NORSAR – Norwegian Research Institute Seismology, Seismic Modelling, and Micro-Seismics.

Speaker: **Isabelle Lecomte, Dr.**

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(part-time Associate Professor, near-surface geophysics; UiO)

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Why does NORSAR exist?

The reason....

Bikini atoll athmospheric nuclear test (1954)

...detection of underground nuclear explosions.

When....

... 1968!

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NORSAR History

- **1968**: The **NORSAR** («**Nor**wegian **S**eismic **Ar**ray») Project
  - Government-to-Government agreement between the United States of America and Norway.
  - **Seismic-array research** to develop methods for verification of a future nuclear-test-ban treaty.
- **1970-1993**: **NORSAR** is a section of the Royal Norwegian Council for Industrial and Scientific Research.
  - **1978**: **Seismic modelling starts as a new research activity.**
- **1993-1999**: **NORSAR** is a Section of the Research Council of Norway (NFR).
- **July 1st, 1999**: **NORSAR is an independent «not-for-profit» research foundation.**
  - **2001: Micro-seismicity starts as a new research activity.**
- **2003-2012**: **NORSAR** is a partner of the **International Centre for Geohazards**, Norwegian Centre of Excellence established by NFR (host: **NGI**; with **NGU**, **UiO** and **NTNU**).
- **2005**: **NORSAR Innovation AS (NIAS)** is established (100%-owned subsidiary).

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NORSAR goals and research

- **NORSAR**'s objectives, as a **Norwegian research institute**:
  - **To promote applications of research results for the benefit of the Norwegian society and Norwegian industry.**
  - To establish and further develop the professional competency of its research staff within its areas of activity.
  - To conduct research and development in the areas of geophysics and geophysical software.
  - **To act as a Norwegian national resource center for verifying compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT).**

- From the early days of devoted **seismic-array research**, NORSAR has broadened its research activities to include subjects like, e.g., **earthquake hazard**, **risk assessment**, **micro-seismicity**, **earthquake engineering**, and **seismic modelling** for the petroleum industry.

Elastic waves have no secret for us, at all scales!

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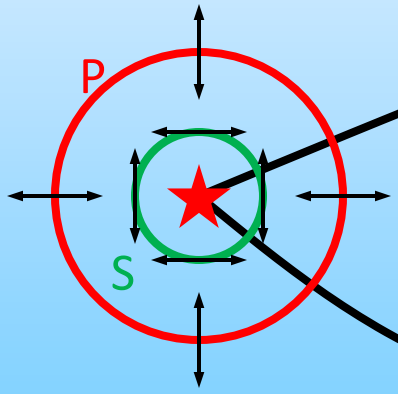
Surfing the seismic waves

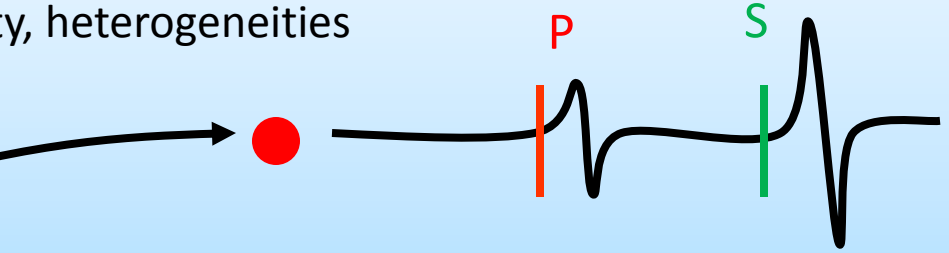
From source… **through wave propagation…** **to stations!**

seismic velocities V_P, V_S,
attenuation, density, heterogeneities

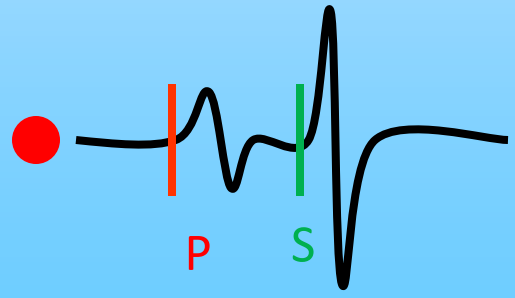


generation of compressional (P)
and shear (S) waves

45 years of experience



seismic waveforms,
P- and S-wave arrival times,
polarization, amplitudes, etc…



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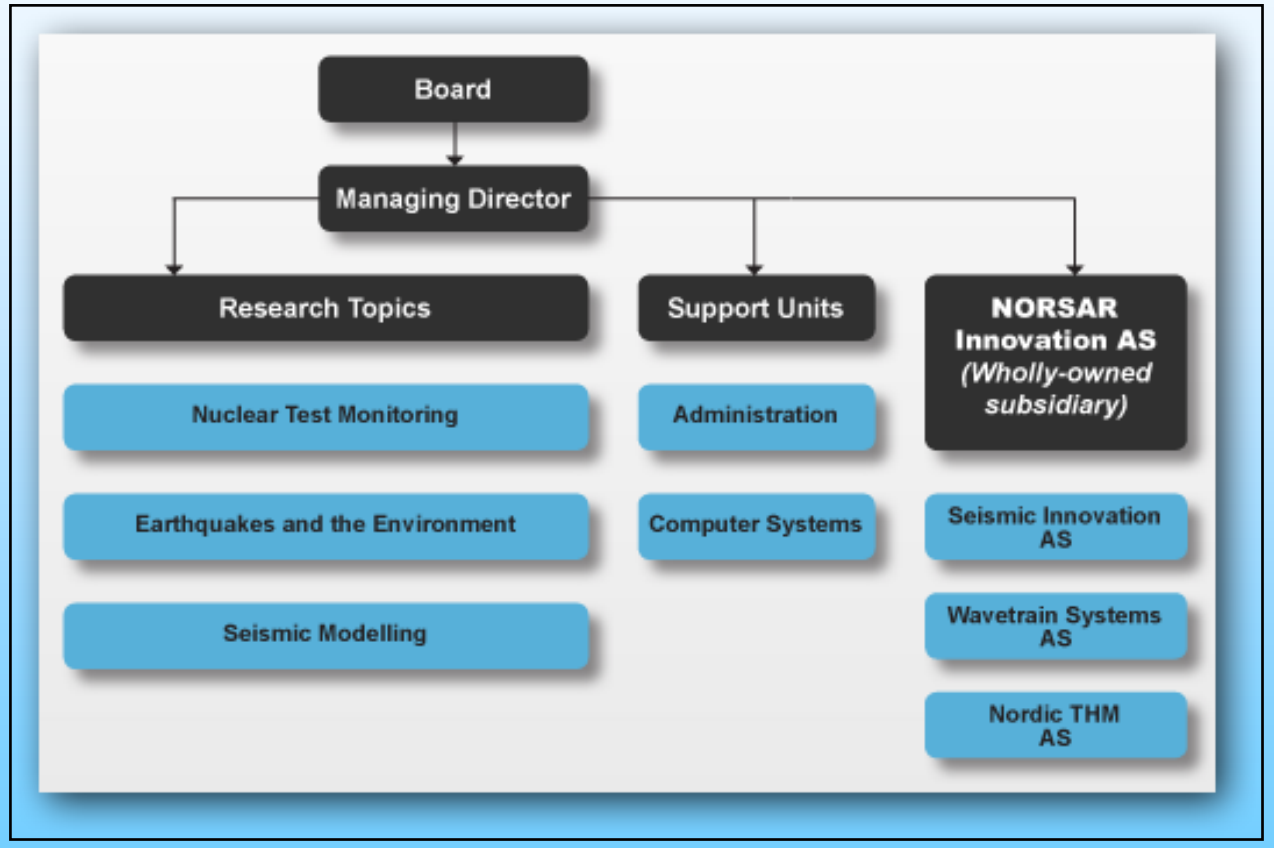
NORSAR Organization

mosquito size...

...about 50 staff in all!
(4 in NIAS)

...but stable R&D people!



