

Intersection of Extended SH azimuths

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ABSTRACT

With

over 10,900 maximum horizontal stress measurements having been compiled and made available through the World Stress Map (Project, 2001) project, the availability and ease of manipulating these data now make it possible to explore global scale correlation of stress. This paper describes a methodology for investigating this data set and suggests possible mechanisms that could lead to the observed patterns. This methodology is still immature, and falls prey to data clustering artifacts, principally, and as yet un-thought of other issues that the author would greatly appreciate being made aware of. All realizations of the data to be described herein are best viewed and evaluated electronically, and can be found at the below referenced web site.

Do the test. Make the measurement. Then decide what it means over beers and on napkins with like-minded friends.

0.1. Introduction

The motivation behind this analysis was the relatively simple-minded observation that while local stress azimuth measurements tend to be quite uniformly quasi-parallel, this quality does indeed diminish at long distance. Therefore in the interest of determination if this was a simple result of distortion of *linearity* due to map projections, or a real correlation of the data due to larger processes, the maps had to be made.

While it is still unclear what the physical meaning of this locus is, or whether or not it is reasonable to perform the analysis on data originating in differing stress regimes (as described by [Anderson \(1951\)](#)), the data are showing a focusing that I believe needs a plausible explanation. Whether this explanation will involve a ridge-push mechanism after [Richardson \(1992\)](#), basal drag from mantle circulation after [Wuming et al. \(1992\)](#), glacial rebound or, most likely, regional differentiation of a combination of all of these (and more).

It is my belief that the next step in such research is to produce many map subsets and overlay these with maps of various other geologic observations to search for clues as to the underlying source of these patterns. Hotspots, active margins, subduction, retreated glaciation, collision zones, triple junctions, failed third arms, and more could all contribute to such long-scale intra- and inter-plate stress transmission of stress. In the long-shot category I would even hazard that we could gain incite into back-arc spreading and Chinese energy flux centers.

0.2. Math and Method

While the code will be included in an appendix and is a tad complex and unreadable, the underlying mathematics remain fairly simple. To contour over the globe the density of intersections of extended stress azimuths the following calculations were made at every map location to be considered

$$\sum_{n=1}^{dataset-trash} |Az_{back} - Az_{stress}|$$

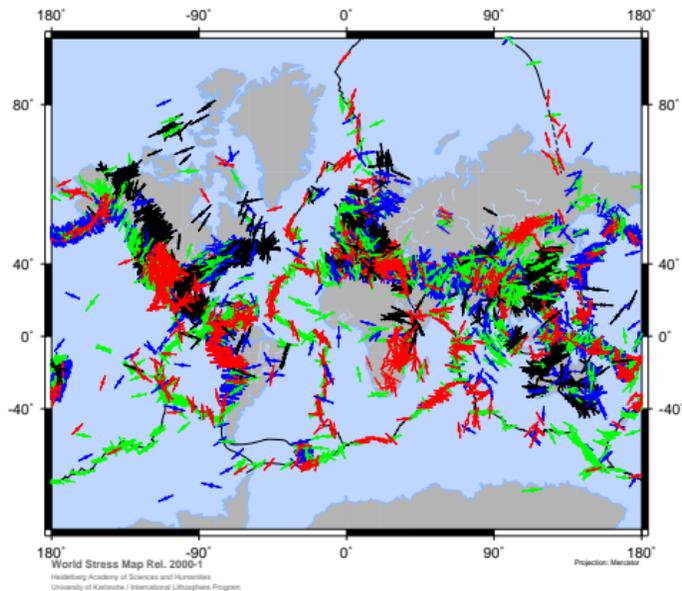


Figure 1: WSM downloadable at ref'd web site. Legend not included to minimize business. Notice convergence zones in east Africa and coast of Norway

wsm_nolegend [NR]

where Az_{back} is the back-azimuth over the surface of the globe from the WSM data point to the current map point, and Az_{stress} is the azimuth from the WSM data set.

Each iteration in the sum results in a zero value when the data azimuths are the same and at most 90° as the code maintains all comparisons to one quadrant. Therefore, as more and more data points don't intersect at the location being calculated, the value grows larger and larger. Thus one needs be mindful to focus on values at the bottom of the color bar of the pictures to come.

There are many options included in the code to delimit the quantity and region of data to use as input as well as the section of the map to perform the calculations over. The WSM data is divided into the following stress regimes, regions, and plates:

Plate Code:

1	North American Plate
2	South American Plate
3	Nazca Plate
4	Cocos Plate
5	Eurasian Plate
6	Indian-Australian Plate
7	Pacific Plate
8	African Plate
9	Antarctic Plate
10	Arabian Plate
11	Juan de Fuca Plate

Regime Code:

1.0	NF - normal faulting
1.5	NS - w/ SS component
2.0	TF - thrust faulting
2.5	TS - w/ SS component
3.0	SS - strike-slip faulting
4.0	U - undetermined stress regime
1.3	for NF and NS
2.3	for TF and TS

- 12 Philippine Plate
- 13 Sandwich Plate

Subregion Code:

- 0.....oceanic part of plate
- 1,4,7,....major continental region in plate
- 2,5,8,....adjacent continental shelf to above
- 3,6,9,....adjacent sea or inland sea, generally not oceanic crust

where the number corresponds to a parameter passed into the code to focus only on that data type or region. As it is possible to combine plate, subregion, and regime delimiters (as well as subtracting 90° from the NF and NS regimes as can be understood from figure 4), many many maps are possible to construct.

For the sake of clarity, it is also possible to seed the data azimuths with normally distributed random values (at the proper locations) to convince yourself that any patterns observed are not simply a product of the spherical earth. Notice that all maps are antipodally symmetric which gives assurance that the codes are performing properly on a spherical coordinate system and then plotted to two dimensions later. It would be interesting to input variable radius of the earth data at a later date.

All code utilizes the Stanford Exploration Project i/o, storage and plotting structure for reproducible research.(Schwab and Schroeder, 1995)

0.3. Data Distribution

While the data from the WSM project is an exhaustive effort of compilation and quality control (Zoback, 1992), there are the usual myriad factors opposed to any such large scale effort. One of the most apparent and immediately obvious is the unequal distribution of the data around the globe. Through no fault of anyone, there still is not a lick of data as to the orientation of the stress field, or state of stress (SoS) in the middle of Greenland ², between mid-ocean ridges, or across some political borders. This has implications for this method as I have not implemented a normalization method for this computation.

