NORSAR
Exploring the Earth

4D seismic simulation using 3D convolution and point-spread functions

FORCE 2018 – Stavanger

L. Zühlsdorff and T. Kaschwich (NORSAR)

I. Lecomte (University of Bergen and NORSAR)

Motivation

4D seismics has evolved a lot during the last 30 years:

From:
Qualitative tool to identify productions zones and bypassed oil

To (ideally):
Quantitative estimates of fluid saturation and pressure

Required to establish a close link between the reservoir and seismic data, e.g., between reservoir engineering and geophysics.
=> **A certain amount of modelling is required**

NORSAR

Simulator to seismics

Typical workflow:

1. Flow simulation
2. Predict reservoir properties like saturation and pressure
3. Geomechanical simulation to predict stress
4. Rock physics modelling to convert reservoir properties into elastic properties
5. **Seismic forward modelling**
    - Predict 4D effects
    - Interprete 4D observations
    - Indicate the need for updating/improving reservoir models

NORSAR

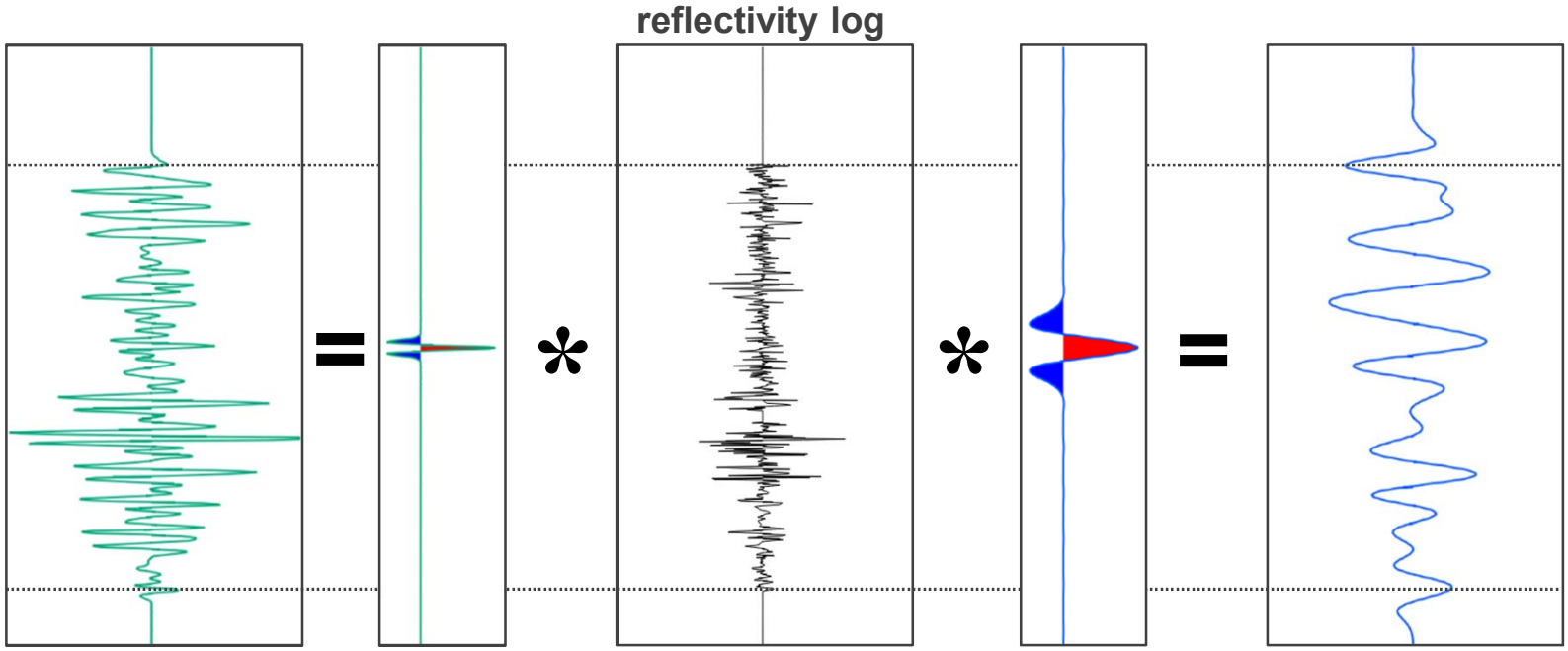
Seismic forward modelling

- Simulating seismic records directly from a reservoir
- Ideally takes into account
  - Reservoir properties
  - Overburden
  - Survey configuration
  - Source signal
- Is simple to use and **efficient**

