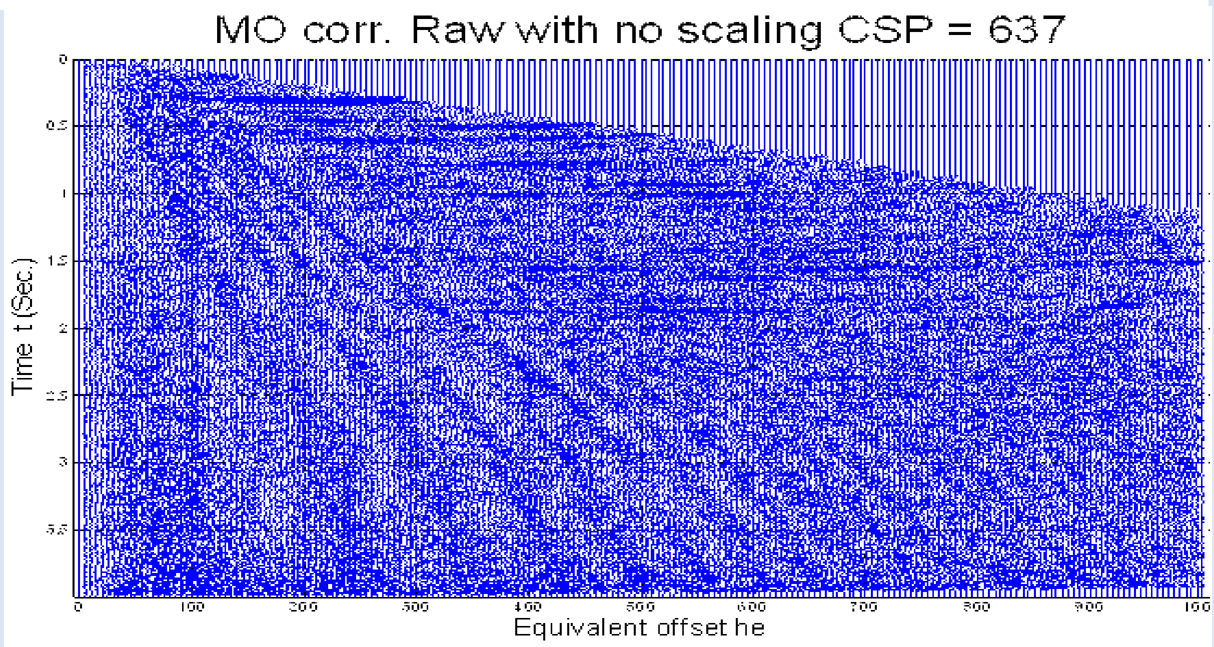
Use h_e to form CCSP gathers

Full CCSP gather

Full EO

Pick Vc3





Time *t* consideration

We have ignored *t* times

$$V_{rms-C} = \frac{2V_{rms-P}(t_p)\ V_{rms-S}(t_s)}{V_{rms-P}(t_p)+V_{rms-S}(t_s)}$$

- γ is defined with ***Vint*** and depth $\hat{z}$
- ***Vp***, ***Vs***, and ***Vc*** are also defined in depth $\hat{z}$
- Using $V_{Ave} \approx V_{RMS}$ map depth $\hat{z}$ to t_c
- Keep all times in t_c