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SEISMOLOGY

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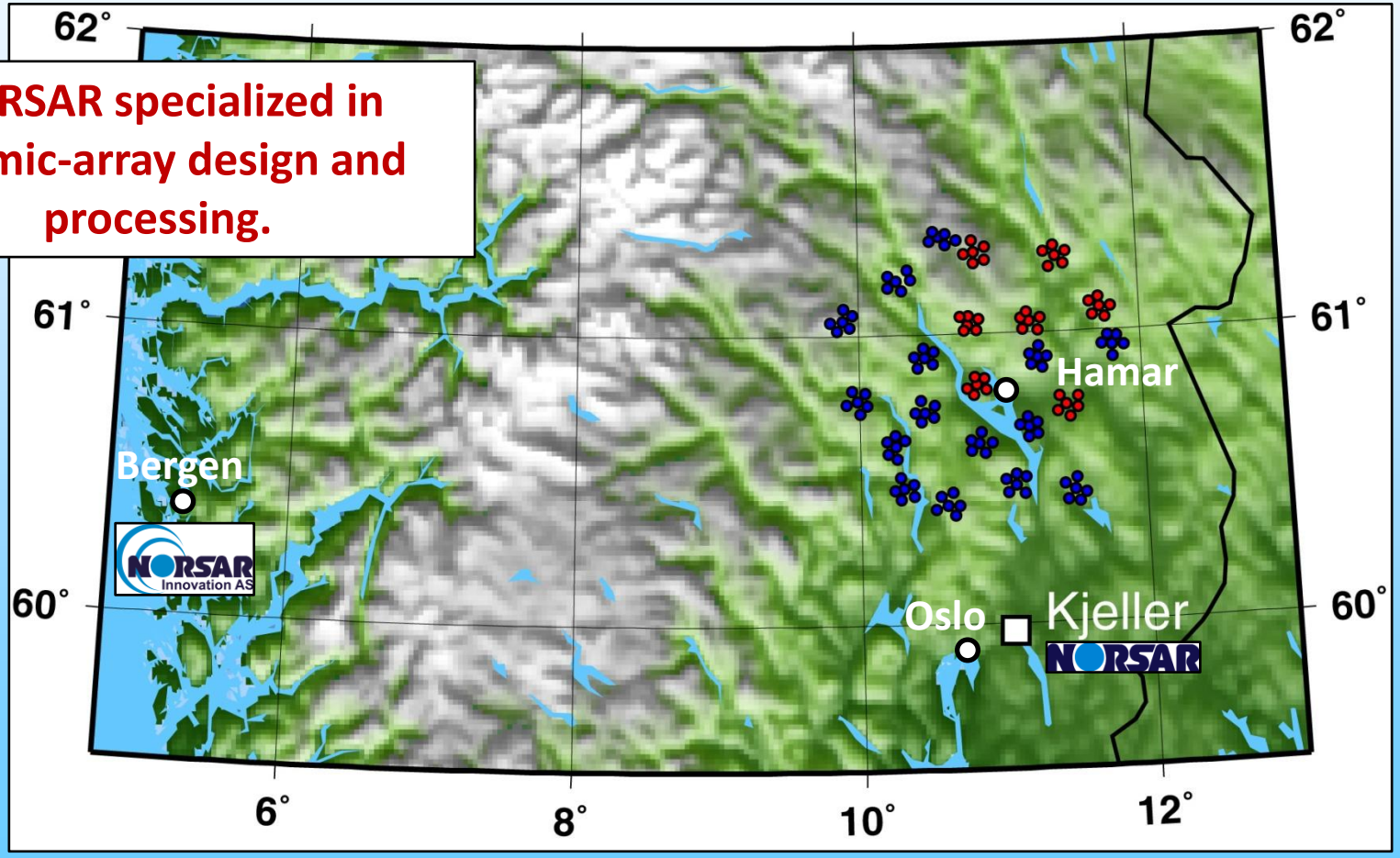
The «NORSAR» array

NORSAR array from 1968: **blue** + **red**
NORSAR array from 1976: **red**

NORSAR specialized in seismic-array design and processing.



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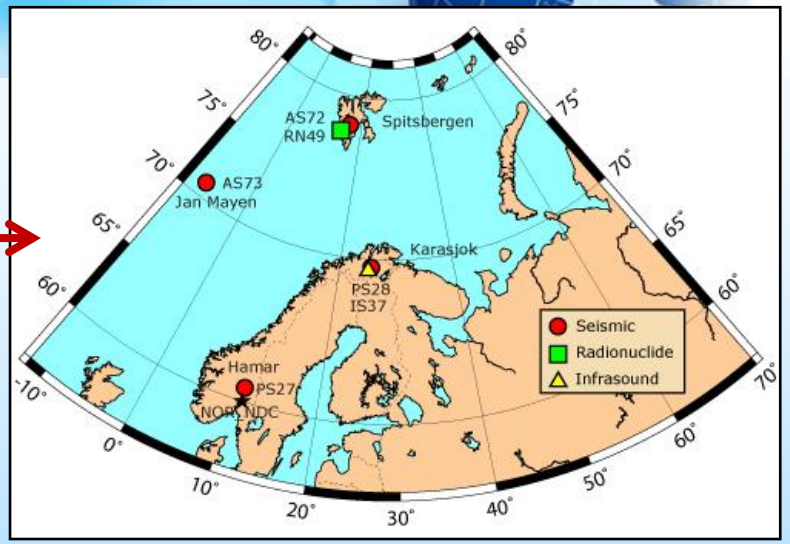
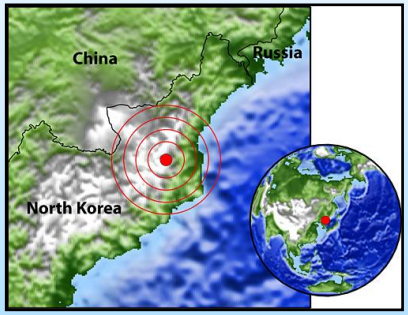
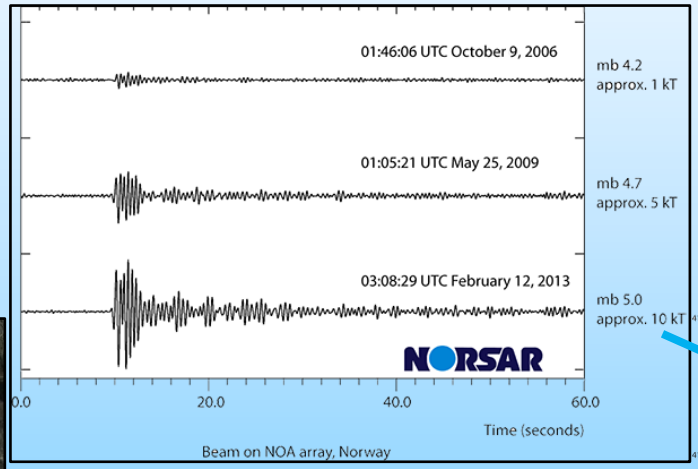
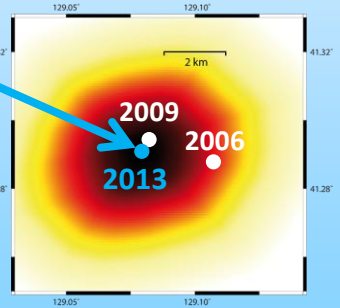
Seismology

Part of the Comprehensive Nuclear-Test-Ban Treaty organization (www.ctbto.org).
In charge of several global stations (4 CTBTO)









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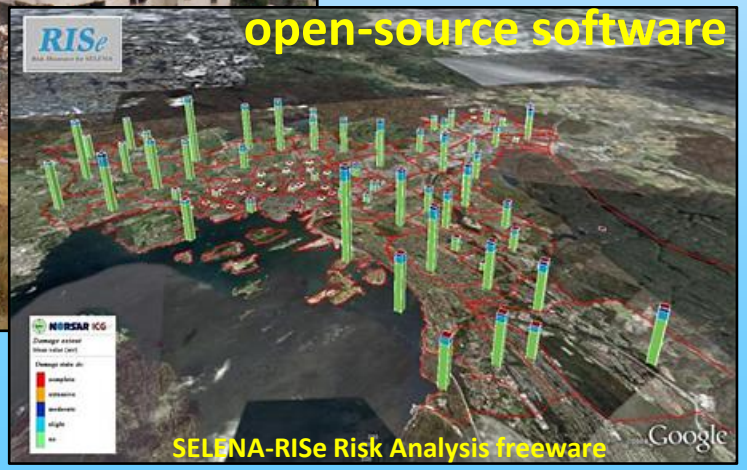
Earthquake Risk and Engineering

NORSAR is working actively internationally concerning the assessment and mitigation of earthquake risk. Applies also for the O&G industry.