NORSAR

1D convolution

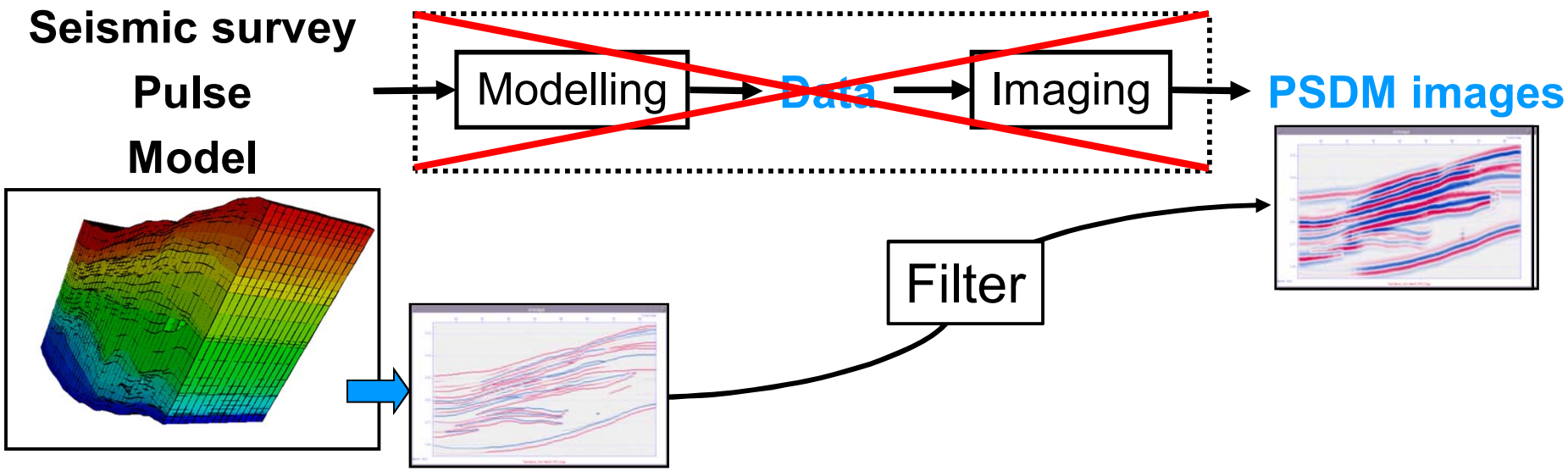
Illumination effects not included!
Lateral resolution not taken into account!
Reflectivity depends on incident angle...



* convolution

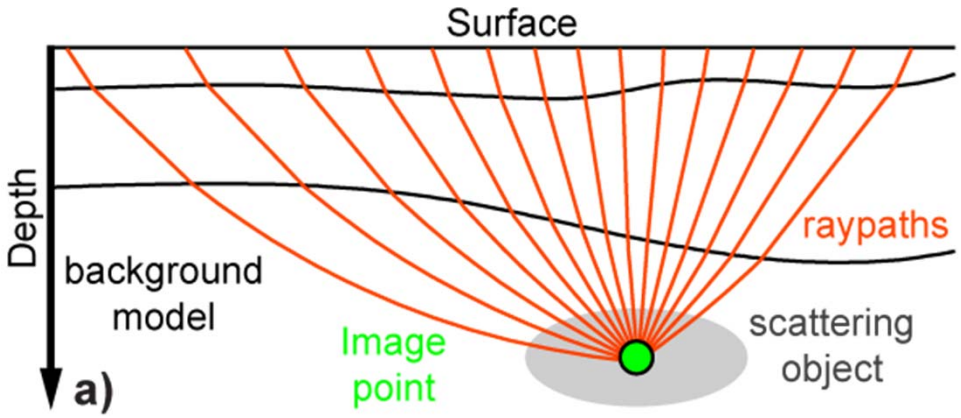
NORSAR

Full wavefield modelling



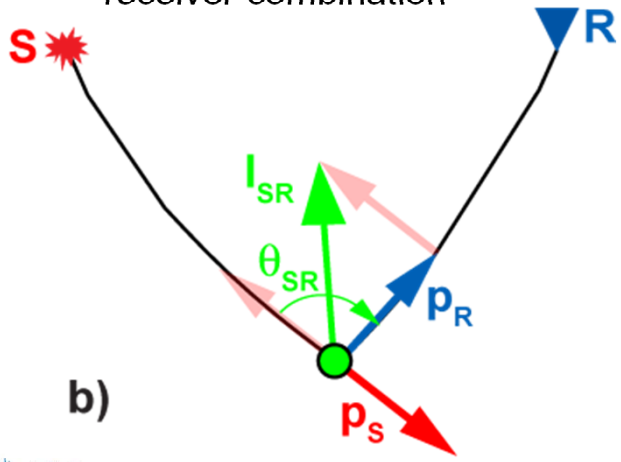
NORSAR

From reflection to diffraction



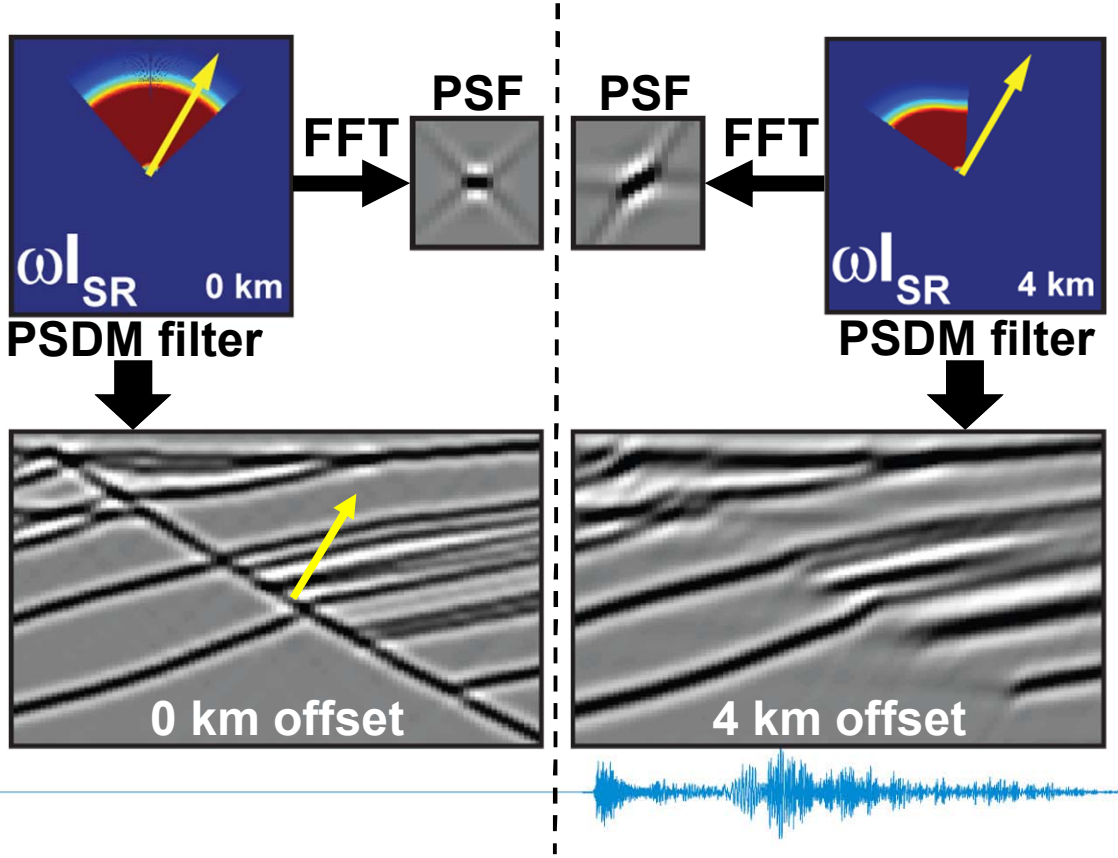
Scattering object at target level: direct ray propagation to each shot and each receiver of a given survey

