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MEMORANDUM

Acoustic Models at SACLANTCEN

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Acoustic Models at SACLANTCEN

H.G. Schneider

Abstract: The Environmental Modelling Group at SACLANTCEN maintains a suite of computer codes to model sound propagation in the ocean. This suite contains numerical models to cover all environmental conditions and acoustic frequencies of interest at the present time. New models will be added if requested or as they become available to supplement the existing ones. Any specific model has its range of applicability in the domain of acoustic and environmental parameters as well as with regard to computer facilities and time. This document aims to provide a brief characterization of the programs, and thus to give the potential user an overview of the capabilities currently available. However, to run any of these models the user will have to resort to the original User Manuals. The models covered are: COUPLE, FEPE, GRASS, GSM, KRAKEN, MOCASSIN, PAREQ, SAFARI, SNAP and those included in the respective program packages. Additional auxiliary programs CONTUR, FIPPLOT, and PULSEPLOT for displaying the modelling results and integrating them with other data are also described.

Keywords: acoustic models ∘ COUPLE ∘ FEPE ∘ GRASS ∘ GSM ∘ KRAKEN ∘ MOCASSIN ∘ PAREQ ∘ SAFARI ∘ SNAP

Contents

Introduction

A large number of numerical models is currently available for the computation of the acoustic field (or a function thereof) for various combinations of ocean-acoustic and geo-acoustic parameters. In 'A Survey of Underwater Acoustic Models ...', Etter et al. (1984) list 45 propagation loss models, 22 noise models and 14 active sonar models, excluding the large number of operational models, and many new developments have appeared since.

The SACLANTCEN Environmental Modelling Group (EMG) currently maintains a carefully selected subset of such models, representing the current state-of-the-art, to meet the specific needs of the scientific staff at the Centre. This task has in the past required the development and validation of models as well as work to increase their numerical efficiency and to adapt the input and output to the specific environment of the Centre.

As new models are acquired, either from outside or as in-house developments, these are integrated into the current set and made generally available. This can lead to the replacement of models by updated versions or entirely new approaches. Models no longer required will be dropped from the current suite but may be reinstalled on request. The same holds for additional output options which are frequently requested to facilitate the further processing of the modelling results.

This memorandum briefly describes the present set of models to give an idea of the scope of the physical phenomena that can be treated; it also contains a summary of some auxiliary programs of general interest. As new models become available, similar information will be distributed. This information should be sufficient to begin the selection of a specific model for the task or set of environmental parameters under consideration. Having done that, the user should consult one of the documents listed under the heading *User Manual* for that model, to run the computer code.

The mathematical derivation of most of the models as well as a large variety of examples illustrating the capabilities of the models may be inferred from Jensen et al. (1994), which is the most recent and most complete treatment of numerical modelling in underwater acoustics [see also Etter (1991) and Harrison (1989)]. Some other reports which deal with intermodel comparisons are also listed in the references.

There will be no general distinction between shallow-water and deep-water models; because of the growing interest in still lower frequencies, the terms deep and shallow water must be reconsidered. It is the relationship between acoustic wavelength and water depth, as well as the more or less continuous and strong interaction of sound with the ocean bottom that determines which term is appropriate.

Similarly, there is no explicit distinction between low- and high-frequency models as might be expected considering low-frequency global propagation and short-range minehunting. The only difference in the acoustic modelling of these extremes of propagation is their sensitivity to the different oceanic processes involved, which usually depends on the acoustic wavelength. However, it should be noted that models used for long-range propagation tend to compute the medium attenuation as a function of horizontal range only, which is an inadequate approximation if the code is used for very high frequencies where the range is less than or only a few water depths.

A short indication of where the models are most conveniently used is given in Table 1.

Table 1 *Characterization and most common use of the models*

Wave number integration techniques	
SAFARI =	Exact solution of the forward wave equation for range-independent environments including elastic bottoms; needs experience
Normal mode solutions	
COUPLE	Exact normal mode solution of the two-way wave equation, serves as international benchmark solution
C-SNAP	Coupled normal mode program for range-dependent environments; easy to use
SNAP	Normal modes program for adiabatically changing environment; easy to use
KRAKEN	Set of normal mode codes, main use similar to SNAP but for 3D environments including horizontal refraction; relatively easy to use
Parabolic wave equation solutions	
FEPE	Set of finite element PE codes for range-dependent environments, including back-propagating waves
PAREQ	Range-dependent split-step PE model including reverberation; relatively easy to use
Ray tracing solutions	
BELLHOP	Geometric beam tracing from the KRAKEN package (range-independent) for transmission loss and ray diagrams; easy to use
GRASS	General range-dependent ray code for incoherent transmission loss and ray plots
GSM	Most general sonar assessment and performance model for range-independent environments; needs experience to set up
MOCASSIN	Ray-based incoherent transmission loss and sonar performance model with stochastic sound speed variability; easy to use

Table 2 *Features of propagation models*

Method	Model	Range depen.	Elast. Bottom	3-D	Re-verb.	Plot package FIP	Plot package own	PULSE PLOT
WI	SAFARI	−	+	−	−	+		+
Mode	COUPLE	+	−	−	+g	+		+
	C-SNAP	+	+b	−	+s	+		+
	SNAP	+a	+b	−	−	+		+
	KRAKEN	+a	+b	+	−		+	
	KRAKENC	+a	+	+	−		+	
PE	FEPE	+	−	−	−	+		+
	FEPES	+	+	−	−	+		
	FEPE2WAY	+	−	−	+g	+		
	PAREQ	+	−	−	+s	+		+
Ray	BELLHOP	−	+b1	−	−		+	
	GRASS	+	+b1	−	−		+	
	GSM	−	+b1	−	+s		+	own
	MOCASSIN	+bp	+b1	−	+s	+	+	

+, yes; −, no; +a, yes, but with restrictions as given below: a, adiabatic approximation (slowly-changing environment); b, not included in mode shape; but accounting for the losses; b1, only losses (if included in the table of reflection loss); bp, for bottom properties (water depth and bottom type); g, geophysical feature scattering; s, generic scattering function for backscatter.

Table 2 gives some basic features of the various models. There are three groups of wave models (based on wave number integration, normal modes, or solutions of the parabolic wave equation), and one group of ray-based models. Most of the models are capable of dealing with range-dependent environments (third column) at least for an adiabatic dependence. Many codes take into account the transmission loss of the compressional waves, caused by the excitation of shear and interface waves in the bottom, but only SAFARI, KRAKENC and FEPES also propagate these shear and interface waves (fourth column). Horizontal refraction, important for three dimensional problems, is covered by two models using Gaussian beams horizontally and local normal modes vertically to describe the sound field (fifth column). Reverberation is either computed via direct scattering of the sound from a geophysical feature provided with the environmental input data, or by using generic scatter functions (sixth column). Not all models have been adapted to the standard plotting package, because they provide their own software (seventh column).

Most of the models use the standard plotting packages FIPPLOT and CONTUR. To solve broadband problems, Fourier synthesis of many frequencies is usually applied, and for this the auxiliary program PULSEPLOT is used. GSM has its own integrated pulse processor.

A brief summary of output options available in a model is given in Table 3. Several graphical output options are generated with the auxiliary programs FIPPLOT,

Table 3 *Output of propagation models*

Output	SAFARI	COUPLE	SNAP	KRAKEN/C	FEPE/-S/-2WAY	PAREQ	GRASS	GSM	MOCASSIN
Standard[1]	✓	✓	✓	✓	✓	✓	✓	✓	✓
Reflection loss, phase	✓								
Particle velocities	✓								
Transform integrand	✓			✓					
Dispersion curves	✓		✓						
Range stacked pulses	✓	✓	✓		✓	✓		✓	
Depth stacked pulses	✓	✓	✓		✓	✓		✓	
Normal mode functions		✓	✓	✓					
Arrival angles			✓					✓	
Backward propagating field		✓			✓				
Reverberation			✓		✓	✓		✓	✓
Ray plots							✓	✓	
Active signal excess								✓	✓
Eigenray parameters								✓	
Pulse correlations								✓	
LOFAR diagram								✓	
ROC curves								✓	

[1] Standard output options are lists and plots of the input data and the computed pressure field in terms of transmission loss versus range or depth and loss contours.

CONTUR and PULSEPLOT, and since important new features have been added to the auxiliary programs since the last documentation, it seemed appropriate to include up-to-date documentation in this report.

