Multicomponent OBS acquisition for wavefield reconstruction

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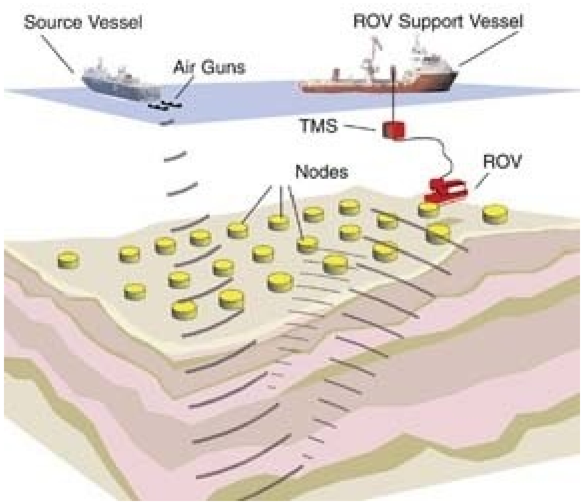
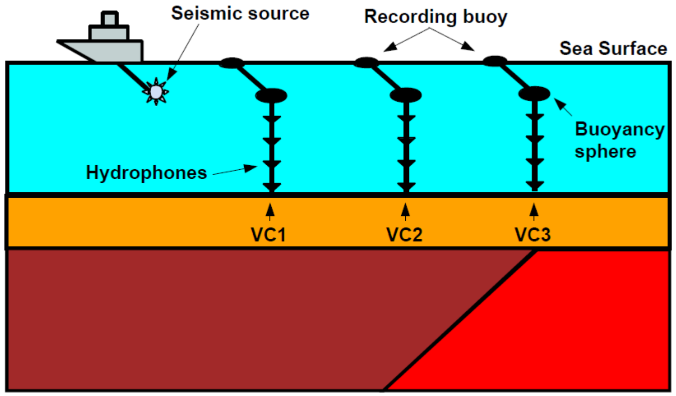
Classification: Internal 2010-04-16 Classification: Internal 2010-04-16

CONTENTS

- OBS/VC surveying
  - to reduce cost, source interval is too large so that CRGs are spatially aliased
- ”Multi-component” sampling of p & v
  - p, d_xp, d_yp, d_x^2p, d_y^2p, v, d_xv, d_yv, d_x^2v, d_y^2v, …
- Interpolation
  - where 1-C CRG data is irrecoverably aliased, multi-C data can be interpolated without assumptions (cfr the extended sampling theorem, proposed by Johan Robertsson to interpolate x-line between towed streamers)
- Simple numerical example
- First field trial and test June-July 2010





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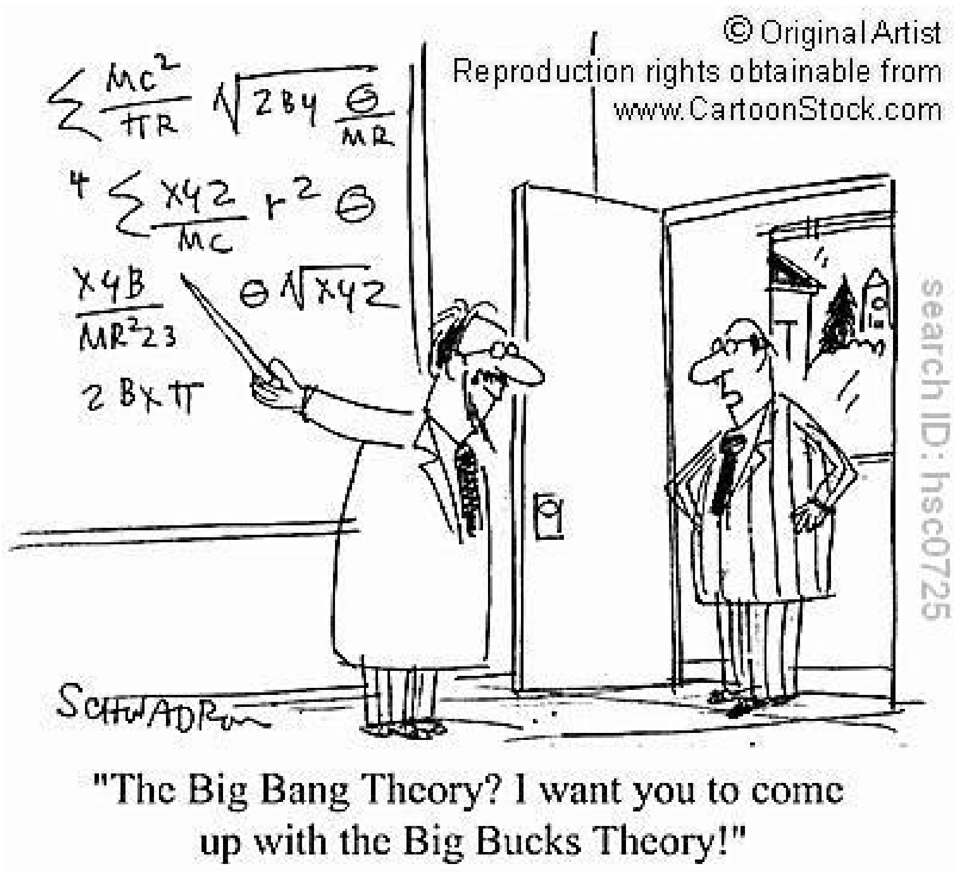
Motivation for interpolation of CRG data = reconstruction of source data



Bandwidth
resolution
multiple attenuation
imaging
interpretation

Big bucks?