²Some researchers contend that measurement of SoS in continental crust and ice sheets are an unfair comparison. As we observe the link between ice-loading and lithospheric rebound, and can thus conclude that ice plays a significant role in tectonic processes, why should these measurements be given less credence than those made in swampy sediments and coastal areas already included in the idea of *crust*. Therefore, as the measurements are fairly easy to make- we should (Hooke and Hanson, 1986). At the very least we could gain insight into the nature of the ice cap.

As a further exercise in exploring this methodology, it would be useful to bin data into crustal segments that vary as a function of the angular distance away from the map point being considered. This will present some challenge as the map will manifest itself as a constantly updating variable grid problem that will be difficult to calculate and nearly impossible to code an effective adjoint.

From the below variogram of the entire data set, it is clear that this method of 'normalization' should be effective and could be faked by simply calculating several maps discriminating data inputs over several distance criteria and then correlating (or rather hoping for a correlation of) each of these.

The variogram corroborates the notion that at small distance scales the stress azimuths are roughly parallel and get more evenly distributed at larger offsets. Local stress pattern investigation such as that undertaken by [Muller et al. \(1992\)](#) in Europe or [Gowd et al. \(1992\)](#) in India, could well be enhanced by this data manipulation.

0.4. Searching for Real Meaning

Unfortunately, as magnitudes for these horizontal stresses are often not available due to the difficulty of the measurement, a valuable check on the observed relationships

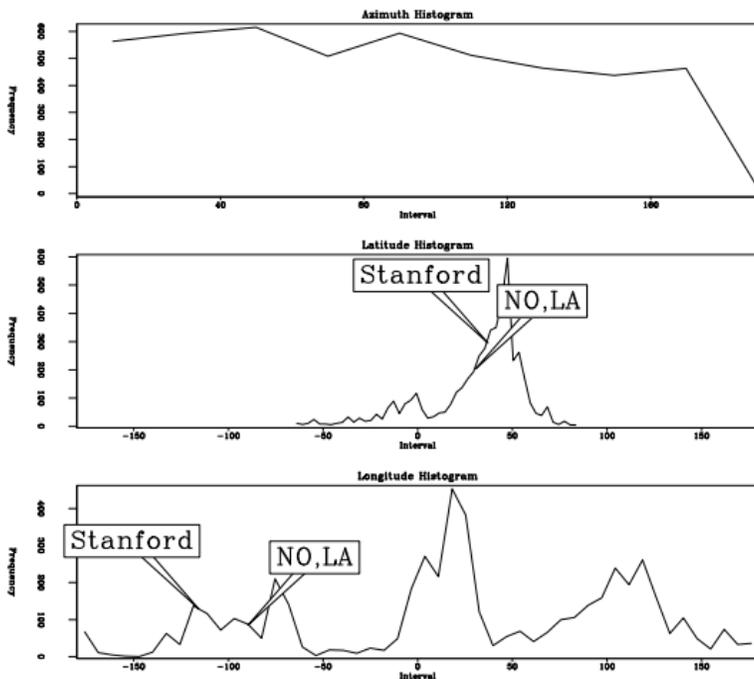


Figure 2: While azimuths are fairly well distributed around the world, sampling locations are woefully Eurocentric. hist_0 [ER]

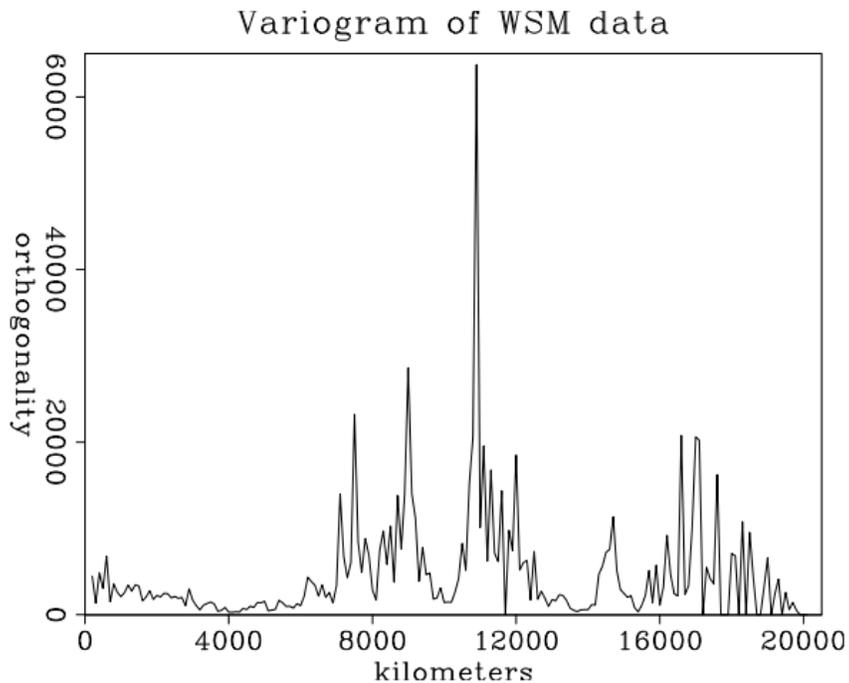


Figure 3: Degree of non-parallelness over angular distance (converted to km's). 20,000 km is half of earth circumference var_0 [ER]

to come have not been made. That is not to say such data is completely unavailable: **Grovers et al. (1992)** propose a method to estimate this quantity from earthquake focal mechanisms, and **Cornet and Burlet** explain its measurement from inducing borehole hydraulic fractures. The suggestion then for this next level of investigation would be to compare the contour plots of stress magnitude with those generated from this methodology.

To address the question posed earlier of whether the combination of various stress regimes is a legitimate logical step, I have prepared the below figure illustrating a confluence of stress directions that intersect in a region. These ideas are in **Figure 4**. Careful study of caption and cartoon should clarify the concept. By thus considering the Sh azimuth on the normal faulting regime, I believe it is plausible to map using all faulting regime data as input.