- Vulnerability
- Earthquake Risk
- Eurocode 8 Regulations for Structural Design
- SELENA-RISe

2010 Chile earthquake



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SEISMIC MODELLING

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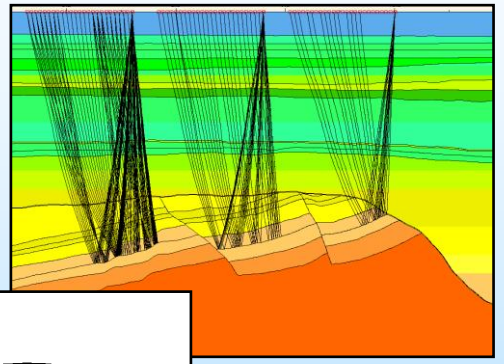
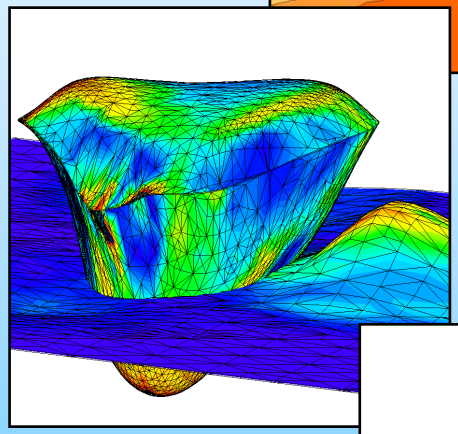
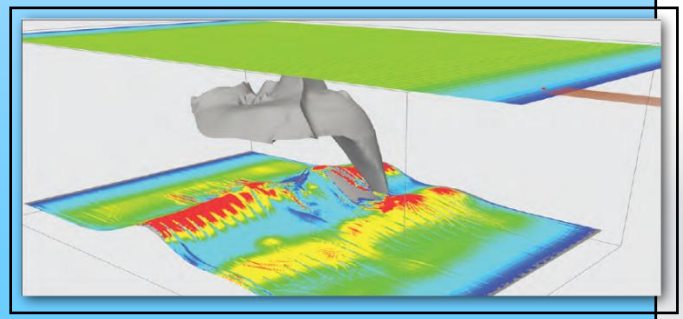
Seismic Modelling

- R&D in seismic modelling since 1978
  - **Ray-based methods**: Isotropy-Anisotropy / Kirchhoff modelling / tomography / imaging / inversion… (Gjøystdal et al., Geophysics, 2007).
  - **Rock Physics**: since 1999.
  - Research projects (NFR- and/or industry-funded).
- Software development
  - **NORSAR-2D / NORSAR-3D / VelRock / SeisRoX**
  - **Sold and applied commercially by NIAS.**
  - **Research tools**: HybriSeis, Imaging, Inversion…
  - **Free at Norwegian universities**.
- NIAS is our industry link.
- Technical support for NIAS.
- Training courses with NIAS.







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3D Wavefront Construction

- Developed at NORSAR in 1992.
- Ray-shooting method with automatic control of ray density.
- Mimics real wavefront propagation in the earth (ray-tracing).
- Associated with flexible 3D model representation.
- Efficient and robust method for large number of receivers.
- Our basic 3D Green's function engine for ray-based tools.
- Applied for trace modelling, survey planning, illumination studies, imaging, tomography, micro-seismicity location, etc.

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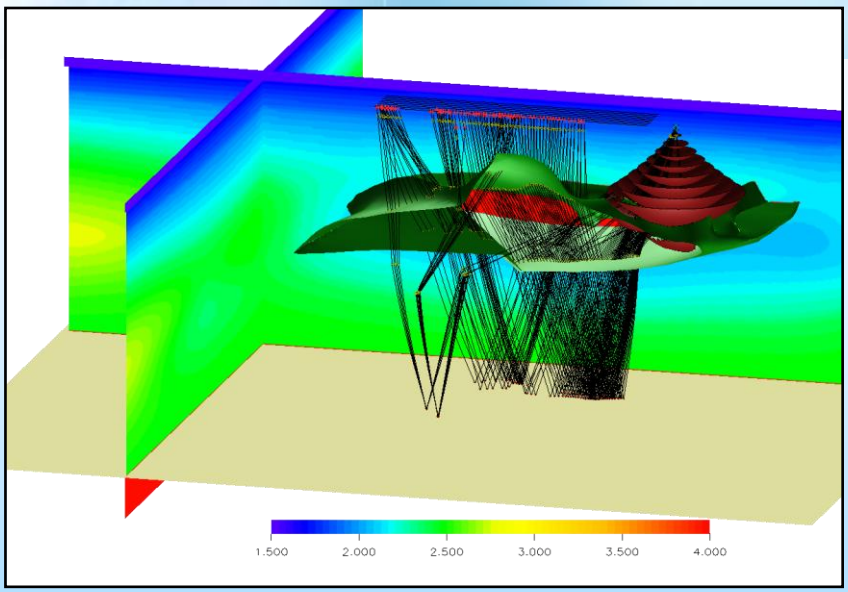
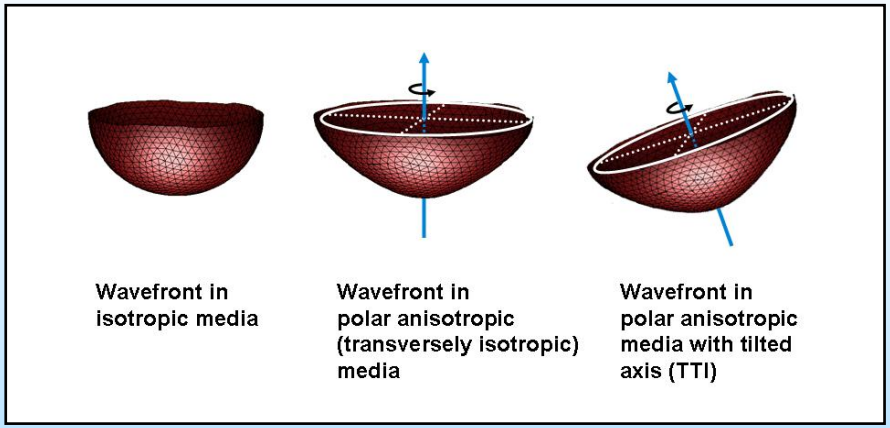
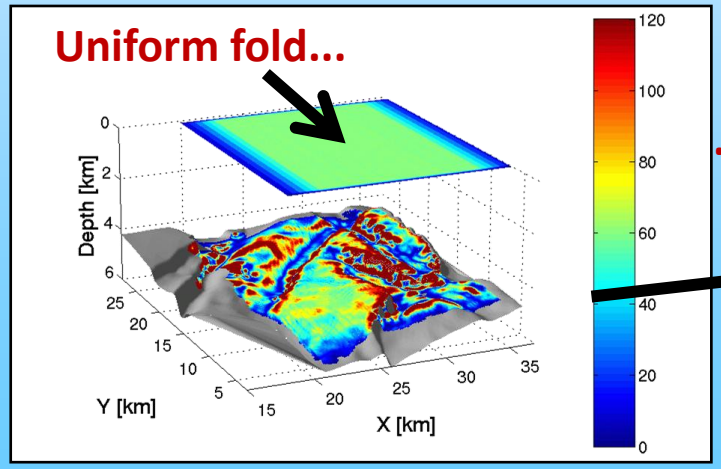
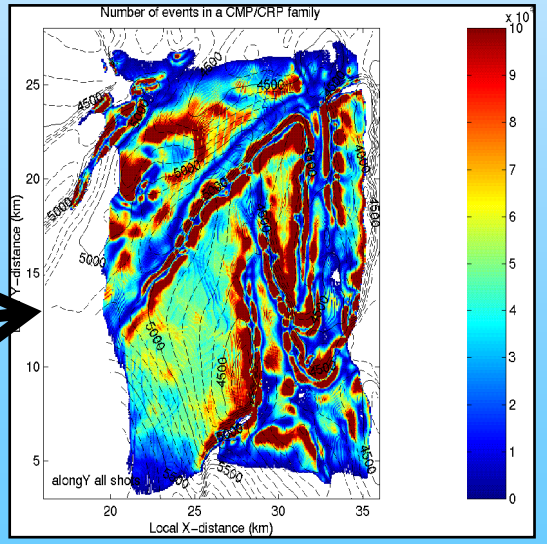
3D ray-tracing examples







...but non-uniform illumination!