A word of caution is necessary at this point. Running any one of these advanced models is rarely successful without some general experience in modelling, and some familiarity with the specific model applied. In most cases the computer code will output the required variable (such as, for example, transmission loss versus range) even if the combination of input parameters (acoustic, environmental, computational) is not consistent and may thus lead to a solution which may not even be physically realistic. Some models need to be run with varying computational parameters to obtain evidence of the successful convergence to a stable result, etc. This memorandum will hint at some of the known problems, but will not reproduce the guidelines given in the model documentation. Instead, whenever possible, reference is made to the original literature. [Massi (1988) presents some useful detailed notes in this context.]

Table 4 *Models available on PC*

Models from the VAXcluster	
C-SNAP	Also SNAP
MOCASSIN	Also includes a ray trace plot (GE)
OASES	Version of SAFARI from MIT, restriction in FFT size
Models from other mainframes	
ASTRAL	Ray-mode approach for range-dependent environments and low frequencies (less than 1000 Hz); US Navy model for very long ranges
FACT	High-frequency ray model for deep water (US); the numerical kernel is also available in GSM
PE	A split-step PE for deep water (i.e. for insignificant bottom interaction)
RAYMODE	Range-independent approach using both rays or modes
Models designed for PC	
ALMOST	Range-independent sonar performance model; linked to a historical database for sound-speed profiles (NL)
HODGSON	Range-dependent ray model with corrections for lower frequencies; linked to a historical database for sound-speed profiles and bottom loss (UK)

There are other sound propagation models currently in use at the Centre which are not included in this memorandum. One example is the FINDIF code by Stephens (Woods Hole) which is an exact time domain solution of the wave equation using finite differences and has been used to study scattering and reverberation. Another is the IFDPE code of Lee and Botseas (NUWC) which is an implicite finite difference solution of the parabolic wave equation. Also worthy of mention is the normal mode-based shallow-water reverberation model of Ellis (DREA) which is currently being developed to also include the effects of bistatic geometries as well as horizontal and vertical line arrays.

In this memorandum each model or model package is briefly summarized in a standardized way; the models are dealt with in alphabetical order: COUPLE, FEPE, GRASS, GSM, KRAKEN, MOCASSIN, PAREQ, SAFARI and SNAP.

How to run these models All models may be executed at the Centre on the VAX cluster using a common command structure. On-line information on this structure as well as on the structure of the input files to be prepared by the user is available for each model (in the file `AAA.EMG`).

PC models At present, the number of acoustic models available for personal computers (PCs), is rapidly increasing, mostly due to the increased computing power of these devices. Some of the above-mentioned models have been sucessfully converted to PC format or were, in fact, written for the PC. The Centre has acquired a package of PC models from the US as well as models from the UK, the Netherlands and

Germany, and all models have been exercised against a common set of test problems (see Dreini et al.). The PC models and some comments are listed in Table 4.

References

Dreini, G., Isoppo, C., Jensen, F.B. (In preparation). PC-based propagation and sonar prediction models. La Spezia, Italy, NATO SACLANT Undersea Research Centre.

Etter, P.C. (1991). Underwater Acoustic Modelling. London, Elsevier Applied Science. [ISBN 1-85166-528-5]

Etter, P.C., Deffenbaugh, R.F., Flum, R.S. (1984). A survey of underwater acoustic models and environmental-acoustic data banks, ASWR-84-001. Washington, DC, Department of the Navy, Anti-Submarine Warfare Systems Project Office.

Harrison, C.H. (1989). Ocean propagation models. *Applied Acoustics*, **27**, 163-201.

Jensen, F.B., Kuperman, W.A. (1979). Environmental acoustical modelling at SACLANTCEN, SACLANTCEN SR-34. La Spezia, Italy, NATO SACLANT Undersea Research Centre.

Jensen, F.B., Kuperman, W.A. (1982). Consistency tests of acoustic propagation models, SACLANTCEN SM-157. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1982. [AD A 115 666]

Jensen, F.B., Kuperman, W.A., Porter, M.B., Schmidt, H. (1994). Computational Ocean Acoustics. New York, NY, American Institute of Physics. [ISBN 1-56393-209-8]

Massi, R. (1988). A guide to the use of some sound propagation models available at SACLANTCEN, Working Paper. La Spezia, Italy, NATO SACLANT Undersea Research Centre.

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COUPLE

Coupled normal modes

Synopsis Fully range-dependent wave theory model based on the expansion of the wave equation into normal modes. In a range-dependent environment either the one-way or the full two-way coupling equations are solved for different boundary matching conditions. This is the benchmark solution for range-dependent conditions which also provides the backward propagating field.

Environmental Input Parameters Sound-speed profile in the water and sediment at various ranges, but only one sediment density and attenuation.

Output Plots and lists of coherent transmission loss (TL) versus range, TL vs. depth, TL contours vs. depth and range.

Limitations

Applicational None.

Computational

- The number of discrete normal modes is proportional to frequency and water depth, thus for high frequencies (kHz) in deep water a large number of modes will require large storage and long running times.
- Execution time is also proportional to the number of range increments.

Convergence

- The user has to specify a range increment for updating the environment and matching the fields at those ranges. A series of decreasing increment sizes should indicate when a stable solution is reached.
- The running time will increase linearly with the number of range increments.

Other Models For range-dependent environments the following models could also be used for most practical applications: C-SNAP, FEPE and PAREQ. However COUPLE is the only solution of the full wave equation which also uses the backward propagating waves components to match the boundary conditions at the vertical interfaces of the changing conditions. FEPE does this for the parabolic wave equation, while C-SNAP and PAREQ use only the forward travelling part.

Description Solves the wave equation in the farfield approximation as local expansion into a complete set of depth-dependent orthonormal functions (i.e. normal modes), *including* continuous modes. The bottom properties cannot be elastic. The range-dependent environment is approximated by a sequence of range-independent intervals. COUPLE then uses the backward propagating wave components to correctly match the boundary conditions at the vertical interfaces created by the changing environmental conditions. The user has to specify the length of those range intervals (or increments) and will require a sequence of runs with decreasing interval lengths to ensure convergence to a stable result. The boundary conditions may be matched for either the pressure or the reduced pressure.

User Manual

Evans, R.B. COUPLE: a user's manual, NORDA TN 332. Stennis Space Center, MS, Naval Ocean Research and Development Activity, 1986. [AD B 106 858]

References

Evans, R.B. A coupled mode solution for acoustic propagation in a wave guide with stepwise depth variation of a penetrable bottom. *Journal of the Acoustical Society of America*, **74**, 1983: 188-195.

FEPE

Finite element parabolic equation

Synopsis Fully range-dependent wave theory model based on the parabolic approximation of the wave equation solved by finite element methods allowing large propagation angles. This set of codes also includes solutions for pulse problems, FEPE_SYN by Fourier synthesis, as well as by a direct time domain solution TDPE. The code FEPE2WAY also computes the backward travelling field and FEPES is the full elastic version of FEPE.

Environmental Input Parameters (at various ranges) Sound-speed profile in the water and bottom sediment, depth-dependent sediment density and attenuation.

Output Plot of bathymetry versus range, plot of sound speed, density and attenuation vs. depth, transmission loss (TL) vs. range, TL contours vs. depth and range; additionally for FEPE2WAY – backward propagating field as TL contours vs. depth and range, and for TDPE – contours of pressure vs. depth and time at various ranges, signal time series at a receiver.

Limitations

Applicational None.

Computational The acoustic field is computed with a depth spacing of the order of $\Delta z \leq \lambda/10$ and range stepsize of $\Delta r = (4 \text{ to } 5)\Delta z$. Hence simultaneous large water depths and high frequencies will tend to exceed the available mesh size and/or will result in prohibitively long execution times.

Convergence An absorbing layer at maximum depth has to be supplied by the user, to avoid reflections from down below. The number of Padé approximations used depends on the steepness of the propagation angles and bottom slopes involved, usually values from 1 to 3 are sufficient. Repeated runs with decreasing Δz are initially required to ensure convergence. For rapid horizontal changes in the environment, FEPE2WAY occasionally diverges.