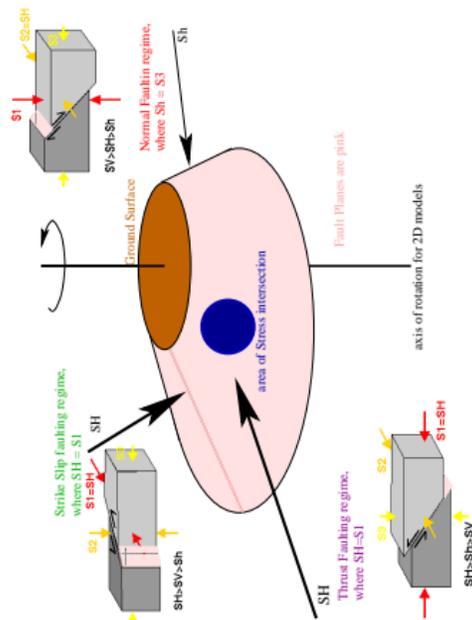


Figure 4: By rotating each of the simple block model faulting styles around an axis somewhere to the left of the block diagrams, it is possible to produce toroids of fault planes that will have conical expression in three dimensions. With a small step in logic, one can then arrive at the above earth model. This idea is scale independent and does not mandate the presence of the faults. regime [NR]

0.5. Pictures at last!

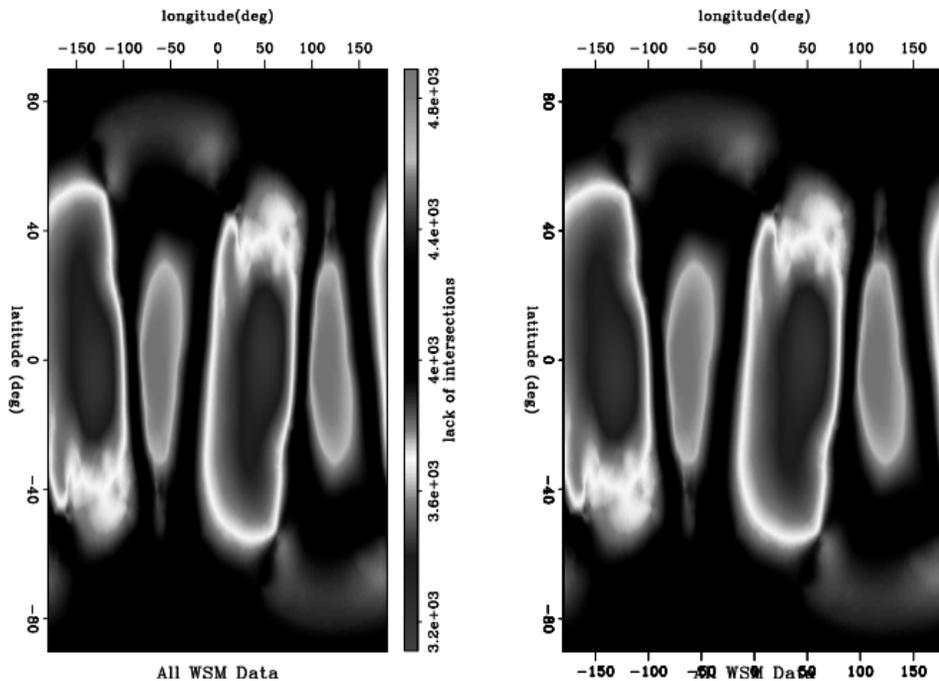


Figure 5: All WSM data (shown at dots) considered. `plot_0` [ER,M]

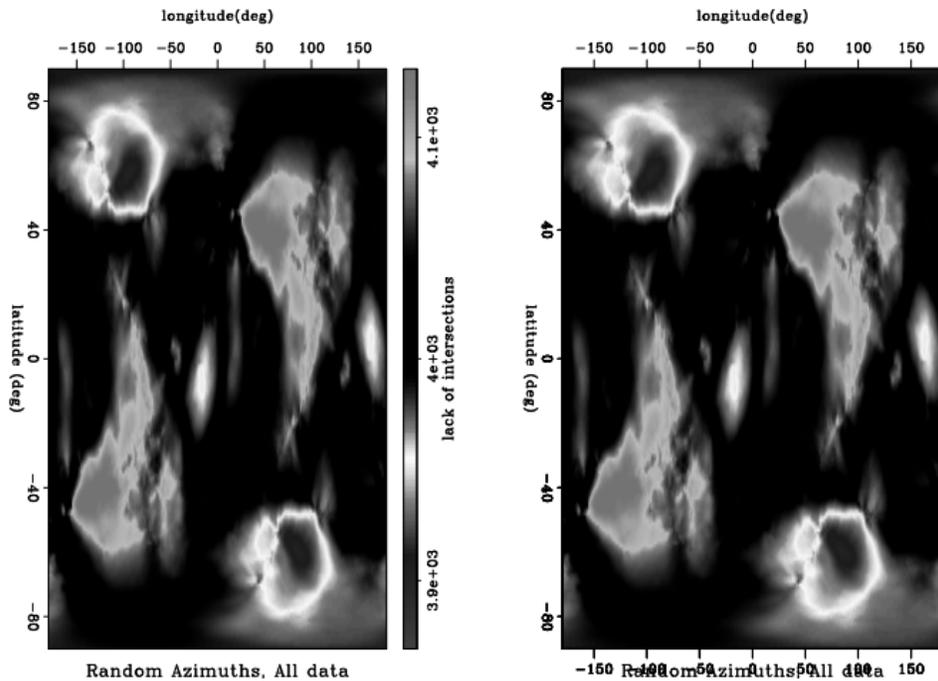


Figure 6: Random azimuths replacing real azimuth data. `plot_rand_0` [ER,M]

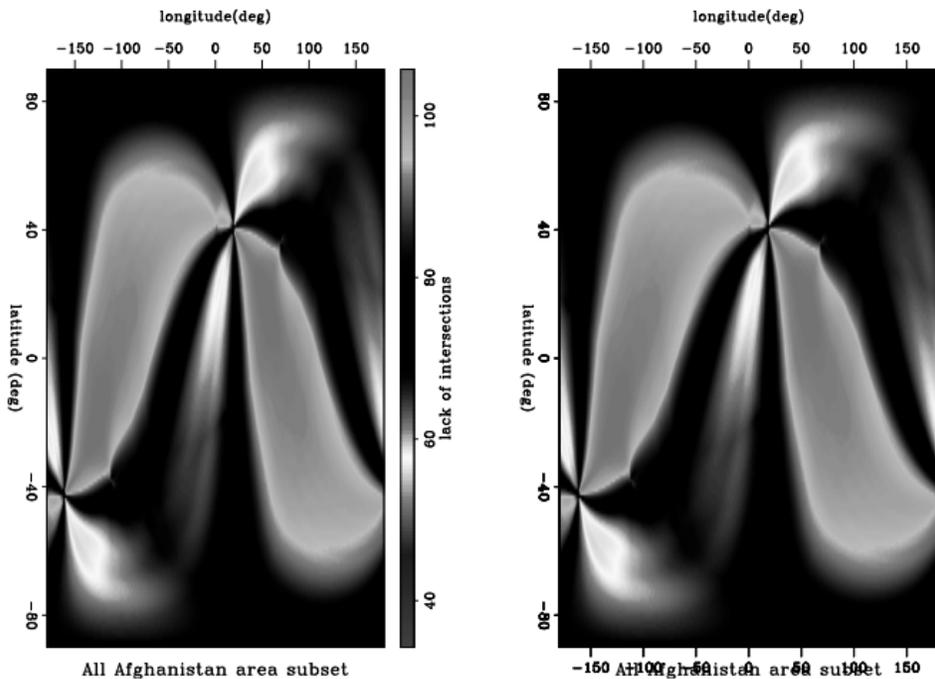


Figure 7: First 100 data points in database `plot_af` [ER,M]

