Manual for Shear-wave splitting (SWS) analysis codes

Note: This version is for using on r43sgao.managed.mst.edu.
It should also work on other 64-bit Linux servers such as gao.nic

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Programs in this directory (/home/sgao/progs/B_XKS) perform the following tasks:

1). Requesting and processing teleseismic XKS (including PKS,SKKS, and SKS) data
    from the IRIS Data Management Center(DMC).

2). Automatically measuring SWS parameters

3). Automatically ranking SWS parameters

4). Manually screening the results

** Please report confusions/errors to sgao@mst.edu

The technique is described in a number of papers. The PDF file of the papers can be downloaded from
http://www.mst.edu/~sgao/publications

You may want to read:
Paper 1 below to learn about the ranking procedure,
Paper 2 for the general procedure,
Paper 3 for an application of single-stations studies
Paper 4 for an application of multiple station studies and anisotropy depth estimate, and
Paper 5 for practices in order to make reliable SWS measurements.

Paper 1). Liu, K. H., S. S. Gao, Y. Gao, and J. Wu (2008),
Shear wave splitting and mantle flow associated with the deflected Pacific slab beneath northeast Asia,
Journal of Geophysical Research, Vol. 113, B01305, doi:10.1029/2007JB005178. Click
http://www.mst.edu/~sgao/publications/Liu_Gao_JGR_2008_China_anisotropy.pdf
to download the paper.

Paper 2). Liu, K.H. (2009),
NA-SWS-1.1: A uniform database of teleseismic shear-wave splitting measurements for North America,
Geochemistry, Geophysics, Geosystems, Vol. 10, Q05011,
doi:10.1029/2009GC002440. Click
http://web.mst.edu/~sgao/publications/Liu_ggg2009_nasks.pdf
to download the paper.

Paper 3). Gao, S. S., and K. H. Liu (2009),
Significant seismic anisotropy beneath the southern Lhasa Terrane, Tibetan Plateau,
Geochemistry Geophysics Geosystems, Vol. 10, Q02008, doi:10.1029/2008GC002227. Click
http://www.mst.edu/~sgao/publications/Gao_Liu_G3_2009_Tibet_SWS.pdf
to download the paper.

Paper 4). Gao, S.S., K.H. Liu, and M.G. Abdelsalam (2010),
Seismic anisotropy beneath the Afar Depression and adjacent areas: Implications for mantle flow,
Journal of Geophysical Research, doi:10.1029/2009JB007141. Click
http://www.mst.edu/~sgao/publications/Gao_etal_2010_JGR_Afar_SWS.pdf
to download the paper.

Paper 5). Liu, K. H., and S. S. Gao (2013),
Making reliable shear-wave splitting measurements,
Bulletin of the Seismological Society of America, Volume 103, No.5, 14 pages,
doi: 10.1785/0120120355. Click
http://www.mst.edu/~sgao/publications/BSSA2013.pdf
to download the paper.

***** Part 1: Copying the useful files to your directory

**Step1.1). Logon to r43sgao

**Step1.2). Choose a sensible name for your project and make a directory for your new
    shear-wave splitting (SWS) project (e.g., mkdir YS_SWS for YellowStone),
    and cd to that directory (e.g., cd YS_SWS)

    For NA-SWS project only: type nasws, then mkdir Block_name (e.g., mkdir J180W) and
    cd to this directory name before you move on. This directory is called your project directory

**Step1.3). Type the following command in your project directory will copy over all
    the useful files from sgao's progs directory to your new project directory:

    /home/sgao/progs/B_XKS/zz_Copy_all.cmd   (note that the "C" in Copy is in capital)

You will have the following structure of your directory tree that created by
the command above. (If you get lost in the future steps, please refer to this roadmap):

Level 1: Project_directory (e.g., YS_SWS)

Level 2: seismic phase directory: 1_PKS, 2_SKK, 3_SKS

Level 3: main work directories under each of the 3 level 2 dirs above

++ Under 0_get_IRIS_data, you have the following 5 directories:
00_breq_fast/ 01_Do_234/ 02_Iris2dtm/ 03_dtm2ucla/ 04_phase_search/
They are used to request and process IRIS DMC Data

++ Files under 1_measu are for automatically measuring SWS parameters

++ Files under 4_ranking are for automatically ranking SWS parameters

++ Files under 4c_rescreen_AB are for manually checking SWS parameters

.... (there are several other dirs)

****Part 2: requesting and processing the data

Note that data for all the 3 phases (PKS, SKKS, SKS) are requested under the 3_SKS directory, meaning that there is no need to separately request PKS and SKKS data.