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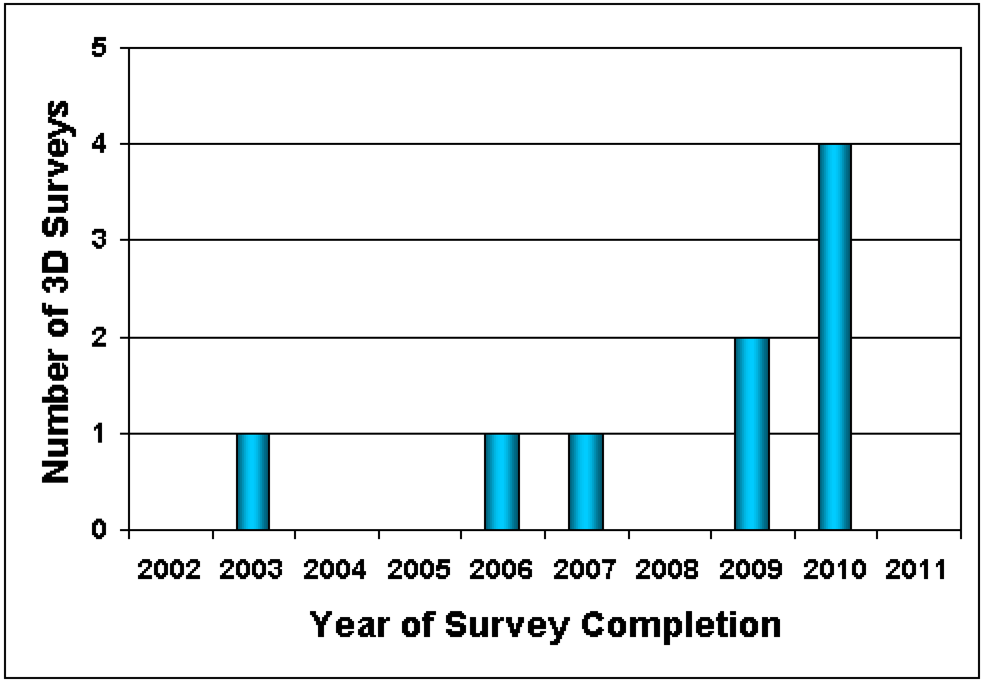
Node technology appears to be taking off as a mainstream technology: a Cinderella tale?

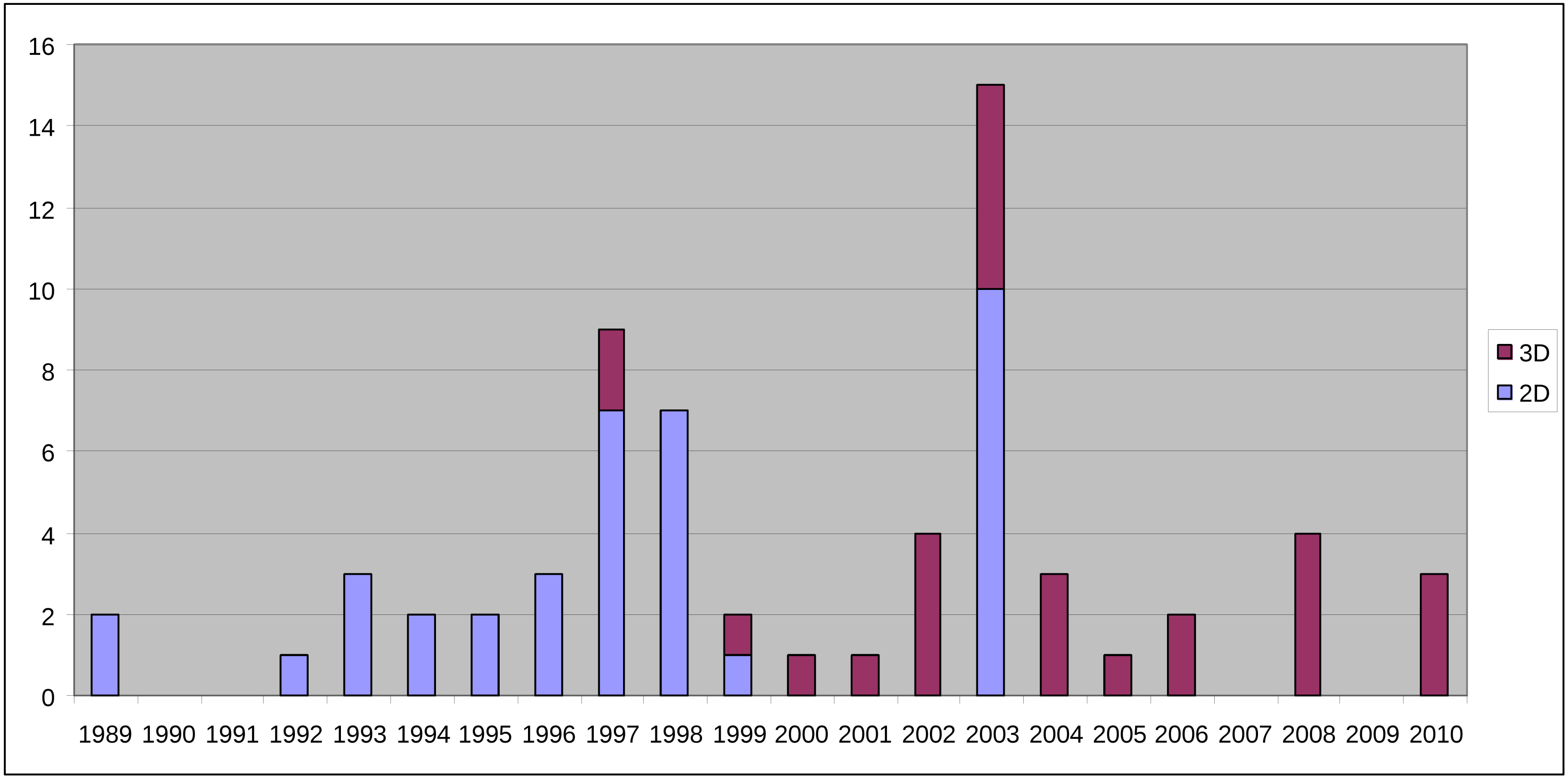


(Volve, North Sea)
Cantarell, GoM
Atlantis (2), GoM
Deimos, GoM
Agbami, Nigeria
Block 17, Angola
Rosebank, W Shetland

Soon coming to an oilfield near you?

Ref: SEG'2010 workshop "OBS nodes: the emergence and future of a novel acquisition method"

OBS activity 1989-2010 in Statoil



....plus partner operated licences!