Other Models For range-independent environments SAFARI or KRAKENC give the same solution. Range-dependent conditions and non-elastic bottoms may also be run with COUPLE. For range-dependent conditions and non-elastic bottoms the fully coupled version of SNAP (i.e. C-SNAP) or PAREQ for moderate propagation angles will serve the same purposes.

Description The parabolic approximation of the wave equation is numerically solved by finite element methods where the square root propagator has been expanded into a Padé series. This is then also accurate for large propagation angles, depending on the number of Padé terms included (usually ≤ 3, maximum available is 7). Mesh sizes in depth Δz and range Δr are typically $\Delta z \leq \lambda/10$ and $\Delta r = (4-5)\Delta z$. The FEPE codes contain an energy conservation correction for range-dependent environments, i.e., they match the boundary conditions at a vertical interface regarding forward and backward travelling wave components. Only FEPE2WAY propagates the backscattered energy. Backscattering due to bottom inhomogeneities, etc., may be modelled by FEPE2WAY entering the scattering geometry and impedance changes directly into the input data. TDPE solves the PE for a pulsed source directly in the time domain (i.e., no Fourier synthesis). TDPE marches a time and depth window of acoustic pressure data out in range; the window translates in time as the solution is marched in range so that the outgoing signal remains within the window. The selfstarter fulfills the boundary conditions of the environment at range r_0 as do modes, but does not require a solution of the modal eigenvalue problem. All these programs solve for either a point source in cylindrical geometry, or a line source in plane geometry.

User Manual

Collins, M.D. FEPE user's guide, NORDA TN 365. Stennis Space Center, MS, Naval Ocean Research and Development Activity, 1988. [AD B 128 889]

References

Collins, M.D. Time domain solution of the wide angle parabolic equation including the effect of sediment dispersion. *Journal of the Acoustical Society of America*, **84**, 1988: 2114-2125.

Collins, M.D. Benchmark calculations for higher order parabolic equations. *Journal of the Acoustical Society of America*, **87**, 1990: 1535-1538.

Collins, M.D. Higher order Padé approximations for accurate and stable elastic parabolic equations with applications to interface wave propagation. *Journal of the Acoustical Society of America*, **89**, 1991: 1050-1057.

Collins, M.D., Evans, R.B. A two way parabolic equation for acoustic backscattering in the ocean. *Journal of the Acoustical Society of America*, **91**, 1992: 1357-1368.

Tollefsen, D. Some tests of the FEPE acoustic propagation model. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1990.

GRASS

Germinating ray acoustic simulation system

Synopsis Fully range-dependent ray acoustic sound propagation model for ray paths and incoherent intensities. Takes sound speed or CTD information and generates the sound-speed field by horizontal interpolation (depth and range) and extrapolation (depth).

Environmental Input Parameters Salinity/temperature or sound-speed profile in the water at arbitrary ranges, surface loss parameter, medium attenuation, bottom loss versus grazing angle tables, bottom depth at arbitrary ranges.

Output Plot and list of sound-speed profiles versus depth and range. Plot of ray paths, transmission loss vs. range and as depth/range contours.

Limitations

Applicational Restricted to ray acoustics. The coherent summation of energy should not be used, since no phase corrections are applied.

Computational None.

Convergence The iteration is controlled by the step sizes along the ray arc and sound-speed accuracy parameters which have to be adapted to the problem.

Other Models For ray paths in a range-dependent environment this is the only model available. For transmission loss computations under these conditions, PAREQ, C-SNAP and FEPE may also be used. Ray paths in range-independent environments may also be created by BELLHOP from the KRAKEN package or by GSM.

Description The model is restricted to the domain of ray acoustics. The program creates a sound-speed field with second-order continuous derivatives and uses a local iterative predictor/corrector method to trace the rays. This requires the maximum and minimum step size along the ray arc to be tuned as well as the tolerable sound-speed accuracy epsilon. Three types of energy summation are available, addition of intensities (i.e., completely incoherent), coherent addition of energy, and a weighted mean for the incoherent intensities over depth around the receiver depth. The coherent summation should not be used since no phase corrections neither at the bottom nor at caustics are applied.

User Manual

Dreini, G., Isoppo, C. Implementation of GRASS, a ray-tracing and transmission loss prediction system, on the SACLANTCEN computer, version E. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1982.

References

Cornyn, J.J. GRASS: a digital-computer ray-tracing and transmission-loss-prediction system, volume 1 – overall description, NRL Report 7621. Washington, DC, Naval Research Laboratory, 1973. [AD 781 230]

Cornyn, J.J. GRASS: a digital-computer ray-tracing and transmission-loss-prediction system, volume 2 – user's manual, NRL Report 7642. Washington, DC, Naval Research Laboratory, 1973. [AD 778 925]

GSM

Generic sonar model

Synopsis Range-independent sound propagation and sonar performance evaluation model based on eigenrays (choice of 5 different approaches). Most complete sonar assessment model – covers everything from transmission loss to active signal excess, pulse correlations and LOFAR-grams (built-in broadband capability). The model contains a multitude of sub-models (51) for easy parameterization of environmental conditions and sonar characteristics.

Environmental Input Parameters Temperature or sound-speed profile in the water, attenuation, surface and bottom reflection models or tables as well as for forward-, back- and volume scatter, and also ambient noise spectra input as model or table.

Output Plots and lists all input data or tables as functions of either frequency, angle, or depth. Plots ray diagrams, eigenray levels versus range, source- and target angle, pressure vs. frequency or range, reverberation vs. elapsed time or frequency, auto- and cross-correlation of pulses vs. time delay and time-stacked vs. range, pulse shape vs. time, active or passive signal excess vs. range or frequency, range and bearing errors vs. range, LOFAR diagrams, filter equalizer vs. frequency or vs. frequency and range, ROC curves and probability of detection.

Limitations

Applicational Only for horizontally invariant environments, for shallow-water applications the low-frequency limit is given by the RAYMODE propagation model.

Computational May require large increased page fault access, sometimes heavy on storage.

Convergence The list of eigenrays may also contain 'virtual' eigenrays which are generally of low energy and may be confusing. The parameter `EIGENRAY TOLERANCE` should be adjusted to the problem.

Other Models For transmission loss, any wave model could be used. As far as signal excess and other integrated sonar quantities are concerned, this is the only model with this capability. MOCASSIN gives some combined results for shallow water, but has far fewer options. For ray diagrams see also KRAKEN/BELLHOP and especially GRASS which is for a range-dependent environment.

Description The model is restricted to environments independent of range (horizontal layers). Surface and bottom are treated via reflection coefficient models. For the sound propagation part the user may chose one of 5 eigenray models (Multi-Path Expansion, FACT, Generate Eigenray Model, RAYMODE, AMOS) The Multi-Path Expansion uses generalized ray theory and does well at low frequencies. FACT is an extremely fast deep water ray model. The Generate Eigenray Model is not documented. RAYMODE as a combination of rays and normal modes is supposed to be also valid for shallow water. AMOS is an outdated empirical model and should no longer be used.

The model contains a multitude of sub-models (51) for easy parameterization of environmental conditions and sonar characteristics. Many parameters have default values, if not specified by the user, which may be different from expectation; e.g. the default is not a plane earth geometry but the real earth radius. (The most recent version F with bistatic reverberation is now also available at the Centre, and will be assessed later.)

User Manual

Weinberg, H. Generic sonar model, NUSC TD 5971D. Newport, RI, Naval Underwater Systems Center, 1985. [AD B 095 689]

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Spofford, C.W. The FACT model, volume I, MC–109–VOL–I. Washington, DC, Maury Center, 1974. [AD A 078 581]

Weinberg, H. Application of ray theory to acoustic propagation in horizontally stratified oceans. *Journal of the Acoustical Society of America*, **58**, 1975: 97-109.

Yarger, D.F. The user's guide for the RAYMODE propagation loss program, NUSC TM 222-10-76. Newport, RI, Naval Underwater Systems Center, 1976.

KRAKEN

Normal mode program

Synopsis Wave theory model based on the expansion of the wave equation into normal modes including elastic bottoms, adiabatic range-dependence and 3D geometries. In contrast to SNAP the shear in the ocean bottom is treated exactly (KRAKEN-C). The horizontal refraction is modelled with Gaussian beams. Additionally the package contains a ray/beam program (BELLHOP), a fast field program (SCOOTER), a pulse model (SPARC) and a reflection coefficient model (BOUNCE).

