
Nucleus is a modular software package designed for a wide range of applications in seismic exploration. The full advantage allowing the simulation of almost any acquisition scenario is gained through the close integration of:

- the different modelling methods
- the various subsurface model representations
- the flexible survey definition and vessel configurations and
- the unique combination of marine source modelling with seismic wavefield modelling.

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Module categories & general concept

Survey Design:
- **Marine Source Modelling**: realistic airgun array signature including ghost effects, source & receiver directivity and recording instrument filter.
- **Marine Survey Planning**: target oriented analysis of directivity, azimuth & offset effects, stack response and 3D reflection point coverage analysis.
- **Wavelet Analysis**: 1D time series analysis.
- **Noise Analysis**: realistic modelling of interference, weather and/or white noise.

Seismic Modelling:
- **1D Reflectivity modelling**: marine & land, VTI anisotropy, AVO inversion, linked with PetroTools.
- **Visco-elastic Finite Difference modelling**: 2D & 3D, variable spatial operators, source & receiver directivity, OBS mode.
- **2D Raytracing General Model** (uses NORSAR2D).
- **3D Raytracing General Model** (uses NORSAR3D).
- **3D Raytracing Plane Layers**: efficient 3D seismic data generation for P-waves, includes diffractors.

Utilities:
- **PetroTools by Solid Rock Images** (PetroSoft).
- **JRock Rock Physics Diagnosis**: Java-based interactive cross-plotting, specialised for rock physics.
- **Seismic Data Processing**: interactive 2D seismic processing, data comparison and analysis.
- **Data Handling**: file handling and format conversion.

Seismic Modelling = Subsurface Model + Survey + Vessel with Source Array

Survey types:
- **Streamer surveys**: point, line or area; using streamer vessel (option for streamer feathering, asymmetric spread and overlap shooting); line direction and alternating sail lines.
- **Streamer survey definition based on real navigation data** (e.g. PI/90) via Data Handling.
- **Fixed cable surveys**: Vertical hydrophone cables (VC), OBS and Dragged Array survey to be combined with separate shooting vessel (vessel without streamer).
**Marine Source Modelling (MASOMO)**

- Core module for modelling of the source signature and 3D directivity of arbitrary marine airgun arrays based on the notional source concept.
- Based on an extensive calibrated test data library for different airgun types and volumes measured at different depth and pressure.
- After modelling of the notional source signatures for a specified array (gun types, pressure, geometry, depth, instrument filter), the 3D array response is available as source signal for seismic modelling in other modules.
- Extensive recording instrument filter library including total system response filter for Syntrak 16-bit and 24-bit system.
- Automatic drop-out modelling and analysis based on standard peak-peak, primary/bubble ratio and correlation coefficient criteria and frequency.
- Stability and filter performance analysis.
- User defined filter library.
- Continuously updated with new gun and recording filter types.

**Application:**
Marine airgun array design, marine source specifications including drop-out specifications, farfield generation, analysis of source and receiver directivity.

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**Wavelet Analysis (WAVANA)**

- Interactive time series analysis based on workfiles.
- Synthetic wavelet generation: Band-pass, low-pass, high-pass & notch filter, Ricker wavelet, earth filter, ghost filter, vibroseis sweep, etc.
- Wavelet transformations: Zero and minimum phase equivalent, normalisation, resampling, phase shift, deconvolution and shaping filter, convolution, correlation.
- Data maths for individual spectral transformations or difference analysis.
- Wavelet comparison in time and frequency domain.
- Frequency versus time analysis (sweep analysis), amplitude and phase versus time, overlay plots.
- Import of Nucleus and ASCII formatted data (single trace).

**Application:**
Comparison analysis of different time series. Designature and shaping filter design. Synthetic source signature generation for modelling.
3D Raytracing Plane Layers (PMOD3D)

- Dynamic raytracing and seismic modelling in 3D plane layer model with variable dip and diffractors for shot, CMP and zero-offset geometry.
- PP-reflections, multiples and diffracted events. Model import/exchange from 1D Reflectivity module, e.g. blocked soniclog.
- Synthetic seismogram generation including optionally geometrical spreading, elastic reflection and transmission losses, absorption, source & receiver directivity; option for adding white noise.
- Display of travel times, ray paths and reflection points for primary, multiple and diffracted events.

In development:
- Extension to PS-converted reflections and diffractions.
- 3D CFP (common focusing point) analysis for PP and PS wavefields.