**Step2.1). cd 3_SKS/0_get_IRIS_data/00_breq_fast

**Step2.2). find the coordinates of your study area from a map. For MST Seismology users, the big tectonics map on the wall of B40 is a good one.

If you only do one station, typing
stloc station_name
can give you the coordinates of the station.
(where station_name is the name of the seismic station.
E.g., stloc TAM. The last number is the longitude, and the second from the last is the latitude).

Then type
evselect.exe
in the directory 3_SKS/0_get_IRIS_data/00_breq_fast

You will be asked to input the 4 coordinates values for your study area. Pay attention to the fact that for the western hemisphere, −120 is smaller than −100 etc. You also will be asked to enter your name and your email address.

If you are doing one station only, calculate your coordinate ranges by including the station in a 0.1 by 0.1 degree square.

For NA−SWS project: Please do NOT use your own name, but instead, put the name of the block that you are working on (e.g., J180W).

**Step2.3). E−mail setup
If you are a MST user, you need to set up your rule which deletes all the emails from dmsque@iris.washington.edu to avoid thousands of emails from IRIS to mess up your email account.

The steps ensure that the emails are in the Deleted Items (or Spam) folder which can be easily cleaned by right−click and "Empty Deleted Items". You need to frequently empty this folder, otherwise your mailbox will be full and no emails can be sent or received.

**Step2.4). For MST users only!

When the program evselect.exe is finished,
cd mailfiles
and type
email_iris.cmd

This should produce a file called "zz_send_requests.cmd".
Do not worry about the "... not found" warning message.

**Step2.5). For MST users only!

more zz_send_requests.cmd
and make sure that it is what you want, and type
zz_send_requests.cmd
to make the request. This might take some time. Do not logoff until all the emails were sent.

**Step2.6). After some minutes (5−30?), check your MST email. You should have many emails from dmc.iris.edu in the "Deleted Items" or "Spam" or "Junk" folder

Note that the initial email will be sent to sgao@mst.edu, and gets forwarded.
But you should be able to receive confirmations from IRIS in your Spam or deleted items dir.

**Step2.7). Check "request status" by going to
http://ds.iris.edu/ds/nodes/dmc/data/request−status/
You should be able to see your name and the status of your requests.
You may also want to try "recent shipments" by going to

http://ds.iris.edu/ds/nodes/dmc/data/recent-shipments/
to see if your requests have been shipped or not.

If the traffic at IRIS is heavy, your requests can stay in the 'MainQueue"
for a while (up to several hours) before they are processed.
Do not re-send your request.

**Step2.8). Check to make sure that all of your requests are finished (this can be
verified using several ways, e.g., you no longer receiving emails from iris, you
cannot find your name in the "request status" entry in Step 2.7, or you find your
last request is under "recent shipments").

**Step2.9). Get the files from IRIS.
When you are sure that all of your requests are finished,
cd 3_SKS/0_get_IRIS_data/02_Iris2dtm/iris, and type
irisftp.
After Name, put ftp, and put your email address as the password.
cd pub, cd userdata, cd Your_Name (e.g., Barack_Obama) or your block_name.

For NA-SWS project: cd Block_name (e.g., cd J180W)

mget * (note: mget * gets all the files. "*" is a "wildcard")
This step takes some time (hours?).
When it is done, type "quit"
You should see your SEED files under 02_Iris2dtm/iris

Note: 1). Your data will be deleted by the IRIS staff after about 5-7 days after the
request is completed. So please monitor the progress of the request and do the ftp
as soon as possible.

2). If you have many stations (e.g., more than 50), you may want to do the request in
groups (e.g., mget seed.0* seed.1* .... seed.A* first, and do more when they are done).
The reason is that ftp can stop anytime due to Internet and other problems, and by getting
the files in groups, you can start from where it stops and do not have to re-ftp everything.

**Step2.10). Start the processing:
Under your project directory (e.g. YS_SWS), type yy_Do_0_1_4.cmd. This will takes a
lot of time (hours to days, depending on the amount of data). Do not logoff your
computer until it is done.