Environmental Input Parameters (at various ranges) Upper halfspace followed by layers and a lower halfspace; all take pressure and shear speed as well as attenuation and density. At the upper halfspace under-ice scatter (Twersky) may be included, at both halfspaces the boundaries my be rough and the halfspace information may be substituted by complex reflection coefficients.

Output Plots of sound-speed profiles, transmission loss (TL) versus range, TL vs. depth, TL contours vs. depth and range, normal mode functions vs. depth, Green's function, triangulation of the 3D area, additionally from BELLHOP – ray paths, and SPARC – depth and range stacked pulses and snapshots of the field.

Limitations

Applicational

- KRAKEN: Source functions are to be built from modes, hence steep propagation angles at short ranges will not be covered.
- In the adiabatic approximation only small changes in oceanographic parameters are allowed.

Computational

- The number of discrete normal modes is proportional to frequency and water depth, thus for high frequencies (kHz) in deep water a large number of modes will require large storage and long running times.
- For Twersky scatter the perturbative approach in KRAKEN may be much faster than the exact one in KRAKENC.

Convergence May be slow in the case of interfacial (Scholte or Stoneley) waves.

Other Models For a range-independent environment SAFARI should give the same answer. KRAKEN and SNAP actually use the same numerical techniques. For high frequencies and large water depths either **BELLHOP** or the range-dependent ray model **GRASS** could be used. For the 3D capability there is presently no other model available.

Description

KRAKEN/KRAKENC Solves the wave equation in the farfield approximation as local expansion into a complete set of depth-dependent orthonormal functions (i.e. normal modes), excluding continuous modes. The 'C' denotes the uses of a complex arithmetic, thus including the medium attenuation in the elastic layers in finding the mode functions. (The root finder for the real problem is the fast and unconditionally stable eigenvalue finding procedure of Porter and Reiss.) Any range dependence of the environment is assumed to be adiabatic (conservation of mode numbers, no coupling). For the 3D option, sets of normal modes are computed on a horizontal triangular grid and the azimuthal refraction equation (where the index of refraction is given by the horizontal wavenumber of the mode) is solved by tracing Gaussian beams.

BELLHOP Computes the sound field for a range-independent environment by geometric beam tracing, also plots the central rays.

SCOOTER Is a finite element FFP (Fast-Field Program) approach. This includes also the near field effects at the source which are difficult to obtain with normal modes.

SPARC Is a time-marched FFP (SACLANTCEN Pulse Acoustic Research Code) for broadband or transient pulses.

BOUNCE Gives the reflection coefficient versus grazing angle.

User Manual

Porter, M.B. The **KRAKEN** normal mode program, SACLANTCEN SM-245. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1991. [AD A 252 409]

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MOCASSIN

Monte Carlo stochastic sound intensities

Synopsis Sound propagation and sonar performance evaluation model based on stochastic ray tracing. Takes one sound-speed profile and varying water depth along the track. Simple sonar assessment model covers transmission loss, boundary reverberation and active signal excess.

Environmental Input Parameters Sound-speed profile in the water and stochastic variability of the profile, medium attenuation (or temperature and salinity), wind-speed (for Chapman-Harris backscatter and for loss due to bubbles), wave height, varying water depth and types of bottom reflectivity, bottom backscatter strength.

Output Plots and lists of input data (sound speed and bottom contour), transmission loss (TL) versus range or depth or as depth/range contours, reverberation vs. range, effective backscattering strength vs. range, sonar range evaluation vs. noise and reverberation, signal excess contours vs. depth and range.

Limitations

Applicational Limited to ray acoustics, one deterministic horizontally invariant sound-speed profile.

Computational None.

Convergence If the number of rays used is too small, the result will not be statistically relevant.

Other Models For range-independent environments GSM is the most complete active sonar range assessment system. For transmission loss and reverberation in range-dependent environment C-SNAP and PAREQ are good choices.

Description The model was designed to assess active sonar ranges in shallow water. It is based on ray theory and is restricted to one deterministic sound-speed profile but allows for varying bathymetry. The sound-speed profile may stochastically vary along the track, which is treated by ray diffusion. The scattering from the random rough surface also includes the off-specular components and introduces no loss. This is accounted for by absorption due to the subsurface bubbles (empirical formula). For sea-surface reverberation the formula of Chapman and Harris (see Urick) is applied, while for bottom backscattering Lambert's rule is used. The energy is computed as summation of incoherent intensities and averaged over depth intervals given by the user.

The active sonar module allows for all quantities of the sonar equation, such as noise levels, directivity indices, detection thresholds and target information to estimate the active sonar range versus noise and reverberation.

User Manual

Schneider, H.G. MOCASSIN – Sound propagation and sonar range prediction model for shallow-water environments: User's guide, TB 1990-9. Kiel, Forschungsanstalt der Bundeswehr für Wasserschall- und Geophysik, 1990.

References

Mellen, R.H., Schneider, H.G. Diffusion loss in refractive sound channels. *Journal of the Acoustical Society of America*, **62**, 1977: 1038-1041.

Schneider, H.G. Rough boundary scattering in ray-tracing computations. *Acustica*, **35**, 1976: 18-25.

Schneider, H.G. Average sound intensities in randomly varying sound-speed structures. *In*: Potter, J., Warn-Varnas, A., *eds.* Proceedings of a workshop on oceanic variability and acoustic probability, La Spezia, Italy, 4–8 June, 1990. Dordrecht, the Netherlands, Kluwer, 1991: pp.283–292. [ISBN 0-7923-1079-9]

Urick, R.J. Principles of Underwater Sound, second edition. New York, NY, McGraw-Hill, 1975. [ISBN 0-07-066086-7]

PAREQ

Split-step parabolic equation

Synopsis Fully range-dependent wave theory model based on the parabolic approximation of the wave equation. Numerical method used is the split-step marching solution allowing interpolation of environmental data with range.

Environmental Input Parameters (at various ranges) Sound-speed profile in the water and bottom sediment, one sediment density and attenuation, subbottom: compressional speed, density, attenuation; an option allows for the interpolation of the environmental input parameters in range; surface roughness for loss, backscattering strength or windspeed for reverberation from the sea surface and backscattering strength for reverberation from the bottom.

Output Plots of sound-speed profiles and contours, transmission loss (TL) versus range, TL vs. depth, reverberation vs. time, TL contours vs. depth and range, range- or depth-stacked pulses vs. time (PULSE option).

Limitations

Applicational

- Propagation is limited to angles of less than than about 25° from the horizontal and to no-shear properties in the bottom.
- To compute reverberation the water depth has to be greater than 20 wavelengths.

Computational The acoustic field is computed with an internal depth spacing of the order of ($\Delta z \leq \lambda/4$ or $\lambda/2$) for shallow or deep water, respectively. The number of depth points determines the size of the sine-transform which is executed twice each range step $\Delta r = (2 \text{ to } 5)\Delta z$ for shallow water and $\Delta r = (20 \text{ to } 50)\Delta z$ for deep water (i.e. weak bottom interaction). Hence simultaneous large water depths and high frequencies will tend to exceed the available transform size and/or will result in prohibitively long execution times.

Convergence The depth and range spacing has to be sufficiently small to give a correct result. These values should be varied for a representative example and results compared up to the maximum propagation range under consideration.

Other Models Generally FEPE or the fully coupled version of SNAP (i.e. C-SNAP) will serve the same purposes. The latter will even be faster if the environment is constant over large parts of the track and a range dependence occurs only in a small range interval. For high frequencies and large water depths the ray model GRASS could be used in a range-dependent environment.

Description The parabolic approximation of the wave equation is numerically solved using the split-step Fourier transform technique. The original version, as developed at AESD and documented by Brock, has been modified and extended to allow for range-dependence in the sound-speed structure and the water depth as well as in the bottom parameters. This now includes the option to interpolate the range-dependent parameters between two input ranges in order to avoid sharp discontinuities in range. The code further allows for the selection of either the standard Tappert-Hardin parabolic equation or the wide angle parabolic equation of Thompson-Chapman. Additionally corrections of the phase velocity may be applied as proposed by Buchal or by Pierce. The increased loss due to a Gaussian surface roughness applies the method of Moorehead et al. which was extended to also compute the reverberation from the sea surface and bottom as discussed by Schneider (1992). The bottom backscatter function follows Lambert's rule, while for the sea surface either Lambert's rule or Chapman and Harris backscatter can be activated.