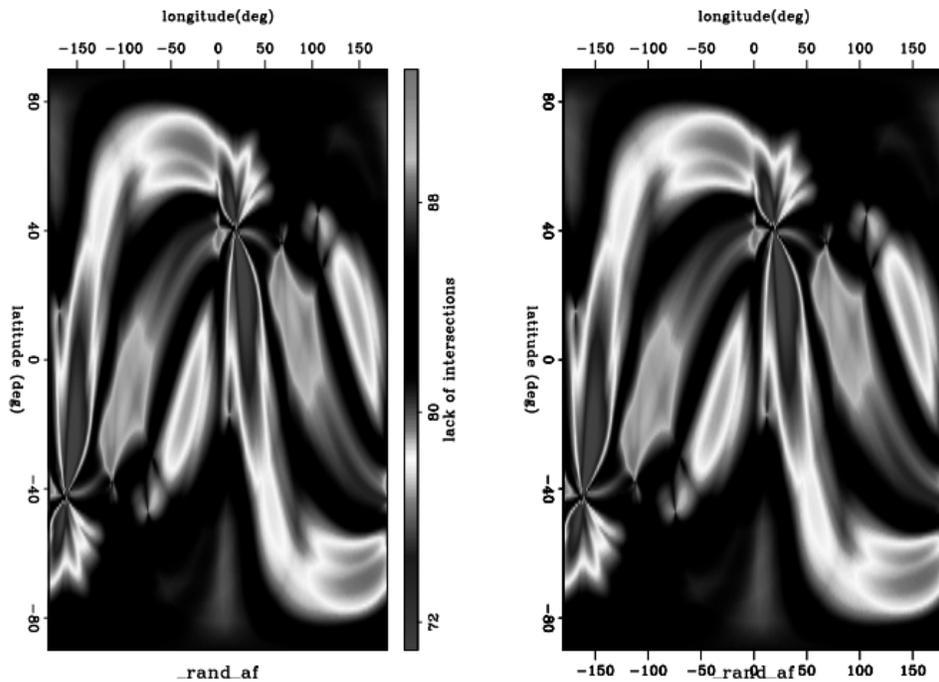


Figure 8: Neat patterns from random azimuths. `plot_rand_af` [ER,M]

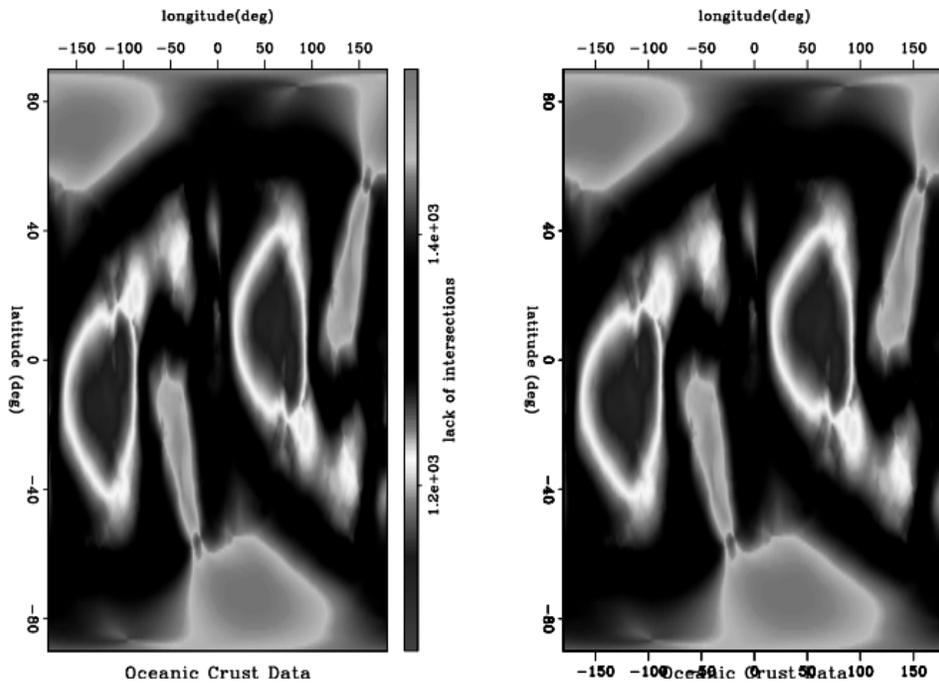


Figure 9: Only oceanic crust data. `plot_ocean` [ER,M]