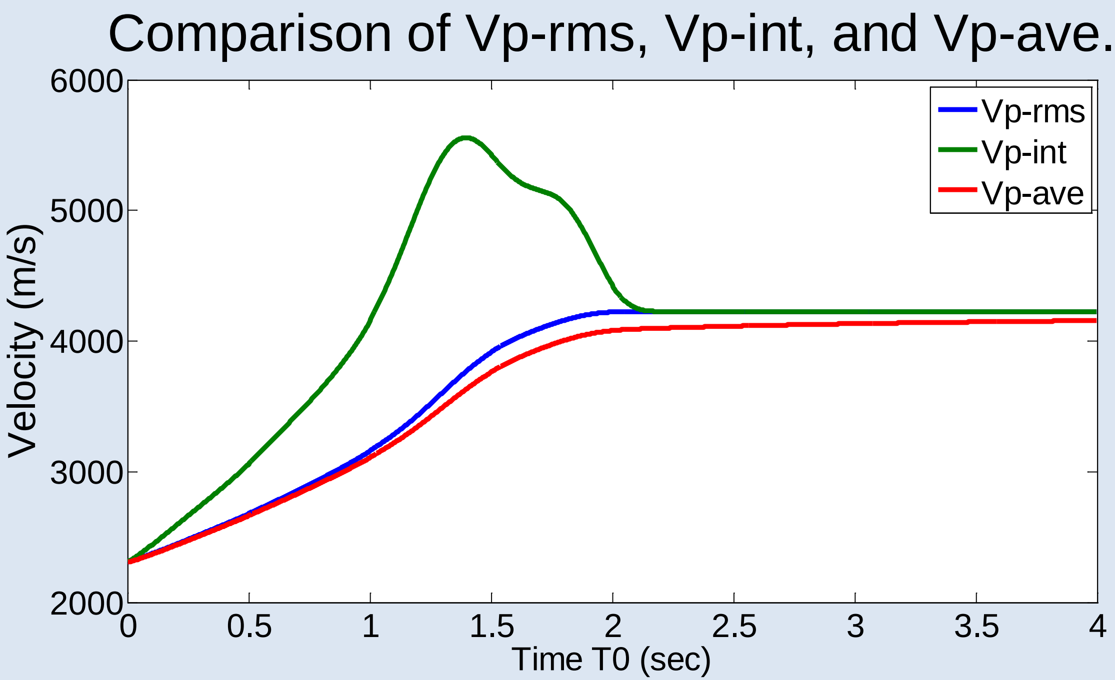
Matching the traveltime for P- and C-wave data

Method 1

1. **Convert *Vrms-p*(top) to interval *Vint-p* (top)**

2. **Use interval velocities to map the times to depth** $t_{op} \Rightarrow z_0$

3. **Get average velocity Vave-p of Vrms-p**



Matching the traveltime for P- and C-wave data

Method 1 (continued)