User Manual

Jensen, F.B., Martinelli, M.G. The SACLANTCEN parabolic equation model (PAREQ). La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1985.

References

Brock, H.K. The AESD parabolic equation model, NORDA TN 12. NSTL Station, MS, Naval Ocean Research and Development Activity, 1978. [AD A 101 594]

Jensen, F.B., Krol, H. The use of the parabolic equation method in sound propagation modelling, SACLANTCEN SM-72. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1975. [AD A 016 847]

Schneider, H.G. Surface loss, scattering and reverberation with the split-step PE, SACLANTCEN SR-193. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1992. [AD B 171 009]

SAFARI

Seismo-acoustic fast field algorithm for range-independent environments

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Synopsis The wave equation is solved exactly for strictly range-independent but otherwise arbitrary environments, also including propagation of interface and shear waves. The package consists of three parts: FIPR to compute the plane wave complex reflection coefficient due to an arbitrary layered medium, FIP for general single frequency wave propagation, and FIPP the pulse propagation part.

Environmental Input Parameters Properties of an upper halfspace, arbitrary horizontal layers, and a lower halfspace; parameters of the halfspaces or layers are density, compressional sound speed either constant speed or constant gradient, attenuation, shear speed and attenuation, layer thickness, roughness amplitude and correlation length at the layer interface.

Outputs

FIPR Plot of the sound-speed profile, reflection loss and phase angle versus grazing angle, contour plot of the reflection loss vs. frequency and grazing angle.

FIP Normal stress (pressure), vertical and horizontal particle velocities, transmission loss vs. depth for specified receivers, depth averaged transmission loss, transmission loss as a function of range, and as range/depth contours and plots of the Hankel transform integrands.

FIPP Depth- or range-stacked pulses of pressure and horizontal as well as vertical particle velocity, dispersion curves.

Limitations

Applicational None.

Computational None.

Convergence Quotation from the user's guide concerning the selection of the integration parameters:

FIP: *A user with a reasonable knowledge of the physics of wave guide problems will – after gaining some experience – be able to determine the proper parameters relatively quickly. All problems are, however not equally easy to predict, and it is therefore advisable – also for the experienced user – to use the guidelines for estimating the integration parameters for every new application.*

FIPP: *It is obvious that the additional frequency integration . . . makes this module even more difficult to use than FIP. It is therefore important that the user be extremely confident in running FIP before trying to use the pulse model.*

Other Models The full scope of capabilities in FIP is given by the finite element FFP models SCOOTER and SPARC contained in the KRAKEN package which, however, are sparsely documented. Otherwise equivalent solutions for specific problems which do not require the full wavenumber spectrum may be obtained by SNAP, KRAKENC or the FEPE package.

Description Solves the time-independent wave equation by analytically evaluating the Green's function (the kernel of a Hankel transform) for each horizontal layer and then matching all layer boundary conditions in the global matrix approach.

FIPR To compute the reflection coefficient for plane waves the Hankel transform can easily be performed.

FIP For a single-frequency transmission loss computation the Hankel transform integral over wave number space is done by using the 'fast field' approach thereby relating the horizontal wavenumber k and range r as Fourier transform pairs ($\Delta r \Delta k = \pi / M$, where M is the number of sampling points equal to an integral power of 2. Δk has to be sufficiently small to correctly sample the Green's function from k_{min} to k_{max}; the maximum range is $R = M \Delta r$.) Note that the Green's function is depth dependent and the sampling requirements may differ with depth.

FIPP For evaluating the pulse response the standard technique of computing multiple frequencies and applying a Fourier transform over frequency is used. (Sampling $\Delta t \Delta \omega = 2\pi / N$, total time $T = N \Delta t$.)

An updated version of SAFARI which is called OASES and is a product of MIT is available on request. The upgrade concerns numerical efficiency, numerical accuracy and two new options for seismic problems. One is for transversely isotropic media and the other for frequency-dependent wave speeds in elastic media. Also the use of the code has been made more user friendly in terms of robustness and the wavenumber sampling may be done automatically.

User Manual

Schmidt, H. SAFARI, seismo-acoustic fast field algorithm for range-independent environments, user's guide, SACLANTCEN SR-113. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1988. [AD A 200 581]

Schmidt, H. OASES,version 1.6, application and upgrade notes. Cambridge, MA, Department of Ocean Engineering, Massachusetts Institute of Technology, 1993.

SNAP

SACLANTCEN normal-mode acoustic propagation

Synopsis Fully range-dependent wave theory model based on the expansion of the wave equation solution in normal modes. Range dependence of the environment is either treated in the adiabatic approximation (conservation of mode number, (programs SNAP50RD and SNAP100RD) or in the fully (one-way) coupled solution (program C-SNAP).

Environmental Input Parameters (at various ranges) Sound-speed profile in the water and sediment, one sediment density and attenuation, density, compressional speed, shear speed and attenuation in the subbottom, roughness of the sea surface and/or bottom for transmission loss.

Output Plots of sound-speed profiles and contours, transmission loss (TL) coherent or random phase versus range, TL vs. depth, TL contours vs. depth and range, normal mode functions vs. depth, arrival angle at receiver, acoustic phase vs. depth, group velocity vs. frequency, depth averaged TL vs. range or frequency, range- or depth-stacked pulses versus time (PULSEPLOT option).

Limitations

Applicational

- Source functions are to be built from modes, hence steep propagation angles at short ranges will not be covered.
- In the adiabatic approximation only small changes in oceanographic parameters are allowed, while in the fully coupled version there is no such restriction for the range dependence.

Computational

- The number of discrete normal modes is proportional to frequency and water depth, thus for high frequencies (kHz) in deep water a large number of modes will require large storage and long running times.
- In range-dependent environments the execution time is also proportional to the number of range segments.

Convergence Unconditionally stable

Other Models For a range-independent environment SAFARI or KRAKEN could also be used. For range-dependent environments FEPE or PAREQ could also be used, but will be slower if the environment is constant over large parts of the track and a range dependence occurs only in a small range interval. For high frequencies and large water depths in range-dependent conditions the ray model GRASS could be used.

Description Solves the wave equation in the farfield approximation as local expansion into a complete set of depth-dependent orthonormal functions (i.e. normal modes), excluding continuous modes. The elastic bottom properties are not used in determining the mode functions, but their influence on the transmission loss is accounted for. The prefix 'SUPER' which was used previously with SNAP and is omitted here, indicated the use of a fast and unconditionally stable eigenvalue finding procedure of Porter and Reiss. In the adiabatic approximation the conservation of wavenumber is used, while in the coupled mode solution the total incident field at the left side of the segment boundary is expanded into the normal mode basis valid to the right of the boundary. An automatic procedure has been devised by Ferla et al. (1993), which splits the range-dependent environment into range increments which are sufficiently small to yield a continuous derivative of the incoherent field with range across the segment boundary. The size of any range increment is determined by the change in the local properties of the environment. Forward propagating energy is conserved across the segment boundary, i.e. backward propagating energy as occurring in the two way solution is neglected.

In a range-independent environment C-SNAP may be even faster than SNAP because a large amount of intermediate data is now stored in memory rather than on disk files.

User Manual

Jensen, F.B., Ferla, M.C. SNAP: The SACLANTCEN normal-mode acoustic propagation model, SACLANTCEN SM-121. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1979. [AD A 067 256]

Ferla, M.C., Porter, M.B., Jensen, F.B. C-SNAP: coupled SACLANTCEN normal mode propagation loss model, SACLANTCEN SM-274. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1993.

References

Porter, M.B. The KRAKEN normal mode program, SACLANTCEN SM-245. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1991. [AD A 252 409]

CONTUR

Package for line or raster contour plots

Synopsis This package plots contours as either contour lines using the MINDIS package or raster graphics using UNIRAS. It is used by the propagation models COUPLE, FEPE, MOCASSIN, PAREQ, SAFARI and SNAP. If requested to create a plot, the acoustic model stores the data in ASCII files which then serve as input to this plotting package. The most commonly used options are `CONDR` for transmission loss plots versus depth and range, `CONFR` for loss plots vs. frequency and range and `CONSV` for sound speed contours vs. depth and range. The package is also used to display experimental data with data points not on a regular grid. For loss vs. depth and range the option is `EXPDR`, while for loss plots vs. frequency and range `CONFR` can be used.