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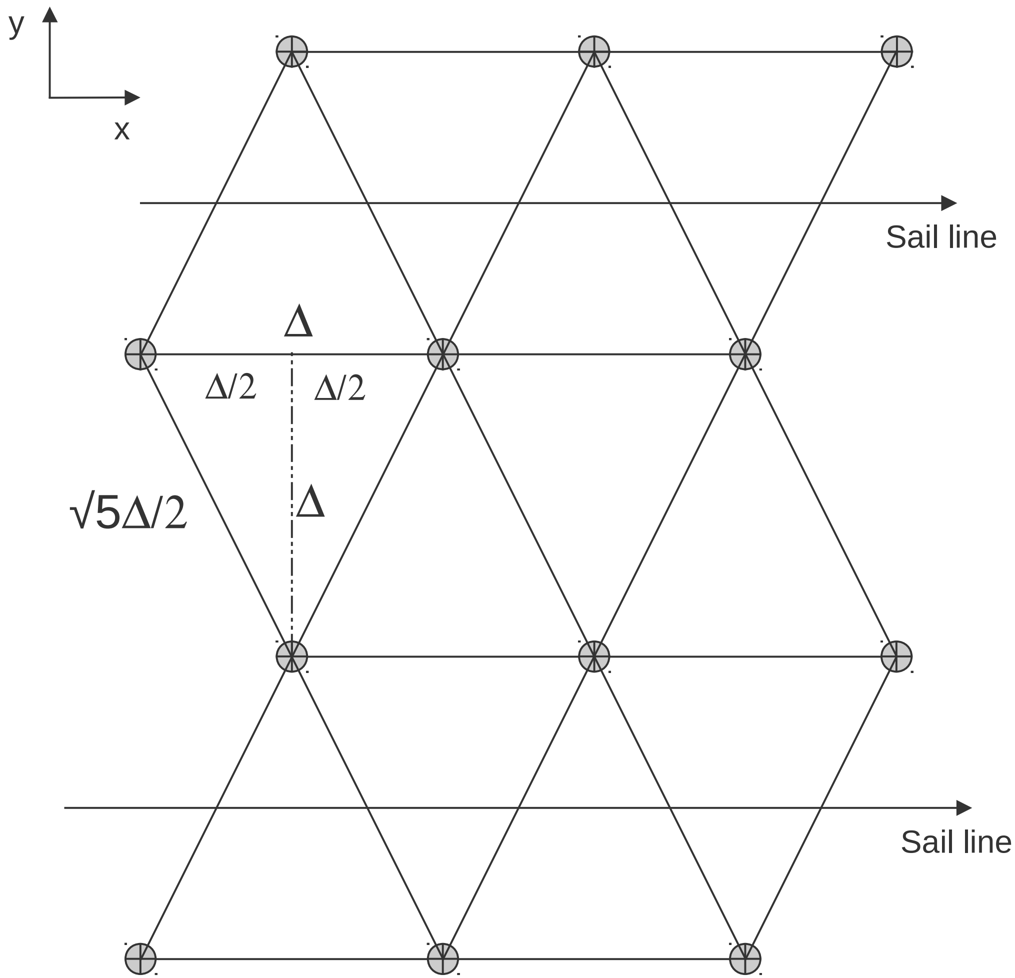
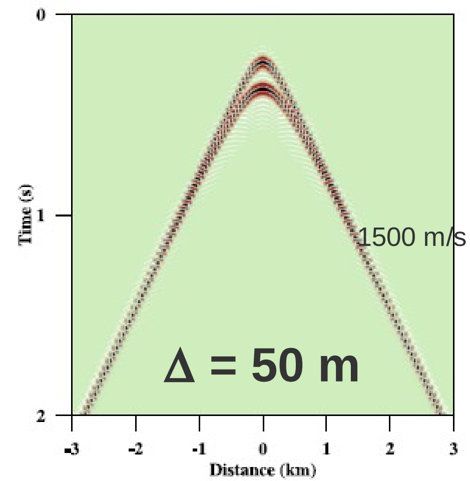
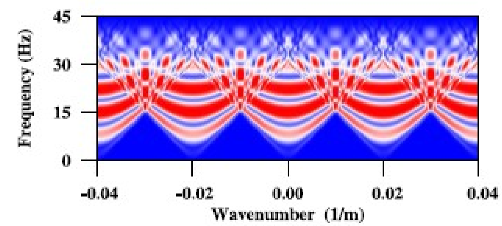
Typical OBS source grid



PROBLEM:
Data in common receiver gathers are undersampled.
Δ is 50 m or larger!





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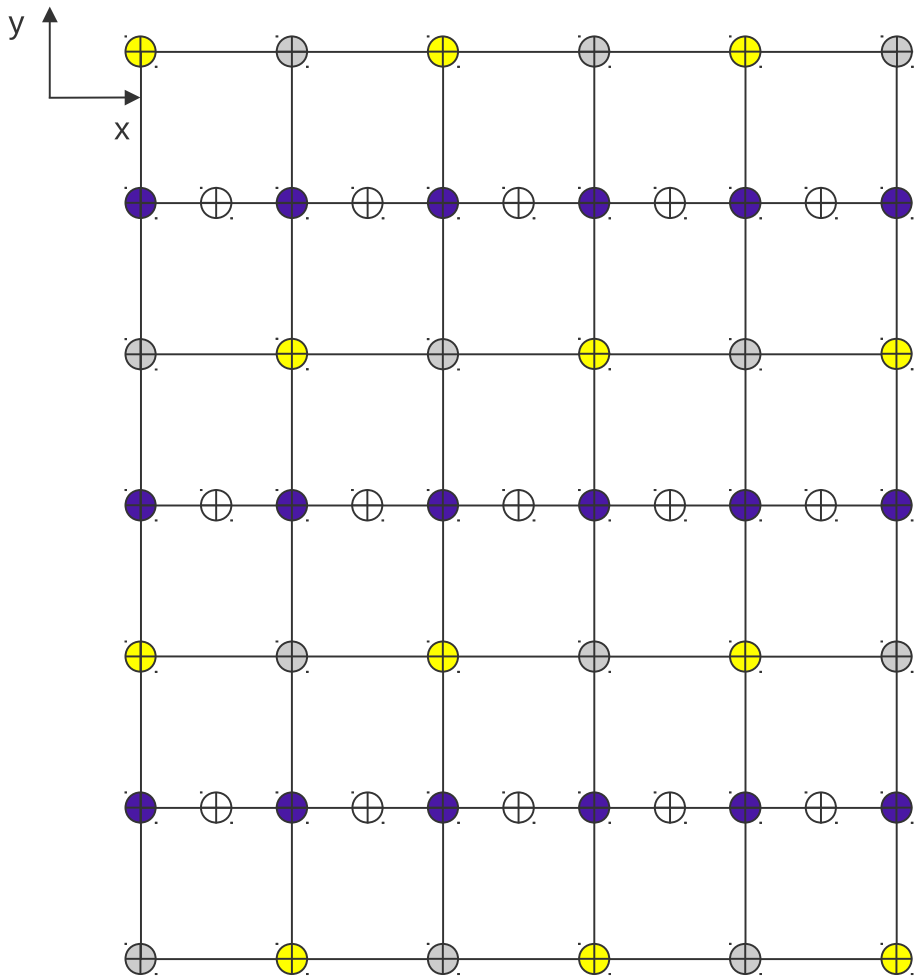
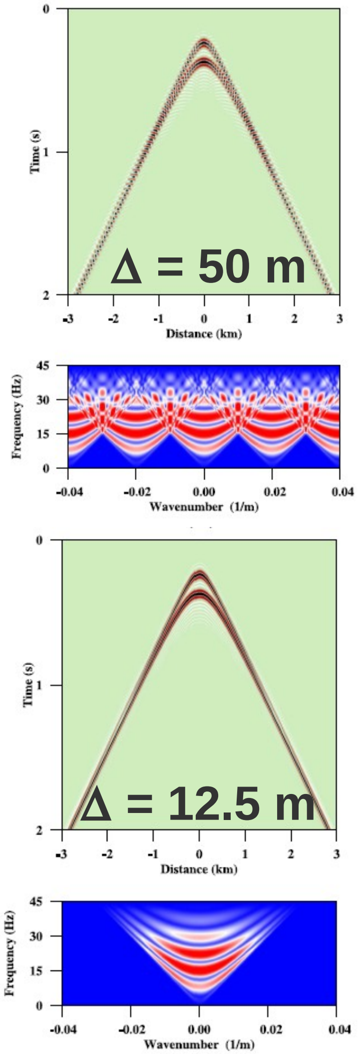
Objective: Reconstruction of source data