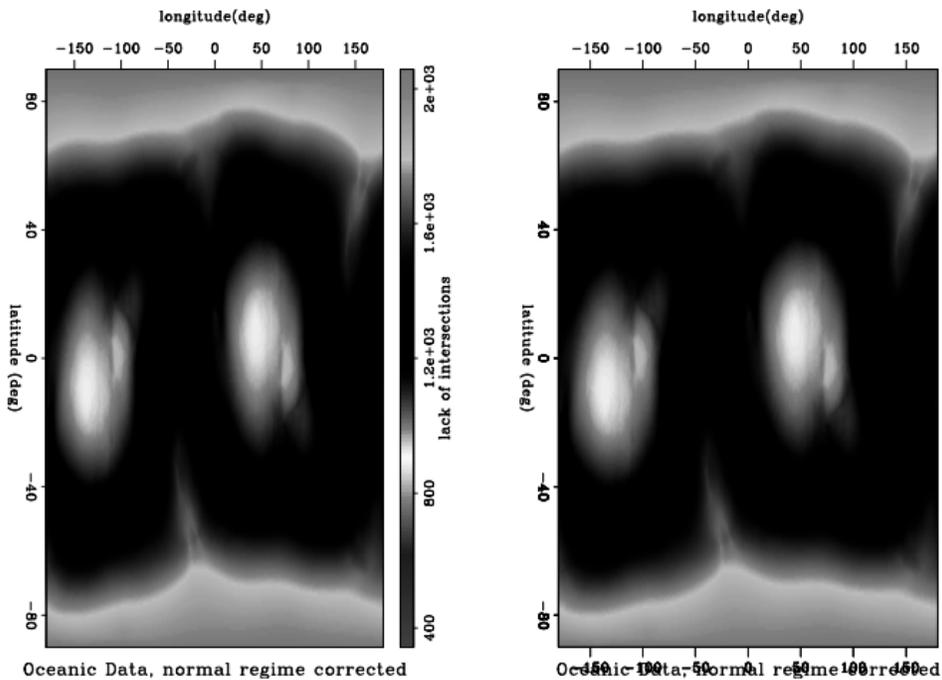


Figure 10: Oceanic data with normal- 90° correction. `plot_nocean` [ER,M]

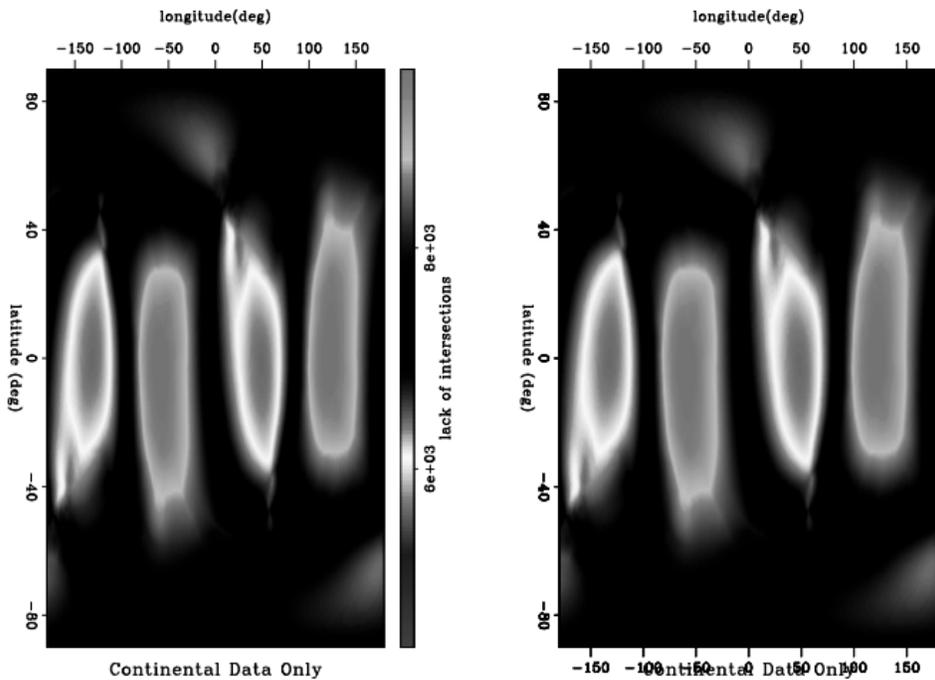


Figure 11: All data on continental crust. `plot_cont` [ER,M]

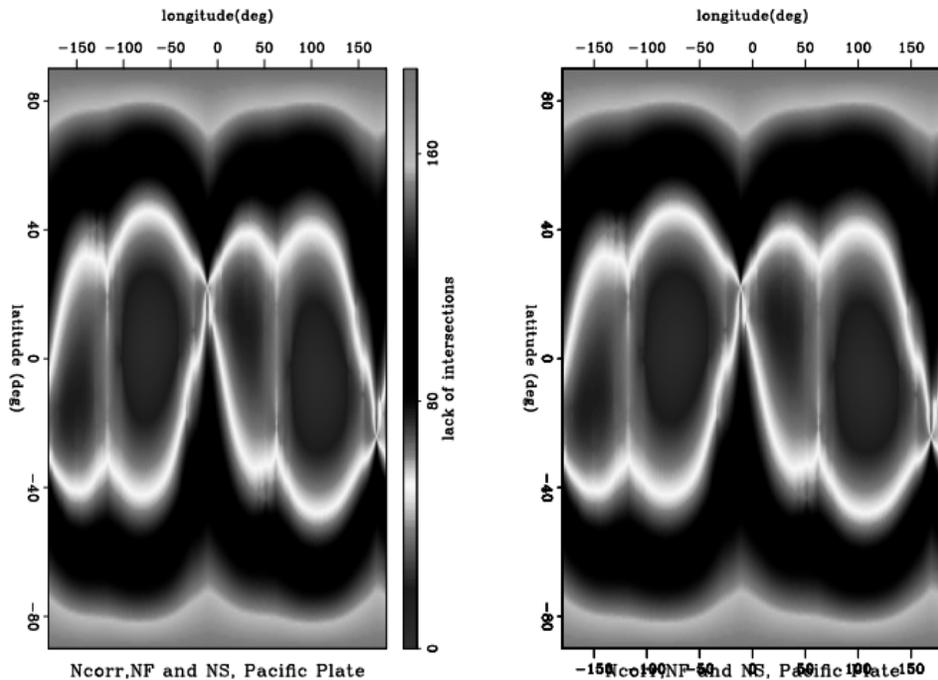


Figure 12: Normal and NS regime (Sh) data on pacific plate.
[ER,M]