Input Parameters These come from two ASCII files: one containing the information on the layout which has the extension `CDR`, and actual data file with extension `BDR`.

Output Plots contours as annotated lines or colour countours with a separate colour legend at the right. The output may be generated on various hardware devices and in appropriate file formats for later processing as e.g. PostScript files to be included into documents.

Description Generally some program (e.g. a numerical model) creates two files `USER.CDR` and `USER.BDR` of which the first contains all the information for the layout and the second contains the data. The plot program is either automatically executed after the modelling run, or may be started independently. Since the two files are formatted in ASCII, they are easy to manipulate to change the layout. Because the structure of these files is quite general, it may be (and has been) used for various purposes, thus avoiding the need to write new plotting programs.

The file structure will be outlined below and the various suboptions explained. Most of this is taken from the SAFARI manual, however, since numerous new sub options have been added it seemed reasonable to compile the information into one document.

Example of the file structure of the `CDR` *file*

```
PAREQ,(TC,GA),UNI,TEK,COL              IDENTIFIER,OPTIONS
CZ bottom (11,20,400,0)(1,0)d=120      TITLE ( max 80 char)
CZB.BDR                                NAME OF DATA FILE
Range (km)$                            AXIS ANNOTATION
                       0.0000          RMIN
```

```
                  70000.0000        RMAX
                      0.0000        XLEFT
                  70000.0000        XRIGHT
                     15.0000        X AXIS LENGTH IN CM
                  10000.0000        XINC
Depth (m)$                          AXIS ANNOTATION
                      0.0000        YUP
                   3000.0000        YDOWN
                     10.0000        Y AXIS LENGTH IN CM
                    500.0000        YINC
                    251.0000        NUMBER OF DATA POINTS ALONG THE X AXIS
                    101.0000        NUMBER OF DATA POINTS ALONG THE Y AXIS
                      0.0010        DIVX
                      1.0000        DIVY
                      1.0000        FLAGRC (=0 DATA STORED BY ROWS, =1 BY COLUMNS)
                      0.0000        MIN DEPTH (m)
                   3000.0000        MAX DEPTH (m)
                    250.0000        SOURCE DEPTH (m)
                    251.0000        NUMBER OF GRID POINTS ALONG THE X AXIS
                    101.0000        NUMBER OF GRID POINTS ALONG THE Y AXIS
                    100.0000        FREQUENCY (Hz)
                      0.0000        DUMMY
                      5.0000        CAY
                      5.0000        NRNG
                     50.0000        ZMIN
                    100.0000        ZMAX
                      5.0000        ZINC
                      2.0000        X ORIGIN OF PLOT IN INCHES
                      0.0000        DUMMY
                      2.0000        Y ORIGIN OF PLOT IN INCHES
                      5.0000        NSM
                      0.1000        HGTPT
                      0.1400        HGTC
                     -3.0000        LABPT
                      1.0000        NDIV
                      5.0000        NARC
                     -1.0000        LABC
                     -1.0000        LWGT
BOTTOM 1
                   0.0000000E+00    3000.000
                  60.0000           3000.000
                  62.0000           1500.000
                  65.0000           1500.000
                  68.0000           3000.000
                  70.0000           3000.000
  @EOF
```

Notes on the CDR *file* The first line starts with a 5-character identifier followed by a series of 3-character plot sub-options separated by commas. Generally the identifier is `CONDR`. In case of files generated by PAREQ the identifier is `PAREQ` and two 3-character groups are used to identify operational mode and the source funtion. (The `CDR` file created by SAFARI does not list the options used for the plot.) The following options are currently available:

General

`BIN`	The `BDR` file is an unformatted file.
`B/W`	Black and white plot (default).
`COL`	A colour raster plot is generated.
`LIN`	A line contour is produced using the UNIRAS package.
`MIN`	Using the MINDIS plotting package, producing a line contour.
`NCL`	No contour lines.
`NCS`	No colour scale is plotted.
`NWR`	No writing on the upper part of plotting frame.
`REV`	Reverse colour scale.
`ROT`	The UNIRAS plot is rotated by 90°.
`SCS`	Small colour scale is used.
`SYM`	A symmetric colour scale is used (if specified).
`UNI`	Using the UNIRAS plotting package, generating a grey-scale raster contour (default, unless `COL` sub-option is used).

Characters and axis annotation

`CPX`	The complex character generator will be used instead of the default simplex character set.
`DUP`	The duplex character generator is selected.
`ITA`	The italic character generator is used.
`IXA`	Integer format will be used for plotting the x-axis tick mark numbers instead of the default decimal format.
`IYA`	Integer format will be used for plotting the y-axis tick mark numbers instead of the default decimal format.

Output devices

In demand mode the default device is `VTT`.

In batch mode the default is `TEK` if sub-option `COL` has been specified. For sub-option `B/W` the default is either `LAS` for the MINDIS package, or `PS3` for the UNIRAS package.

`EPS`	Encapsulated PostScript file (300 dpi).
`HTK`	PostScript Tek 4698 Phaser3 (A3) (300 dpi).
`HVG`	PostScript viewgraph HP 1200C (300 dpi).
`LAS`	Laser printer.
`PHA`	PostScript Tek Phaser PX (A4) (SRD).
`PS3`	PostScript B/W (A3) (COM).
`PS4`	PostScript B/W (A4) (COM).
`PSS`	PostScript B/W (A4) (SAG).
`TEK`	PostScript Tek 4698 Phaser3 (A3) (150 dpi).
`T92`	Viewgraph Tek 4692.
`T93`	PostScript Tek 4693 Phaser3 (A4) (SEC Room).
`VTT`	Terminal screen.
`VUG`	PostScript Viewgraph HP 1200C (150 dpi).

The next line `USER TITLE` specifies the main title of the plot, followed by the name of the data file (`.BDR`) on a separate line. The name of this file should be the same as that of the `.CDR` file.

The next seven lines contain the axis annotation, range information of the data and the parameters for the x-axis of the plot. `XLEFT` and `XRIGHT` are the data values at the left and right borders of the plot frame, respectively, whereas `XINC` is the distance in the same units between the tick marks. The parameters for the y-axis are given in the same way in the next five lines.

`DIVX` and `DIVY` convert the users units to the desired axis annotation units (e.g. 0.001 would display data given in metres on an axis notation in kilometres).

`MIN DEPTH` and `MAX DEPTH` specify the range of the data on the vertical axis.

`CAY` determines the type of interpolation used to fill the grid from arbitrarily placed data points. If `CAY` $= 0$ Laplacian interpolation is used. With increasing value of `CAY` spline interpolation dominates the Laplacian and the surfaces pass more smoothly through the data points. (For most TL plots values of 5 or 10 give good results.)

`NRNG` controls the spatial extend of the interpolation: any grid points more than `NRNG` grid spaces from the nearest data point are set to undefined and will not be used for this data point.

`ZMIN, ZMAX, ZINC` define the minimum and maximum contour level to be drawn, while `ZINC` denotes the level increment.

`X1PL, Y1PL` is the offset of the lower left corner from the plot device zero. Note, these two values are in inches!

`NSM` is the number of Laplacian smoothings to be applied to the grid after the interpolation is done.

`HGTPT` is the size of the star symbol denoting the source depth.

`HGTC` is the size of all characters of the title and axis annotation.

`LABPT` marks and labels data points if positive or null, denoting the number of digits after the decimal points, else if $= -1$: omits decimals, $= -2$: omits labels, $= -3$: omits marks and labels.

`NDIV` $= 1, 2, 4$. The grid is subdivided `NDIV` times in both directions using cubic splines for interpolation. `NDIV` $= 1$ has no effect.

`NARC` $= 1, 2, \ldots, 10$ is the number of subsegments replacing each straight line segment of a contour by an arc of a smooth flowing curve.

`LABC` is the umber of digits after the decimal on the contour label, if postive or null, else if $= -1$: omit decimals, $= -3$: omit labels.

`LWGT` Line type of contour ($= 1$: standard, $= 2$: heavy, $= 3$: dotted)

`BOTTOM` The following lines up to `@EOF` or between two `BOTTOM` lines correspond to the coordinates of a closed polygon to be coloured or shaded, with the shading level given by the number following right after `BOTTOM`. Note that the first and last point given will be connected to close the polygon. To plot the bathymetry in a depth vs. range contour plot the line following `BOTTOM` should be the coordinates of the lower left corner (or larger depth) and the last line the coordinates of the lower right corner (or larger depth).