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Theory or big bucks solution (?): ”multi-component” acquisition for wavefield reconstruction

Multi-C means

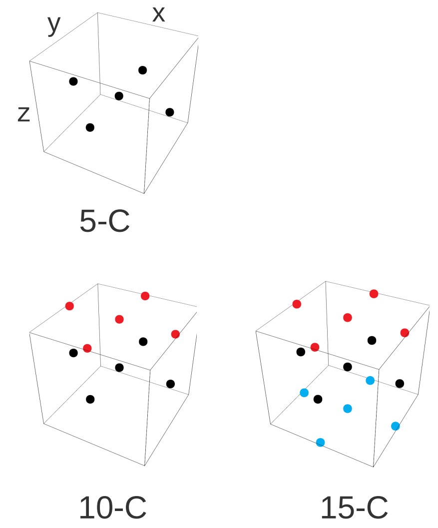
pressure and its derivatives

$p, d_x p, d_y p, d_x^2 p, d_y^2 p, \ldots$

vertical component of particle velocity and its derivatives

$v, d_x v, d_y v, d_x^2 v, d_y^2 v, \ldots$

Examples of hydrophone cluster receiver stations



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Alias frequency vs velocity vs source interval vs 1-C and multi-C data (nb! using EST)

Apparent velocity (m/s)	1500				2000			
Source interval (m)	100	75	50	25	100	75	50	25
Aliasing freq (Hz) 1-C data	7.5	10	15	30	10	13.3	20	40
Aliasing freq (Hz) 3-C data	15	20	30	60	20	26.6	40	80
Aliasing freq (Hz) 5-C data	22.5	30	45	90	30	39.9	60	120

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ILLUSTRATION OF THE BENEFIT OF SAMPLING THE FUNCTION AND ITS DERIVATIVE:

THE EXTENDED SAMPLING THEOREM

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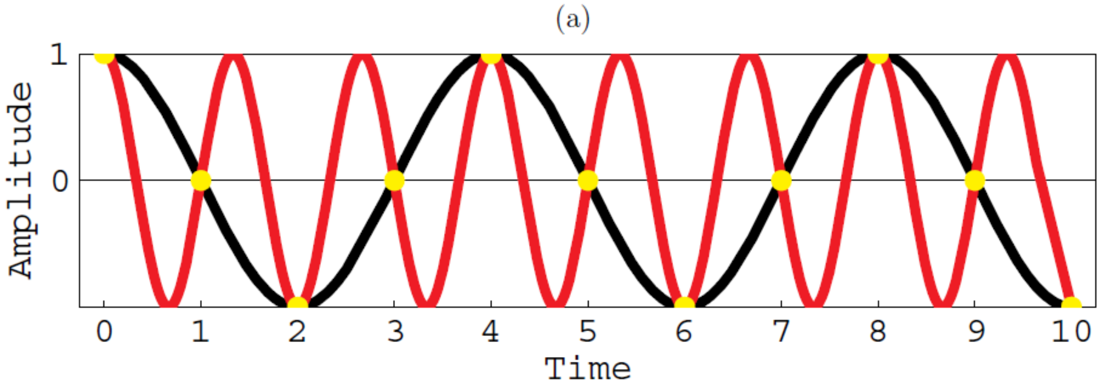
Two sinusoids that fit the yellow dot samples



$p_{red}=\cos(2\pi\ f_{red}\ t)$ $f_{red}=0.75$ Hz

$p_{black}=\cos(2\pi\ f_{black}\ t)$ $f_{black}=0.25$ Hz

Sample rate $f_s = 1$ Hz

Nyquist frequency $f_N=0.5$ Hz

When a sinusoid of frequency f is sampled with frequency f_s the resulting samples are indistinguishable from those of another sinusoid of frequency $\mathbf{f_{image}(n)=|f-nf_s|}$ for any n

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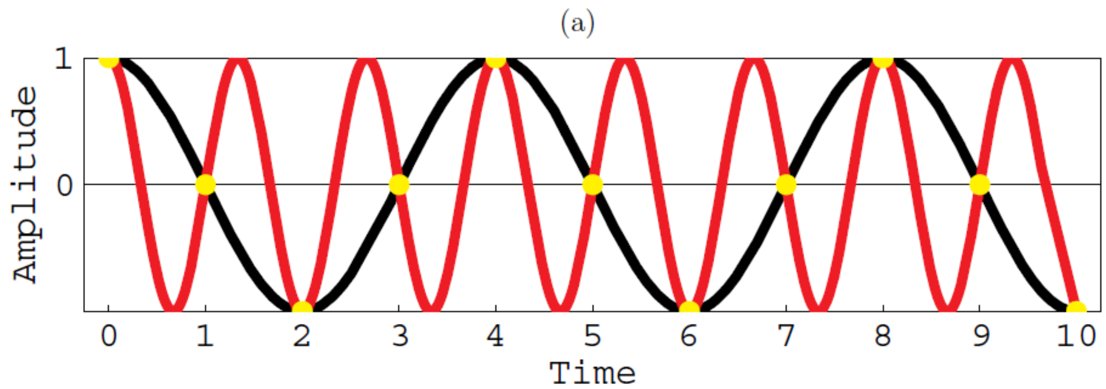
$$p(t) = \sum_{m=-\infty}^{\infty} p(t_m)\,\mathrm{sinc}\left[\frac{1}{\Delta}(t - t_m)\right]$$