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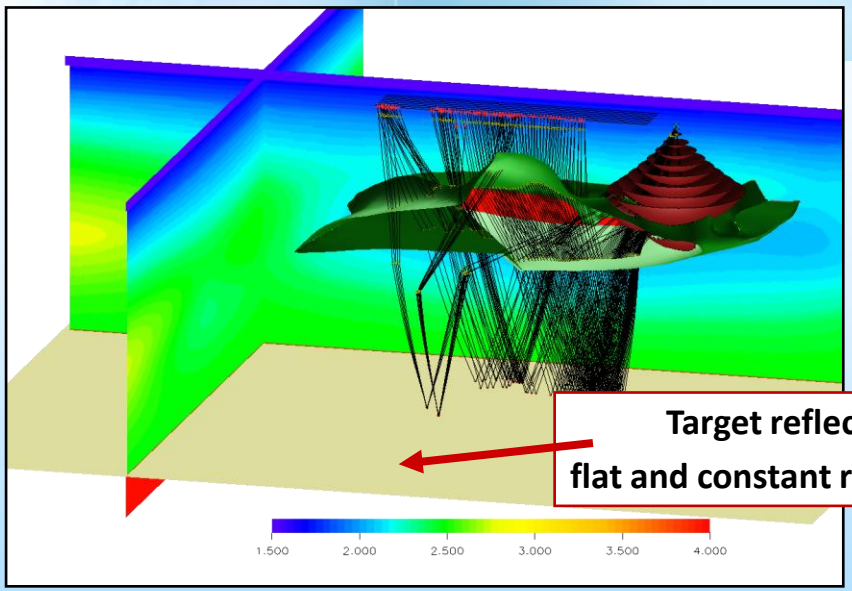
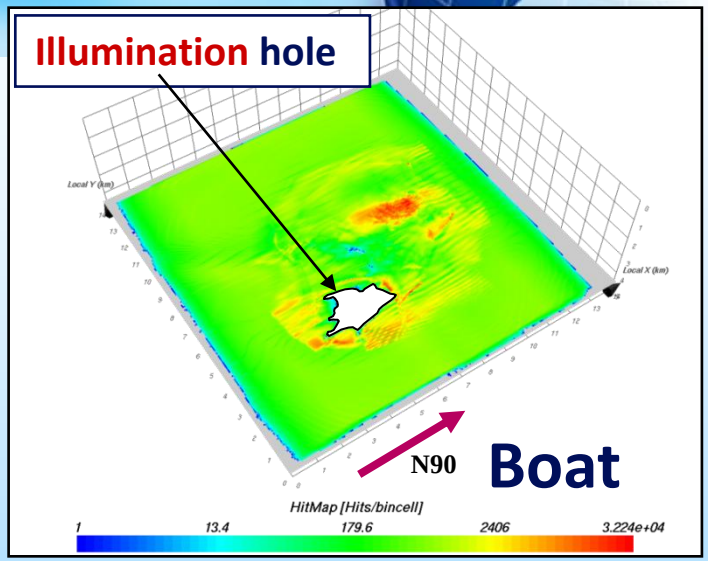
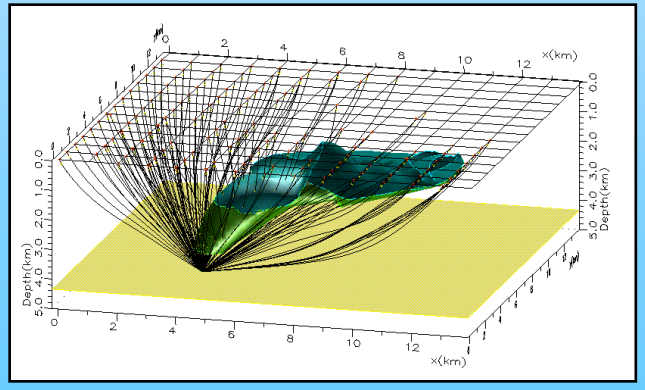
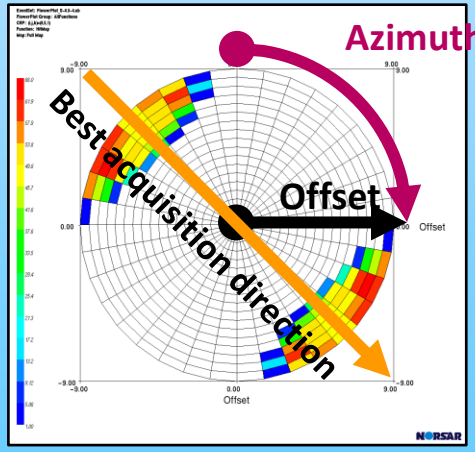
Illumination and survey planning

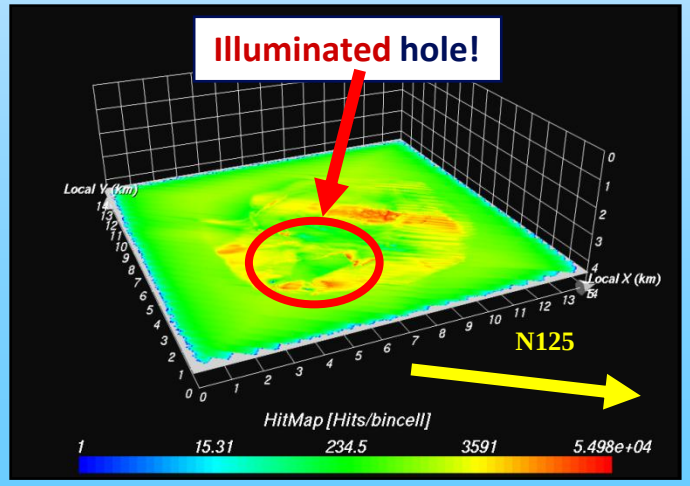




Ray-based illumination analysis







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Salt illumination for industry

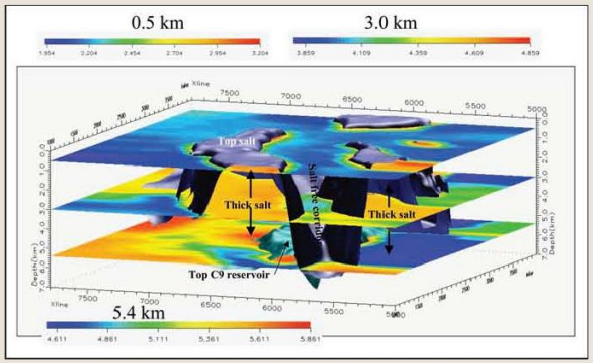

Figure 6. Final 3D velocity-depth model. For clarity only three slices from the velocity cube are displayed with Top evaporite and top C9 reservoir interfaces. Note the high-velocity values within the salt body. The salt-free areas (corridors) have much lower velocity. The scale bars show velocity ranges at each depth.

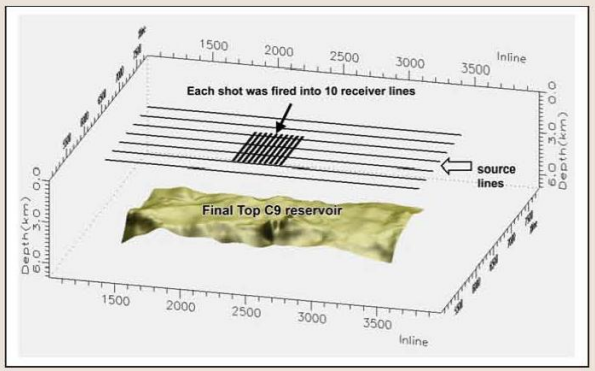

Figure 7. Survey configuration. For clarity, only every fifth source line is shown. The 35 receiver lines and 32 source lines result in 14 000 stations and 19 200 source points. Each shot was fired into a full spread of 10 receiver lines (with 160 receivers per line). Note, even after editing and smoothing, Top C9 reservoir still shows varying topography (ridges, peaks, troughs, etc.).

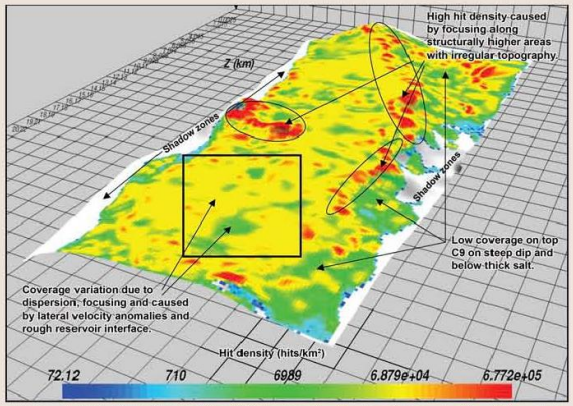

Figure 8. Hit density for Top C9 reservoir, illustrating considerable variation in illumination coverage. Note the illumination holes and shadow zones on the steeply dipping parts of the interface.