plot_nNFSpecific

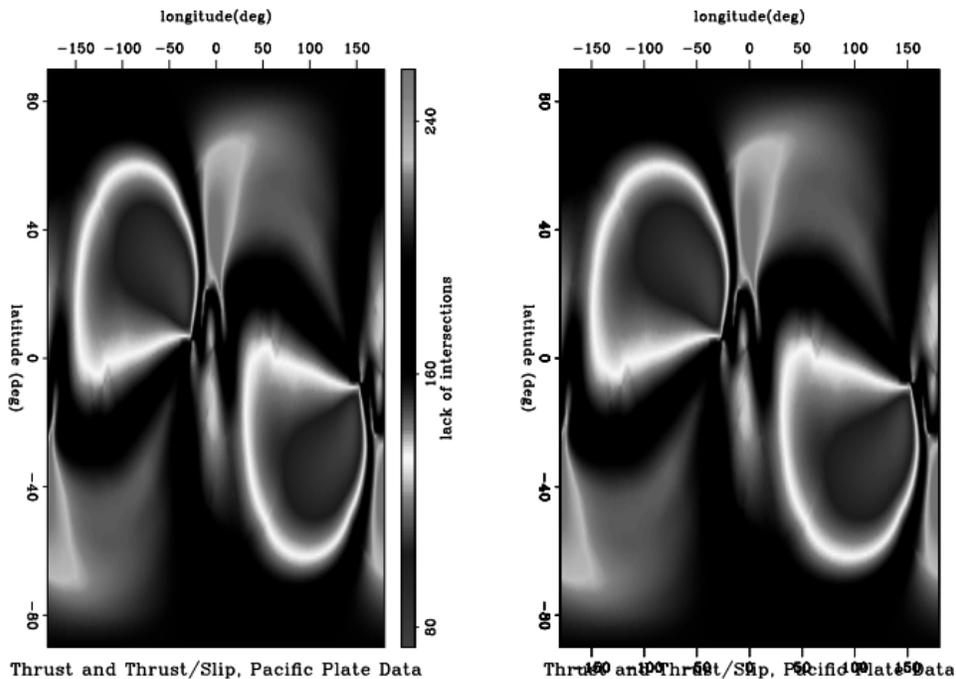


Figure 13: Thrust and TS regime data on pacific plate. `plot_TFSpacific` [ER,M]

1. Code Appendix

1.1. Sample Parameter File

All data on oceanic crust, and transposing normal faulting regime looks like:

```
o1=-90  
o2=-180
```

```
d1=1  
d2=1
```

```
nv=200  
ov=200  
dv=100.
```

```
# if the below =0. the tests will result in all data used  
# value dictates what data segment to consider  
# codes are in ./src/mapmaker.f90 file and ./Data/wsm.ref.codes.txt  
fixnorms=1.  
platetest=0.  
regimetest=0.  
subregiontest=-1. # -1 for ocean, 1 for inland sea, 2 for major cont., 3 for cont. she
```

1.2. Mapping code

Program mapmaker

```
use sep
use random_mod
use globecal

implicit none
real                :: backaz,foraz,distance,ilat_tmp,ilon_tmp
real                :: ptest,rtest,ntest,stest, pi
real,dimension (:) , pointer  :: lat,lon,shaz,temp,regime,plate,subregion,datalat
integer,dimension (:) , pointer  :: subr
real,dimension (:,:), pointer  :: azdiff
integer             :: ilat,ilon,idat,pos1,pos2,k,maxk
integer             :: n1,m1,m2,o1,o2,d1,d2,stat,t,r,s

call sep_init ()

call from_history("n1",n1)

allocate ( lat(n1),lon(n1),shaz(n1),regime(n1),plate(n1),subregion(n1) )
allocate ( subr(n1) )

call sep_read (lat)
call sep_read (lon)
call sep_read (shaz)
call sep_read (regime)
call sep_read (plate)
call sep_read (subregion)
!write(0,*) 'lat is ', lat
```

```

!write(0,*) 'lon is ', lon
!write(0,*) 'az is ', shaz

call from_param( "o1", o1)
call from_param( "o2", o2)
call from_param( "d1", d1)
call from_param( "d2", d2)
m1= abs((2*o1)/d1)
m2= abs((2*o2)/d2)

call from_param( "platetest",      ptest,0.)
call from_param( "regimetest",     rtest,0.)
call from_param( "subregiontest",  stest,0.)
call from_param( "fixnorms",       ntest,1.)

!----all data are used when tests /=0

if( exist_file("randaz") ) then
  call to_history( "n1", n1, "randaz")
  call to_history( "o1", 1, "randaz")
  call to_history( "d1", 1, "randaz")
end if
call to_history("n1",m1+1)
call to_history("n2",m2+1)
call to_history("o1",o1)
call to_history("o2",o2)
call to_history("d1",d1)
call to_history("d2",d2)
call to_history("label1","latitude (deg)")
call to_history("label2","longitude(deg)")
call to_history("label3","lack of intersections")

```

```

call sep_close()
pi=3.141593
!-----Convert degrees lat/long to radians-----
lat= lat * (pi/180)
lon= lon * (pi/180)
shaz=shaz* (pi/180)
!--NF regime should consider Sh=SH-90, not SH-----
if (ntest/=0) where ( int(regime)==1 ) shaz=abs(asin(sin( shaz(idat)-(pi/2.) )))
!----- change ocean subcode to -1 from 0
where ( (subregion)==0. ) subregion=-2.
subr=int(subregion)
write(0,*) 'region test?',rtest,'plate test?', ptest,'subregion test?', stest,'fix no
mals?', ntest

!-----Test with random azimuths at each data location-----
if( exist_file("randaz")) then
  allocate(temp(n1))
  call random_number(temp)
  datashaz=temp*pi
end if

if ((rtest==1.3).or.(rtest==2.3)) then
  regime=int(regime)
  rtest=int(rtest)
end if
!-----count how many data points going to use
k=0
do idat=1,n1
  if (shaz(idat) <=2*pi) then !-----null values in data file =999
    if ( (rtest==0).or.(regime(idat)==rtest) ) then!--only consider one stress regime

```

```

if ( (ptest==0).or.(ptest==plate(idat)) ) then!--only consider one plate
if ( (stest==0).or.( (stest==4).and.(subregion(idat)>0) ).or.(stest==mod(subr(idat)
    k=k+1
end if
end if
end if
end if
end do
maxk=k
allocate(datalat(maxk))
allocate(datalon(maxk))
allocate(datashaz(maxk))
write(0,*) 'You are about to consider ', maxk,' points of 10921.'
k=0
do idat=1,n1
if (shaz(idat) <=2*pi) then!--null values in data file =999
if ( (rtest==0).or.(regime(idat)=rtest) ) then!--only consider one stress regime
if ( (ptest==0).or.(ptest==plate(idat)) ) then!--only consider one plate
if ( (stest==0).or.( (stest==4).and.(subregion(idat)>0) ).or.(stest==mod(subr(idat)
    k=k+1
    datalat(k)=lat(idat)
    datalon(k)=lon(idat)
    datashaz(k)=shaz(idat)
end if
end if
end if
end if
end do
maxk=k

```

```

!-----Test with random azimuths at each data location-----
if( exist_file("randaz")) then
  allocate(temp(n1))
  call random_number(temp)
  datashaz=temp*pi
  call sep_write(datashaz*(180/pi),"randaz")
end if