Illumination vectors indicate target dip that can be illuminated by each shot and receiver combination



NORSAR

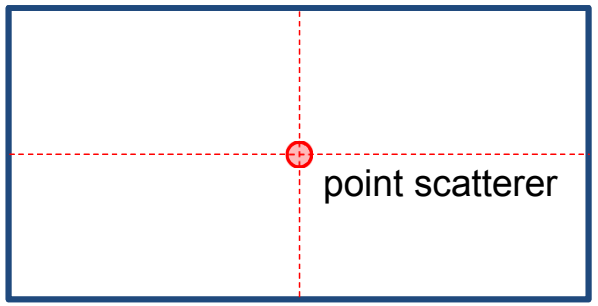
From reflection to diffraction

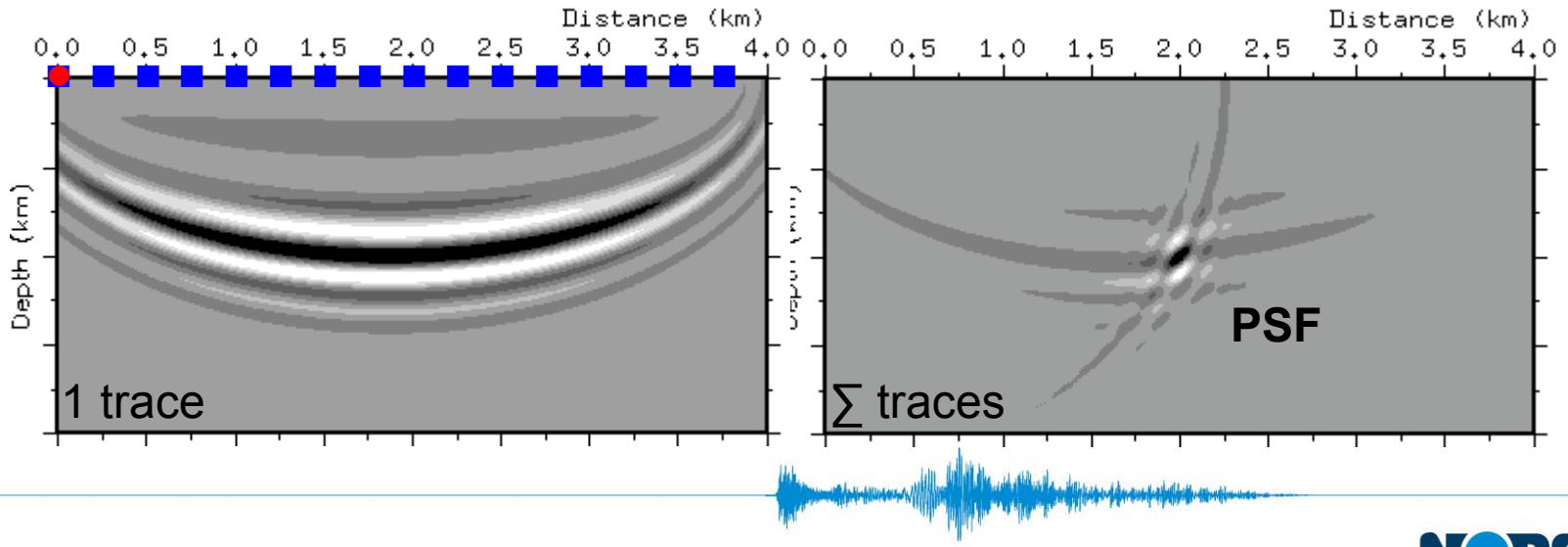


NORSAR

PSF and migration

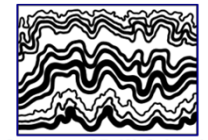
Model: constant velocity
Data: point scatterer