4. Scale the amplitude Vint-c to Vint-p at z (same as top) using λ

4. Use *V*int-c (z) and the corresponding depth increments, compute the C time at each depth.

5. Resample *Vint-c* from irregular times to equal time increments

6. Convert the interval C velocities to RMS C velocities

7. Get the depth of every Vc time sample using Vint-c

Matching the traveltime for P- and C-wave data

Method 2

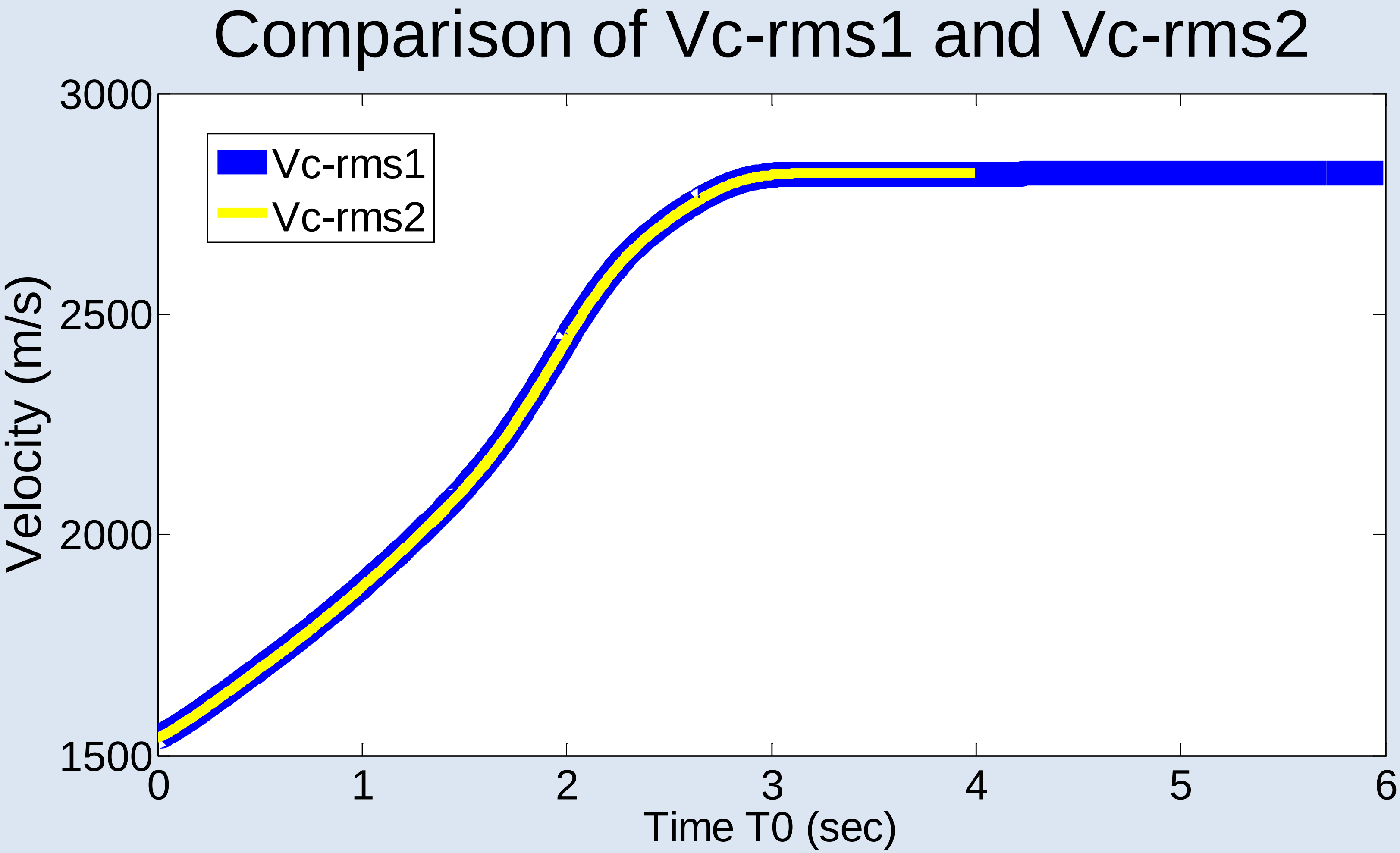
1. Using the corresponding average velocities

