JAMES RENNELL CENTRE FOR OCEAN CIRCULATION

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Evaluation on Cruise CD 62A of a Magnavox MX 4200 GPS receiver and KVH fluxgate compass to provide ship speed and heading

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REQUIREMENTS OF THE SYSTEM 1

1. EVALUATION OF THE MAGNAVOX GPS SYSTEM 1

1.1 Description of System and Comparison Data 1

1.2 Evaluation 2

1.3 Data Editing 2

1.4 Conclusions 4

2. EVALUATION OF THE FLUXGATE COMPASS 4

2.1 Data used 4
2.1.1 GPS system Compass 4
2.1.2 Ship's gyro data 4

2.2 Comparison Results 5

2.3 Explanation of the correction curve 6

2.4 Conclusions. 6

REFERENCES 6

APPENDIX 1 - MODIFICATIONS TO SAMPLING SOFTWARE MADE SINCE CD62A A1

APPENDIX 2 - LISTING OF PROGRAM GPSREAD A2

APPENDIX 3 - EXAMPLE OF UNIX SCRIPT TO QUALITY CONTROL GPS DATA A4

EVALUATION ON CRUISE CD62A OF A MAGNAVOX MX 4200 GPS RECEIVER AND KVH FLUXGATE COMPASS TO PROVIDE SHIP'S SPEED AND HEADING.

REQUIREMENTS OF THE SYSTEM

It is hoped to use the GPS / Compass combination to provide ship's speed and heading when the output of the ship's GPS navigation is not logged. This will allow calculation of true wind speed and direction. The accuracy of the ship's speed required is to within 0.1 m/s and heading is required to within 5° for a 15 minute average. The system was run on RRS Charles Darwin Cruise 62a (CD62a) and output compared to the logged data from the ship's navigation system.

1. EVALUATION OF THE MAGNAVOX GPS SYSTEM

1.1 Description of System and Comparison Data

The ship runs a sophisticated GPS system containing a rubidium clock. This allows timing errors from the satellites to be identified and also allows navigation during periods when only two satellites are available to the receiver. Without system enhancements, such as the rubidium clock, three satellites are necessary for horizontal positioning (four if altitude is also required). GPS fixing in the region of cruise CD62a was theoretically possible for all but two half-hour periods per day.

The GPS receiving aerial was positioned on the aft port corner of the wheelhouse top and data were logged in the plot. The Magnavox system was run in 2-d navigation mode and fixes were written to disk every minute along with the heading from the KVH compass. Birch and Pascal (1992) contains technical details of the sampling software for both the GPS and compass systems and Pascal and Birch (1992) is a user guide for both systems (both references apply to a later version of sampling software than was used on CD62a; details of system changes are included as Appendix 1 to this report). The record logged contains the time of the fix, latitude, longitude, heading, number of satellites visible, number of satellites being tracked, GPS mode (which indicates whether the GPS is receiving enough good signals to navigate), dilution of precision factors (which indicate the reliability of the fix), course over the ground, speed over the ground and an identification number, azimuth, elevation and signal to noise ratio for each of the satellites being tracked (maximum eight).

During the cruise an attempt was made to optimise both the period and quality of the fixes being received using setup parameters in the Navigation Modes Display. Information on the Magnavox system can be found in the Magnavox Technical Manual (Reference 3). The parameters changed were the minimum elevation of satellites to be tracked, the maximum horizontal dilution of precision (hdop) and the maximum horizontal and vertical accelerations of the ship. The elevation limit attempts to improve the quality of fixes by only using satellites above a certain angle above the horizon which should reduce ionospheric and tropospheric delays. As a result the number of satellites tracked may be reduced and gaps in the period of coverage will result if the number falls below three. The hdop value refers to the position of the satellites in the sky relative to the receiver, a wide angular separation is required for a fix to be reliable and the combination of satellites which provides the best geometry is chosen. A low hdop value indicates a good satellite configuration. When the hdop rises to an unacceptably high value, navigation mode is disabled and the GPS receiver merely tracks the satellites in the sky. The acceleration limit, simply the maximum acceleration of the ship, determines how the fixes received are filtered, the relatively low acceleration of the ship allows more averaging of the fixes than a faster moving vehicle.