Application:
Simulation of various realistic acquisition scenarios, wide tow analysis, strike versus dip acquisition analysis, generation of large volume synthetic data sets for test processing.
Marine Survey Planning (MASUPL)

Based on 3D Raytracing Plane Layers. Simulation and analysis of PP-reflections including source & receiver directivity, geometrical spreading, reflection/transmission loss, absorption, model-based NMO and stretch mute.

Analysis methods (target horizon oriented):

- Streamer feathering: Influence on velocity analysis and NMO stack response (2D binning).
- Bin size expansion: Comparison of stack response for different bin sizes assuming random cross-line offset distribution within bin.
- Directivity effects: Compare emitted (prestack) wavelet for different inline and cross-line offsets in time & frequency domain.
- NMO effects: Compare (post-) stack response at different cross-line offsets in time and frequency domain.
- Angle and AVO analysis: Comparison of source emission & azimuth angles, spreading factors, incidence angles, reflection/transmission amplitude factor for all defined inline and cross-line offsets.
- NMO/DMO stack response: Cross-line stack responses for given horizon, source array, survey & vessel geometry are compared in time, amplitude and phase domain; 3D data cube, navigation data based surveys.
- Reflection point fold in 1D model for PP- & PS-converted waves.
- Reflection point fold analysis for all survey, calculates target horizon fold, minimum & maximum offset, offset range, offset and azimuth distribution; detailed offset and azimuth distribution.

In development:

- Reflection point fold analysis for shear and converted waves.
- DMO fold analysis.
- Artefact modelling.
- Wavefield regularisation.

Application:

Model-based survey planning for streamer surveys. Wide tow analysis. Reflection point coverage on defined bin grid for all survey types.
1D Reflectivity Modelling (RMOD1D)

- Full wavefield modelling including converted waves, internal and surface multiples, refractions, thin layer effects.
- Includes inline source directivity for marine arrays, line or point source spreading characteristic.
- Uses 3D horizontally layered model: Vp, Vs, density, Qp, Qs and optional VTI anisotropy.
- Interactive model exchange between 3D plane layer model and 1D model for comparison studies.
- Model import and blocking from LAS data format.
- Streamer, OBS, VC, VSP and land acquisition geometries.
- Link to rock physics software PetroTools and JRock for reservoir characterisation and time lapse studies based on fluid substitution.
- AVO analysis and inversion for PP and PS converted waves, angle range stacking.
- Zöppritz reflection coefficients and layered target response in time & frequency domain.
- New: Rapid AVO Modeler (RAM) for fast evaluation of optimal cross-plot domains for a given rock property contrast with specified uncertainty. Theoretical AVO attributes as well as derived (i.e. linearised least square estimation) can be analysed.

Application:
Realistic modelling of full wavefield including multiples, e.g. based on well log data. Multiple or penetration issues. Interference of refracted or converted waves with primaries. Seismic monitoring feasibility studies through link to PetroTools or JRock.

JRock Rock Physics Diagnosis

- Interactive colour coded cross-plot analysis.
- Input file format: tab-separated ASCII columns.
- Linked to 1D Reflectivity model format.
- Generic data maths & transformations, de-spiking, differentiation and integration.
- Elastic moduli, velocity, impedance, Poisson’s ratio.
- Fluid substitution using Gassman formula.
- Reference data sets with rock physics core data from Stanford Rock Physics consortium for Han’s data, Jizba’s tight gas sandstones, Troll & Oseberg.
- Theoretical and empirical rock physics model curves showing M, K, G, Vp, Vs, Ip, Is versus porosity for Critical porosity, Contact cement, Constant cement, Unconsolidated, Han, Raymer, Marine sediments models.
- Vp-Vs relations: Castagna, Castagna & Greenberg.
- Vp-density relations: Castagna, Krief, Gardner.

In development:
Time-depth conversions, calculation of anisotropy parameters, geophysical survey planning equations (resolution, aliasing, migration distance).