**Step2.11). Checking the progress:
You have several ways to check the progress and to see if the jobs are finished.
a). type "top" and see if your jobs (rdseed, dtm2ucla.exe, or 1_SKS.exe etc.) are
still running;
b). go to 3_SKS/4_ranking/Out_all to see if there are *.out files in the dir.

When everything is finished, you will also find the processed seismograms in
04_phase_search/Outp. The seismograms are organized into events (that is,
an event directory holds all the seismograms from all the stations for this event).

For instance, directory EQ070480002 holds all the data for the event occurred in 2007,
Julian day 048, at 00 hour and 02 minute. Under this directory, the file
N12Axx_TA0r070480002.sac is a seismogram in SAC format from station N12A which is a
station in the TA network. 0r indicates that it is the radial component. The rest of
the name indicates the event time.

After the steps above, all of your PKS, SKKS, and SKS splitting measurements are done,
and are ranked. The resulting parameters and the associated waveforms can be found
under the 1_measu/Data directory under each of the 1_PKS, 2_SKK, and 3_SKS directories.

The ranked results can be found under the 4_ranking/Out_all directory.
The good measurements (A, B, S, and N) are under 4_ranking/Out_good.

To take a quick look of the pre-checking good results, cd 4_ranking/Plot_good and type Do*

Part 3: Manually checking the splitting parameters. This is the most time-consuming and
most critical step. It requires experience and a deep understanding of seismic
wave propagation and shear-wave splitting. Your results could be publishable or trashy,
all depending on how careful and knowledgeable you are when you are doing this step.

You need to do this in each of the 1_PKS, 2_SKK, and 3_SKS directories:

**Step3.1). Checking 1_PKS results.

cd 1_PKS

cd 4c_rescreen_AB

type 4c_screen_ABS.exe

and follow the instructions. You will be asked to enter the full name (9-letter) of the
station to be checked. The stations can be found under the 4_ranking/Out_all directory

**Step3.2). Checking 2_SKK results.

cd 2_SKK

cd 4c_rescreen_AB

type 4c_screen_ABS.exe and follow the instructions.

**Step3.3). Checking 3_SKS results.

cd 3_SKS

cd 4c_rescreen_AB

type 4c_screen_ABS.exe and follow the instructions.

Part 4: Displaying the checked results in various waves

This can be done by typing a single command under your project dir:
zzz_Do_5c_6c_7c_cc_dd.cmd

The final splitting parameters for all the 3 phases plotted at the ray piercing points
can be found at 3_SKS/7d_plot_at_piercing_points_3phases/tmp.ps

The GMT program that produced tmp.ps is:
3_SKS/7d_plot_at_piercing_points_3phases/plot_pie.gmt
You may want to modify this program to make a prettier plot for your manuscript.

Part 5: Setup a website for your project on your MST homepage.

**Step5.1). Open a brand new PUTTY window and logon to r43sgao.managed.mst.edu if you
have been working on r43sgao, or to gao.nic.mst.edu if you have been working on
gao.nic (Note: for NA-SWS project, all work is done on gao.nic)

**Step5.2). If you are working on gao.nic, type
cd /tmp/.userweb/your_user_name/your_username (or simply www)

If you are working on r43sgao, cd /mnt/dfs/your_user_name/userweb/your_user_name (or www)

For NA-SWS project only: cd NASWS after the cd command above

**Step5.3). mkdir project_name (e.g., YS_SWS)

For NA-SWS project: use block name as project_name (e.g., J180W)

**Step5.4). cd project_name (note: For NASWS project, the following command must be typed
under the Block_name (e.g., J180W)

**Step5.5). type /home/sgao/progs/B_XKS/3_SKS/9_web_setup/*.exe or copyswsweb
Note that the required input is your project directory
(for instance, for my Tibet project, it is /home/sgao/Proj/09N_Tibet_Perm_SWS.
For NA-SWS project, an example is /share/gao/data07/har5gd/NASWS2/J180W)

**Step5.6). View the results: on your PC, open IE, and go to
http://www.mst.edu/~your_user_name/project_name
Click on a station name to view the splitting parameters, and
click on "plot" at the end of each line to see the waveform

Part 6: Fine tuning results. You can modify your results (e.g., the *.out
files in 4c*/Out) using one of the two ways:

**Step6.1). If you are sure that a measurement should not be included, pico or vi
the *.out file in the directory 4c_*/Out/ for this station, and change the ranking
from A or B to N or C.

