Teleseismic modelling for DAS

(a) Geometry for DAS cable locations for teleseismic events

Uses same approach as for regional events but with slightly different file structure for output

(i) Extraction of azimuth information for cable locations
cable-azim1

Input required – station locations (latitude longitude)
Output: Azimuths of cable, northings and eastings

Sample input:

```
KNSG-coord.in                              ! coordinate file
KNSG-cabazp.lis                           ! azimuth file
```

(ii) Range azimuth information for synthetics
sta-dasrt

Sample input:

```
KNSG-cazim.lis                                ! cable-azim file
WAs-sta.in                                    ! distance list
WAs-K1.dts                                    ! output file for synthetics
-29.7226  -177.2791                           ! source lat, lon
TE                                            ! reg/teleseismic (RE/TE)
```

Sample files:

Coordinate file: KNSG-coord.in - positions in km along cable + latitude, longitude

```
KNSG
       0.263852     -31.993734     115.884987
       0.280046     -31.993711     115.884819
       0.293565     -31.993711     115.884674
       0.310255     -31.993664     115.884506
       0.321200     -31.993641     115.884399
       0.323905     -31.993641     115.884369
       0.340600     -31.993591     115.884201
       0.352333     -31.993544     115.884087
       0.453730     -31.992638     115.883942
       0.537969     -31.992498     115.883064
…
```

Azimuth file: KNSG-cazim.lis

```
92
       0.263852     -31.993734     115.884987     280.000000
       0.280046     -31.993711     115.884819     279.134186
       0.293565     -31.993711     115.884674     270.000000
       0.310255     -31.993664     115.884506     288.519348
       0.321200     -31.993641     115.884399     284.179779
       0.323905     -31.993641     115.884369     270.000000
       0.340600     -31.993591     115.884201     289.206757
       0.352333     -31.993544     115.884087     296.164429
       0.453730     -31.992638     115.883942     352.272247
       0.537969     -31.992498     115.883064     280.598358
…
```

Station file: WAs-sta.in

```
10
 0.300
 0.400
 0.500
 0.600
 0.700
 0.800
 0.900
 1.000
 1.100
 1.200
……
```

Output file for synthetics: WAS-K1.dts

Epicentral distance [deg], azimuth from source, position on cable, cable azimuth, latitude, longitude, epicentral distance [km]

```
      10
  56.5760     249.3914       0.3000      -5.2419       -31.99368    115.88457    6292.709
  56.5766     249.3919       0.4000      39.2743       -31.99306    115.88401    6292.779
  56.5771     249.3924       0.5000      33.3448       -31.99258    115.88354    6292.837
  56.5777     249.3923       0.6000      -6.0240       -31.99246    115.88284    6292.905
  56.5784     249.3925       0.7000      16.8355       -31.99206    115.88217    6292.978
  56.5788     249.3938       0.8000      70.4115       -31.99096    115.88210    6293.020
  56.5791     249.3950       0.9000      70.4108       -31.98986    115.88203    6293.060
  56.5795     249.3963       1.0000      70.4100       -31.98877    115.88197    6293.101
  56.5799     249.3966       1.1000     -79.0315       -31.98843    115.88165    6293.141
  56.5802     249.3965       1.2000       8.9033       -31.98841    115.88129    6293.174
```

(b) Modelling of DAS response by frequency-slowness integration

The modelling uses the slowness bundle approach of Marson-Pidgeon & Kennett (2000) *Geophys. J. Int*. **143**, 689–699

Teleseismic body-wave seismograms are calculated allowing for reverberations in the upper zone near the source and receiver, and a single reflection from beneath the separation level. (e.g. P,pP,sP,S,pS,sS+multiples). The calculation uses a representation in terms of reflection and transmission properties. The source, mantle and receiver responses and handled separately. Source and receiver velocity models are flat layer models that are allowed to be different, and the mantle velocity model is a spherical earth model. A general point source is specified by an arbitrary moment tensor. Attenuation is allowed for by specifying frequency-independent loss factors for both P and S waves (Qai and Qbi) in the velocity models, and calculating complex wavespeeds.

The inverse transforms are calculated using the spectral method so integration over slowness first is performed first (for a bundle of slownesses clustered around the geometric slowness) and then an inverse fft is used to generate a theoretical seismogram time series for each distance. The P and S response are calculated separately (ips = 1 or 2). DAS response is implemented via acceleration along the cable scaled by slowness along cable for each slowness component

Form of input: (read from a command file)

velocity models:

irm = YE read a different receiver model for each station
= NO use same receiver model for each station
nrmod = number of receiver models (if irm = "YE", then nrmod = nstat)
(if irm = "NO", then nrmod = 1)
smod = name of source model file
mmod = name of mantle model file
rmod = name of receiver model file
zfil = name of zst output data file (P-wave or S-wave)

indices:

irs = 0 FULL RESPONSE
= 10 P and S at source, P at receiver
= 11 P at source, P at receiver
= 12 S at source, P at receiver
= 20 P and S at source, S at receiver
= 21 P at source, S at receiver
= 22 S at source, S at receiver

ifs = YE free surface
= NO upper half space

idebug = YE write output for debugging
= NO no output

cseis = GD displacement seismograms
= GV velocity seismograms

= GA acceleration seismograms
= DT DAS simulation – strain rate
= DV DAS simulation - velocity along cable

timing:
npts = total number of time points in series
ipts = index (npts=2**ipts)
deltat = time step in time series

frequency taper (low):
flo = lower limit of frequency window
fl2 = cosine taper up from flo to fl2
(zero response for frequencies less than flo and unit response
for frequencies higher than fl2 with cosine taper between)

frequency taper (high):
fu2 = cosine taper down from fu2 to fup
fup = upper limit of frequency window
(unit response for frequencies less than fu2 and zero response
for frequencies higher than fup with cosine taper between)

source:
sdepth = depth of source (in spherical model)
mxx mxy mxz
myx myy myz = moment tensor components of source
mzx mzy mzz

farfield source time function:
trise = rise time of trapezoid
tconst = duration of constant portion
tfall = fall time of trapezoid

wave-type:
ips = wave-type index: P-wave (1) or S-wave (2)?