$$\left|V_{rms-c}\right| = \frac{2\left|V_{rms-p}(z)\right|}{(1+\gamma(z))}$$

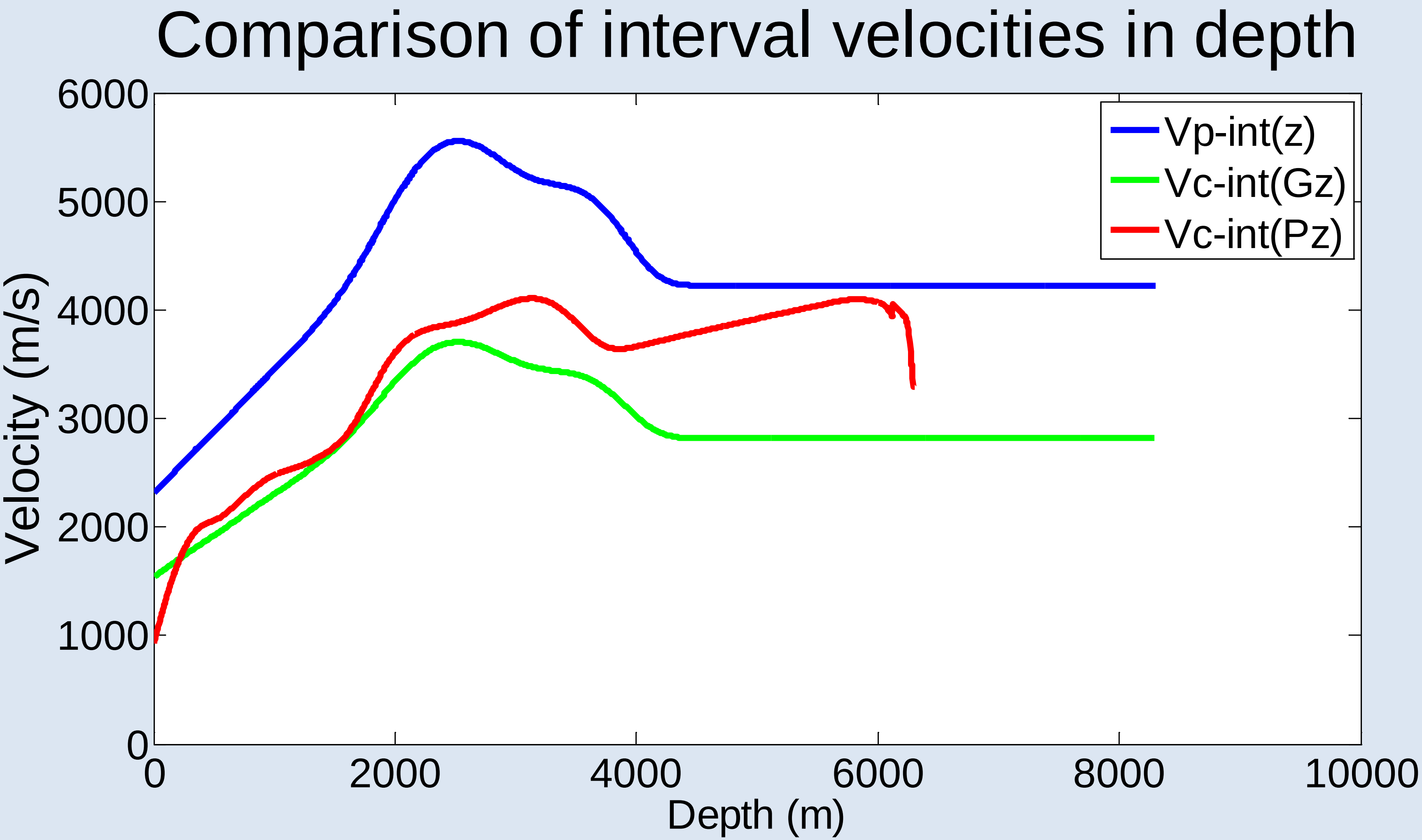
2. Resample Vrms-c(n) to Vrms-c(m) using equal increments of m

$$t_{oc} \approx t_{op}\frac{1+\gamma}{2} \qquad m = \frac{1+\lambda}{2}n$$

Estimating the C velocities



Estimating the C velocities



Estimating the S velocities

Method 1

1. **From the Vc picked:**

$$V_{\text{int}-s}(z) = \frac{V_{\text{int}-p}V_{\text{int}-c}}{2V_{\text{int}-p} - V_{\text{int}-c}}$$

2. **Convert shear interval $V_{int\text{-}s}$ from depth to time**

3. **Convert $V_{int\text{-}s}$ in S time into $V_{rms\text{-}s}$**

$$V_{rms-s}(t_{0s}) = \sqrt{\frac{\sum_{n=0}^{N} V_{\text{int}-s}^{2}(n)t_n}{\sum_{n=0}^{N} t_n}}$$