**Step6.2). If you cannot decide if the measurement is good or not from what is shown on the web browser,
you can run the program *exe in 4d to re-measure this single event for the station.
The program makes changes to your output file in 4c_*/Out.

**Step6.3). Sometimes it is convenient to view all plots for a given phase together. To do so,
on r43sgao, cd to the project directory on your web folder, then cd to a phase name
(e.g., sks), and then cd abcns. Then type jpeg_icon_huge which will produce an index.html
file for all the *jpg files in the folder. To view the plots, open a web browser and
goto   http://www.mst.edu/~your_user_name/project_name/phase_name/abcns
You will see all the plots without the need of going back and forth.
You may want to open another browser window to view the summary plot for each station, so
that you know the general distribution of the results for this station.

Some general rules about a good measurement:

a). The STD of Phi (the 8th column of your meas.html in Step5.6) should be less than 20.0
If larger than 20.0, you need to run *exe in 4d to change the a and f values, and/or
to filter the waveform, or to change the ranking to N or C for this station in 4c_*/Out

b). The DT value cannot be larger than 2.5 s. It is extremely rare for it to be larger than
2.5. Take the same actions if DT is greater than 2.5. As a general rule, caution is
needed if DT is larger than 2.0 s. Most likely it is caused by cycle skip. However, it
must be mentioned that as always, if the XKS signal is good on both the original R and
T component and the XKS energy is alost gone on the corrected transverse component,

a measurement should be kept no matter how large DT is.

c). The STD of DT cannot be greater than 2 seconds.

d). Be very careful for 'outliers' in the parameter-versus-BAZ plots (which can be found by clicking the station name under "Station" on the browser mentioned in Step 5.6 above).

Step6.4). After you are done with the checking and the changes, you should update the results by re-running zzz_Do_5c_6c_7c_cc_dd.cmd in your project directory.

The revised results must be copied again to your web page by using Step 5.5 above. You can then view and re-refine the results using Step 5.6 and Steps 6.1-6.4 until the results are satisfactory.

Step6.5). After you are done with zzz*, go to your project directory (that is, the directory level where if you type ls, you can see the 1_PKS, 2_SKK, 3_SKS etc. directories), and type

sws-cleanup.cmd (this will remove the large and no-longer useful files to save disc space)

For NA-SWS project: Stop here

For Advanced Data Processing Class: Stop here

Part 7: Fitting the results using a two-layer model

**Step 7.1). cd 3_SKS/8a* and run the *exe program

**Step 7.2). cd 3_SKS/8b*, vi or pico 2do.stlist, and add the 9-letter station name (e.g., TAMxxx_IU) to the list. Do not leave blank lines in the file. Save the file and quit the editor.

**Step 7.3). Type *exe to run the program. This takes a lot of time (hours or days). The results are under Out/station_name. Type plot.gmt and gv tmp.ps to view the original data and fitted curves. The optimal parameters are in data.par

Stop here

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Part 8: For Drs. Gao or Liu to merge the NA-SWS2 results together:

**Step 8.1). cd to /home/sgao/Proj/12d_NASWS/ by typing nasks or nasws

**Step 8.2). copyfinal (this is /home/sgao/Proj/12d_NASWS/z_merge/01_copy_final/*exe)
You need to enter the username and block name, and the full path of the block.

The copied results are under user_name/block_name under the project 12d_NASWS

This program will also execute z_finalcopy.cmd under the block dir. This is the same as zzz_Do* but the JPEG files under 6d_ will not be produced to save space and CPU time.

Check the results of the block (go to the web of the student user) and make changes of the files under 4c_*/ of nasks (Note: this 4c_* is not the one under the student's account, but the one copied over to the project account).