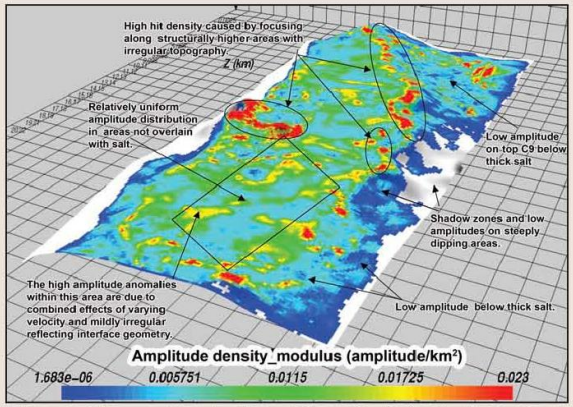

Figure 9. 3D perspective view for top C9 amplitude density illustrating coverage variation associated with overburden structures and irregular reservoir interfaces.

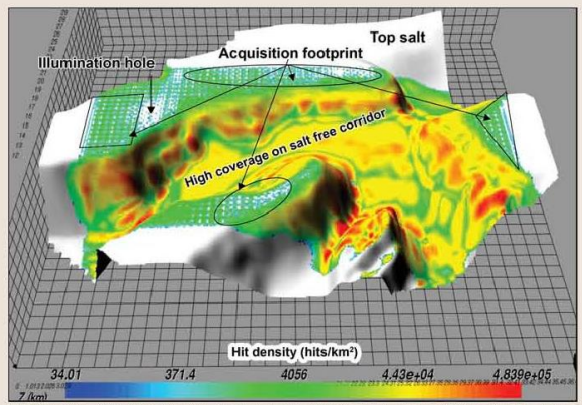

Figure 15. Hit density for the top salt. Observe the acquisition footprint, the low coverage, and the illumination holes on the shallow section and the good coverage within the salt-free corridor.

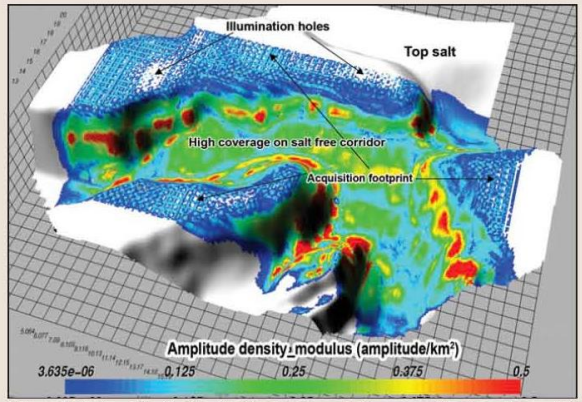

Figure 16. Amplitude density for the top salt. Low amplitude and acquisition footprint are quite noticeable on the shallower parts of the top salt. Good coverage within the salt-free corridors is very evident.

From Ibrahim, The Leading Edge, September 2005

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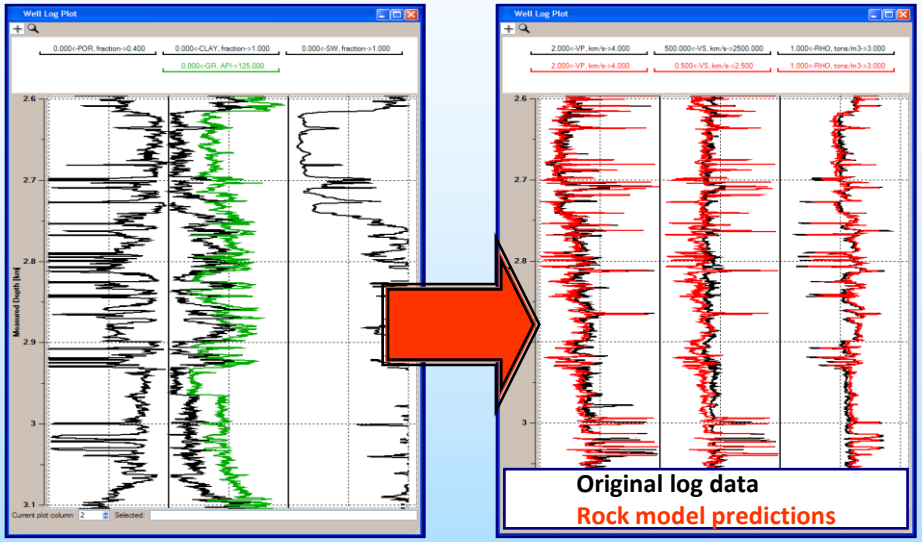
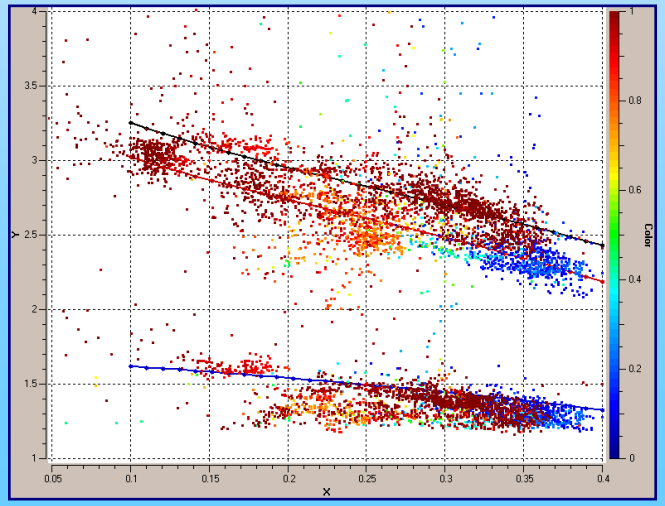
Rock Physics

- **Prediction of geophysical properties in wells and models:**
  - Data / model validation.
  - Lithology / fluid / pressure substitution.
  - Production scenario testing.
- **Calibration and validation of rock physics parameters by well logs.**
- **Rock-physics model-assisted analyses of well log data.**
- **and more…**
- **Used in VelRock and SeisRoX.**





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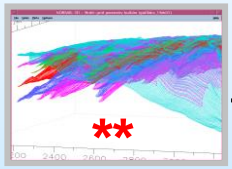
SeisRoX – our latest baby

Target (Eclipse, etc) *

*Storvola model courtesy of the Statoil-sponsored SVALEX project

**Gullfaks model courtesy of Statoil

Interpretation



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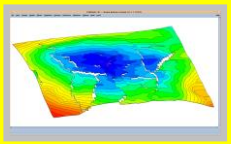
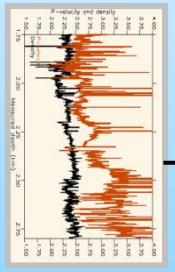
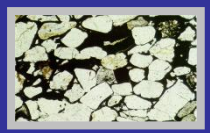
Horizons Attributes



Well Analysis

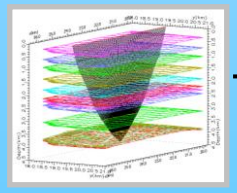


Rock Physics

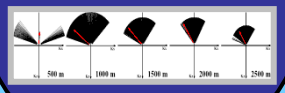


Survey Background model

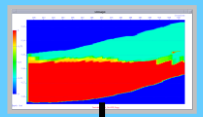
Ray Tracing



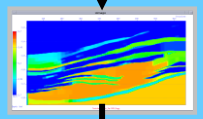
Illumination vectors



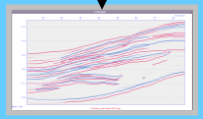
SeisRoX Multidomain Modelling



Geologic

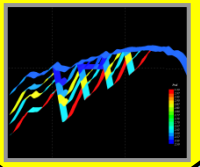


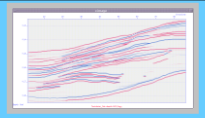
Elastic



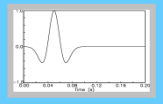
Reflectivity

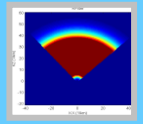
N2D/N3D models





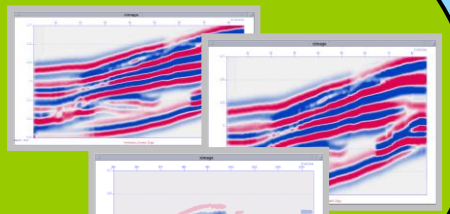
SimPLI*: PSDM simulator





*Norway patent 322089, US patent 7,376,539

PSDM Cubes 4D, attributes, etc.



Depth/Time

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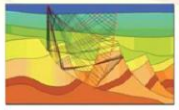
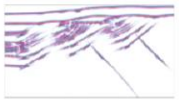
Seismic Modelling Software

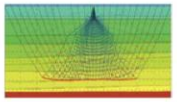
NORSAR-2D



Ray Path Analysis: Improve your understanding of ray coverage within a target area. Includes interactive re-ray tracing functionality.