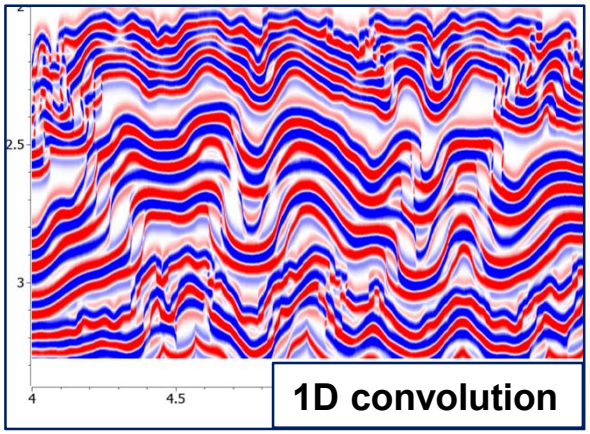


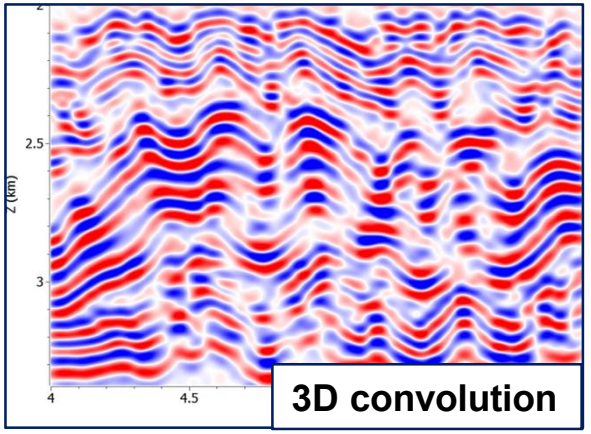
NORSAR

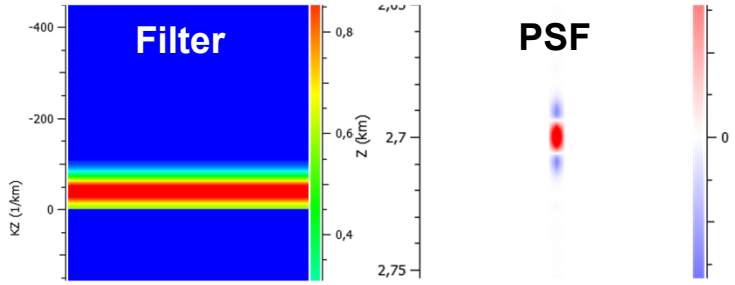
PSF for 3D convolution

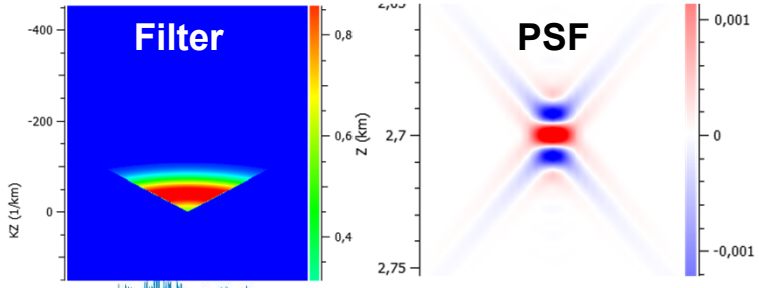


Courtesy of D. W. Schmid.



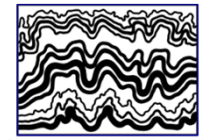


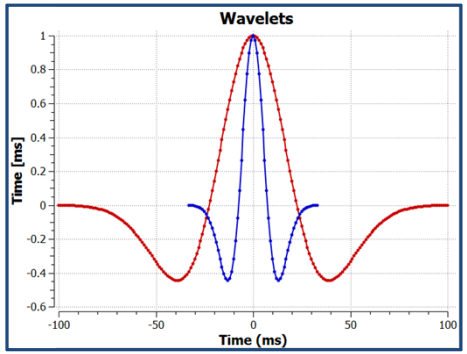


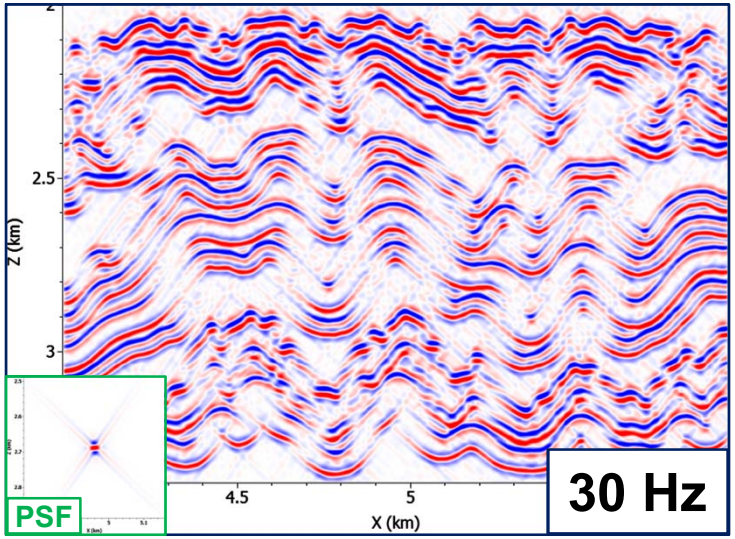


NORSAR

Effect of frequency


Courtesy of D. W. Schmid.

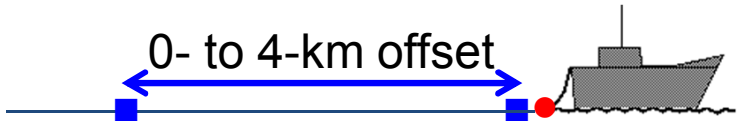




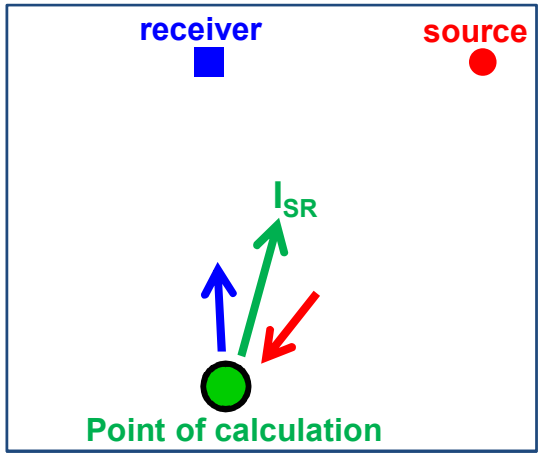
Higher frequencies improve resolution… but cannot compensate for lack of illumination.

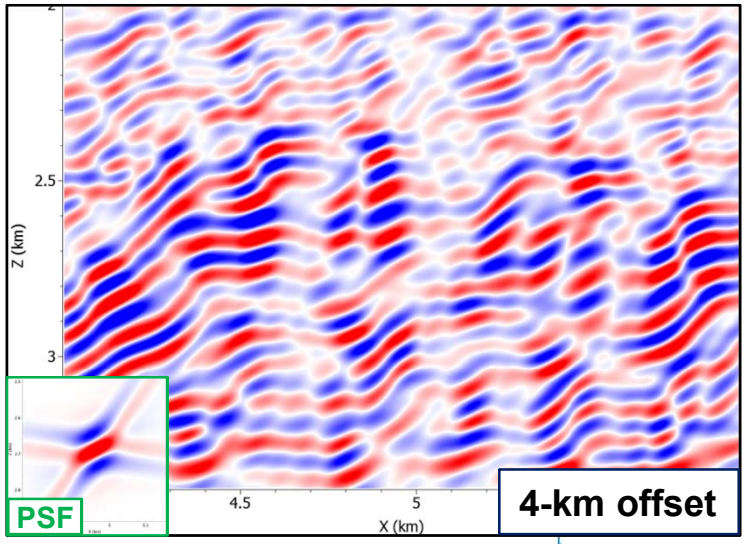
NORSAR

Effect of survey



marine survey sailing ➔



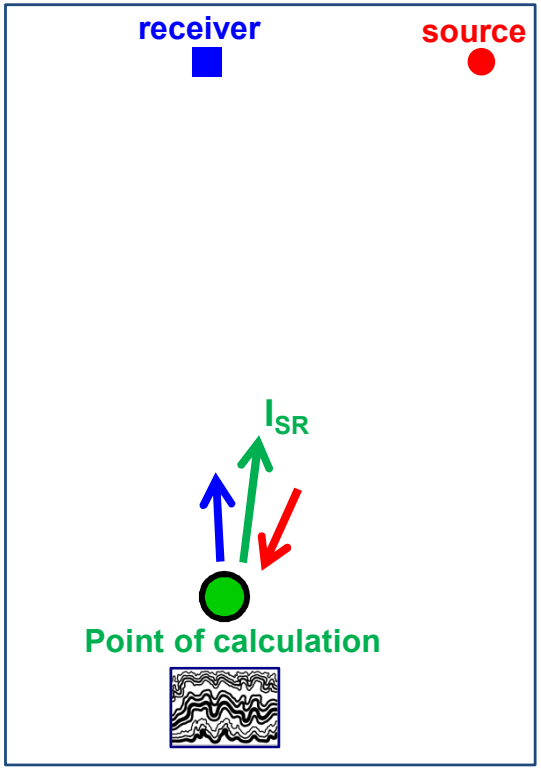


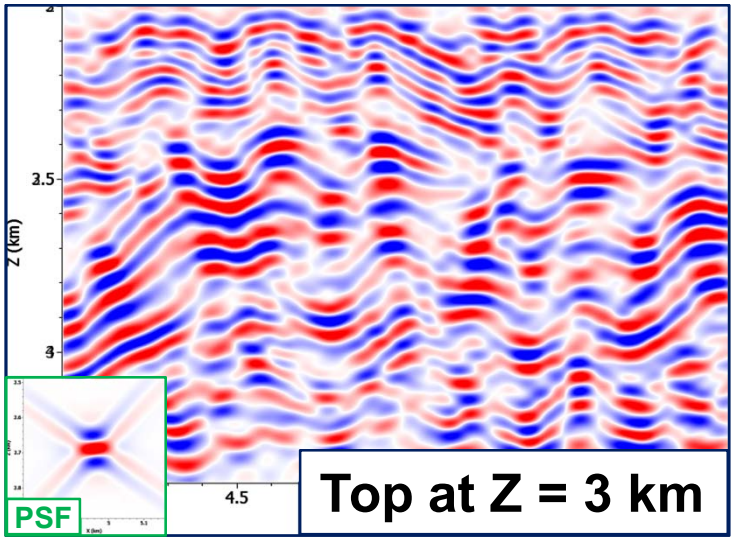
Large offsets do not see the same as small offsets, especially in marine surveys…

Courtesy of D. W. Schmid.

NORSAR

Effect of reservoir depth



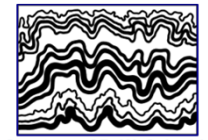


Illumination and resolution may vary over the selected imaged zone…

Courtesy of D. W. Schmid.

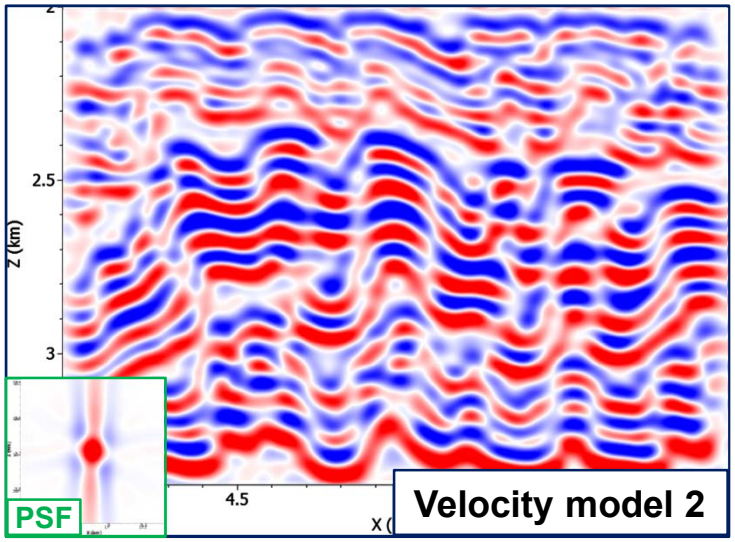
NORSAR

Effect of overburden


Courtesy of D. W. Schmid.