The data was read from MSDOS floppy disk (after substituting the 'x's in the file for zeros) using the program gpsread.F (Appendix 2).

1.2 Evaluation

The GPS was run in three different setup combinations during the cruise (see Table 1):

	Start	Stop	hdop	elevation	acceleration
Set up 1	249 00:00	264 12:17	≤ 15	$\geq 5°$	1 m/s
Set up 2	264 12:17	266 10:20	≤ 7	$\geq 20°$	1 m/s
Set up 3	266 10:20	270 00:00	≤ 7	$\geq 10°$	0.05m/s

Table 1 - GPS Configurations used during cruise CD62a

Problems with the data logging program caused gaps in the data when the data recording system failed. This was corrected by the end of the cruise.

It should be noted that the hdop value logged corresponds to the systems estimate of the best possible hdop at the time. This should be lower than the hdop for the constellation actually being tracked as the receiver may not be able to track one of the satellites in the optimum constellation. It was found that even though a limit on the hdop value was set at either 7 or 15, the theoretical minimum hdop reported was often much higher. The reason for this was not clear.

1.3 Data Editing

An editing scheme was devised for the data which would remove large spikes in the ship's speed time series. The standard deviation of the speed differences between the two systems was used as a measure of the success of the editing. Figures 1.1a and 1.1b show the two measures of ships speed for day 268 before editing (sog is the Magnavox measure of the ship's speed and smg is the ships' GPS output). Figure 1.1a shows the one minute samples and Figure 1.1b shows fifteen minute averages of the same data.

Data was initially selected for mode 0, this is data when the receiver is navigating. The difference in speed measurements between successive Magnavox GPS fixed was then found. A running 5 point mean of the Magnavox ships' speed centred on a particular data point was subtracted from that data point. Genuine ship's accelerations occur over several minutes; the subtraction of the running mean removed accelerations on this time scale. The resulting time series represents short time scale accelerations and this was used to identify fixes when unrealistically large ship's accelerations were reported. Most of these correspond to erroneous fixes and data associated with 'accelerations' greater than 2 knots were therefore removed. In this way the standard deviation of the speed differences between the two systems was reduced by approximately 10%, all of the large spikes having been removed. Figures 1.2a and 1.2b show the one minute and fifteen minute ships' speeds after 'acceleration' editing. Table 2 gives the characteristics of data recorded in the three different set ups, before and after editing to remove large accelerations.

		Mean Speed Difference (Ship - Magnavox) knots	Standard Deviation
Whole Cruise	All Data	0.001	1.042
	Mode 0	0.024	0.986
	Edited	0.007	0.722
	15 Minute Average	0.006	0.205
Set up 1	All Data	0.000	1.040
	Mode 0	0.020	0.972
	Edited	0.006	0.717
	15 Minute Average	0.008	0.199
Set up 2	All Data	-0.002	1.031
	Mode 0	0.057	1.124
	Edited	0.019	0.760
	15 Minute Average	0.014	0.266
Set up 3	All Data	0.005	1.061
	Mode 0	0.031	0.969
	Edited	0.003	0.732
	15 Minute Average	-0.009	0.01

Table 2 - (Ship GPS - Magnavox) Speed Differences

Further editing using the hdop value from the file (theoretical hdop) reduced the standard deviation of the differences further, but on examination of the velocity time series of the two systems, appeared to remove valid data. Figures 1.3a and 1.3b show the one minute and fifteen minute speeds after 'acceleration' editing and editing using the theoretical hdop value. Comparison with

Figures 1.2a and 1.2b shows that valid data has been removed. The hdop reported therefore seems not to be well correlated with the hdop used by the system. No editing using the reported hdop values was therefore carried out.