The file structure of the `BDR` *file* The file structure varies according to the options and parameters in the `CDR` file. Generally a block of 28 values containing control parameters is followed by data. Note: the data are not stored directly as a matrix as in a spreadsheet.

For **CONDR** the flag **FLAGRC** indicates whether data should be stored in colums or rows (i.e. columns means all loss data at range r_1 are followed by all loss data at range r_2, etc., where data for a new range start on a new line).

For **CONFR** the value **DELTAX** = 0 requires that the **BDR** file be started with the range values, otherwise a regular spacing of **DELTAX** is assumed.

User Manual

Schmidt, H. SAFARI, seismo-acoustic fast field algorithm for range-independent environment, user's guide, SACLANTCEN SR-113. La Spezia, Italy, NATO SACLANT Undersea Research Centre 1988. [AD A 200 581]

References

Schmidt, H. SAFARI, seismo-acoustic fast field algorithm for range-independent environments: User's guide, SACLANTCEN SR-113. La Spezia, Italy NATO SACLANT Undersea Research Centre, 1988. [AD A 200 581]

Jensen, F.B., Martinelli, M.G. The SACLANTCEN parabolic equation model (PAREQ). La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1985.

Jensen, F.B., Ferla, M.C. SNAP: The SACLANTCEN normal-mode acoustic propagation model, SACLANTCEN SM-121. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1979. [AD A 067 256]

FIPPLOT

Line plotting package

Synopsis This line plotting package is used by the propagation models COUPLE, FEPE, MOCASSIN, PAREQ, SAFARI and SNAP. If requested to create a plot, the acoustic model stores the data in ASCII files which then serve as input to this plotting package. Editing these files allows easy manipulation of the layout and merging of data from different sources into one plot.

Input Parameters These come from two ASCII files: one containing the information on the layout which has the extension `PLP`, and actual data file with extension `PLT`. The number of curves in one plot frame and the number of frames in the files are arbitrary.

Output Plots of one or more curves in different line styles. The output may be generated on various hardware devices and in appropriate file formats for later processing as e.g. PostScript files to be included into documents.

Description Generally some program (e.g. a numerical model) creates two files `USER.PLP` and `USER.PLT` of which the first contains all the information for the layout and the second contains the data. The plot program is either automatically executed after the modelling run, or may be started independently. Since the two files are formatted in ASCII, they are easy to manipulate and data from other sources may easily be merged. Because the structure of these files is quite general, it may be (and has been) used for various purposes, thus avoiding the need to write new plotting programs.

The file structure will be outlined below and the various options explained. Most of this text is taken from the SAFARI manual, however, since various new options have been added it seemed reasonable to compile the information into one document.

Example of the file structure of the `PLP` *file*

```
␣1024                       MODULO
␣SNAP␣␣␣TLRAN,TEK,CPX,DSH   MODEL, OPTIONS
␣Arctic Profile             USER TITLE ≤ 80 Char
␣GAUSS( 0., 0.)             MODEL SUBTITLE
␣3                          NUMBER OF LABELS
␣F = 500.0Hz$               STANDARD LABEL 1
␣SD= 150.0m$                STANDARD LABEL 2
␣RD= 25.0m$                 STANDARD LABEL 3
␣0.150000+002               XLEN
```

```
␣0.100000+002                       YLEN
␣0                                  GRID TYPE. 0:  NO GRID
␣0.400000+005                       XLEFT
␣0.500000+005                       XRIGHT
␣0.500000+004                       XINC
␣0.100000-002                       XDIV
␣Range (km)$                        XAXIS ANNOTATION
␣LIN                                LINEAR SCALE
␣0.850000+002                       YDOWN
␣0.650000+002                       YUP
␣0.500000+001                       YINC
␣0.100000+001                       YDIV
␣Loss (dB)$                         YAXIS ANNOTATION
␣LIN                                LINEAR SCALE
␣2                                  NC=NUMBER OF CURVES
␣501␣␣5␣␣3                          NPT,NSP,CURVE IDENTIFIER
␣0.000000+000                       OFFSET ON X AXIS
␣0.000000+000                       STEP INC ON X AXIS
␣0.000000+000                       OFFSET ON Y AXIS
␣0.000000+000                       STEP INC ON Y AXIS
␣501␣␣5␣␣3                          NPT,NSP,CURVE IDENTIFIER
␣0.000000+000                       OFFSET ON X AXIS
␣0.000000+000                       STEP INC ON X AXIS
␣0.000000+000                       OFFSET ON Y AXIS
␣0.000000+000                       STEP INC ON Y AXIS
␣FIP␣␣␣PLTEND
```

Notes on the `PLP` *file* To generate several independent plots or frames repeat the lines between `MODULO` and `␣FIP␣␣␣PLTEND`. Notice the initial space (denoted by ␣) which is necessary for `FIPPLOT` to correctly read the file. The first line here is a block size modulo which is actually a dummy in the new version and may be omitted except for `PAREQ` stacked plots where it is mandatory.

The second line starts with a 12-character field of which the first 5 characters identify the propagation model (here `SNAP␣`) that generated the file and the following characters `TLRAN` give the detailed specifications (model suboptions) for the run that created the file. These suboptions determine the type of plot leading to specifications of the axes.

This is followed by a series of 3-character plot options separated by commas.

The following plot options are currently available:

General

`ADD`	This option will add all the curves of the independent plots having this option using axis specification given by the first plot containing `ADD`. These independent plots must be consecutive in the files, where the option `NOP` can be used to omit an interfering plot from the sequence.
`NOP`	Omits this plot.
`NDT`	Suppresses the identification line on top of the plot containing the date and user name.
`B/W`	Black and white plot (default).
`COL`	Colour plots (with MINDIS plotting package colours only on screen).

Output devices

`LAS`	Default laser.
`PHA`	Plot on postscript queue PRPHASER.
`PSR`	Plot on SRD postscript LPS17 in A4 format.
`PSS`	Plot on SAG postscript LPS17 in A4 format.
`PST`	Plot on postscript queue PRMINDIS_PS.
`PS3`	Plot on COM black and white LPS20 in A3 format.
`PS4`	Plot on COM black and white LPS20 in A4 format.
`TEK`	Plot on postscript TEK4698.
`VTT`	Plot on terminal screen, in batch mode on default laser.
`VUG`	Plot on HP1200C viewgraph (tranparencies).

Characters and axis annotation

`CPX`	The complex character generator will be used instead of `SPX`.
`DUP`	The duplex character generator is selected.
`ITA`	The italic character generator is used.
`SPX`	The simplex character generator is used (default).
`IXA`	Integer format will be used for plotting the x-axis tick mark numbers instead of the default decimal format.
`IYA`	Integer format will be used for plotting the y-axis tick mark numbers instead of the default decimal format.
`SCA`	The default character size has been selected to yield a reasonable 'balance' of the plot when the length of the axis is 20 cm. This option will scale the character size accordingly for larger or smaller sizes. This is important when a

	uniform character size is desirable independent of the size of the original plots.
ULC	This writes the user title in enlarged characters directly over the upper frame of the data plot.

Curve identification

CDO	Line style is dashed-dotted.
CDS	Line style is long dashed.
CNT	Line style is continuous.
DOT	Line style is dotted.
DSH	Line style is dashed.
COL	This option will plot individual curves in different colours, using the repeatable sequence: red-green-blue-cyan-magenta-yellow. With the MINDIS package colours are only on the screen.
BLU	The curve(s) are plotted in blue.
CYA	The curve(s) are plotted in cyan.
GRE	The curve(s) are plotted in green.
MAG	The curve(s) are plotted in magenta.
RED	The curve(s) are plotted in red.
YEL	The curve(s) are plotted in yellow.
DSD	If the plot contains more than one curve (`NC`> 1), then the first curve will be plotted with a solid line, the second with a dashed line, the third with a dotted line, the fourth with long dashes and the fifth with a dot-dashed line. If more than five curves are plotted, this sequence will be repeated.
MRK	A marker will be plotted for each 10th data point on the curve. In the case of more curves, different markers will be used for each.
TAX	Plots the timing lines and annotations on a seismic section.