Velocity model 2

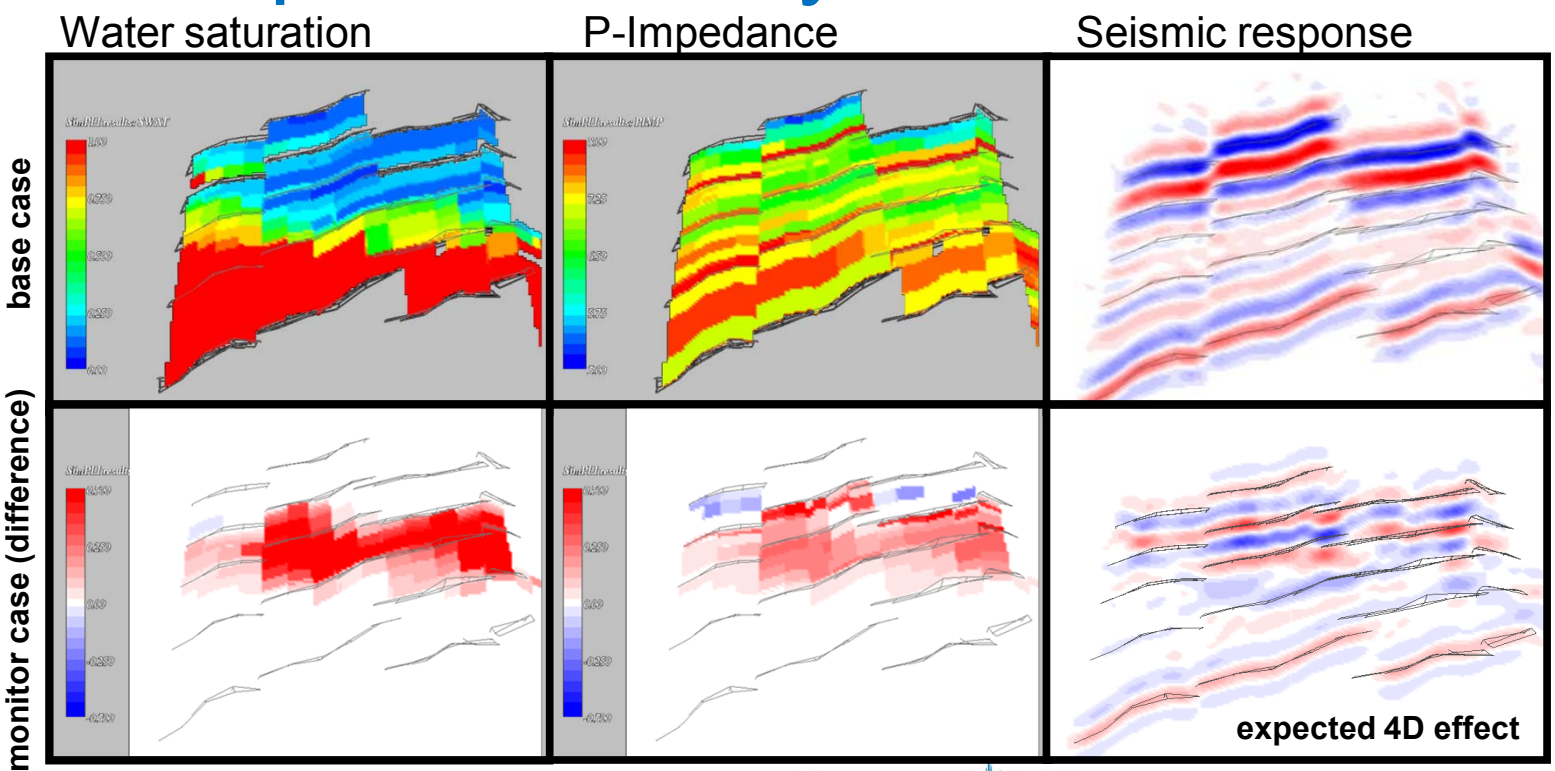
complex



Propagation is highly dependent on the background velocity model, hence illumination and resolution as well…