A UNIX script to automatically edit the data as described using pexec programmes is included as Appendix 3.

1.4 Conclusions

Using the 'acceleration' editing scheme outlined above the error (using the ships system as truth) in fifteen minute averages of ship's speed can be reduced to within the ±0.1 m/s required for a fifteen minute average true wind speed calculation.

2. EVALUATION OF THE FLUXGATE COMPASS

2.1 Data used

2.1.1 GPS system Compass

The compass used was a KVH Fluxgate Compass which was located at the forward, inboard corner of the port bench in the Plot. This type of compass has a self-correcting facility but attempts to initiate this failed,. so the comparison presented here shows the errors in uncorrected compass readings. Although the GPS processing system sampled the compass at five second intervals, the data written to disk consisted of the last compass sample obtained in each one minute interval. These data were recorded as part of the GPS data file on an MS-DOS disk and transcribed to the ship's Sun computer system; 8239 samples were obtained for the period from day 252, 0855 gmt, to 259, 1349 gmt.

2.1.2 Ship's gyro data

Since the ship's gyro data were recorded as one second samples in a file which was overwritten cyclically, the data used for comparison were the one minute values of the ship's head recorded as variable 'heading' in the 'abnav file'. These data appeared to be equivalent to the gyro data, although it was believed that 'heading' included a modification based on the EM log values. It was therefore necessary to determine how closely 'heading' represented the gyro data.

On the basis that, given EM log readings PS (port/starboard) and FA (fore/aft), the relationship would have been :

$$\text{heading} = \text{gyro} \pm (\text{ATAN(PS/FA)} \qquad (1)$$

then 83% of the heading values would have been within ±40° of the gyro value, 63% within ±5° and 36% within ±1° (Figure 2.1). An alternative source of ship's gyro data was the MultiMet system which recorded one minute averaged values of the gyro. Comparisons between these data and 'heading' are shown in Figure 2.2. Excluding the 2% of the points for which the difference was more than ±30°, the mean difference was -1° with a standard deviation of 3.4°. These comparisons are much closer than would be expected if equation (1) had been used suggesting that 'heading' is a good representation of the gyro reading.

2.2 Comparison Results

Figure 2.3a shows the KVH compass values compared to the 'heading' variable while Figure 2.3b shows the comparisons between the KVH value and the MultiMet gyro values. The MultiMet comparison shows more scatter, possibly due to poor time matching between the MultiMet and GPS data, however the mean curves are identical. The mean shape of this curve was calculated by removing values for which the difference was more than ±30°, averaging over 10 ° intervals, and smoothing with a three point boxcar filter (Figure 2.4). From this mean curve, the values necessary to correct the KVH compass readings to the 'heading' are given in Table 3.

True Heading °	Indicated Heading °	Correction °	True Heading °	Indicated Heading °	Correction °
0	-12.7	12.7	185	239.2	-54.2
5	-10.1	15.1	195	247.4	-52.4
15	-4.9	19.9	205	254.7	-49.7
25	0.9	24.1	215	263.1	-48.1
35	6.1	28.9	225	270.7	-45.7
45	10.2	34.8	235	279.0	-44.0
55	15.6	39.4	245	285.3	-40.3
65	20.4	44.6	255	292.5	-37.5
75	28.2	46.8	265	298.2	-33.2
85	34.2	50.8	275	304.8	-29.8
95	43.3	51.7	285	310.3	-25.3
105	55.2	49.8	295	316.2	-21.2
115	78.8	36.2	305	321.3	-16.3
125	113.7	11.3	315	326.5	-11.5
135	153.2	-18.2	325	331.2	-6.2
145	187.3	-42.3	335	335.5	-0.5
155	207.6	-52.6	345	339.4	5.6
165	221.3	-56.3	355	344.7	10.3
175	229.7	-54.7	360	347.3	12.7

Table 3. Values to correct the KVH compass readings to the 'heading' value.

The corrections vary from -56.3° to +51.7°. The result of applying this correction to the KVH values is shown in Figure 2.5a and the residual errors are shown in Figure 2.5b. Excluding the 1.3% of values which were outside ±30° and which could be removed by simple filtering, the standard deviation of the residual errors (Figure 2.5b) was ±4.9°. Given that some of this error is due to the comparison with the gyro (the gyro comparisons had a standard deviation of 3.4°), this suggests that the compass can provide data to accuracies well under ±5°.

2.3 Explanation of the correction curve

The large correction required for the KVH compass values can be explained in terms of the vector addition of the fixed, earth's magnetic field and the magnetic field due to the ship which varies in direction with the ships head. This gives a characteristic curve which is plotted in figure 2.6 for different values of the ship's magnetic field. The data suggest that, at the position of the compass, the strength of the ship's magnetic field was about 0.8 of the earth's field. It is presumably the predictable form of this curve which is used by the compass in its self calibrating facility.

2.4 Conclusions.

If enough gyro values are available to calibrate the compass then accuracies significantly better than ±5° should be routinely obtained. The efficiency of the self-calibrating facility has not been tested.

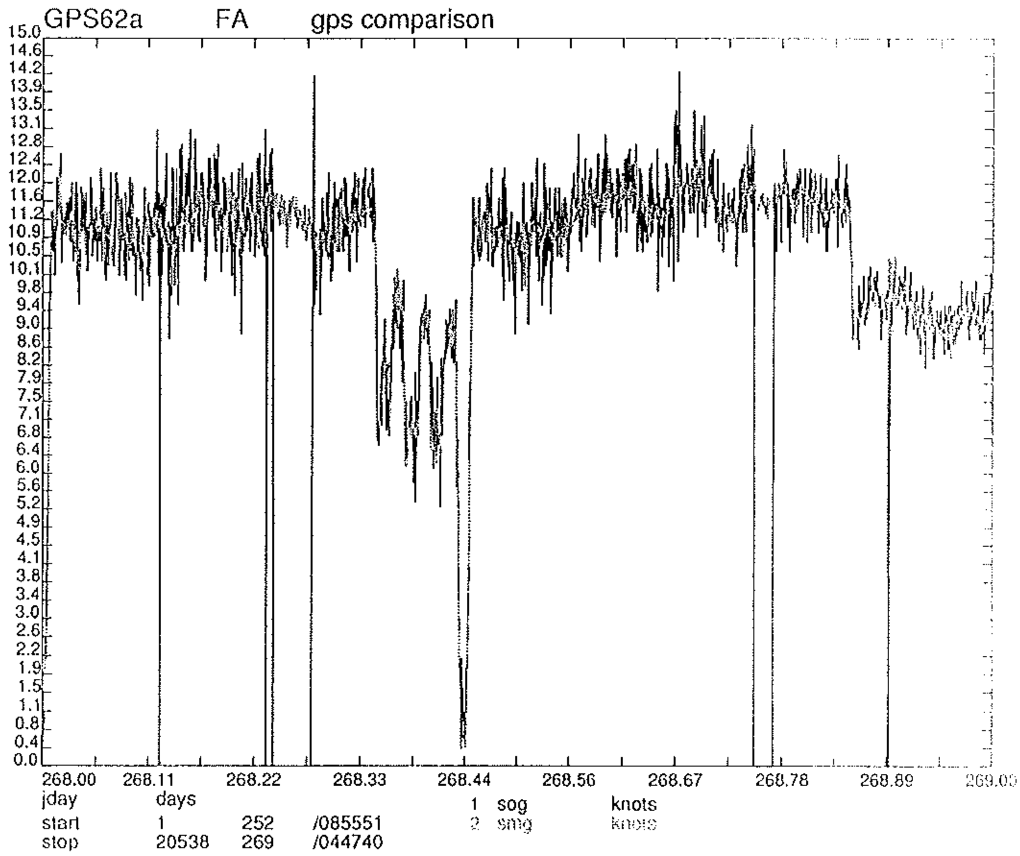
REFERENCES

1. GPS and Fluxgate Recording System (GAFERS) - Operational Handbook Birch K. G., Pascal R. W. and Williams A. L. - IOS Internal Document in Preparation (1992)