sinc interpolation;

well-known by average geophysicist



$p_{red}=\cos(2\pi\, f_{red}\, t)$ $f_{red}=0.75$ Hz

$p_{black}=\cos(2\pi\, f_{black}\, t)$ $f_{black}=0.25$ Hz

Sample rate $f_s=1$ Hz

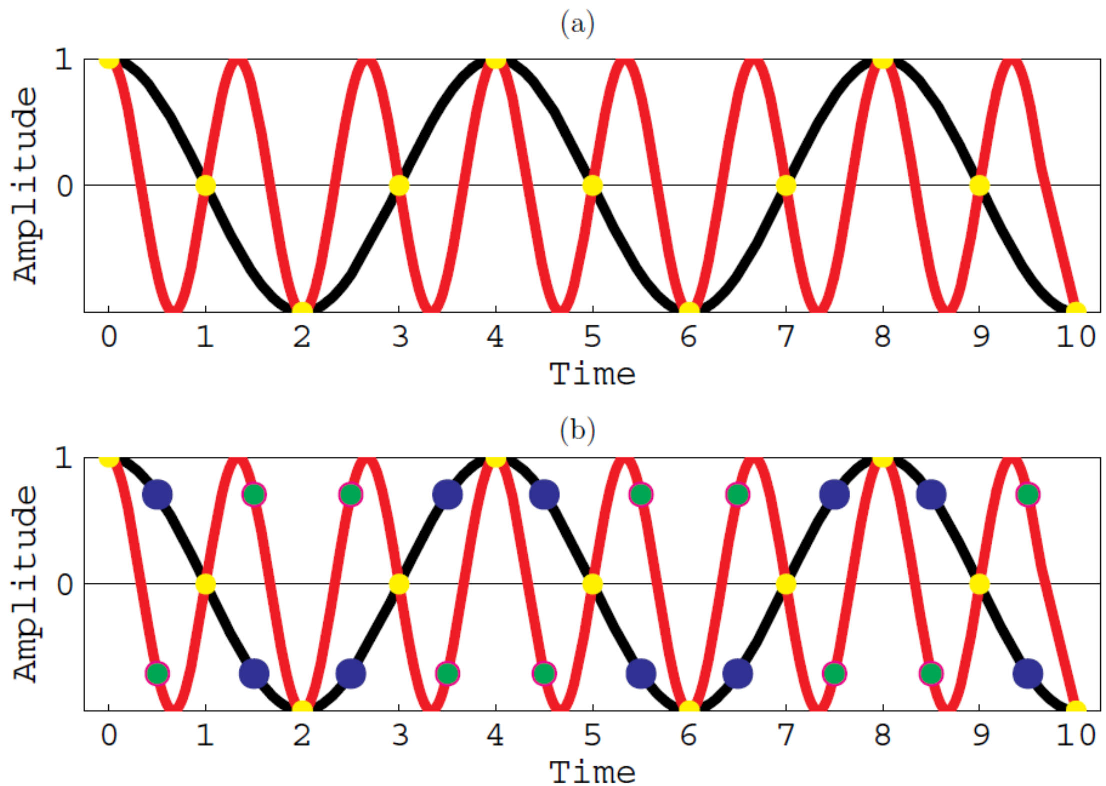
Nyquist frequency $f_N=0.5$ Hz

Sampling the red function at the yellow dot locations at 0,1, 2, 3, 4, … sec, what is the result of sinc interpolation, say at 0.5, 1.5, 2.5, 3.5, … sec?

$$p(t) = \sum_{m=-\infty}^{\infty} p(t_m)\,\mathrm{sinc}\left[\frac{1}{\Delta}(t - t_m)\right]$$

sinc interpolation;

well-known by average geophysicist



$p_{red}=\cos(2\pi\, f_{red}\, t)$ $f_{red}=0.75$ Hz

$p_{black}=\cos(2\pi\, f_{black}\, t)$ $f_{black}=0.25$ Hz

Sample rate $f_s=1$ Hz

Nyquist frequency $f_N=0.5$ Hz

sinc interpolation gives the blue dots; $f_{image}(n)=\min|f-nf_s|$

But observe that the derivatives of the red and black functions differ at the yellow sample locations …

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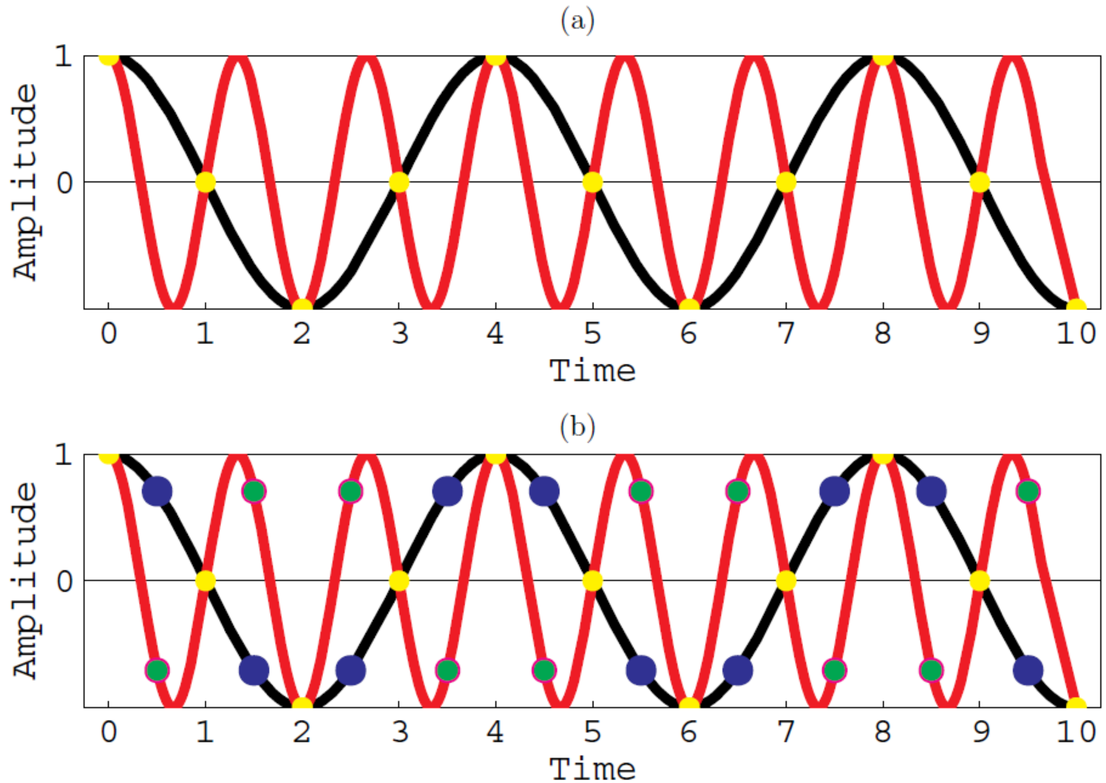
$$p(t) = \sum_{m=-\infty}^{\infty} \left[p(t_m) + (t - t_m) p^{(1)}(t_m) \right] \mathrm{sinc}^2 \left[\frac{1}{\Delta}(t - t_m) \right]$$