```

```

!----prepare a file w/ data locations used when discarding with tests
if (exist_file("datafile") ) then
  call sep_init()
  call to_history("n1",maxk,"datafile")
  call to_history("n2", 3,"datafile")
  call sep_write (datalon*(180/pi), "datafile")
  call sep_write (datalat*(180/pi), "datafile")
  call sep_write (datashaz*(180/pi), "datafile")
  call sep_close()
end if

```

! goto 100 ! for only making actually used data file

```

write(0,*) 'Now mapping. Please take your seat.'
allocate ( azdiff(ml+1,m2+1) )
azdiff=0 !----safety zeroing
do ilat=01,01+m1,d1
write(0,*) 'done ',(ilat-01)/d1,' of ',m1
do ilon=02,02+m2,d2
  ilat_tmp = ilat * (pi/180)!-----temporary radians of model grid points
  ilon_tmp = ilon * (pi/180)
do k=1,maxk

```

!-----finally to the meat of the program-----

```

-----
                call calc( datalat(k),datalon(k),ilat_tmp,ilon_tmp,distance,backaz,
                posl=ilat-o1      ;      pos2=ilon-o2
                azdiff(pos1,pos2) = azdiff(pos1,pos2) + asin(sin( (datashaz(k)-
backaz)))*2
                end do ! idata
            end do ! ilon
        end do ! idatalat

        call sep_write(azdiff)

100 k=2

end program mapmaker

```

1.3. Makefile

```

# -----
# Makefile - Created by Brad Artman
#           Wed Mar 14 18:23:55 2001.
# -----
# Usage:
# Parameters:
# Description:manipulate WSM data found at
#             http://www-wsm.physik.uni-karlsruhe.de/
# -----
include ${SEPINC}/SEP.top

HTMLDIR = /net/sepwww/sepwww/pub/sep/brad/Stress

```

```
RESDIR = ./Fig
SRCDIR = ./src
PARDIR = ./par
BINDIR = ./bin/${MTYPE}
OBJDIR = ./obj/${MTYPE}
INCDIR = ./inc/${MTYPE}
DATDIR= ./Data
R = ${RESDIR}
B = ${BINDIR}
P = ${PARDIR}
D = ${DATDIR}

#UF90FLAGS = -Mbounds

UF90INCLUDES = -I${INCDIR}

ifeq (${ARCH},LINUX) # LINUX
    F90C = pgf90 -v
    F90LD = pgf90 -v

    UF90LIBS = -lsepgeef90 -lsep2df90
else # SGI64
    F90C = f90 -64
    F90LD = f90

    UF90LIBS = -lgeef90 -lsep2df90 ${GEELIB}
endif

RESULTSCR =
RESULTSNR = wsm_nolegend hist_rand regime
RESULTSER = world plates coast var_0 hist_0 hist_af \
```

```
plot_0 plot_af plot_nContNFSpl plot_rand_af plot_cont plot_Namerica plot_nNamerica \  
plot_ocean plot_nocean plot_rand_0 plot_nNFSspecific plot_TFSspecific  
.PRECIOUS = ${R}/regime.ps ${D}/coast.dat ${D}/plates.dat ${D}/wsm2000-1.csv ${D}/ws  
  
GP = Graph min1=-180 max1=180 min2=-5 > /dev/null  
GA = Graph min1=0 max1=180 > /dev/null  
GW = Graph min1=-180 max1=180 min2=-90 max2=90 symbol="." title=" " > /dev/null  
G = Grey min1=90 max1=-90 min2=-180 max2=180 color=v title=" " > /dev/null  
  
#compile%: ${B}/variogram.x ${B}/mapmaker.x  
# echo "stress"  
# echo $*  
  
#  
#----- Make seplib format from World Stress Map database format  
#----- original data file awk'ed with script: ./src/get.awk  
#----- original data file in: ./Data/wsm2000-1.csv  
data_0.HH:${B}/wsm2seplib.x ${D}/wsm2000-1.csv  
gawk -f src/get.awk Data/wsm2000-1.csv > ws.dat  
src/changereg.sed > ${D}/wsm.dat  
${B}/wsm2seplib.x fname=${D}/wsm.dat > $@  
\rm ws.dat  
  
#  
#----- mapping density of intersecting data azimuths, where (biggest value)=(fewest i  
map%.HH: # data_0.HH ${B}/mapmaker.x ${P}/model%.P  
< data_af.HH ${B}/mapmaker.x par=${P}/model$*.P datafile=actualdata$*.H > $@  
touch par/plot$*.P  
  
#
```

```

#----- Plots colorscale intersection map w/ world geography overlays
${R}/plot%.v ${R}/plot%.v3: #${P}/plot%.P ${R}/world.v map%.HH
  <map$*.HH Reverse which=1 | ${G} title=$* par=${P}/plot$.P out=${R}/plots$*.v
  <map$*.HH Reverse which=1 | ${G} title=$* par=${P}/plot$.P out=${R}/plot2$*.v
  <map$*.HH Reverse which=1 | ${G} title=$* par=${P}/plot$.P out=${R}/plot3$*.v
bar=y color=a
  < actualdata$.H Window n2=1 f2=0 > lon.H
  < actualdata$.H Window n2=1 f2=1 > lat.H
  Cmplx lon.H lat.H | ${GW} plotcol=0 plotfat=7 title=" " out=${R}/loc$.v
  vp_Overlay ${R}/plot2$*.v ${R}/loc$.v > ${R}/plotlocs$*.v
  vp_Overlay ${R}/plot2$*.v ${R}/world.v ${R}/loc$.v > ${R}/plotworld$*.v
  vp_SideBySideAniso ${R}/plots$*.v ${R}/plotworld$*.v > ${R}/plot$.v
  vp_Movie ${R}/plots$*.v ${R}/plot3$*.v ${R}/plotlocs$*.v ${R}/plotworld$*.v >
  Rm lat.H lon.H

#-----
#----- Make variogram of azimuth dotproducts (almost) vs. angular distance
var_0.H: #data_0.HH ${B}/variogram.x ${P}/model%.P
  <data_0.HH ${B}/variogram.x par=${P}/model$*.P > @$

${R}/var%.v:# var.H
  < var%.H Graph title="Variogram of WSM data"$* min1=0 min2=-10 out=${R}/$@ >/de

#-----
#----- Make histogram of az's and location to show data bunching

${R}/hist%.v: data_0.H
  <data_0.HH Window n2=1 f2=2 | Histogram | ${GA} title="Azimuth Histogram" out=a
  <data_0.HH Window n2=1 f2=0 | Histogram | ${GP} title="Latitude Histogram" out=
  <data_0.HH Window n2=1 f2=1 | Histogram | ${GP} title="Longitude Histogram" out
  vp_OverUnderAniso az$.v lat$.v lon$.v > temp$*.v