Application:
Rock diagnosis based on log data. Derivation of rock physics transformations for reservoir monitoring feasibility studies. Fluid substitution. General event analysis, e.g. detailed 3D illumination analysis for raytracing results for NMOD2D/NORSAR2D or SMOD3D/NORSAR3D event listings.
Visco-elastic Finite Difference Modelling (FDMOD)

- 2D & 3D FD scheme of variable order in space and 2nd order in time using optimised parameters on a staggered grid.
- 8 Modelling modes: from acoustic constant density (only Vp needed) to fully visco-elastic (Vp, Vs, Rh, Qp and Qs needed)
- Generation of shot gathers or zero-offset sections (i.e. exploding reflector geometry).
- Automatic time-step adjustment according to stability condition and QC procedure for numerical dispersion.
- Local model concept, optional free surface condition.
- Parallelised and optimised executable for SGI O-2000.
- Interactive model builder (same as for 2D Raytracing General Model module) with automatic model scanner for generation of gridded subsurface models.
- Includes source & receiver directivity via modelled notional sources in MASOMO.
- Source type: explosive or directional force.
- Arbitrary source & receiver positions in gridded model.
- Simultaneous modelling of streamer, OBS and VC surveys.
- Automatic OBS mode for undulating sea floor.
- Batch job modelling capability.
- Wavefront snapshot movies for pressure, horizontal and vertical acceleration and shear motion.
- Synthetic seismograms for pressure, horizontal and vertical particle velocity components.

In development:
- 2D & 3D elastic reverse-time migration.
- 2D anisotropic elastic reverse-time migration.
- 1D & 2D anisotropic modelling.

Application:
Seismic modelling in very complex subsurface structures, analysis of wave propagation through wavefront snapshots, generation of realistic synthetic seismograms for processing tests.
2D Raytracing General Model (NMOD2D)

- NORSAR2D raytracer including all extensions
- Integrated in Nucleus using the common survey & vessel modelling concept.
- Seismogram generation with full source & receiver directivity.
- Fast and flexible Model Builder, horizon and property pre-processing as well as digitisation of SEG-Y seismic sections.
- Common Shot Raytracer for streamer surveys: two-point raytracing, integrated with Nucleus’ survey/vessel/source array concept and source and receiver directivity; OBS/Dragged array profiling through projection of shots or receivers on interface.
- Zero Offset Raytracer (NIP rays) to simulate unmigrated stacked section.
- Zero Offset Raytracer (image rays) to simulate migrated section.
- VSP Raytracer: two-point raytracer, shots and/or receivers along arbitrary well trajectory, can be used for VSP, VC and OBS geometry.
- Shot Direction Raytracer: initial value raytracing.
- Green’s Function Wavefront Tracer using wavefront reconstruction technique; wavefront snapshots.
- Option to project shot or receivers onto interfaces.
- Detailed interactive ray event analysis through Event Handler for Evaluation of offset and coverage in 2D complex model.
- Velocity Estimator for interval velocity estimation from stacking velocities using NIP or image rays.

New tools:
- Depth Mapper for constrained time-depth conversion.
- Anisotropic Ray Mapper (ARM) for anisotropic pre- and poststack kinematic modelling and map migration.

Application:
3D Raytracing General Model (SMOD3D)

- NORSAR3D raytracer with all extensions
- Integrated in Nucleus using the common survey & vessel modelling concept for all survey types.
- Seismogram generation with full source & receiver directivity.
- General 3D wavefront tracer in 3D complex subsurface model.
- Model built from complex 3D surfaces, e.g. from a seismic interpretation station or Gocad surfaces.
- Easy extension of 2D model from 2D Raytracing General Model to 2.5D model.
- Raytracing for P- and S-waves, multiples and converted waves.
- Shot gather and NIP zero-offset wavefront raytracer.
- Option to project shot or receivers onto interfaces.
- Event and reflection point analysis.
- 3D reflection point analysis for PP- and PS-waves in complex models including overhangs (3D binning).

Application:
Noise Analysis (NOISEGEN)

- Simulation of different noise components for given vessel geometry including recording instrument filter.
- Shot gather, CMP gather or stacked data (with specified mute).
- Interference noise for specified vessel speed, shot interval, direction and randomised firing time, based on measured reference database.
- Weather noise at specified level, based on measured database.
- White noise at specified level.

Application:

Seismic Data Processing (RECPRO)

- Interactive 2D seismic processing tool with basic functionality: spherical divergence correction, filtering, (de-) convolution and correlation, CMP sorting, velocity analysis, NMO correction with stretch mute, stacking, poststack migration (forward and inverse).
- Data transformation between t-x, f-x and f-k domains.
- Generation of synthetic data with spikes or dipping interfaces for decimation tests via forward and reverse migration.
- Data maths for simple data manipulation and comparison.

Application:

Data Handling (DATAIO)

- Seismic data conversion from/to SEG-Y, tape scanning utility.
- Import of navigation data in P1/90, P1/84 or SPS format for seismic modelling.
- Combining navigation data lines to "Collection setup" for DMO stack response.
- Customisation of default parameters, seismic data plotting.
- File handling of Nucleus format files.

Application: