

OASES
Version 3.1
User Guide and Reference Manual

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1 Introduction

OASES is a general purpose computer code for modeling seismo-acoustic propagation in horizontally stratified waveguides using *wavenumber integration* in combination with the *Direct Global Matrix* solution technique [?, ?, ?]. It is basically an upgraded version of SAFARI [?]. Compared to SAFARI version 3.0 distributed by SACLANTCEN, OASES provides improved numerical efficiency, and the global matrix mapping has been re-defined to ensure unconditional numerical stability in the few extreme cases where the original SAFARI has proved unstable. OASES is downward compatible with SAFARI, and the preparation of input files follows the guidelines of the SAFARI manual [?]. The SAFARI manual focused on VMS implementation, but this note will assume UNIX to be the operating system. However, the bulk of the code is operating system independent and is easily implemented under VMS, MS-DOS etc.

2 Installing OASES

OASES is available on all nodes of the computational environment of the MIT/WHOI acoustics group. The information on installation provided in this section is therefore only intended for recipients of new export versions. The MIT/WHOI user should proceed to Section 3.

2.1 Loading OASES files

For recipients running UNIX, the whole OASES directory tree will be shipped in compressed **tar** files, compressed with the standard `compress` and `gzip` utilities, respectively.

```
oases.tar.Z
oases.tar.gz
```

The “export” subset of oases is available via anonymous ftp from `ftp@keel.mit.edu`, or via the World-wide-Web: `ftp://keel.mit.edu/pub/oases/` The files are placed in the `pub/oases` directory, which also contains a `README` file..

To install, download the tar file(s) in your desired root directory `$HOME` and issue the commands

```
uncompress oases.tar.Z
tar xvf oases.tar
mv oases_export oases # Only for Export package
```

or, if you use `gzip` use the command

```
gunzip -c oases.tar.gz | tar xvf -
mv oases_export oases # Only for Export package
```

which will install the directory tree:

<code>\$HOME/oases</code>	OASES root directory
<code>\$HOME/oases/src</code>	Source files for 2-D OASES
<code>\$HOME/oases/src3d</code>	Source files for 3-D OASES
<code>\$HOME/oases/bin</code>	OASES scripts and destination of executables
<code>\$HOME/oases/lib</code>	Destination of OASES libraries
<code>\$HOME/oases/tloss</code>	Data files for OAST
<code>\$HOME/oases/pulse</code>	Data files for OASP
<code>\$HOME/oases/rcoef</code>	DATA files for OASR
<code>\$HOME/oases/plot</code>	Source files for FIPLOT
<code>\$HOME/oases/contour</code>	Source files for CONTUR
<code>\$HOME/oases/mindis</code>	MINDIS graphics library
<code>\$HOME/oases/pulsplot</code>	Source files for Pulse Post-Processor
<code>\$HOME/oases/doc</code>	This document in LaTeX format

2.2 Building OASES Package

Version 2.1 shipped after May 5, 1997 have a new Master `Makefile` in the `oases` root directory `$HOME/oases`, which automatically detects the platform type and sets compiler options accordingly. The only modification needed to this file is the specification of the `bin` and `lib` directories for the executables and libraries, respectively. The defaults are `$HOME/oases/bin` and `$HOME/oases/lib`. For Linux platforms a few additional changes may necessary, as described below. The entire package is installed by the statement

```
make all
```

which will recursively execute all the individual makefiles in the package.

In version 2.3 shipped after Feb. 11, 2000 the makefile `$HOME/oases/Makefile` uses the environment variables `$HOSTTYPE` and `$OSTYPE` to determine platform-specific compiler flags, object and library paths etc.. This allows for using a single OASES root directory on networks with different platform and operating systems, for example Alpha workstations running either OSF or Linux. The following platform/OS combinations are supported at present:

<code>alpha-osf1</code>	Alpha workstations running OSF1
<code>alpha-linux</code>	Alpha workstations running Linux
<code>decstation</code>	DEC RISC workstations (e.g. 5000/240)
<code>sun4</code>	SUN SPARC workstations
<code>i386-linux-linux</code>	PC platforms running Linux
<code>i486-linux-linux</code>	PC platforms running Linux
<code>iris4d</code>	SGI workstations

Any other platform is easily added by editing `Makefile` as described in the following sec-

tion.

Once the package is built, include the executable directory in your path, e.g. in your `.cshrc` file:

```
setenv OASES_SH ${HOME}/Oases/bin # OASES scripts
setenv OASES_BIN ${OASES_SH}/${HOSTTYPE}-${OSTYPE} # OASES executables
set path = ( $OASES_SH $OASES_BIN $path )
```

2.2.1 Compiler Definitions

The compiler options are set in the master makefile **Makefile** in the OASES root directory. Hosts not supported may be added by including in `Makefile` a block with the compiler/linker definitions, e.g. for a `HOSTTYPE hosttype`, running `OSTYPE ostype`

```
#####
#
# host-type Workstations
#
#####
#
# Compiler flags
#
# Fortran statement
FC.hosttype-ostype = f77
# CC Flags
CFLAGS.hosttype-ostype = -O
# Linker/loader flags
LFLAGS.hosttype-ostype =
# ranlib definition
RANLIB.hosttype-ostype = ranlib
# Additional run-time libraries
LIB_MISC.hosttype-ostype =
# Run-time library emulation
MISC.hosttype-ostype =
#
```

The default works on most platforms, but for LINUX some changes may be necessary, depending on which compiler you are using. For example, if you use the Absoft FORTRAN compiler on a Linux box (`HOSTTYPE = i386-linux`, `OSTYPE = linux`), then the Linux header in `Makefile` should look as follows:

```
#####
#
# PC HARDWARE RUNNING LINUX
#
#####
#
# Compiler flags
#
#
# For the ABSOFT FORTRAN compiler, un-comment the following
# lines:
#
FC.i386-linux-linux = f77 -f -s -N2 -N9 -N51
LIB_MISC.i386-linux-linux = -lV77 -lU77
MISC.i386-linux-linux =
#
# For the standard F2C FORTRAN compiler, un-comment the following
# lines:
#
# FC.i386-linux-linux = fort77
# LIB_MISC.i386-linux-linux = $(LIBDIR)/libsysemu.a
# MISC.i386-linux-linux = misc.done
#
CFLAGS.i386-linux-linux = -I/usr/X11R6/include
LFLAGS.i386-linux-linux = -L/usr/X11R6/lib
RANLIB.i386-linux-linux = ranlib
```

After performing the changes, set the default directory to the OASES root directory, and compile and link by issuing the command:

```
make objdir
make all
```

2.2.2 Parameter settings

If the default parameter settings are insufficient they may be altered in the parameter include file

```
$(OASES_ROOT)/src/compar.f
```

The controlling parameters are

Parameter	Description	Default
NLA	Max number of layers	200
NPEXP	Max number of wavenumber and time samples is 2^{NPEXP}	16
NRD	Max number of receiver depths	101

2.3 Building Plotmtv

Plotmtv is a public domain package, producing high quality colour graphics. It is included in the distribution as compressed tarfiles.

```
Oases/plotmtv/Plotmtv1.4.1.tar.gz  
Oases/plotmtv/mtvpatch.tar.gz
```

To install, execute the commands:

```
gunzip -c Plotmtv1.4.1.tar.gz | tar xvf -  
gunzip -c mtvpatch.tar.gz | tar xvf -
```

Then follow the instructions in the `Plotmtv1.4.1/README` file. The installation requires that you have `xmkmf` installed (in Ubuntu: `apt-get install xmkmf`). Once you have built `plotmtv` remember to move the executable `plotmtv` to a directory in your path, e.g. `/usr/local/bin`.

3 System Settings

Before using OASES you must change your `.login` to properly.

3.1 Executable Path

First of all, include the directory containing the OASES scripts and executables in your path, e.g using the statement

```
setenv OASES_SH ${HOME}/Oases/bin # OASES scripts
setenv OASES_BIN ${OASES_SH}/${HOSTTYPE}-${OSTYPE} # OASES executables
set path = ( $OASES_SH $OASES_BIN $path )
```

In the MIT/WHOI computational environment the paths to the OASES executables and scripts are

Node	Path	CPU
keel	/keel0/henrik/Oases/bin	Alpha OSF
boreas	/keel0/henrik/Oases/bin	Alpha Linux
frosty1	/fr1/henrik/Oases/bin	Alpha OSF
frosty2	/fr1/henrik/Oases/bin	PC Linux
frosty3	/fr3/henrik/bin	PC Linux
arctic	/keel0/henrik/Oases/bin	Alpha OSF
acoustics	/keel0/henrik/Oases/bin	PC Linux
reverb	/reverb0/henrik/Oases/bin	PC Linux
vibration	/reverb0/henrik/Oases/bin	PC Linux
sonar	/keel0/henrik/Oases/bin	Alpha Linux
monopole	/dipole0/henrik/Oases/bin	Alpha Linux
dipole	/dipole0/henrik/Oases/bin	PC Linux

3.2 Environmental Parameters

You may want to set your terminal type to avoid having to specify it everytime you use `mplot` or `cplot`. If you are running X-windows, set the `DISPLAY` environmental variable properly and insert the statement

```
setenv USRTERMTYPE X
```

in your `.login` file or simply type it in if you are not usually using X-windows.

If you are running from a Tektronix 4100-series terminal or emulator, replace 'X' by 'tek4105'. Similarly, for the Tektronix 4000-series, replace 'X' by 'tek4010' or 'tek4014'.

The default contour package is Mindis, creating black and white line contour plots. To make Plotmtv your default contour package, execute the command, either manually or in your `.login` file:

```
#
# MTV environment
#
setenv CON_PACKGE MTV
setenv MTV_WRB_COLORMAP "ON"
setenv MTV_COLORMAP hot
setenv MTV_PRINTER_CMD "lpr"
setenv MTV_PSCOLOR "ON"
```

The 'hot' colour scale is chosen in this case, overwriting the WRB colorscale which is a red-to-blue colorscale close to the classical one used e.g. in acoustics, e.g. in Ref. [?]. The other variables should be self-explanatory. The 'hot' colourscale has the advantage that it yields a gradual greytone scale when printed on a b/w printer. The default MATLAB color scale is 'jet'.

Similarly, version 2.1 and later include a filter `plp2mtv` which translates the line plot `plp` and `plt` files to an `mtv` file and executes `plotmtv`. This filter may be used directly as a plot command instead of `mplot file`

```
plp2mtv file
```

Alternatively, `plotmtv` may be chosen as the default line plot package used by the `mplot` command by setting an environment variable:

```
setenv PLP_PACKGE MTV
```

It should be noted that some `mplot` options may not be fully supported by `plp2mtv`.

4 OASES - General Features

4.1 Environmental Models

OASES supports all environmental models available in SAFARI, i.e. any number and combination of isovelocity fluids, fluids with sound speed gradients and isotropic elastic media. In addition, as a new feature any number of transversely isotropic layers may be specified (all with vertical symmetry axis). Further, media with general dispersion characteristics can be included.

Version 2.0 of OASES in addition allows for stratifications including an arbitrary number of poro-elastic layers, with the propagation described by Biot's theory. This modification has been performed by Morrie Stern [?] at the University of Texas at Austin, in collaboration with Nick Chotiros and Jim tencate at ARL/UT. Nick and Morrie suggested I include their modifications in the general OASES export package, for the use and benefit of the general underwater acoustics community. This is a significant additional capability of OASES, and the contribution of the Austin group in that regard is highly appreciated.

4.1.1 Transversely Isotropic Media

A transversely isotropic layer is flagged by stating the usual parameter line for the layer:

$$D \quad c_c \quad c_s \quad \alpha_c \quad \alpha_s \quad \rho \quad \gamma \quad [L]$$

with $c_c < 0$ as a flag. Here only the interface depth D has significance. The other parameters for the transversely isotropic layer should then follow in one of two ways, depending on the value of c_c :

$c_c = -1$: The medium is specified as a periodic series of thin layers as per Schoenberg:

NC							Number of constituents (≤ 3)
c_c	c_s	α_c	α_s	ρ	h		Speeds, attns., density, fraction
c_c	c_s	α_c	α_s	ρ	h		Speeds, attns., density, fraction

$c_c = -2$: The 5 complex elastic constants and the density of the transversely isotropic medium are specified directly after the flagged layer line:

Value	Value	Units
Re(C_{11})	Im(C_{11})	Pa
Re(C_{13})	Im(C_{13})	Pa
Re(C_{33})	Im(C_{33})	Pa
Re(C_{44})	Im(C_{44})	Pa
Re(C_{66})	Im(C_{66})	Pa
ρ		g/cm ³

If option **Z** was specified in the option line, then a slowness diagram is produced for each transversely isotropic layer.

4.1.2 Dispersive Media

For pulse problems where causality is critical, non-zero attenuation must be accompanied by frequency-dependent wave speeds. Since this is of main importance for seismic problems with relatively high attenuation, the specification of dispersive wave speeds has been limited to elastic media only. A dispersive layer is again flagged by a negative value of c_c :

$c_c = -3$: A dispersive layer is specified as follows in the file **input.dat**:

```
D   -3  0  0  0  ρ  γ  [L]
LTYP
```

The only significant parameters for the layer are the depth D , the density ρ and the roughness parameters γ and L . The parameter **LTYP** is a type-identifier for the layer. The frequency dependence of the wave speeds and attenuations should be specified in the file **input.dis**, which may contain several dispersion laws. The file should contain a block of data in the form of a frequency table, for each value of **LTYP** specified in **input.dat**, with the first block corresponding to **LTYP** = 1, the second corresponding to **LTYP** = 2 etc. The format for each block is as follows:

```
NF                                     # Number of freqs.
F (1)   CC (1)   CS (1)   AC (1)   AS (1)   # Freq, speeds, atten.
F (2)   CC (2)   CS (2)   AC (2)   AS (2)   # Freq, speeds, atten.
:       :       :       :       :
F (N)   CC (N)   CS (N)   AC (N)   AS (N)   # Freq, speeds, atten.
```

The table does not have to be equidistant. OASES will interpolate to create a table consistent with the frequency sampling specified in **input.dat**.

4.1.3 Porous Media

As an additional feature of the OASES 2.0 environmental model layers modelled as fluid saturated porous media (Biot model) may be included with other layer types. The Biot model and its implementation is described in Appendix ??.

A porous sediment layer is flagged by stating the usual parameter line for the layer in the environmental data block:

$$D \quad c_c \quad c_s \quad \alpha_c \quad \alpha_s \quad \rho \quad \gamma \quad [L]$$

with negative values for both c_c and c_s . Only the interface depth D has significance and must be stated correctly; the other parameters listed on this data line are dummy. This line is immediately followed by a line containing the 13 parameters specifying the properties of the porous sediment layer in the order:

$$\rho_f \quad K_f \quad \eta \quad \rho_g \quad K_r \quad \phi \quad \kappa \quad a \quad \mu \quad K \quad \alpha_s \quad \alpha_c \quad c_m$$

where

- ρ_f is the density of the pore fluid in g/cm^3
- K_f is the bulk modulus of the pore fluid in Pa
- η is the viscosity of the pore fluid in kg/m-s
- ρ_g is the grain (solid constituent) density in g/cm^3
- K_r is the grain bulk modulus in Pa
- ϕ is the sediment porosity
- κ is the sediment permeability in m^2
- a is the pore size factor in m
- μ is the sediment frame shear modulus in Pa
- K is the sediment frame bulk modulus in Pa
- α_s is the sediment frame shear attenuation
- α_c is the sediment frame bulk attenuation
- c_m is a dimensionless virtual mass parameter

The sediment frame properties pertain to the drained structure and are assumed to be dissipative. In particular, for harmonic motion the frame shear and bulk moduli are taken to be complex in the form $\tilde{\mu} = \mu(1 + i\mu')$, $\tilde{K} = K(1 + iK')$. The imaginary parts of the moduli are specified through $\alpha_s = 20\pi\mu' \log e$ and $\alpha_c = 20\pi K' \log e$ where α_s corresponds to the attenuation measured in dB/Λ of shear waves in the sediment frame (as in the data specification for elastic layers) when the attenuation is low; α_c is related to the attenuation of both compression and shear waves. However, it should be noted that in contrast to the elastic layer case, the Biot porous sediment model will yield complex wavespeeds even if the frame is elastic since dissipation is inherent in the relative motion of the pore fluid with respect to the frame.

The pore size parameter a is treated as an empirical constant which depends on the average

grain size and shape; for spherical grains of diameter d the value $a = \phi d/3(1 - \phi)$ has been suggested[?]. The virtual mass parameter c_m (called the 'structure factor' or 'tortuosity' by some authors and often denoted α) is also treated as an empirical constant which depends on the pore structure of the frame. For moderate frequencies (long wave length compared to 'average pore size') and porosities from 25% to 50%, Yavari and Bedford[?] have made finite element calculations which suggest that Berryman's relation $c_m = 1 + 0.227(1 - \phi)/\phi$ may be used in the absence of more reliable data. More thorough discussions of the material parameters defining the Biotmodel may be found in other references[?].

If the **K** option is invoked, then receivers in a porous sediment layer will output (negative) pore fluid pressure rather than bulk stress as called for in other fluid or solid layers. The **Z** option, which creates a velocity profile plot, shows the zero frequency limit wavespeeds in porous sediment layers. Note that at present the modifications do NOT permit sources in Biot layers.

The following presents a modification of SAFARI-FIP case 3 to replace the elastic sediment layer by a poro-elastic layer,

```
SAFARI-FIP case 3. Poroelastic.
N C A D J
30 30 1 0
5
  0 0 0 0 0 0 0
  0 1500 -999.999 0 0 1 0 # SVP continuous at z = 30 m
  30 1480 -1490 0 0 1 0
100 -1 -1 0 0 0 0 # Cp<0 Cs<0 flag poro-elastic layer
1 2.E9 .001 2.65 9.E9 .4 2.E-9 1.E-5 3.13E8 5.14E9 .8 1.55 1.25
120 1800 600 0.1 0.2 2.0 0

50
0.1 120 41 40
1350 1E8
-1 1 950
0 5 20 1
20 80 12 10
0 120 12 20
40 70 6
```

4.1.4 Continuous Sound Speed Profiles

OASES version 1.7 allows for specifying a continuous sound speed profile through a flag rather than specifying the negative of the actual value at the bottom of the layer in the shear speed field as in SAFARI (OASES still supports this form also). The flag specification is particularly useful when running through many values of sound speed at a certain depth, such as for matched field inversion for SVP.

The continuity of the SVP at the *bottom of a layer* is activated by the usual parameter line for the layer:

$$D \quad c_c \quad c_s \quad \alpha_c \quad \alpha_s \quad \rho \quad \gamma \quad [L]$$

with $c_s = -999.999$ as a flag, i.e. by setting the shear speed for the layer to -999.999 . All OASES modules will then set the sound speed at the bottom of the layer equal to the speed specified for the top of the next layer below.

As an example, the following is the OAST file `saffip3.dat` corresponding to the SAFARI test case 3 with the SVP being continuous at 30 m depth:

```
SAFARI-FIP case 3
N C A D J
30 30 1 0
5
  0    0    0    0    0    0    0
  0 1500 -999.999 0    0    1    0 # SVP continuous at z = 30 m
30 1480 -1490    0    0    1    0
100 1600   400    0.2 0.5 1.8 0
120 1800   600    0.1 0.2 2.0 0

50
0.1 120 41 40
1350 1E8
-1 1 950
0 5 20 1
20 80 12 10
0 120 12 20
40 70 6
```

4.1.5 Stratified Fluid Flow

OASES version 1.8 allows for computing the field in stratified flow. This option is only valid in the 2-D versions, handling flow parallel to the direction of propagation only (downstream or upstream). Flow is only allowed in *isovelocity fluid layers*!

The flow is activated by specifying the usual parameter line for the layer:

$$D \quad c_c \quad c_s \quad \alpha_c \quad \alpha_s \quad \rho \quad \gamma \quad [L]$$

with $\alpha_s = -888.888$ as a flag, i.e. by setting the shear attenuation for the layer to -888.888 . The flow speed in m/s is in a separate line immediately following the layer data line.

The sign convention is *positive* for flow from source to receiver (*downstream propagation*) and *negative* for flow from receiver towards source (*upstream propagation*).

As an example, the following is the OAST file `saffip1.dat` corresponding to the SAFARI test case 1 with a flow in the water column of 5 m/s towards the source (upstream propagation):

```
SAFARI FIP case 1. Flow -5 m/s.
J N I T
5 5 1 0
4
  0    0    0    0    0    0    0
  0 1500    0    0 -888.888 1.0 0
-5.0                                     # flow speed 5 m/s towards source
100 1600  400    0.2  0.5  1.8 0
120 1800  600    0.1  0.2  2.0 0
95
100 100 1 1
200 1E8
-1 1 1000
0 5.0 20 1.0
20 80 12 10
```

5 OASR: OASES Reflection Coefficient Module

OASR is downward compatible with SAFARI-FIPR Version 3.0 and higher, and therefore supports all options and features described in the SAFARI manual. A couple of new options have been added.

5.1 Input Files for OASR

The input data are structured in 9 blocks. The first 5 blocks, shown in Table 1, specify the title, options, environmental parameters, together with the desired grazing angle and frequency sampling. The last 4 blocks, outlined in Tables 1 and 2, contain axis specifications for the graphical output. Some of these blocks should always be included and others only if certain options have been specified. The single blocks and parameters are described in detail in the following.

5.1.1 Block I: Title

The title printed on all graphic output generated by OAST.

5.1.2 Block II: OASR options

In addition to supporting the SAFARI options described in [?], OASR supports several new options.

- B This option replaces the default P-P wave reflection or transmission coefficient by the P-Slow wave coefficient. Only allowed for Biot layers.
- C Loss contours plotted in frequency and grazing angle.
- L Generates a plot of reflection loss in dB in addition to the default linear magnitude plot vs frequency or angle.
- N This is the default option, which therefore never needs to be specified. It calculates the P-P reflection loss as function of angle and frequency.
- P Phase angle of reflection coefficient plotted in addition to the default magnitude.
- S This option replaces the default P-P wave reflection or transmission coefficient by the P-SV wave reflection coefficient.

Input parameter	Description	Units	Limits
BLOCK I: TITLE			
TITLE	Title of run	-	≤ 80 ch.
BLOCK II: OPTIONS			
A B C	Output options	-	≤ 40 ch.
BLOCK III: ENVIRONMENT			
NL	Number of layers, incl. halfspaces	-	$NL \geq 2$
D,CC,CS,AC,AS,RO,RG,CL	D: Depth of interface.	m	-
.	CC: Compressional speed	m/s	$CC \geq 0$
.	CS: Shear speed	m/s	-
.	AC: Compressional attenuation	dB/ Λ	$AC \geq 0$
.	AS: Shear attenuation	dB/ Λ	$AS \geq 0$
.	RO: Density	g/cm ³	$RO \geq 0$
	RG: RMS value of interface roughness	m	-
	CL: Correlation length of roughness	m	$CL > 0$
	M: Spectral exponent		$\zeta 1.5$
BLOCK IV: FREQUENCY SAMPLING			
FMIN,FMAX,NRFR,NFOU	FMIN: Minimum frequency	Hz	$FMIN > 0$
	FMAX: Maximum frequency	Hz	$FMAX > 0$
	NRFR: Number of frequencies	-	$NRFR \geq 1$
	NFOU: Plot output increment	-	$NFOU \geq 0$
BLOCK V: ANGLE/SLOWNESS SAMPLING			
AMIN,AMAX,NRAN,NAOU	AMIN: Minimum angle/slowness	dg/(s/km)	$AMIN \geq 0$
	AMAX: Maximum angle/slowness	dg/(s/km)	$AMAX \geq 0$
	NRAN: Number of angles/slownesses	-	$NRAN \geq 1$
	NAOU: Plot output increment	-	$NAOU \geq 0$
BLOCK VI: ANGLE/SLOWNESS AXES			
ALEF,ARIG,ALEN,AINC	ALEF: Left border, angle/slws axis	dg/(s/km)	-
RALO,RAUP,RALN,RAIN	ARIG: Right border, angle/slws axis	dg/(s/km)	-
(only for NFOU > 0)	ALEN: Length of angle/slws axis	cm	$ALEN > 0$
	AINC: Distance between tick marks	dg/(s/km)	$AINC > 0$
	RALO: Lower border of R-loss axis	dB	-
	RAUP: Upper border of R-loss axis	dB	-
	RALN: Length of loss and phase axes	cm	$RALN > 0$
	RAIN: R-loss axis tick mark interval	dB	$RAIN > 0$

Table 1: Layout of OASR input files: I. Calculation and plot parameters.

Input parameter	Description	Units	Limits
BLOCK VII: LOSS/FREQUENCY AXES			
FLEF,FRIG,FLEN,FINC RFLO,RFUP,RFLN,RFIN (only for NAOU > 0)	FLEF: Left border of frequency axis	Hz	-
	FRIG: Right border of frequency axis	Hz	-
	FLEN: Length of frequency axis	cm	FLEN > 0
	FINC: Distance between tick marks	Hz	FINC > 0
	RFLO: Lower border of R-loss axis	dB	-
	RFUP: Upper border of R-loss axis	dB	-
	RFLN: Length of loss and phase axes	cm	RALN > 0
	RFIN: R-loss axis tick mark interval	dB	RAIN > 0
BLOCK VIII: LOSS CONTOUR PLOTS (Option C)			
ALEF,ARIG,ALEN,AINC FRLO,FRUP,OCLN,NTKM ZMIN,ZMAX,ZINC (only for option C)	ALEF: Left border, angle/slws axis	dg/(s/km)	-
	ARIG: Right border, angle/slws axis	dg/(s/km)	-
	ALEN: Length of angle/slws axis	cm	ALEN > 0
	AINC: Distance between tick marks	dg/(s/km)	AINC > 0
	FRLO: Lower border of frequency axis	Hz	FRLO > 0
	FRUP: Upper border of frequency axis	Hz	FRUP > 0
	OCLN: Length of one octave	cm	OCLN > 0
	NTKM: Number of tickmarks pr octave	-	NTKM > 0
	ZMIN: Minimum contour level	dB	-
	ZMAX: Maximum contour level	dB	-
ZINC: Contour level increment	dB	ZINC > 0	
BLOCK IX: SVP AXES			
VLEF,VRIG,VLEN,VINC DVUP,DVLO,DVLN,DVIN (only for option Z)	VLEF: Wave speed at left border	m/s	-
	VRIG: Wave speed at right border	m/s	-
	VLEN: Length of wave speed axis	cm	VLEN > 0
	VINC: Wave speed tickmark distance	m/s	VINC > 0
	DVUP: Depth at upper border	m	-
	DVLO: Depth at lower border	m	-
	DVLN: Length of depth axis	cm	DVLN > 0
	DVIN: Depth axis tickmark distance	m	DVIN > 0

Table 2: Layout of OASR input files: II. Plot parameters.

- T Generates a table of computed complex reflection coefficients. The file is in ASCII format and will be given the same name as the input file, but extension `.rco`.
- Z Plot of velocity profiles.
- p Calculates and plots reflection coefficients vs horizontal slowness rather than the default grazing angle. This option allows for computing “reflection coefficients” in the evanescent regime. When this option is specified, the sampling in Block V should be given in slowness in s/km, and similarly for the plot parameters in Blocks VI and VIII.
- s Generates a file with boundary discontinuities for the rough interfaces. Used by OASS for computing scattering kernels.
- t Computes transmission coefficients instead of the default reflection coefficients. The transmission coefficients refer to the lowermost halfspace.

5.1.3 Block IV: Environmental Model

OASR supports all the environmental models allowed for SAFARI as well as the ones described above in Section 4.1. The significance of the standard environmental parameters is as follows

- NL: Number of layers, including the upper and lower half-spaces. These should Always be included, even in cases where they are vacuum.
- D: Depth in m of upper boundary of layer or halfspace. The reference depth can be chosen arbitrarily, and $D()$ is allowed to be negative. For layer no. 1, i.e. the upper half-space, this parameter is dummy.
- CC: Velocity of compressional waves in m/s . If specified to 0.0, the layer or half-space is vacuum.
- CS: Velocity of shear waves in m/s . If specified to 0.0, the layer or half-space is fluid. If $CS() < 0$, it is the compressional velocity at bottom of layer, which is treated as fluid with $1/c(z)^2$ linear.
- AC: Attenuation of compressional waves in dB/λ . If the layer is fluid, and $AC()$ is specified to 0.0, then an imperial water attenuation is used (Skretting & Leroy).
- AS: Attenuation of shear waves in dB/λ
- RO: Density in g/cm^3 .
- RG: RMS roughness of interface in m . $RG(1)$ is dummy. If $RG < 0$ it represents the negative of the RMS roughness, and the associated correlation length CL and spectral exponent should follow. If $RG > 0$ the correlation length is assumed to be infinite.

CL: Roughness correlation length in m.

M: Spectral exponent of the power spectrum as defined by Turgut [?], with $1.5 < M \leq 2.5$ for realistic surfaces, with $M = 1.5$ corresponding to the highest roughness, and $M = 2.5$ being a very smooth variation. For 2-D Goff-Jordan surfaces, the fractal dimension is $D = 4.5 - M$. Insignificant for Gaussian spectrum (option **g** not specified) but a value must be given.

5.2 Execution of OASR

As for FIPR, filenames are passed to OASR via environmental parameters. In Unix systems a typical command file **oasr** (in \$HOME/oases/bin) is:

```
#           the pound sign invokes the C-shell
setenv FOR001 $1.dat      # input file
setenv FOR019 $1.plp     # plot parameter file
setenv FOR020 $1.plt     # plot data file
setenv FOR028 $1.cdr     # contour plot parameter file
setenv FOR029 $1.bdr     # contour plot data file
setenv FOR022 $1.rco     # reflection coefficient table
setenv FOR023 $1.trc     # reflection coefficient table
setenv FOR045 $1.rhs     # scattering output file
oasrl                   # executable
```

After preparing a data file with the name **input.dat**, OASR is executed by the command:

```
> oasr input
```

5.3 Graphics

Command files are provided in a path directory for generating the graphics.

To generate curve plots, issue the command:

```
> mplot input
```

To generate contour plots, issue the command:

```
> cplot input
```

5.4 Output Files

With option **T** specified, OAST will generate a file 'input'.rco containing the magnitude $|R|$ and phase ϕ of the complex reflection coefficient $R = |R|\exp\phi$. Assume you add option **T** to saffipr1.dat , and also add option **p** to select slowness sampling:

```
SAFARI FIPR case 1.
P Z T p
3
0 1500 0 0 0 1 0
0 1600 400 0.2 0.5 1.8 0
20 1800 600 0.1 0.2 2.0 0
50 50 1 1
0.1 4.0 200 0          # Slowness sampling 0.1 - 4 s/km
0 4 20 1              # Slowness axes
0 15 12 5
0 2000 10 1000
-20 40 10 20
```

Then, after issuing the command

```
> oasr saffipr1
```

the file saffipr1.rco will be generated:

```
50.000      50.000      1      1
50.000      200      # Frequency, # of slownesses
0.100000      0.339462      -15.996886
0.119598      0.342714      -15.640528
0.139196      0.346415      -15.196492
0.158794      0.350498      -14.655071
0.178392      0.354880      -14.006412
0.197990      0.359469      -13.240785
0.217588      0.364159      -12.349057
0.237186      0.368833      -11.322515
0.256784      0.373363      -10.153061
0.276382      0.377615      -8.832868
0.295980      0.381445      -7.354058
0.315578      0.384707      -5.707997
0.335176      0.387249      -3.883928
0.354774      0.388919      -1.867177
```

```

      .
      .
      .

```

Note that the reflection coefficients are listed vs *horizontal slowness* in s/km, and phase angles are stated in *degrees*.

Another output file `input.trc` will be generated, identical to the `input.rco` file, except for the reflection coefficients being listed vs grazing angle in degrees. The format of both these output files is compatible with the one required by OAST as input for options `t` and `b`. The file `input.trc` generated by the input file above is as follows

```

50.000      50.000  1  2 # fr1, fr2, nf, slowns/angle(1/2)
 50.000  200          # Frequency, # of angles
81.373070      0.339462  -15.996886
79.665359      0.342714  -15.640528
77.948311      0.346415  -15.196492
76.220207      0.350498  -14.655071
74.479210      0.354880  -14.006412
72.723396      0.359469  -13.240785
70.950676      0.364159  -12.349057
69.158813      0.368833  -11.322515
67.345337      0.373363  -10.153061
65.507576      0.377615   -8.832868
63.642544      0.381445   -7.354058
61.746929      0.384707   -5.707997
59.816971      0.387249   -3.883928
57.848427      0.388919   -1.867177
.
.
.

```

Note that the slowness/angle sampling is identified by the last number in the first line, with 1 indicating slowness sampling, and 2 indicating angle sampling.

5.5 OASR - Examples

As an example of the use of OASR for computing seismo-acoustic reflection coefficients, the following datafile reproduces the results presented for a sand bottom in Stoll and Kan's paper [?]:

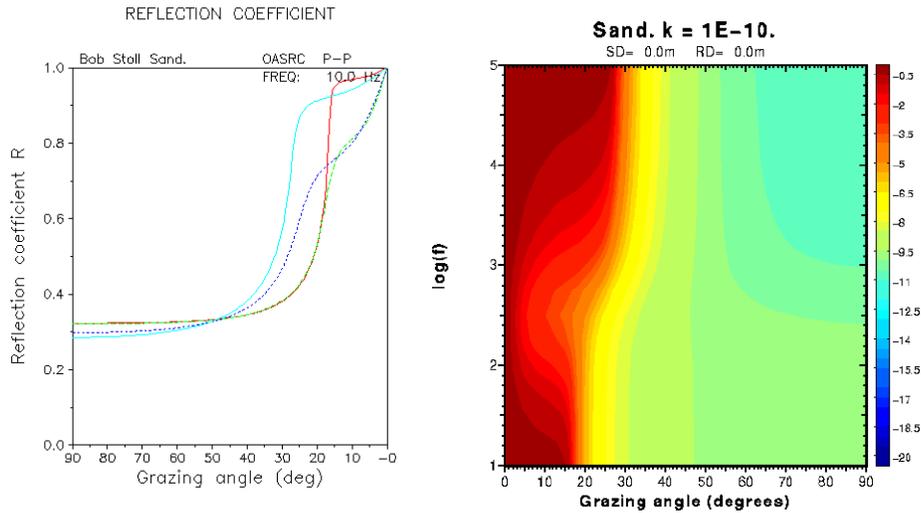


Figure 1: Reflection coefficients vs frequency and angle for porous sand halfspace, reproducing results of Stoll and Kan.

```

Sand. Stoll and Kan 81.
N C Z
2
0 1414 0 0 0 1 0
0 -1800 -600 0.1 0.2 2.0 0
1. 2.E9 .001 2.65 3.6E10 .47 1.E-10 3.9E-5 2.61E7 4.36E7 1.3 1.3 1.25
10 100000 17 4
0 90 181 0
90 0 10 10
0 15 12 5
0 90 12 15
10 100000 1 1
1 20 0.5
0 2000 12 500
-10 10 12 5
    
```

Assembled in one plot, Fig. 1, the resulting reflection coefficients at the 5 frequencies 0.01, 0.1, 1, 10, and 100 kHz reproduce exactly the results shown in Fig. 4 of Stoll and Kan’s paper. In addition, the datafile produces the contour plot in Fig. 1 of reflection coefficients vs angle and frequency.

OASES handles arbitrary poro-elastic stratifications, and Fig. 2(a) shows the equivalent frequency-angle contours of the reflection coefficient of a 1 m thick layer of sand overlying

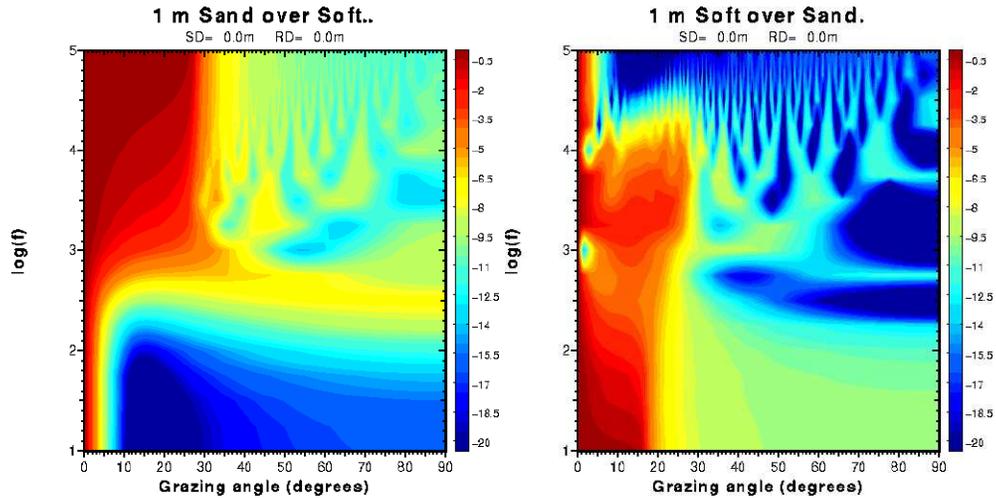


Figure 2: Reflection coefficients vs frequency and angle for (a) a 1 meter layer of porous sand overlying a “soft” halfspace, and (b) a 1 meter thick “soft” layer overlying a sand halfspace. Parameters for both media are consistent with those given by Stoll and Kan.

Stoll and Kan’s “soft” sediment. Similarly Fig.2(b) shows the reflection coefficients for a 1 meter “soft” layer over sand. The datafile for generating Fig.2(a) is

```

1 m Sand over Soft.
N C Z
3
0 1414 0 0 0 1 0
0 -1800 -600 0.1 0.2 2.0 0
1. 2.E9 .001 2.65 3.6E10 .47 1.E-10 3.9E-5 2.61E7 4.36E7 1.3 1.3 1.25
1.0 -1800 -600 0.1 0.2 2.0 0
1. 2.E9 .001 2.65 3.6E10 .76 1.6E-15 1.56E-7 2.21E7 3.69E7 4.3 4.3 1.25
10 100000 17 4
0 90 181 0
90 0 10 10
0 15 12 5
0 90 12 15
10 100000 1 1
1 10 0.5
0 2000 12 500
-10 10 12 5

```

6 OAST: OASES Transmission Loss Module

Except for the specification of frequencies, OAST is downward compatible with SAFARI-FIP Version 3.0 and higher, and therefore supports all options and features described in the SAFARI manual. In addition to improved speed and stability, OAST offers several new options.

6.1 Input Files for OAST

The input files for OAST is structured in 12 blocks, as outlined in Tables 3 and 4. In the following we describe the significance of the various blocks, with particular emphasis on differences between SAFARI-FIP and OAST.

6.1.1 Block I: Title

The title printed on all graphic output generated by OAST.

6.1.2 Block II: OAST options

In addition to supporting the SAFARI options described in [?], OAST supports a wide suite of new options.

- A** Depth-averaged transmission loss plotted for each of the selected field parameters. The averaging is performed over the specified number of receivers (block VI).
- C** Range-depth contour plot for transmission loss. Only allowed for one field parameter at a time.
- F** In versions earlier than 2.3a Filon-FFT is applied to evaluate the wavenumber integrals instead of the default FFP. However, this overestimates the transmission loss and provides no benefit for transmission loss calculations if the sampling criteria are satisfied. In fact it yields up to 3 dB error for automatic sampling and has therefore been disabled in the newer versions of OAST.
- G** Rough interfaces are assumed to be characterized by a Goff-Jordan power spectrum rather than the default Gaussian.
- H** Horizontal velocity calculated.
- I** Hankel transform integrands are plotted for each of the selected field parameters.

Input parameter	Description	Units	Limits
BLOCK I: TITLE			
TITLE	Title of run	-	≤ 80 ch.
BLOCK II: OPTIONS			
A B C ...	Output options	-	≤ 40 ch.
BLOCK III: FREQUENCIES			
FR1,FR2,NF,COFF,[V]	FR1: First frequency FR2: Last frequency NF: Number of frequencies COFF: Integration contour offset V: Source/receiver velocity (only for option d)	Hz Hz dB/ Λ	> 0 > 0 > 0 $COFF \geq 0$
BLOCK IV: ENVIRONMENT			
NL D,CC,CS,AC,AS,RO,RG,CL	Number of layers, incl. halfspaces D: Depth of interface. CC: Compressional speed CS: Shear speed AC: Compressional attenuation AS: Shear attenuation RO: Density RG: RMS value of interface roughness CL: Correlation length of roughness M: Spectral exponent	- m m/s m/s dB/ Λ dB/ Λ g/cm ³ m m	$NL \geq 2$ - $CC \geq 0$ - $AC \geq 0$ $AS \geq 0$ $RO \geq 0$ - $CL > 0$ $i \geq 1.5$
BLOCK V: SOURCES			
SD,NS,DS,AN,IA,FD,DA	SD: Source depth (mean for array) NS: Number of sources in array DS: Vertical source spacing AN: Grazing angle of beam IA: Array type FD: Focal depth of beam DA: Dip angle. (Source type 4).	m - m deg - m deg	- $NS > 0$ $DS > 0$ - $1 \leq IA \leq 5$ $FD \neq SD$ -
BLOCK VI: RECEIVERS			
RD1,RD2,NR,IR	RD1: Depth of first receiver RD2: Depth of last receiver NR: Number of receivers IR: Plot output increment	m m - -	- $RD2 > RD1$ $NR > 0$ $IR \geq 0$
BLOCK VII: WAVENUMBER SAMPLING			
CMIN,CMAX NW,IC1,IC2	CMIN: Minimum phase velocity CMAX: Maximum phase velocity NW: Number of wavenumber samples IC1: First sampling point IC2: Last sampling point	m/s m/s - - -	$CMIN > 0$ - $NW = 2^M, -1(auto)$ $IC1 \geq 1$ $IC2 \leq NW$

Table 3: Layout of OAST input files: I. Computational parameters.

Input parameter	Description	Units	Limits
BLOCK VIII: RANGE AXES			
RMIN,RMAX,RLEN,RINC	RMIN: Minimum range on plots	km	-
	RMAX: Maximum range on plots	km	-
	RLEN: Length of x-axis for all plots	cm	RLEN > 0
	RINC: Distance between tick marks	km	RINC > 0
BLOCK IX: TRANSMISSION LOSS AXES (Only for Options A,D,T)			
TMIN,TMAX,TLEN,TINC	TMIN: Minimum transmission loss	dB	-
	TMAX: Maximum transmission loss	dB	-
	TLEN: Length of vertical TL axes	cm	TLEN > 0
	TINC: Distance between tick marks	dB	TINC > 0
BLOCK X: DEPTH AXES (Only for Options C,D)			
DUP,DLO,DLN,DIN	DUP: Min. depth for plots	m	-
	DLO: Max. depth for plots	m	-
	DLN: Length of depth axes	cm	DCLN > 0
	DIN: Distance between tick marks	m	DCIN > 0
BLOCK XI: CONTOUR LEVELS (Only for Option C,f)			
ZMIN,ZMAX,ZINC (ZMIN: Minimum contour level	dB	-
	ZMAX: Maximum contour level	dB	-
	ZINC: Contour level increment	dB	ZINC > 0
BLOCK XII: SVP AXES (Only for Option Z)			
VLEF,VRIG,VLEN,VINC DVUP,DVLO,DVLN,DVIN	VLEF: Wave speed at left border	m/s	-
	VRIG: Wave speed at right border	m/s	-
	VLEN: Length of wave speed axis	cm	VLEN > 0
	VINC: Wave speed tick mark distance	m/s	VINC > 0
	DVUP: Depth at upper border	m	-
	DVLO: Depth at lower border	m	-
	DVLN: Length of depth axis	cm	DVLN > 0
	DVIN: Depth axis tick mark distance	m	DVIN > 0

Table 4: Layout of OAST input files: II. Plot parameters.

- J** Complex integration contour. The contour is shifted into the upper halfpane by an offset controlled by the input parameter COFF (Block III).
- K** Computes the bulk pressure. In elastic media the bulk pressure only has contributions from the compressional potential. In fluid media the bulk pressure is equal to the acoustic pressure. Therefore for fluids this option yields the negative of the result produced by option N or R.
- L** Linear vertical source array.
- N** Normal stress σ_{zz} ($= -p$ in fluids) calculated.
- P** Plane geometry. The sources will be line-sources instead of point-sources as used in the default cylindrical geometry.
- R** Computes the radial normal stress σ_{rr} (or σ_{xx} for plane geometry).
- S** Computes the stress equivalent of the shear potential in elastic media. This is an angle-independent measure, proportional to the shear potential, with no contribution from the compressional potential (in contrast to shear stress on a particular plane). For fluids this option yields zero.
- T** Transmission loss plotted as function of range for each of the selected field parameters.
- V** Vertical velocity calculated.
- Z** Plot of velocity profile.
 - a** Angular spectra of the integration kernels are plotted. A $0 - 90^\circ$ axis is automatically selected representing the grazing angle (0° corresponds to horizontal propagation). NOTE: The same wavenumber corresponds to different grazing angles in different media!. The vertical axis is selected automatically, representing the angular density (as opposed to the wavenumber density for integrand plots (option I)).
 - b** Solves the depth-separated wave equation with the lowermost interface condition expressed in terms of a complex reflection coefficient. The reflection coefficient must be tabulated in an input file `input.trc` which may either be produced from experimental data or by the reflection coefficient module OASR as described on Page 23. See also there for the file format. The lower halfspace must be specified as vacuum and the last layer as an isovelocity fluid without sources for this option. Add dummy layer if necessary. Further, the frequency sampling must be consistent. Therefore, if this option is combined with option `f`, the input file must have consistent logarithmic sampling. Using OASR this is obtained by using option `C` with the same minimum and maximum frequencies, and number of frequencies. Note: Care should be taken using this option with a complex integration contour, option `J`. The tabulated reflection coefficient must clearly correspond to the same imaginary wavenumber components for OAST to yield proper results. OASR calculates the reflection coefficient for real horizontal wavenumbers.

- c** Contours of integration kernels as function of horizontal wavenumber (abscissa) and receiver depth (ordinate). The horizontal wavenumber axis is selected automatically, whereas the depth axis is plotted according to the parameters given for option C. The contour levels are determined automatically.
- d** Source/receiver dynamics. OAST v 1.7 handles the problem of source and receiver moving through the waveguide at the same speed and direction. The velocity projection V onto the line connecting source and receiver must be specified in Block III, as shown in table 3. Since source and receiver are moving at identical speeds there is no Doppler shift, but the Green's function is different from the static one, as described by Schmidt and Kuperman[?].
- f** A full Hankel transform integration scheme is used for low values of kr and tapered into the FFP integration used for large kr . The compensation is achieved at very low computational cost and is recommended highly for cases where the near field is needed.
- o** Contours of transmission loss plotted vs frequency and range, i.e. the traditional 'optimum frequency' contour plots. Requires $NFREQ > 1$ (see below). A logarithmic frequency axis is assumed for this option. Requires ZMIN, ZMAX and ZINC to be specified in Block XII (same contour levels as for option C which may be specified simultaneously).
- g** Rough interfaces are assumed to be characterized by a Goff-Jordan power spectrum rather than the default Gaussian (Same as G).
- I** User defined source array. This new option is similar to option L in the sense that that it introduces a vertical source array of time delayed sources of identical type. However, this option allows the depth, amplitude and delay time to be specified individually for each source in the array. The source data should be provided in a separate file, **input.src**, in the format described below in Section 6.1.5.
- s** Outputs the mean field discontinuity at a rough interface to the file 'input'.rhs for input to the reverberation model OASS.
- t** Solves the depth-separated wave equation with the top interface condition expressed in terms of a complex reflection coefficient. The reflection coefficient must be tabulated in a input file `input.trc` which may either be produced from experimental data or by the reflection coefficient module OASR as described on Page 23. See also there for the file format. The upper halfspace must be specified as vacuum and the first layer as an isovelocity fluid without sources for this option. Add dummy layer if necessary. Further, the frequency sampling must be consistent. Therefore, if this option is combined with option \hat{f} , the input file must have consistent logarithmic sampling. Using OASR this is obtained by using option C with the same minimum and maximum frequencies, and number of frequencies. Note: Care should be taken using this option with a complex integration contour, option \mathcal{J} . The tabulated reflection coefficient must clearly correspond

to the same imaginary wavenumber components for OAST to yield proper results. OASR calculates the reflection coefficient for real horizontal wavenumbers.

Number (1 – 4) specifying the source type (explosive, forces, moment) as described in Section 6.1.5

6.1.3 Block III: Frequencies

A frequency loop has been incorporated in OAST to allow for computation of transmission loss over a wide frequency band in one run. The frequency specification (Block III in SAFARI Manual) has therefore been changed to:

FR1 FR2 NF COFF [V]

where FR1 and FR2 are the minimum and maximum frequencies, respectively. NF is the number of frequencies, spaced equidistantly between FR1 and FR2, except if option **f** was specified; then the frequencies will be spaced logarithmically. COFF is the complex wavenumber integration contour offset. To be specified in dB/λ , where λ is the wavelength at the source depth SD. As only the horizontal part of the integration contour is considered, this parameter should not be chosen so large, that the amplitudes at the ends of the integration interval become significant. In lossless cases too small values will give sampling problems at the normal modes and other singularities. For intermediate values, the result is independent of the choice of COFF, but a good value to choose is one that gives 60 dB at the longest range considered in the FFT, i.e.

$$\text{COFF} = \frac{60 * \text{CC}(\text{SD})}{(\text{FREQ} * R_{max})}$$

where the maximum FFT range is

$$R_{max} = \frac{\text{NP}}{\text{FREQ} * (1/\text{CMIN} - 1/\text{CMAX})}$$

This value is the default which is applied if COFF is specified to 0.0.

The optional parameter V is the identical speed of source and receiver relative to the medium, projected onto the radial vector connecting them. This parameter is only used for option **d**.

6.1.4 Block IV: Environmental Model

OAST supports all the environmental models allowed for SAFARI as well as the ones described above in Section 4.1. The significance of the standard environmental parameters is as follows

NL: Number of layers, including the upper and lower half-spaces. These should Always be included, even in cases where they are vacuum.

D: Depth in m of upper boundary of layer or halfspace. The reference depth can be choosen arbitrarily, and D() is allowed to be negative. For layer no. 1, i.e. the upper half-space, this parameter is dummy.

CC: Velocity of compressional waves in m/s . If specified to 0.0, the layer or half-space is vacuum.

CS: Velocity of shear waves in m/s . If specified to 0.0, the layer or half-space is fluid. If $CS() < 0$, it is the compressional velocity at bottom of layer, which is treated as fluid with $1/c(z)^2$ linear.

AC: Attenuation of compressional waves in dB/λ . If the layer is fluid, and AC() is specified to 0.0, then an imperial water attenuation is used (Skretting & Leroy).

AS: Attenuation of shear waves in dB/λ

RO: Density in g/cm^3 .

RG: RMS roughness of interface in m . RG(1) is dummy. If $RG < 0$ it represents the negative of the RMS roughness, and the associated correlation length CL and spectral exponent M should follow. If $RG > 0$ the correlation length is assumed to be infinite.

CL: Roughness correlation length in m .

M: Spectral exponent of the power spectrum as defined by Turgut [?], with $1.5 < M \leq 2.5$ for realistic surfaces, with $M = 1.5$ corresponding to the highest roughness, and $M = 2.5$ being a very smooth variation. For 2-D Goff-Jordan surfaces, the fractal dimension is $D = 4.5 - M$ Insignificant for Gaussian spectrum (option **g** not specified) but a value must be given.