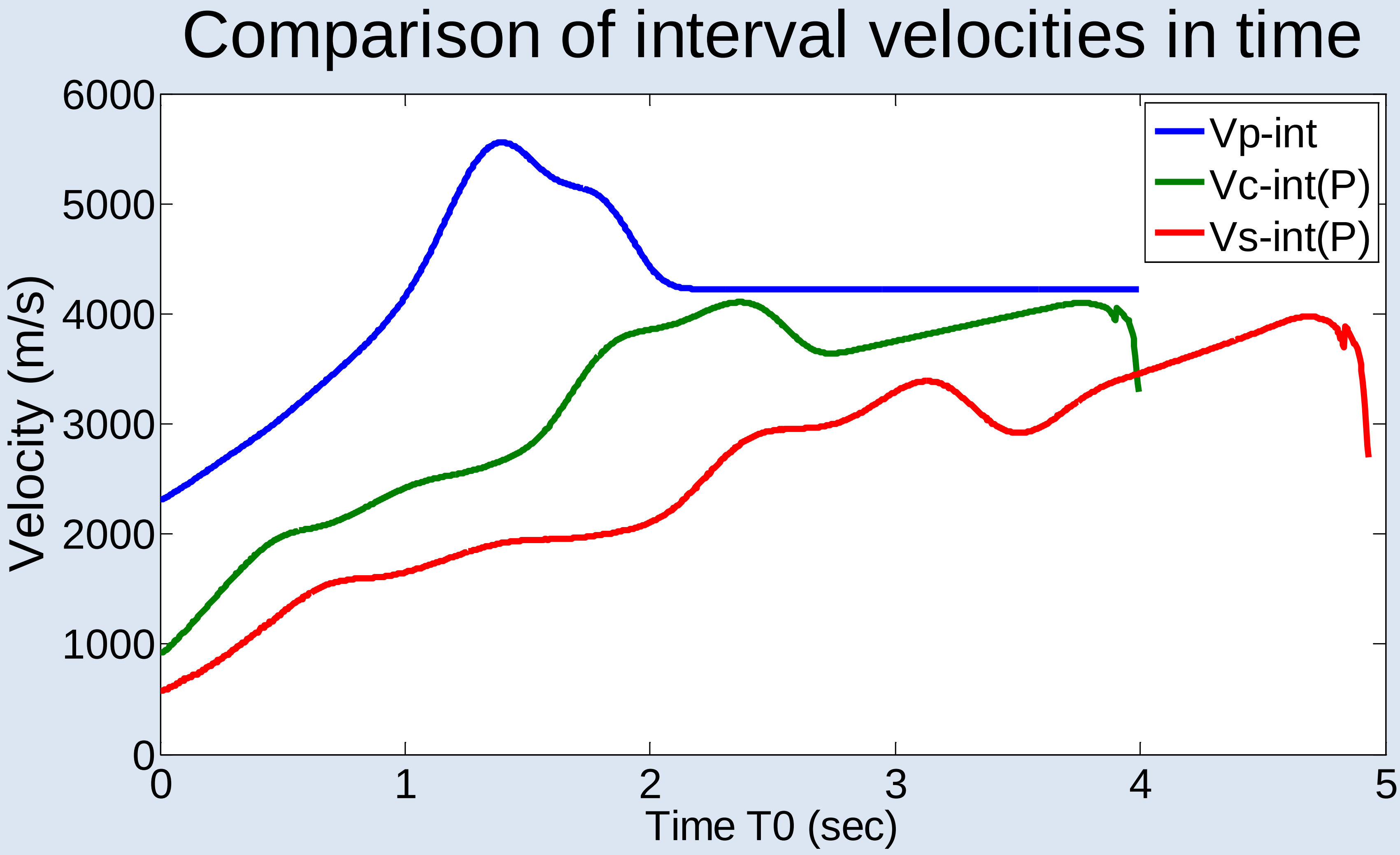
4. **Convert t_{os} to t_{op}**

5. **Get the RMS gamma function in time**

$$\lambda_{rms}(t) = \frac{V_{rms-p}(t_p)}{V_{rms-s}(t_p)}$$