pc = reduction slowness to use for calculation

stations:
nstat = number of stations
for each station:
dist = distance (in degrees)
azim = azimuth (in degrees)
xc = distance along DAS cable (km)
caz = cable azimuth (in degrees)

slownesses:
nrp = number of slownesses
plo = number of points over which to apply lower slowness taper
phi = number of points over which to apply upper slowness taper

csl = YE - reuse slowness bundle for first station
(ignores minor azimuth variations)

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source and receiver velocity models: (read from external file)
(source and receiver = flattened model)
nlay = number of layers
for each layer:
alf = P-wave velocity
bet = S-wave velocity
rho = density
zd = depth to layer (compute hl = layer thickness)
Qai = 1.0/Qa (attenuation for P-waves)
Qbi = 1.0/Qb (attenuation for S-waves)

mantle velocity model: (spherical model)
nlay = number of layers
for each layer:
z = depth to layer
r = radius to layer
alf = P-wave velocity
bet = S-wave velocity
Qai = 1.0/Qa (attenuation for P-waves)
Qbi = 1.0/Qb (attenuation for S-waves)

Example command file for telebundle-dasn

```
NO                                          !  different receiver model?
1                                           !  number of receiver models
ak135.mod                                   !  source velocity model
ak135qs.vel                                 !  mantle velocity model
ak135_r.mod                                 !  receiver velocity model
PWAdn-K6V.txz                               !  T-X output file
DV                                          !  seis type (GD,GV,GA,DT,DV)
   0                                        !  response  (0 = full)
   1                                        !  wave-type: P-wave(1) or S-wave(2)?
  YE                                        !  free surface
  8192     13     0.04                      !  no. time pts, index, increment
  0.01  0.05                                !  lower cosine frequency taper
  1.00  2.00                                !  upper cosine frequency taper
  29.0                                      !  source depth
  -0.064  -0.256   0.254                    !  moment tensor:  mxx  mxy  mxz
  -0.256  -0.914  -1.250                    !                  myx  myy  myz
   0.254  -1.250   0.978                    !                  mzx  mzy  mzz
  1.25  2.50  1.25                          !  trapezoidal source time function
  100                                       !  number of slownesses
  3    3                                    !  lower and upper slowness tapers
  YE                                        !  reuse slowness bundle
  0.0                                       !  reduction slowness
WAS-K6n.dts                                 !  station file
 NO                                         !  debug
```

(c) Seismogram output and display

The seismogram file structure and the display routine are the same as used for the local and regional case.

The seismograms are written out by **telebundle_dasn** in a simple ascii format in a loop over stations (index JX):
XD(JX), AZD(JX), CDC, DELT, NT, PR, TCAL, SMP, (FR(LK),LK=1,NT)

XD – distance along cable
AZD – azimuth
CDC – type identifier
DELT – time increment
NT – number of time points
PR – reduction slowness
TCAL – starting reduced time
SMP – maximum amplitude
FR – time series

Example showing first few time points:

```
-4.30000015E-02   90.0000000     DASL   5.00000024E-04       4096   0.00000000
-0.100000001      2.13151979      -3.98850441E-03  -3.68603622E-03  -3.41499783E-03
-3.22220637E-03  -3.14382929E-03  ....
```

Display zsyd

The zsyd routine displays seismograms with the distance axis vertical and time horizontally, a style suitable for comparison with DAS records.
Travel times will normally be suppressed for the teleseismic case

A sample input file for a teleseismic event is:

```
YE                                Plot seismograms? (YE/NO)
DA                                <se> Plot components (DA,ZC,RC,TC,3C,)
1                                 <se> Number of files for seismograms(<3)
PWAb-K1.txz                       <se> Name of file
37                                <se> Number of distances to plot
0.0                               <se> Reduction slowness for plot
0.0   0.00                        <se> Minimum red time for seismograms, time shift
0.0   5.0                         <se> Component offset, polarisation window
1  3 2                            <se> Pen colours for seismic components
NO                                <se> Trace normalisation? (YE/NO)
 20.00  0.01  0.01  1.0  1.0      <se> Amp,b1,b2,xr,eps | amp*(b1+b2/xr)**eps
NO                               Plot travel times? (YE/NO)
1                                 <tt> number of files for travel times (<3)
flp.t.z                           <tt> Name of file
LI                                <tt> line or symbol mode (LI/SY)
3                                 <tt> Pen colour
FR                               Frame: FR - full frame , NL - no labels
3                                 <fr> font choice
   0.00     1.50                  <fr> Rmin, Rmax
   15.00                          <fr> length of R-axis
   500.0    900.0                 <fr> Trmin,Trmax
   25.0                           <fr> length of T-axis
```

```
    0.25   100.0                <fr> Large Tic spacing R,T
    0.05    10.0                <fr> Small Tic spacing R,T
    2       1                   <fr> # of dec. in label R,T
   0.5000   0.47500             <fr> character size text,title
Distance [km]                                                    X-txt
Time [s]                                                         Y-txt
KNSG cable - Mw8.1 Kermadec                                      Title
```

The product is a Postscript file **zsy.ps** in landscape format