6.1.5 Block V: Sources

OAST supports the same sources as SAFARI-FIP, i.e explosive sources in fluids or solids or vertical point forces in solids (option X). Multiple sources in a vertical array are supported. If sources with horizontal directionality are desired, the 3-dimensional version OASP3D must be used. The significance of the source parameters are as follows

SD: Source depth in m . If option 'L' has been specified, then SD defines the mid-point of the vertical source array.

NS: Number of sources in the array.

DS: Source spacing in m .

AN: Specifies the nominal grazing ANG of the generated beam in degrees. $ANG > 0$ corresponds to downward propagation.

IA: Array type

1. Rectangular weighted array
2. Hanning weighted array
3. Hanning weighted focusing array
4. Gaussian weighted array
5. Gaussian weighted focusing array

FD: Focal depth in m for an array of type 3 and 5.

DA: Dip angle in degrees for dip-slip sources (type 4).

Source Types

As in SAFARI the default source type in OAST is an explosive type compressional source. In addition to the optional vertical point force, and axisymmetric seismic moment source has been added to OAST. The source type is specified by a number (1 – 3) in the option field (line 2). The translation is as follows:

1. Explosive source (default) normalized to unit pressure at 1 m distance.
2. Vertical point force with amplitude 1 N.
3. Horizontal (in-plane) point force with amplitude 1 N.
4. Dip-slip source with seismic moment 1 Nm. Dip angle specified in degrees in block V, following the other parameters.
5. Omnidirectional seismic moment source representing explosive source. Same as type 1, but all three force dipoles have seismic moment 1 Nm.

Source Normalization

In SAFARI, the source strength was normalized to yield unit pressure (in Pa) at a distance of 1 m from the source (for solids the negative of the normal stress 1 m below the source).

In OASES, the same source normalization has been maintained for point sources (explosive sources) in fluid media. For solid media, however, the sources are normalized to unit volume ($1 m^3$) injection for explosive sources and unit force 1 N for point sources or 1 N/m for line sources.

User defined Source Arrays

Version 1.6 of OAST has been upgraded to allow a user-defined source array through option **I**.

Option **I** is intended for general physical arrays with uneven spacing or special shadings. As for the built-in arrays, such user-defined arrays may be present in fluid as well as elastic media. The array definition should be given in the file **input.src** in the following format

```

LS
SDC (1)  SDELAY (1)  SSTREN (1)      # Depth (m), Delay (s), Amplitude
SDC (2)  SDELAY (2)  SSTREN (2)
SDC (3)  SDELAY (3)  SSTREN (3)
  :      :          :
  :      :          :
SDC (LS) SDELAY (LS) SSTREN (LS)

```

6.1.6 Block VI: Receivers

The default specification of the receiver depths is the same as for SAFARI, i.e. through the parameters RD1, RD2, NR and IR in Block VI, with

RD1 Depth of uppermost receiver in m

RD2 Depth of lowermost receiver in m

NR Number of receiver depths

IR Depth increment for options I and T

By default, the NR receivers are placed equidistantly in the vertical.

Non-equidistant Receiver Depths

In OASES the receiver depths can optionally be specified individually. The parameter NR is used as a flag for this option. Thus, if $NR < 0$ the number of receivers is interpreted as $-NR$, with the individual depths following immediately following Block VI. As an example, SAFARI FIP case 2 with receivers at 100, 105 and 120 m is run with the following data file:

```

SAFARI-FIP case 2.
N I T J Z
30 30 1 0
5

```

```

0      0      0 0    0 0    0
0 1500 -1480 0    0 1    0
30 1480 -1490 0    0 1    0
100 1600    400 0.2 0.5 1.8 0
120 1800    600 0.1 0.2 2.0 0
50
100 100 -3 1          # 3 receiver depths
100.0 105.0 120.0    # Receiver depths in meters
700 1E8
1024 1 512
0 5 20 1
20 80 12 10
1450 1550 10 25
0 100 10 20

```

6.1.7 Block VII: Wavenumber Integration

This block specifies the wavenumber sampling in the standard SAFARI format. The critical issues involved in selecting the wavenumber sampling is described in the SAFARI manual [?], but even more detailed in *Computational Ocean Acoustics* [?]. The structure of this input block is as follows:

CMIN: Minimum phase velocity in m/s. Determines the upper limit of the truncated horizontal wave- number space:

$$k_{max} = \frac{2\pi * \text{FREQ}}{\text{CMIN}}$$

CMAX: Maximum phase velocity in m/s. Determines the lower limit of the truncated horizontal wave- number space:

$$k_{min} = \frac{2\pi * \text{FREQ}}{\text{CMAX}}$$

In plane geometry (option P) CMAX may be specified as negative. In this case, the negative wavenumber spectrum will be included with $k_{min} = -k_{max}$, yielding correct solution also at zero range. In contrast to SAFARI, OAST allows for complex contour integration (option J) in this case.

NW: Number of sampling points in wavenumber space. Should be an integer power of 2, i.e. $NW = 2^m$. The sampling points are placed equidistantly in the truncated wavenumber space determined by CMIN and CMAX.

IC1: Number of the first sampling point, where the calculation is to be performed. If $IC1 > 1$, then the Hankel transform is zeroed for sampling points 1,2...IC1-1, and the discontinuity is smoothed.

IC2: Number of the last sampling point where the calculation is to be performed. If $IC2 < NWN$, then the Hankel transform is zeroed for sampling points $IC2+1, \dots, NWN$, and the discontinuity is smoothed by Hermite polynomial extrapolation.

Automatic wavenumber sampling

OAST Version 1.5 has been supplied with an automatic sampling feature, making it possible for inexperienced users to obtain correct answers in the first attempt without the usual convergence testing. The automatic sampling is activated by specifying the parameter $NW = -1$ and it automatically activates the complex wavenumber integration contour even though option J may not have been specified. The parameters $IC1$ and $IC2$ have no effect if the automatic sampling is selected.

As an example, to run the SAFARI-FIP case 2 problem with automatic sampling, change the data file as follows:

```
SAFARI-FIP case 2. Auto sampling.
N I T J Z
30 30 1 0
5
  0 0 0 0 0 0
  0 1500 -1480 0 0 1 0
 30 1480 -1490 0 0 1 0
100 1600 400 0.2 0.5 1.8 0
120 1800 600 0.1 0.2 2.0 0
50
100 100 1 1
1300 1E8 # CMIN = 1300
-1 0 0 # NW = -1
  0 5 20 1
20 80 12 10
1450 1550 10 25
  0 100 10 20
```

6.2 Execution of OAST

As for SAFARI, filenames are passed to the code via environmental parameters. In Unix systems a typical command file **oast** (in $\$HOME/oases/bin$) is:

```
# the pound sign invokes the C-shell
setenv FOR001 $1.dat # input file
setenv FOR002 $1.src # Source array input file
setenv FOR019 $1.plp # plot parameter file
```

```
setenv FOR020 $1.plt      # plot data file
setenv FOR023 $1.trc      # reflection coefficient table (input)
setenv FOR028 $1.cdr      # contour plot parameter file
setenv FOR029 $1.bdr      # contour plot data file
setenv FOR045 $1.rhs      # file for scattering discontinuities
oast2                     # executable
```

After preparing a data file with the name **input.dat**, OAST is executed by the command:

```
> oast input
```

6.3 Graphics

Command files are provided in a path directory for generating the graphics.

To generate curve plots, issue the command:

```
> mplot input
```

To generate contour plots, issue the command:

```
> cplot input
```