sinc^2 interpolation;

unknown by average geophysicist (until Johan’s publication)



$p_{red}=\cos(2\pi\, f_{red}\, t)$ $f_{red}=0.75$ Hz

$p_{black}=\cos(2\pi\, f_{black}\, t)$ $f_{black}=0.25$ Hz

Sample rate f_s =1 Hz

Nyquist frequency f_N=0.5 Hz

sinc^2 interpolation doubles the Nyquist and gives the green dots at 0.5, 1.5, 2.5, … sec.

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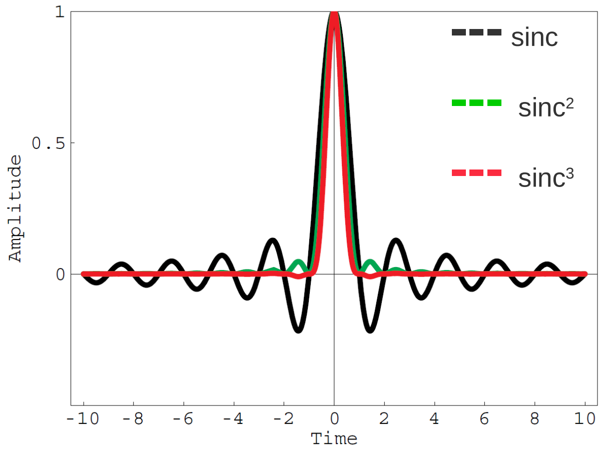
Extended sampling theorem
(Poularikas 1996)



sinc interpolation (Shannon's sampling theorem); $f<f_N$

$$p(x) = \sum_{m=-\infty}^{\infty} p(x_m)\mathrm{sinc}\left[\frac{1}{\Delta}(x-x_m)\right]$$

$sinc^2$ interpolation (multichannel sampling theorem); $f<2f_N$

$$p(x) = \sum_{m=-\infty}^{\infty} \left[p(x_m) + (x-x_m)p^{(1)}(x_m)\right] \mathrm{sinc}^2\left[\frac{1}{\Delta}(x-x_m)\right]$$

Linden 1959
Robertsson et al 2008

$sinc^3$ interpolation; $f<3f_N$

$$p(x) = \sum_{m=-\infty}^{\infty} \left[p(x_m) + (x-x_m)p^{(1)}(x_m) + \frac{(x-x_m)^2}{2}\left(ap(x_m) + p^{(2)}(x_m)\right)\right] \mathrm{sinc}^3\left[\frac{1}{\Delta}(x-x_m)\right]$$

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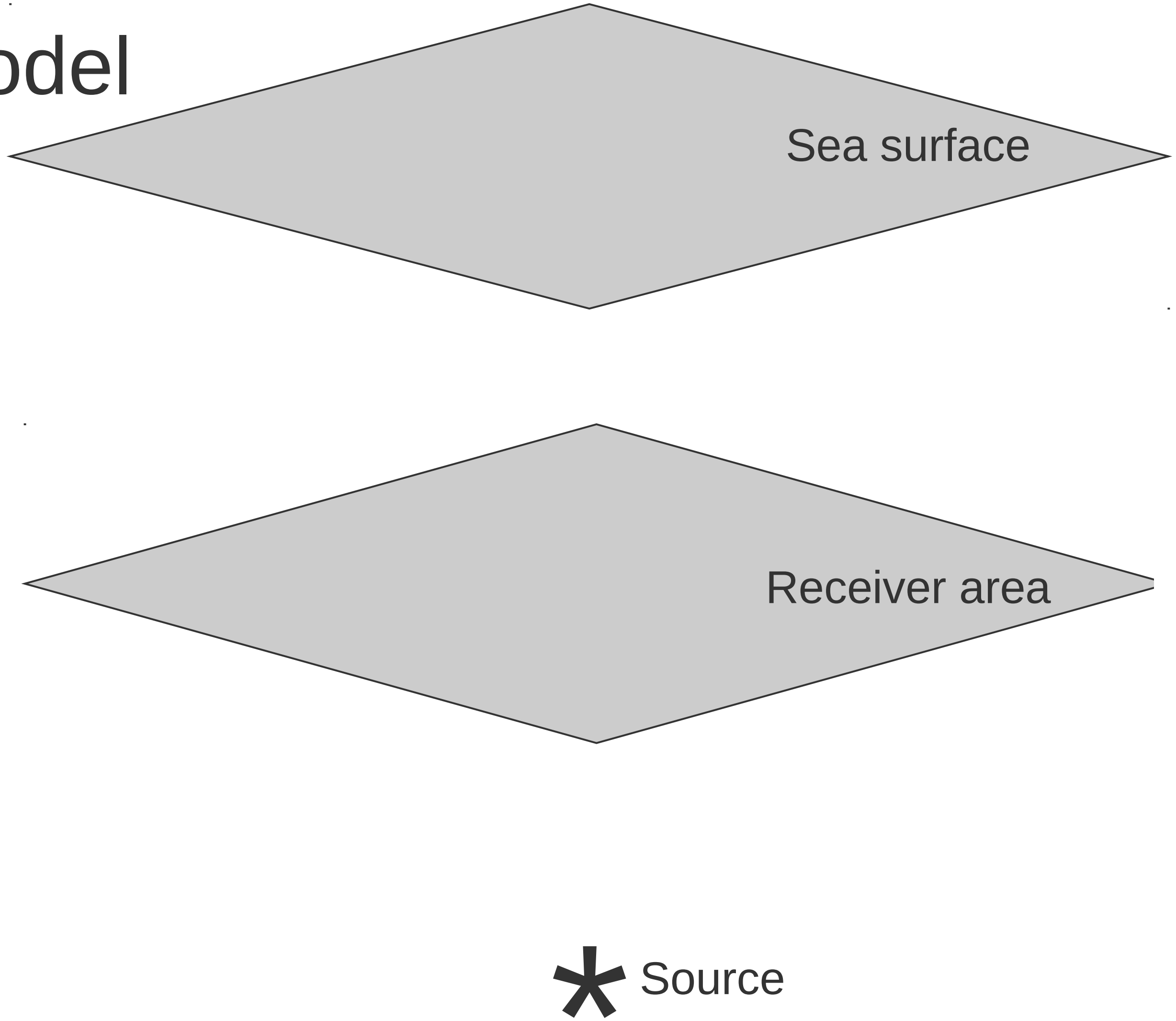
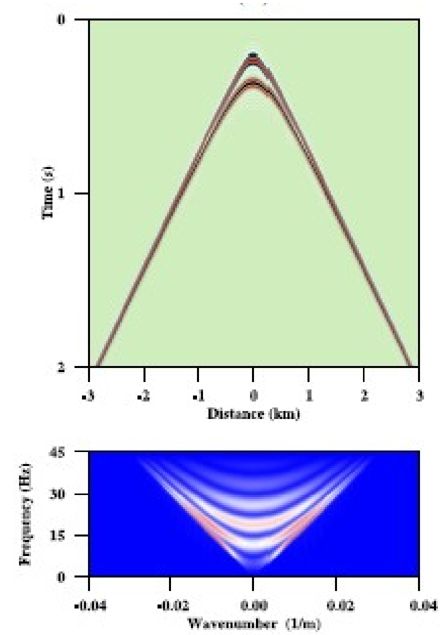
Model

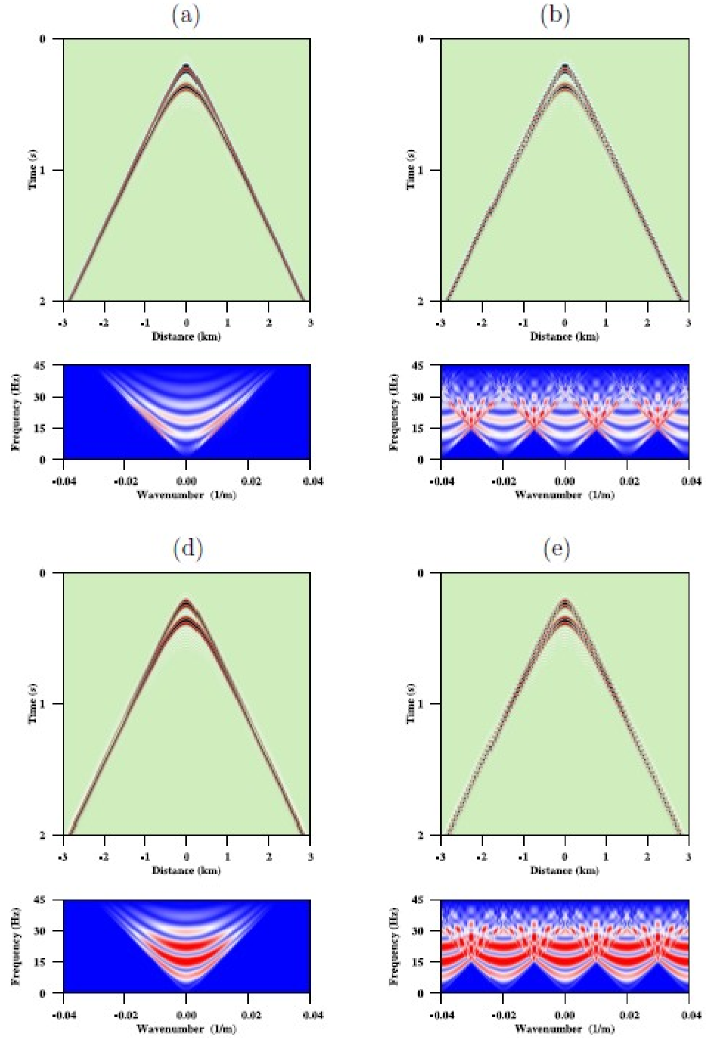

Sea surface
Receiver area
Source

Data


Time (s)
Distance (km)
Frequency (Hz)
Wavenumber (1/m)