NORSAR

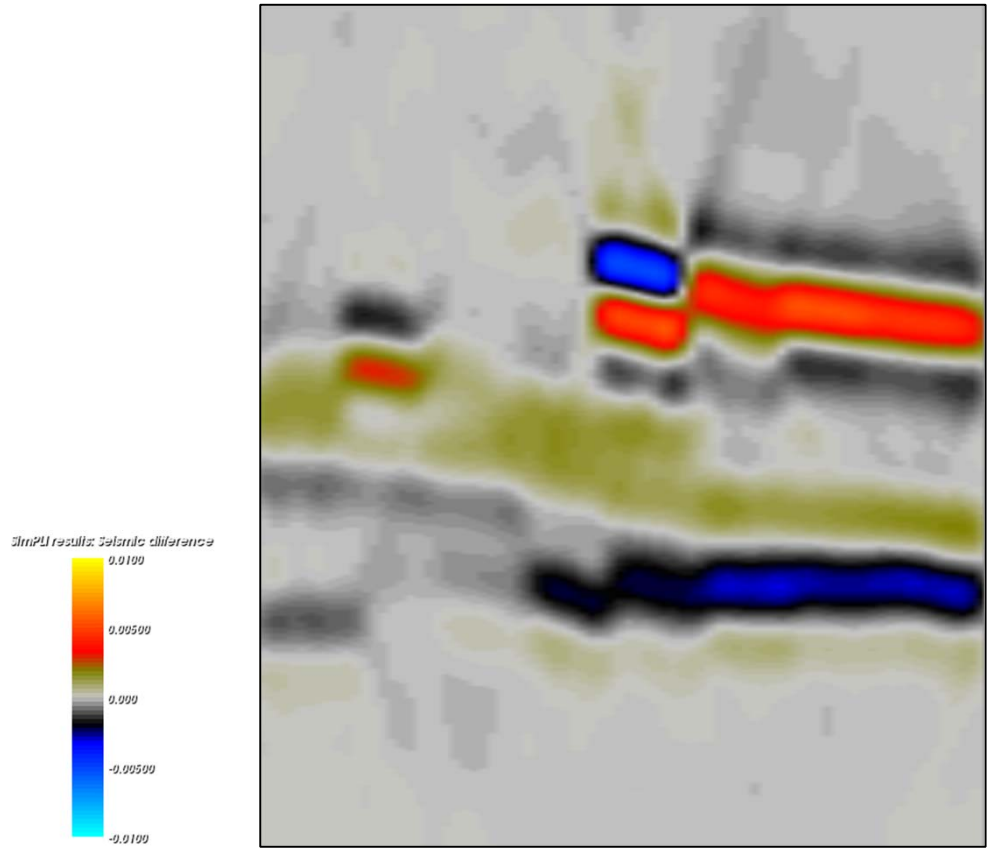
Time lapse feasibility



NORSAR

4D effects

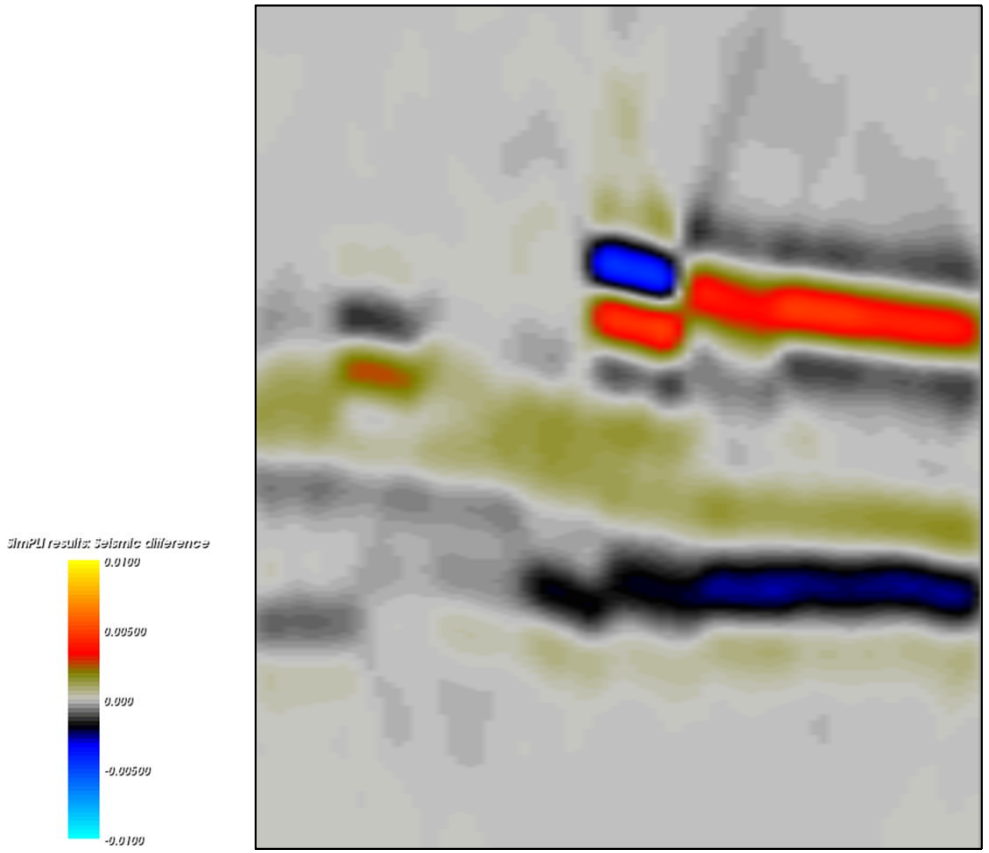
Simulated seismic 4D signal from test model.