Synthetic Seismic: Full elastic simulation of seismic data (PP, PS & SS, multiples, diffractions, etc.), including shot gathers, unmigrated and time-migrated sections.



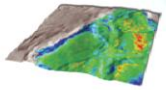
Seismic Event Analysis: Uses 2D wavefront construction method, includes anisotropy and provides detailed analysis of event attributes.

Also available in the NORSAR Seismic Modelling Software Suite

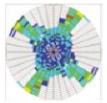
NORSAR-3D: Survey Planning, Illumination Analysis, PSDM Traveltimes, Infill Analysis

SeisRoX: 4D Studies, Reservoir to Seismic, Seismic Simulations, Rock Physics

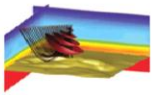
NORSAR-3D



Illumination Analysis: Create advanced illumination and simulated migration amplitude maps to assess target coverage.



Survey Planning: Simulate full 3D seismic surveys including **COIL**, **WAZ**, **VSP** and **OBS** in addition to conventional Land and Marine surveys.



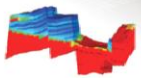
PSDM Traveltimes: Calculate multi-arrival traveltimes and amplitudes using TTI anisotropy to improve prestack depth migration.

Also available in the NORSAR Seismic Modelling Software Suite

NORSAR-2D: Ray Coverage, Multiple Analysis, Time-Depth Studies, Event Attributes

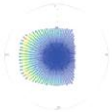
SeisRoX: 4D Studies, Reservoir to Seismic, Seismic Simulations, Rock Physics

SeisRoX



Reservoir to Seismic: Bridge the gap between the reservoir and seismic by coupling advanced rock physics with PSDM simulation.

4D Feasibility and Analysis: Improve your history match by including the illumination and resolution effects of the survey and overburden.



Imaging Feasibility: Generate PSDM data for multiple acquisition designs. Maximise your ROI in a fast, flexible and accurate manner.

Also available in the NORSAR Seismic Modelling Software Suite

NORSAR-2D: Ray Coverage, Multiple Analysis, Time-Depth Studies, Event Attributes

NORSAR-3D: Survey Planning, Illumination Analysis, PSDM Traveltimes, Infill Analysis

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MICRO-SEISMICS

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Micro-seismicity

- **Micro-seismic research at NORSAR since 2001:**
  - **Combine long experience in detection seismology with seismic modelling tools.**
  - International academic cooperation.
  - Industry sponsors include Statoil, ConocoPhillips, BP, Sonatrach, Lundin, etc.
  - R&D results implemented in general software tool called "**MIMO**".

Why?

- change of stress field.
- **change of pore pressure.**
- change of load.

Analyses of micro-seismic data has the potential to:

- image the internal structure of the subsurface (faults, fractures).
- **monitor fluid pressure-front movements.**
- identify regions of reservoir compaction.
- map thermal fronts.
- **provide input for production optimization.**
- provide input for hazard mitigation.

UNIS CO2 Lab Park

Where?

Induced micro-seismicity:

- **hydrocarbon reservoirs.**
- **geothermal reservoirs.**
- **subsurface gas storage.**
- Mines.
- Dams.

Natural micro-seismicity:

- active tectonic regions.
- Volcanoes.
- cliffs/steep slopes.

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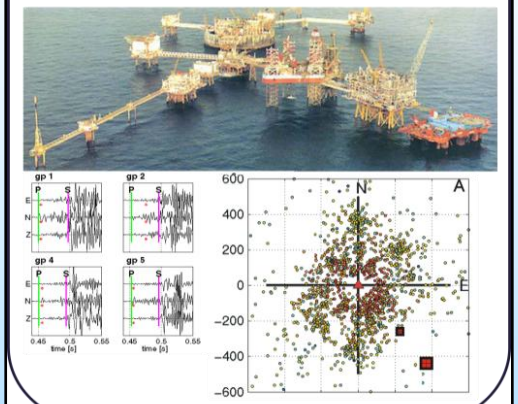
Micro-Seismic experience