Range-dependent sound-speed plot (if model option = `PROFL`*)*

RDP	The profiles are displaced according to the ranges where they occur.
SUP	The profiles are superimposed on one another.

Stacked pulse plots (if model option = `STCK` *or =* `STDP`*)*

RES	When this option is selected, `FIPPLOT` will request a scaling factor (1.0 = no scaling) which will be applied to all curves in the plot, but *not* to the axis values. This option is particularly useful for the range- and depth-stacked time series produced by `SAFARI-FIPP` or `PULSE`.

`TCT`	This option is used in connection with the stacked time series plots in order to truncate the amplitude of each trace at a value corresponding to half the distance between traces. Used in particular to avoid overlap of curves when rescaling with a large factor (option `RES`).
`NEG`	The area between the baseline and the negative deflections are filled.
`POS`	The area between the baseline and the positive deflections are filled.
`KT0`	Monochrome wiggle variable area.
`KT1`	Only the wiggle trace line is plotted.
`KT2`	or `KT3` Coloured wiggle variable area, with colour depending on the maximum amplitude of the individual wiggle.

The next line `USER TITLE` specifies the main title of the plot, followed by a line `MODEL SUBTITLE` specified by the model for this actual plot, which will be plotted just above the plot frame.

Then follows a sub-block containing the labels to be plotted in the upper right corner of the plot frame. The number of labels (≥ 0) is given first, followed by the label texts, each of which should be on separate lines and terminated by a $.

The following numerals are in free format.

The parameters `XLEN, YLEN` specify the length of the x- and y-axis, respectively. The parameter `GRID TYPE` indicates whether a grid should be plotted at the major tick marks: $= 0$ no grid, $= 1$ grid.

The next six lines contain the parameters for the x-axis of the plot. `XLEFT` and `XRIGHT` are the data values at the left and right borders of the plot frame, respectively, whereas `XINC` is the distance in the same units between the tick marks. `XDIV` is a multiplication factor which will be applied to both the axis parameters and the data values. Next the title on the x-axis is specified, terminated by a $, and finally `LIN` indicates that the x-axis should be linear. Another possibility is a logarithmic axis, which exists for a few options.

The parameters for the y-axis are given in the same way in the next 6 lines.

The parameter `NC` specifies the number of curves to be plotted into the same frame.

For each curve a sub-block of five lines has to be specified. The first parameter `NPT` gives the number of points in the curve; the second parameter `NSP` indicates the number of smoothing points for a running average (should be odd), and the third parameter the `CURVE IDENTIFIER CI` is only used if `NPT` is set negative. Then a positive value of `CI` will add symbols at each data point to the continuous curve, while a negative value of `CI` will give symbols only.

The parameter `OFFSET ON X AXIS` is the x-coordinate of the first data point, whereas `STEP INC ON X AXIS` is the equidistant spacing of the data points. If this latter value is zero, then the `NPT` x-coordinates of the curve are read from the `PLT` file. In this case `OFFSET ON X AXIS` would be interpreted as an x-offset to be applied to the curve. The same applies to the variables of the `Y AXIS`. In most cases the y-values (e.g. transmission loss) will be read from the `PLT` file. The offsets are important in context with rescaling the amplitude in stacked time series plots without changing the trace offset. If both `STEP INC ON X AXIS` and `STEP INC ON Y AXIS` are specified as 0, then `FIPPLOT` will first read all `NPT` x-values and then all y-values for the `PLT` file.

The next five lines refer to the second curve in this example.

The last line indicates the end of the file.

File structure of the `PLT` *file* This file is free ASCII format with a record length of 80 characters (one line). If `STEP INC ON X AXIS = 0` then the first value read is interpreted as the first x-value of the first curve, and all `NPT` values have to be specified. The corresponding y-values start on a new line (if `STEP INC ON Y AXIS = 0` otherwise no y-values). The data for the next curve start again on a new line.

Special structure for range-dependent sound-speed profiles In this case the model option reads `PROFL` and the plot option is either `RDP` or `SUP`. In the first case three axes are specified: range, depth and sound speed, and the profiles are plotted displaced according to the ranges. In the second case, where the plot option reads `SUP` the profiles are plotted versus depth and are superimposed on one another. These plot options cannot be changed once the files have been created. The filename then is `USER_SV.PLP` and `USER_SV.PLT`.

User Manual

Schmidt, H. SAFARI, seismo-acoustic fast field algorithm for range-independent environments, user's guide, SACLANTCEN SR-113. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1988. [AD A 200 581]

References

Jensen, F.B., Martinelli, M.G. The SACLANTCEN parabolic equation model (PAREQ). La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1985.

Jensen, F.B., Ferla, M.C. SNAP: The SACLANTCEN normal-mode acoustic propagation model. SACLANTCEN SM-121. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1979. [AD A 067 256]

PULSEPLOT

Fourier synthesis of a pulse

Synopsis Interactive, self-explanatory program to plot the time series of a pulse propagated to given range and depth points based on the acoustic field which has been computed with COUPLE, PAREQ, SAFARI or SNAP.

Input Parameters

- *Propagation model*
  To create a transfer file that serves as input to PULSEPLOT the following information has to be added to the input file of the models:

  models COUPLE, SNAP and PAREQ add the following lines:

  PULSE
  No-of-samples($= 2^m$), Freq-min, Freq-max [Hz], Delta-t [s]
  Rec-min, Rec-max, Delta-R [km]
  Dep-min, Dep-max, Delta-dep [m]
  Source-depth [m] (only for SNAP)

  model SAFARI-FIPP: choose option C
- *At runtime of the PULSEPLOT program it is necessary to:*

- input the name of the transfer file (extension TRF); and then either to
- select one of the five pulse types as documented in the SAFARI manual; or to
- input the time series of a user defined pulse with time increment Delta-t.

Output Plots of the time series and power-spectrum of the source pulse and received pulses at defined range and depth values, also as range stacked (for a selected receiver depth) or depth stacked (for a selected receiver range), or a snap shot display of the pulse for a particular time as a depth/range contour. For SAFARI-FIPP the same plots are also available for the vertical and horizontal particle velocities.

Limitations

Applicational
As given with the propagation model.

Computational
See those of the propagation model applied.
The number of samples should be a power of two ($= 2^m$). The frequency

sampling is given by $d_f = 1/(N_{samples} * \delta t)$ and the number of frequencies to run the model is $N_f = (f_{max} - f_{min})/d_f + 1$. The time $N_{samples} * \delta t$ should be sufficiently large to contain all arrivals at max range, otherwise a wrap around occurs.

Description This pulse option is integrated into SAFARI-FIPP, so that no transfer file is required. Otherwise, i.e. with option C or other models, a transfer file is created which contains the complex acoustic pressure field from the propagation model at the specified depth and range points. For each frequency the acoustic field is read, this frequency spectrum is then multiplied by the source spectrum and Fourier tranformed into the time domain to yield the time sequence of the received pulse.

User Manual

None, but pertinent information is given in the SAFARI user's guide.

References

Schmidt, H. SAFARI, seismo-acoustic fast field algorithm for range-independent environments, user's guide, SACLANTCEN SR-113. La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1988. [AD A 200 581]

Jensen, F.B., Martinelli, M.G. The SACLANTCEN parabolic equation model (PAREQ). La Spezia, Italy, NATO SACLANT Undersea Research Centre, 1985.

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Title

Acoustic Models at SACLANTCEN

Abstract

The Environmental Modelling Group at SACLANTCEN maintains a suite of computer codes to model sound propagation in the ocean. This suite contains numerical models to cover all environmental conditions and acoustic frequencies of interest at the present time. New models will be added if requested or as they become available to supplement the existing ones. Any specific model has its range of applicability in the domain of acoustic and environmental parameters as well as with regard to computer facilities and time. This document aims to provide a brief characterization of the programs, and thus to give the potential user an overview of the capabilities currently available. However, to run any of these models the user will have to resort to the original User Manuals. The models covered are: COUPLE, FEPE, GRASS, GSM, KRAKEN, MOCASSIN, PAREQ, SAFARI, SNAP and those included in the respective program packages. Additional auxiliary programs CONTUR, FIPPLOT, and PULSEPLOT for displaying the modelling results and integrating them with other data are also described.

Keywords

acoustic models, COUPLE, FEPE, GRASS, GSM, KRAKEN, MOCASSIN, PAREQ, SAFARI, SNAP

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