```

```

vp_annotate <temp$.v text=${D}/georef.txt > $@
Rm temp$.v lat$.v lon$.v az$.v

#${R}/hist_af.v: data_af.HH
# <data_af.HH Window n2=1 f2=2 | Histogram | ${GA} title="Azimuth Histogram" out=
# <data_af.HH Window n2=1 f2=0 | Histogram | ${GP} title="Latitude Histogram" out
# <data_af.HH Window n2=1 f2=1 | Histogram | ${GP} title="Longitude Histogram" out
# vp_OverUnderAniso az.v lat.v lon.v > temp.v
# vp_annotate <temp.v text=${D}/afghan.txt > ${R}/$@
# Rm az.v lat.v lon.v temp.v

#-----
#----- insert random azimuths at data locations to test
mmap_rand%.HH:data%.HH ${B}/mapmaker.x ${P}/model%.P
< data$.HH ${B}/mapmaker.x par=${P}/model$.P randaz=randaz.H datafile=data$.H
Mv $@ map_rand$.H
Rm $@

#-----
#-----make data subset(s)
#----- first ~100 data points happen to be around afghanistan (40, 20)(lat,lon)
#data_af.HH: data_0.HH
# < data_0.HH Window n1=100 f1=0 > $@

#-----
#-----plate boundaries and coastlines
plates.H: ${D}/plates.dat ${B}/plabo2seplib.x
${B}/plabo2seplib.x fname=${D}/plates.dat npick=5535> $@

```

```

${R}/world.v: #coast.HH plates.H
  < plates.H Window n2=1 f2=0 > lon.H
  < plates.H Window n2=1 f2=1 > lat.H
  Cmplx lon.H lat.H | ${GW} plotcol=0 plotfat=4 title=" " out=${R}/plates.v
  < coast.HH Window n2=1 f2=0 > lat.H
  < coast.HH Window n2=1 f2=1 > lon.H
  Cmplx lon.H lat.H | ${GW} plotcol=0 plotfat=4 title=" " out=${R}/coast.v
  vp_Overlay ${R}/coast.v ${R}/plates.v title=" " > $@
  Rm lat.H lon.H
done: paper.tex
  gmake paper.ps
  rm -fR ${HTMLDIR}
  mkdir ${HTMLDIR}
  gmake html
#   cp paper.pdf ${HTMLDIR}/.

# to make an adobe presentation type:
#make LATOPTS=option=web aread

clean: jclean

xclean:
  cd bin/${MTYPE}; \rm *.x
  cd obj/${MTYPE}; \rm *.o
include ${SEPIINC}/SEP.bottom

```

1.4. Variogram code

Program variogram

```

use sep
use bin1
use globecalr

implicit none
real                                :: az1,az2,ov,dv,a,b,c,d,pi
real,dimension (:) , pointer       :: lat,lon,shaz,temp,anglesum,ang,delta,ones,fold
integer                             :: idat,idat2,nv,n1,k,stat

call sep_init ()

call from_history("n1",n1)

allocate (lat(n1),lon(n1),shaz(n1))

call sep_read (lat)
call sep_read (lon)
call sep_read (shaz)
!write(0,*) 'lat is ', lat
!write(0,*) 'lon is ', lon
!write(0,*) 'az is ', shaz

call from_param( "nv", nv)
call from_param( "ov", ov)
call from_param( "dv", dv)

call to_history("n1",nv)
call to_history("n2", 1)
call to_history("o1",ov)
call to_history("d1",dv)

```

```

call to_history("label2","orthogonality")
call to_history("label1","kilometers")

call sep_close()
pi=3.141593
!-----quadrant tests for the subtraction -----
! k=1
! if (k/=0) then
!   a=asin(sin( 0.17453295-pi )) !10 in radians
!   b=asin(sin( 3.3161259 -pi )) !190 in radians
!   a=asin(sin( 10*(pi/180) ))           ! = 0.17453295
!   b=asin(sin(-10*(pi/180) ))          ! =-0.17453295
!   c=asin(sin(170*(pi/180) ))          ! = 0.174532562
!   d=asin(sin(190*(pi/180) ))          ! =-0.174533218
!   write(0,*) '10 -90=',a*(180/pi),' 190 -90=',b*(180/pi),' 170=',c,' 190=',d
!
! else  !-----to use, must also take out end if at end of program----
!-----
lat= lat * (pi/180)           !-----Convert degrees lat/long to radians ---
lon= lon * (pi/180)
shaz=shaz* (pi/180)

write(0,*) 'Doing the variance bit'
allocate(delta ( n1*(n1-1)/2) )
allocate(ang ( n1*(n1-1)/2) )
delta=0. ; ang=0.
!   write(0,*) 'allocated'
!   write(0,*) 'size of ang is ',size(ang),'delta is ',size(delta)

```

```

k=0
do idat =1,n1-1
  !      write(0,*) 'Finished ',k,' of ',size(ang),' loops.'
  if( shaz(idat) <=180 ) then
    do idat2=idat+1,n1
      k=k+1
      if( shaz(idat2) <=180 ) then
        call calc( lat(idat),lon(idat),lat(idat2),lon(idat2),delta( (idat-
1)*n1+(idat2-1) ),az1,az2)
        ang(k) = sqrt( abs(asin(sin( shaz(idat)-shaz(idat2) ))) )
      end if
    end do
  end if
end do

!-----
!-----putting data into distance bins -----
!-----
delta= delta * 6371
allocate( anglesum(nv) )
anglesum=0
!      write(0,*)'size of anglesum is ', size(anglesum)
call bin1_init( nv, ov, dv, delta )
stat = bin1_lop( .true., .true.,anglesum, ang)
!      anglesum is output

!-----to normalize anglesum, fold=Btrans (ones) -----
!-----
allocate( ones(n1) )
allocate( fold(nv) )
ones=1.; fold=0.

```

```

call bin1_init( nv, ov, dv, delta )
stat = bin1_lop( .true., .false., fold, ones)
! write(0,*) 'anglesum at 1 is ', anglesum
where(fold/=0)
    anglesum=anglesum/fold
elsewhere
    anglesum=0
end where
! write(0,*) 'fold at 1 is ', fold
! write(0,*) 'anglesum is now', anglesum

call sep_write( anglesum)
! end if !-----for when you don't really want to run the program
end program variogram

```

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