If changes for 4c were made, re-run z_finalcopy.cmd

**Step 8.3). When all blocks are done, type wwwnasks, and run copyswswebfinal
(this is /home/sgao/Proj/12d_NASWS/z_merge/02_web_setup_for_final/*exe)

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Part 9: For Drs. Gao or Liu to merge and check NCUS SWS results together under /home/sgao/Proj/12l_NCUS_SWS

** Step 9.1). Type ncus to go to the project, and xx* to copy useful data over from individual user's account

** Step 9.2). Goto 3_SKS/4c*, and mkdir Out_good, cd Out_good, and type sws_grep_good. This will grep out the A, B, S, N, and C results in ../Out and write to this Out_good dir. They are ordered based on ranking (and thus easy for the eyes).

** Step 9.3). vi *.out in Out_good and scan through the measurements. To check an event, in another window, type
ncus_check_4c, enter the phase name (SKS, PKS, or SKK) and copy/paste the station and event name from the *out file under Out_good/ that you are checking. Two plots should be shown. If the ranking needs to be changed, vi the corresponding *.out file under Out_good/ (again, vi the files under Out_good/, and NOT the ones under Out/.
Type killps.cmd to erase the plots.
Type :w to save if changes are made to the file. Otherwise, type :next to vi next file.

** Step 9.4). When all stations are done, cd ../Out under 4c* (note: Not Out_good), type zz_copy.cmd
(this command include mkdir Junk, mv *.out Junk, and cp ../Out_good/*out .)
zz_copy.cmd will copy all the checked *.out files from Out_good/ to the Out/ dir.
They will be used by zz* to make the final plots/results when all the 3 phases are done.

**Step 9.5). Repeat 9.2-.94 for 1_PKS and 2_SKK

**Step 9.6). under the project dir, type zz* to make the final plots and web sites.
Note that only the measurements in the 4c*/Out/*out will be processed.
Also, 6d* will not be executed due to the huge amount of the "C" measurements.

Note 1. that once the stations are checked, you should not type xx* again. Otherwise the files under 4c*/Out will be replaced by the unchecked ones. If this happens, remove the *out file under Out and copy over the *.out files under Out_good to Out.

Note 2. All the changes to *out, even if they are done using other approaches, should be made in Out_good and then copy the *out file from Out_good to Out.

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Summary -- the Fortran programs were executed in the following order
(note: there is one and only one Fortran program in each directory):

1). 3_SKS/0_get_IRIS_data/00_breq_fast

2). 3_SKS/0_get_IRIS_data/02_Iris2dtm

3). 3_SKS/0_get_IRIS_data/03_dtm2ucla

4). 3_SKS/0_get_IRIS_data/04_phase_search

5). 1_PKS/0_get_IRIS_data/04_phase_search

6). 2_SKK/0_get_IRIS_data/04_phase_search

7). 1_PKS/1_measu

8). 1_PKS/4_ranking

9). 2_SKK/1_measu

10). 2_SKK/4_ranking

11). 3_SKS/1_measu

12). 3_SKS/4_ranking

13). 1_PKS/4c_rescreen_AB

14). 2_SKK/4c_rescreen_AB

15). 3_SKS/4c_rescreen_AB

16). 1_PKS/5c_plot_summary_rescreened/

17). 1_PKS/6c_plot_ind_JPEGs_rescreened

18). 1_PKS/6d_plot_ind_JPEGs_rescreened_all_events

19). 1_PKS/7c_plot_at_piercing_points_rescreened

20). 1_PKS/cc_make_webpage_rescreened

21). 2_SKK/5c_plot_summary_rescreened/

22). 2_SKK/6c_plot_ind_JPEGs_rescreened

23). 2_SKK/6d_plot_ind_JPEGs_rescreened_all_events

24). 2_SKK/7c_plot_at_piercing_points_rescreened

25). 2_SKK/cc_make_webpage_rescreened

26). 3_SKS/5c_plot_summary_rescreened/

27). 3_SKS/6c_plot_ind_JPEGs_rescreened

28). 3_SKS/6d_plot_ind_JPEGs_rescreened_all_events

28). 3_SKS/7c_plot_at_piercing_points_rescreened

29). 3_SKS/7d_plot_at_piercing_points_3phases

30). 3_SKS/cc_make_webpage_rescreened

31). 3_SKS/dd_make_webpage_pks_skks_sks

32). 3_SKS/ee_make_webpage_pks_skks_sks_all_events

33). 3_SKS/9_web_setup

34). 3_SKS/8a_freq_dependent

35). 3_SKS/8b_two_layer_fits