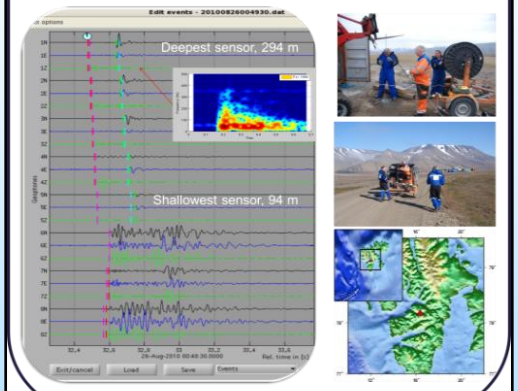
Oilfield monitoring

Passive Seismic Monitoring of Offshore Oil Field



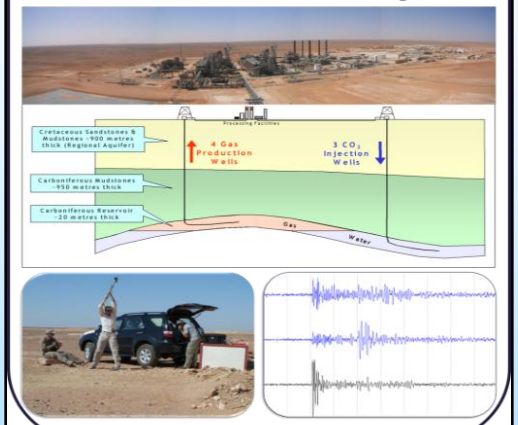
CO2

Feasibility for CO2 storage at Longyearbyen, Svalbard, Norway



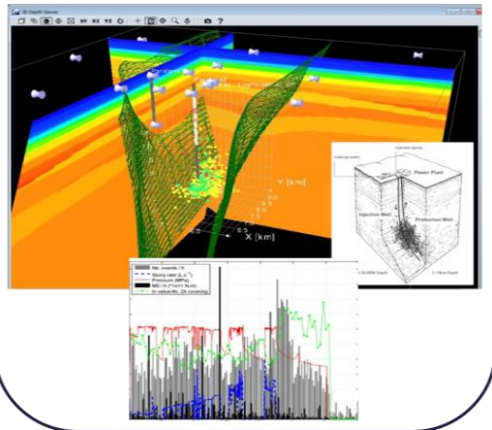
CO2

Monitoring of CO2 injection at Krechba Field, In Salah, Algeria



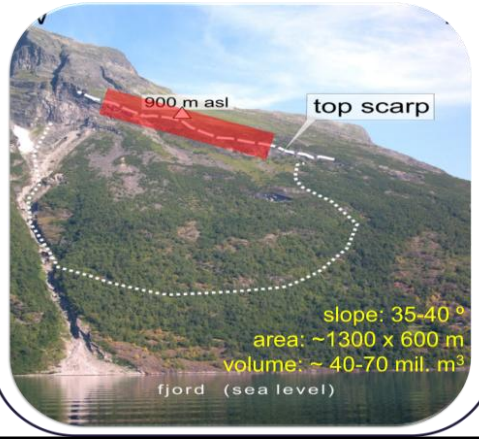
Geothermal

Monitoring hydraulic fracturing in Geothermal System, Australia



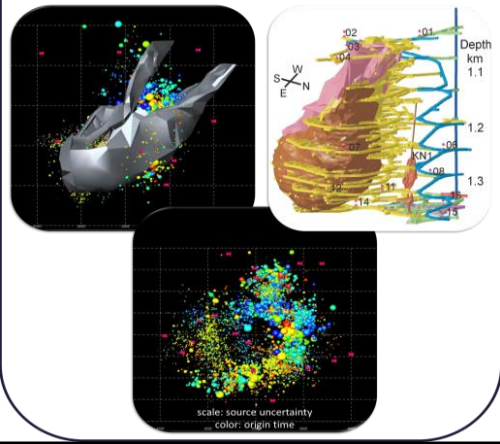
Geohazards

Monitoring of instable rock slope at Åknes, Norway



Mines

Safety monitoring of mining operations, Finland



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«MIMO» software

Real-time data processing

Event detection

+

Arrival times of seismic phases

+

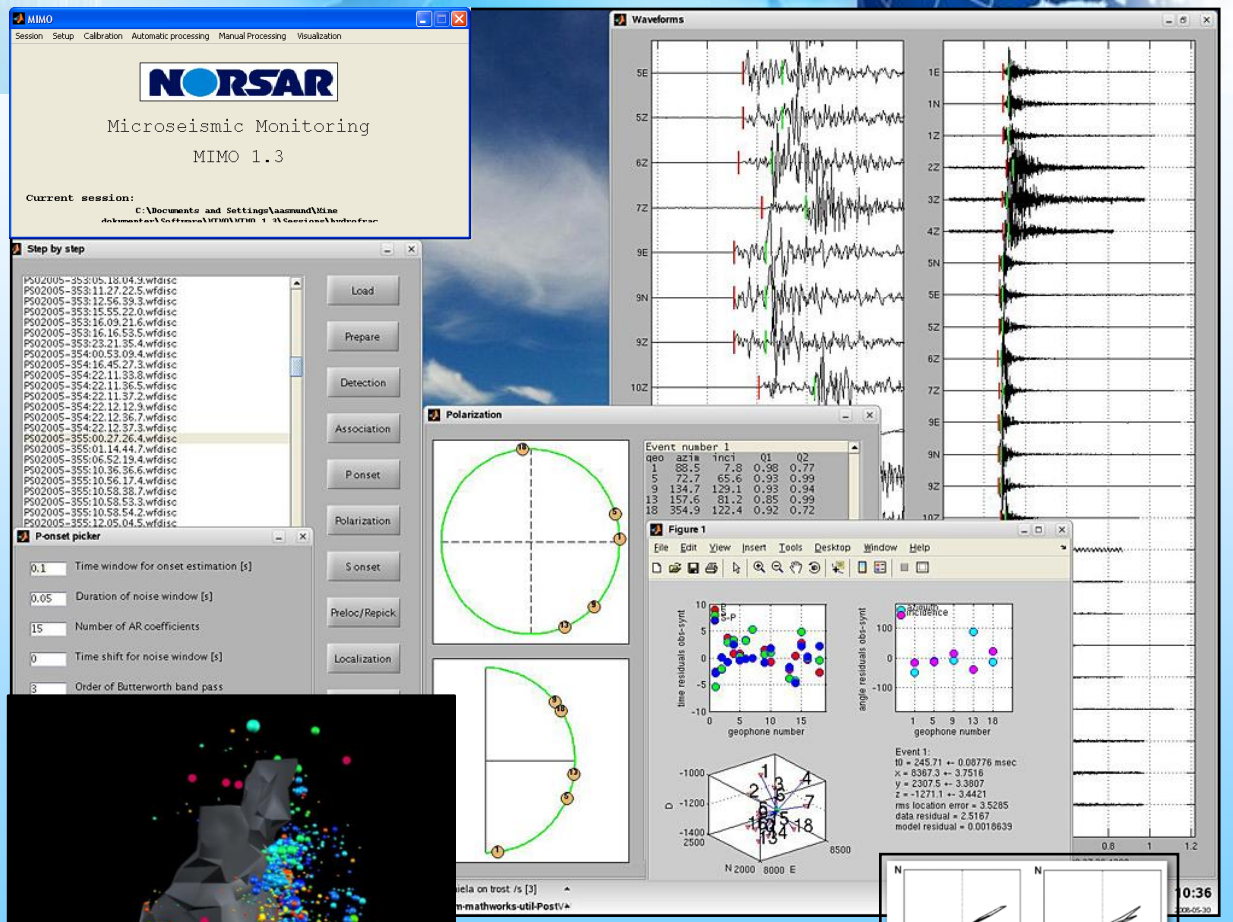
Polarization angles

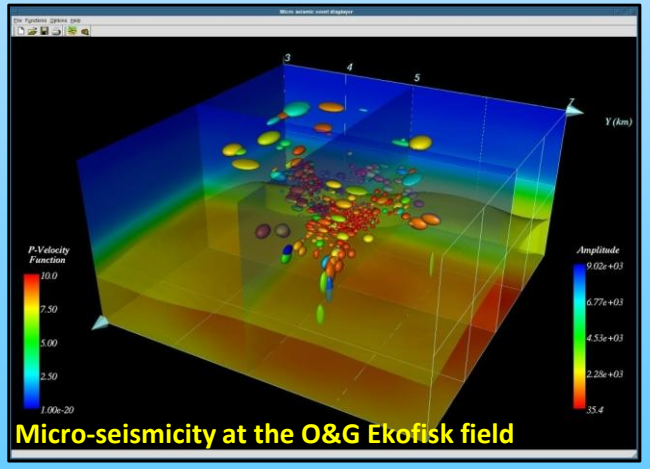
+

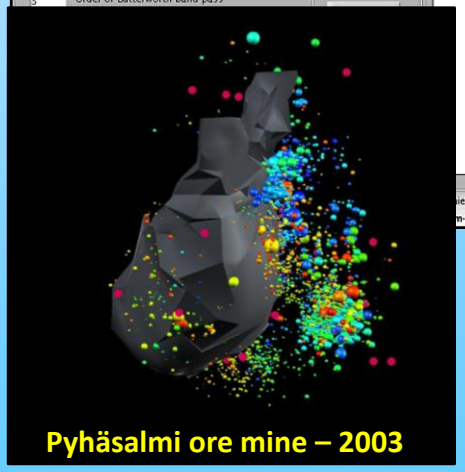
Velocity model (homog/**3D**)

=

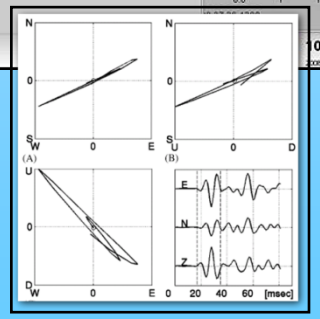
Event location + origin time







Polarization analyses with 3-C geophones



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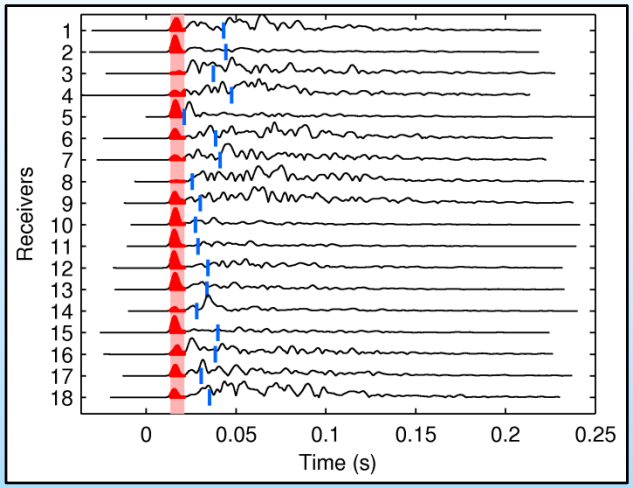
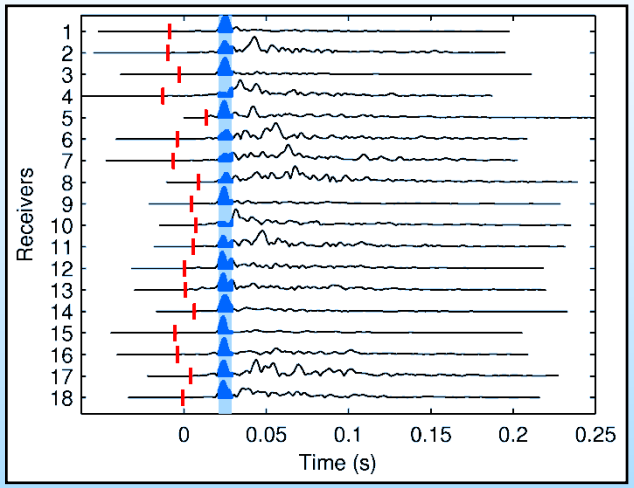
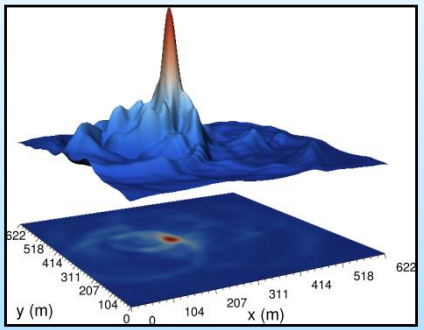
Migration-based location method

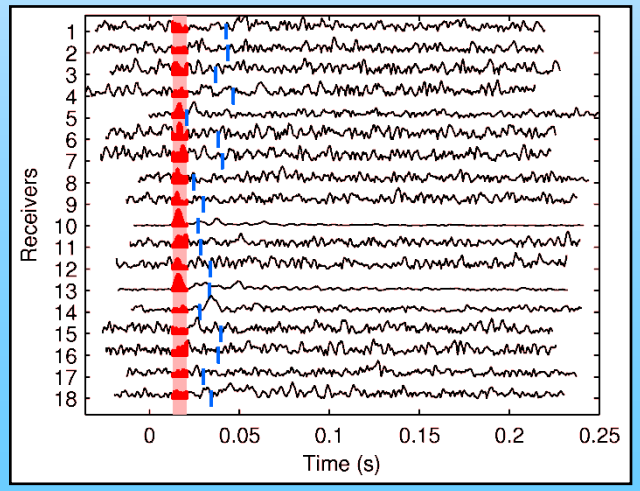
Advanced location methods for weak micro-seismicity (oilfield, CO2 storage, etc).