NORSAR

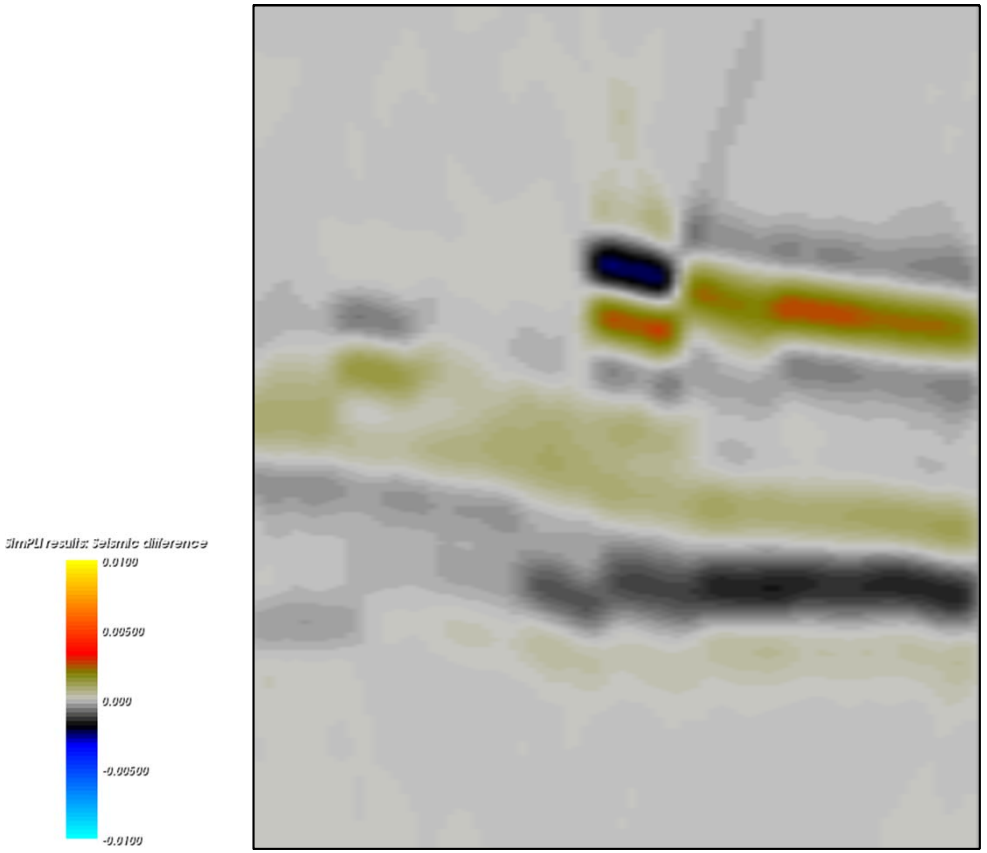
4D effects

Added pressure correction

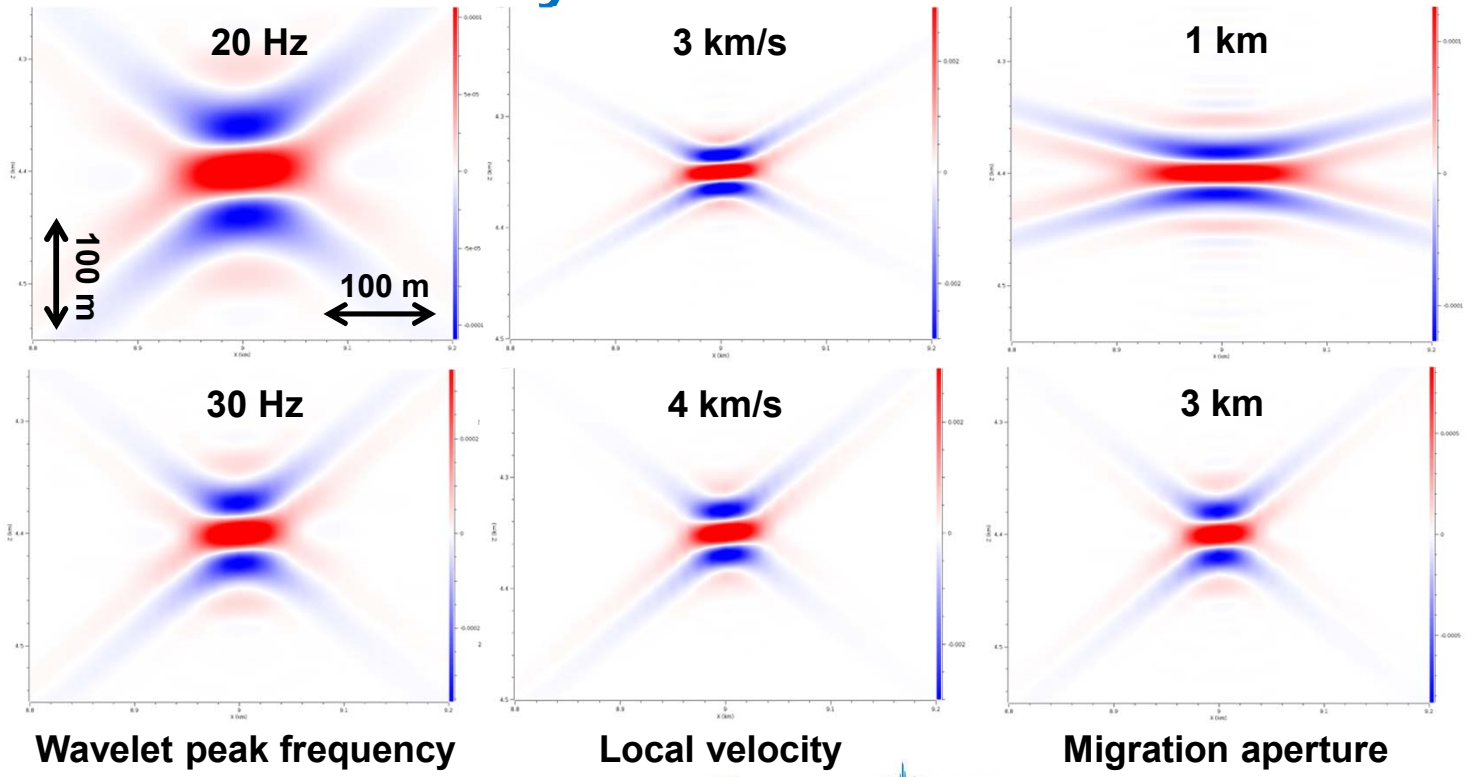


4D effects

Added rock calibration as based on a well log



Resolution study



Summary

- In many cases, ray-based PSDM simulation may be an efficient alternative to full wavefield modelling
- A fast-track approach can be based on a filter, that is either applied in wavenumber domain or in depth domain (point spread function)
- Wide range of applications:
  - Quick check on how a complex target would translate into a seismic image for a given wavelet, survey and overburden model
  - Fast-track time-lapse simulation, including 4D seismic difference and angle decomposition
  - Evaluating lateral and vertical resolution through point-spread functions

3D convolution is almost as efficient as 1D convolution but integrates illumination and resolution effects within the same process.

NORSAR