6. **Convert RMS gamma to depth assuming $V_{rms} = V_{ave}$**

Estimating the S velocities



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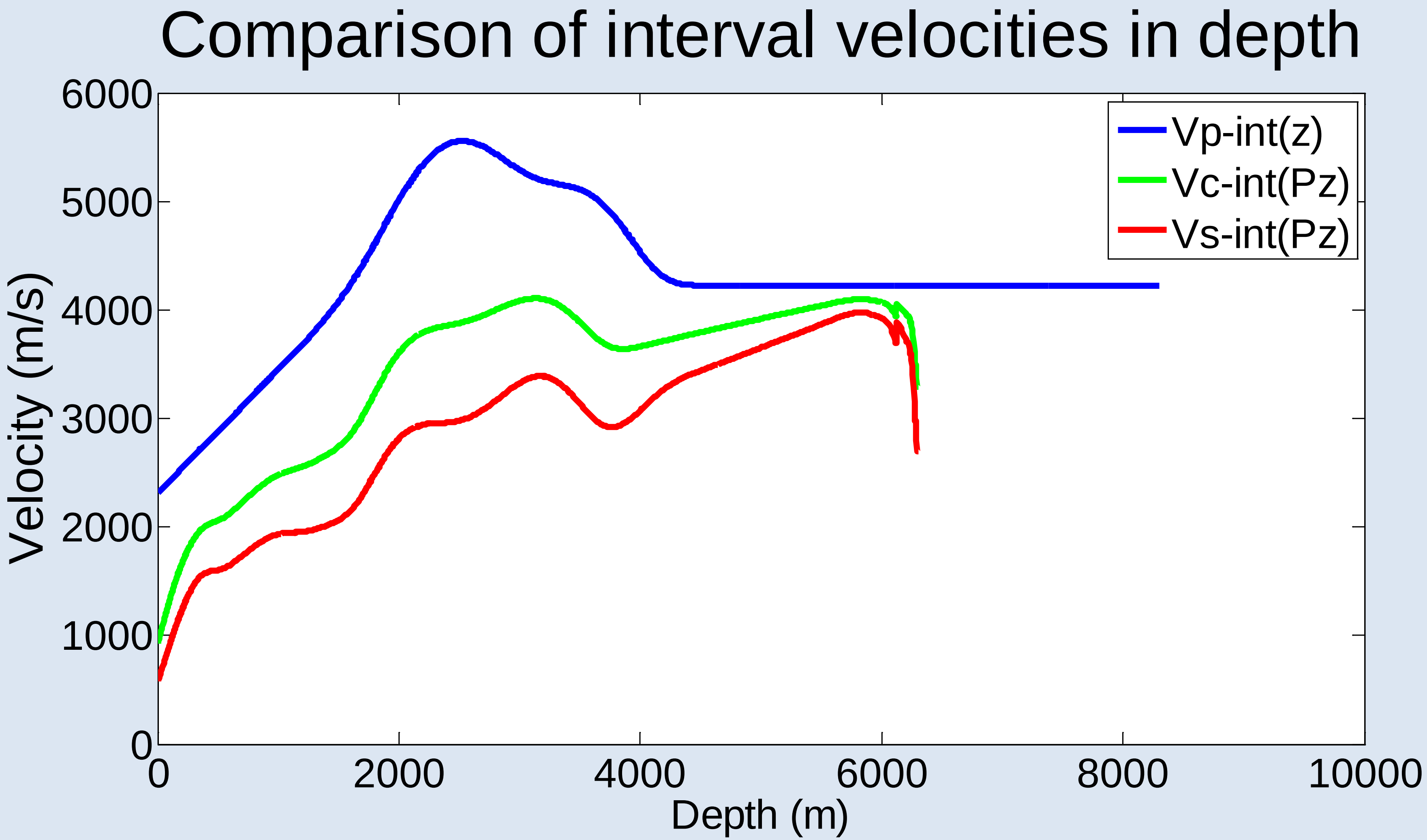