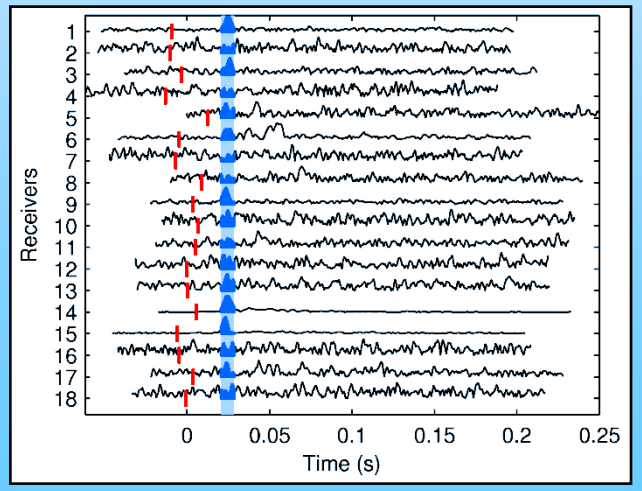




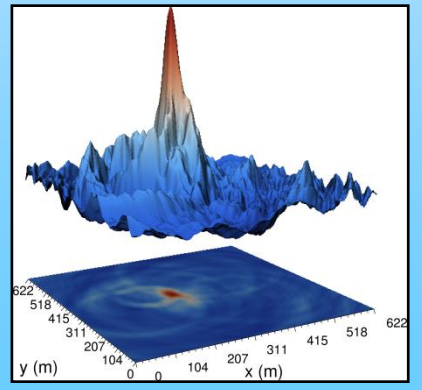
No noise







High-noise case



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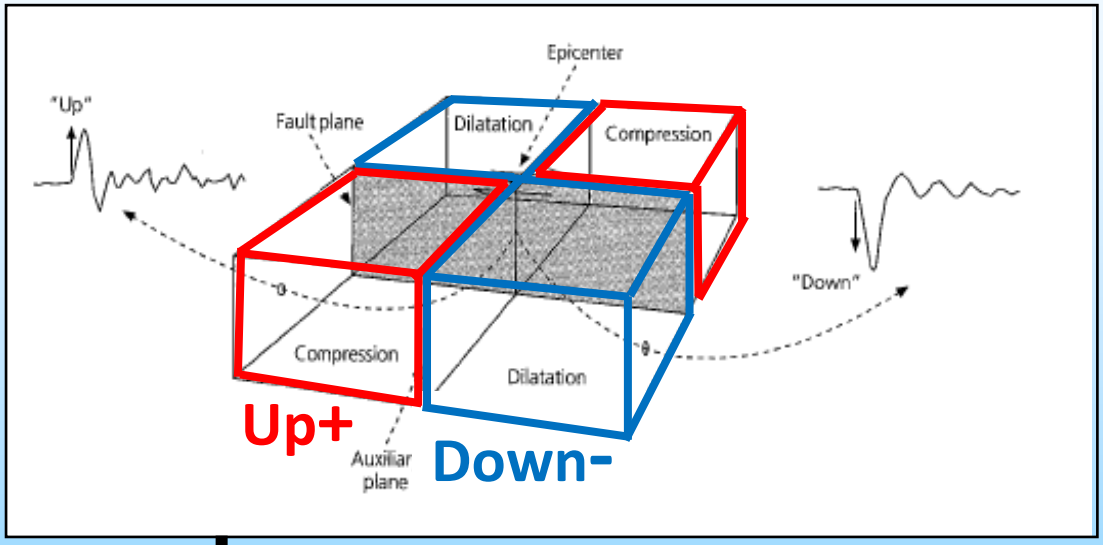
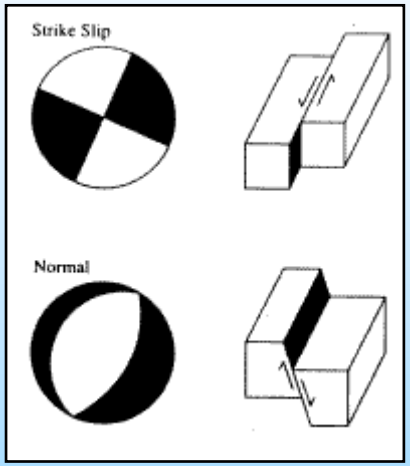
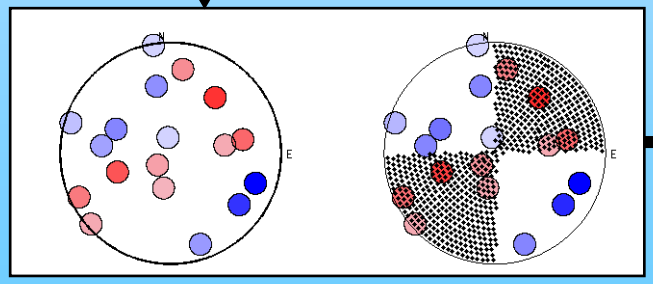
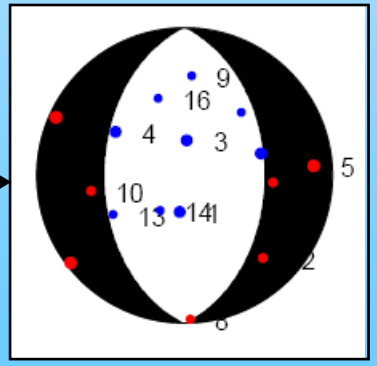
Source mechanisms

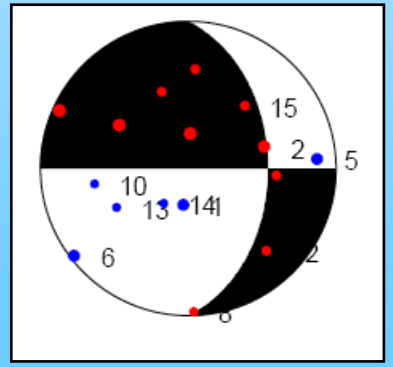
Source mechanisms, if retrieved, tell something about fracturing in reservoir.











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CONCLUSIONS

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On-going and future research

- **Further integration of micro-seismic and seismic modelling competency.**
- **Efficient routine processing of dense arrays (e.g., permanent oilfields, CO2 storage, etc).**
- **Efficient/accurate micro-seismicity location of weak events.**
- **Stress-field modelling.**
- **More S-waves in seismic modelling, as both needed for micro-seismics (e.g., source mechanisms) and O&G exploration/4D (e.g., converted waves, etc).**
- **More anisotropy in seismic modelling (TTI and P-wave per today).**

... And much more! All ideas are welcome!

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Students and academia/institutes

- Many students stay at NORSAR for summer jobs, masters, and PhDs. **Important resource in research** (**if funding available!**). Other academic visitors (EU-funding, etc).
- **Regular postdoc. positions** (**project-based**; several permanent NORSAR employees started as postdoctoral fellows).
- **Cooperation with Norwegian Universities**:
  - 1 adj. prof. at UiB, 1 assoc. prof. at UiO; 1 UiB prof. 20% NORSAR.
  - Teaching, master and PhD supervising; software for education/research.
  - **Research and industry projects**. Staying in touch with basic research.
- **Cooperation with Norwegian Institutes**:
  - **NGI**, **NGU**, **NR**, **IFE**, etc.
  - **Research and industry projects**.
- **International cooperation** with universities, research institutes and governmental agencies.

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NORSAR and industry

- **A necessity:**
  - **Funding...**
  - **To know the problems to solve.**
  - **To stay in touch with «real life».**

- **But not always easy for a small institute!**
  - **Important to know the key contacts (but they move a lot...).**
  - **Industry partners are more and more required for research-project applications.**
  - **Confidentiality issues preventing research publications.**
  - **...but we are still judged on publication rate (NFR).**

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Acknowledgements

- NORSAR slide materials from:
  - **Anders Dahle, NORSAR Foundation CEO.**
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  - **Volker Oye, micro-seismicity program manager.**

Thanks for your attention!

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