Data reconstruction

12.5m 50 m



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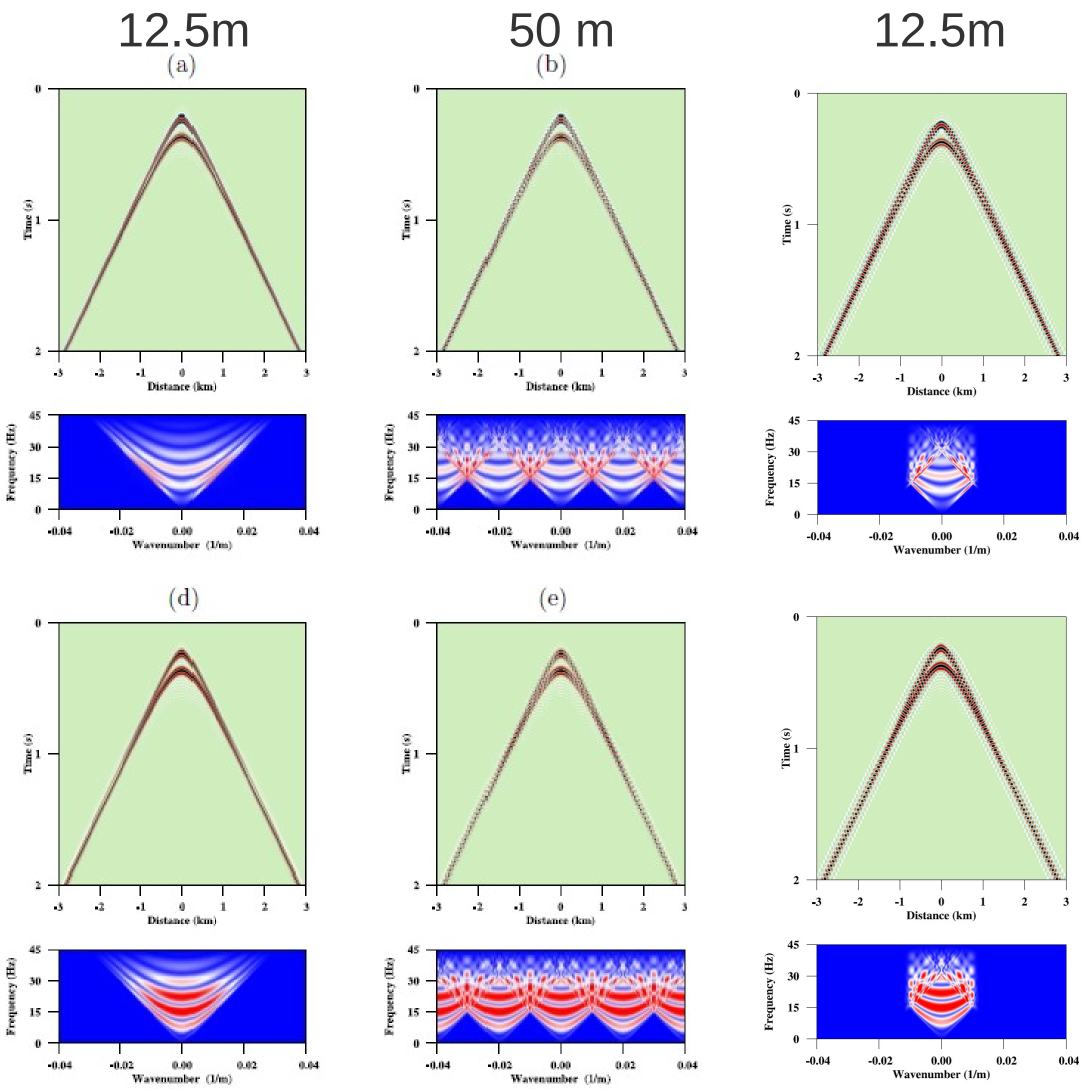
Data reconstruction: sinc interpolation



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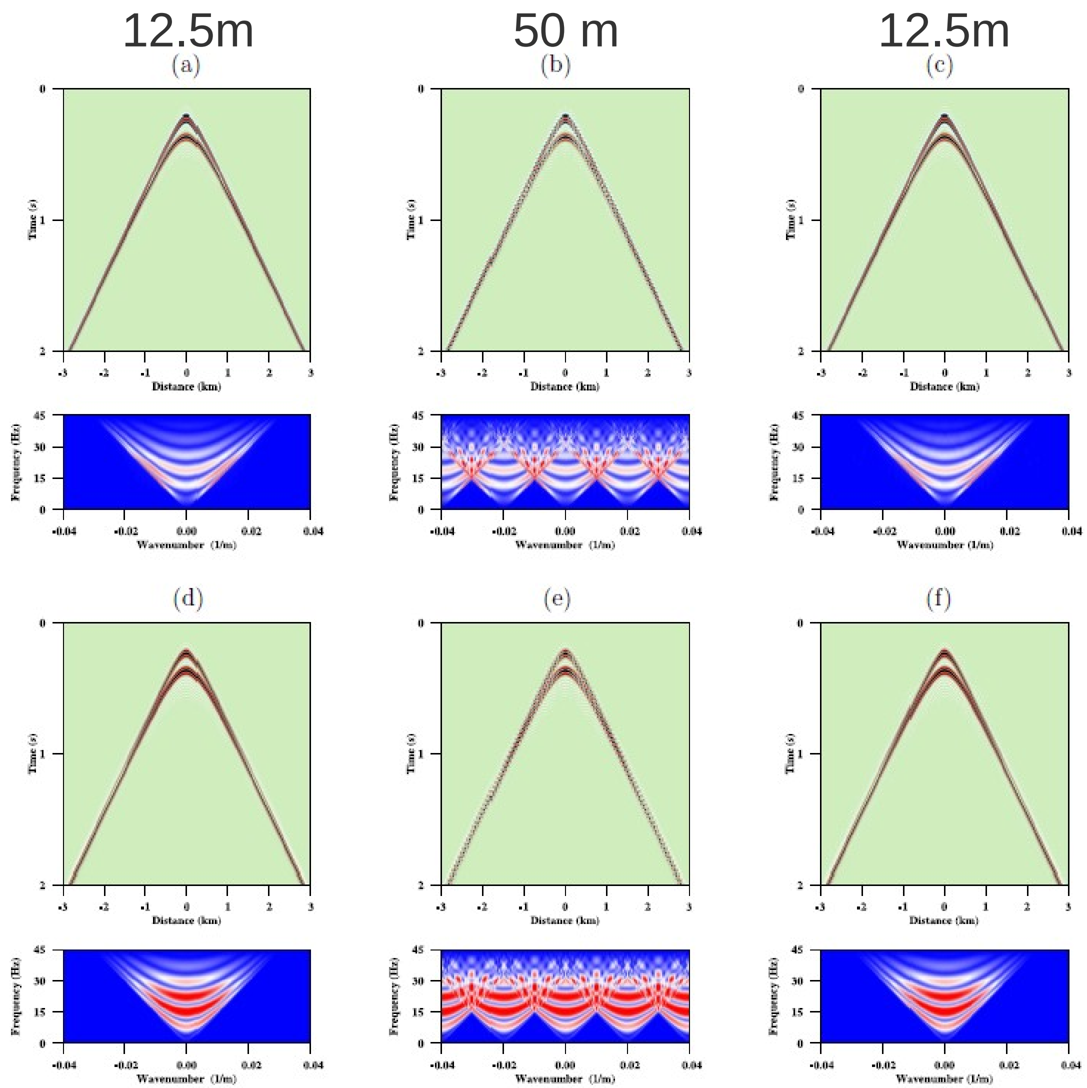
Data reconstruction: $sinc^3$ interpolation



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CONCLUSIONS

- The seismic industry is in the process of developing multi-C streamers
- The seismic industry is in the process of carrying out research on new multi-C receiver stations
- The seismic industry is in the process of carrying out research on new multi-C wavefield reconstruction techniques
- If successful – bandwidth preserved, resolution obtained, multiples effectively attenuated, imaging improved, interpretation improved, …
- Multi-C large potential (big bucks?) for OBS/VC?
- Statoil's first research field test summer 2010

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ACKNOWLEDGMENTS

- Harald Westerdahl, for suggesting multi-C recordings in the water column
- Jon Andre Haugen for producing some of the data examples
- Statoil, for allowing me to hold this presentation