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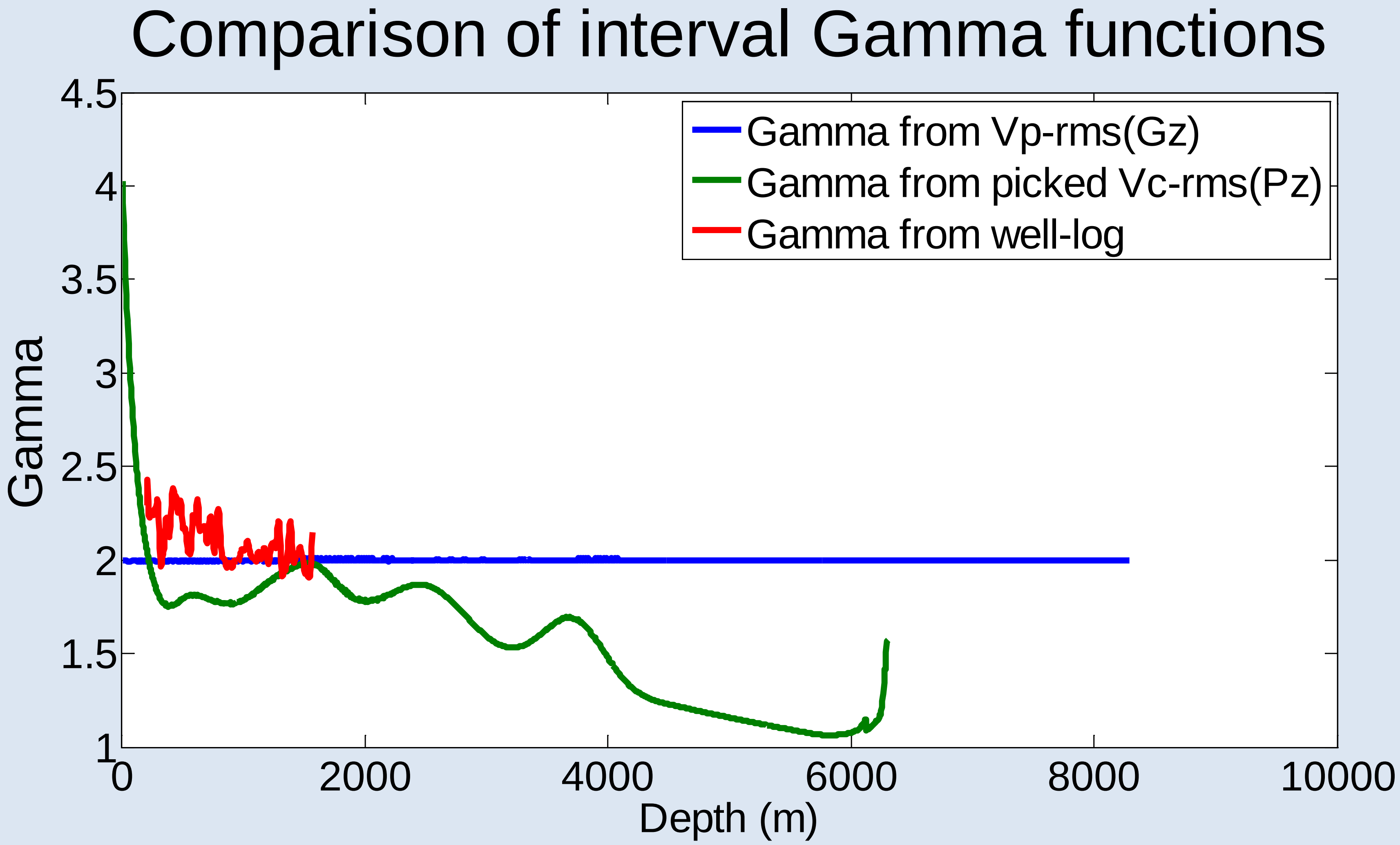
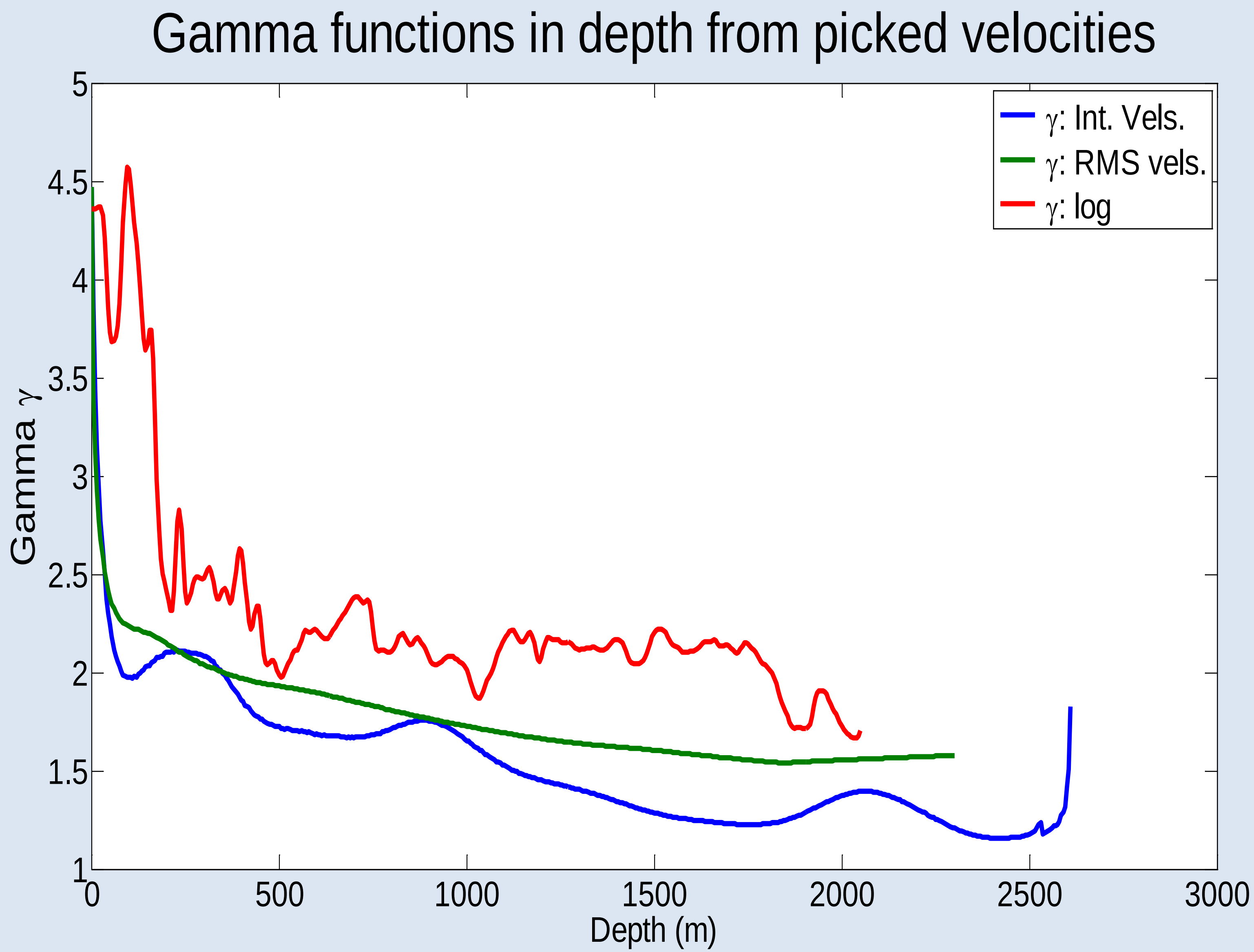


Another project in N.E. BC



Examples of data

- Not yet
- Next talk
- Posters

Comments and conclusions

- Use EO concepts to process P-S data

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- Need approximate velocity starting velocities Vp and Vs

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  - $Vc1$ from Vp and γ
  - $Vc2$ from initial gather
  - Vs from Vp and $Vc2$

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- Simple process to estimate of Vc and Vs
  - $Vc1$ from Vp and γ
  - $Vc2$ from initial gather
  - Vs from Vp and $Vc2$
- Produced reasonable values for γ
- Can approximate $Vave$ with $Vrms$

Acknowledgments

All CREWES staff
CREWES sponsors

Thanks