2. GPS and Fluxgate Recording System (GAFERS) - Technical Handbook Pascal R. W., Birch K. G., and Williams A. L. - IOS Internal Document in Preparation (1992)

3. A MX 4200GPS Receiver and MX4200D Differential GPS Receiver Technical Manual - Magnavox Advanced Products and Systems Company.

a



b

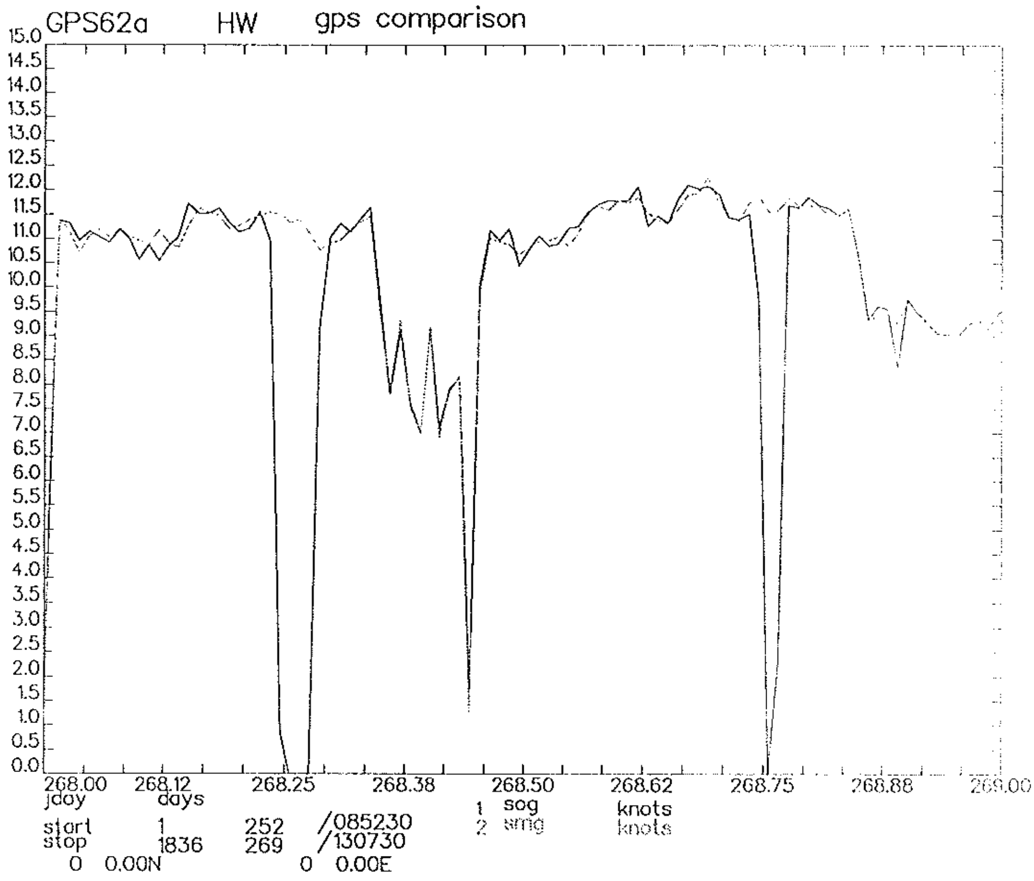
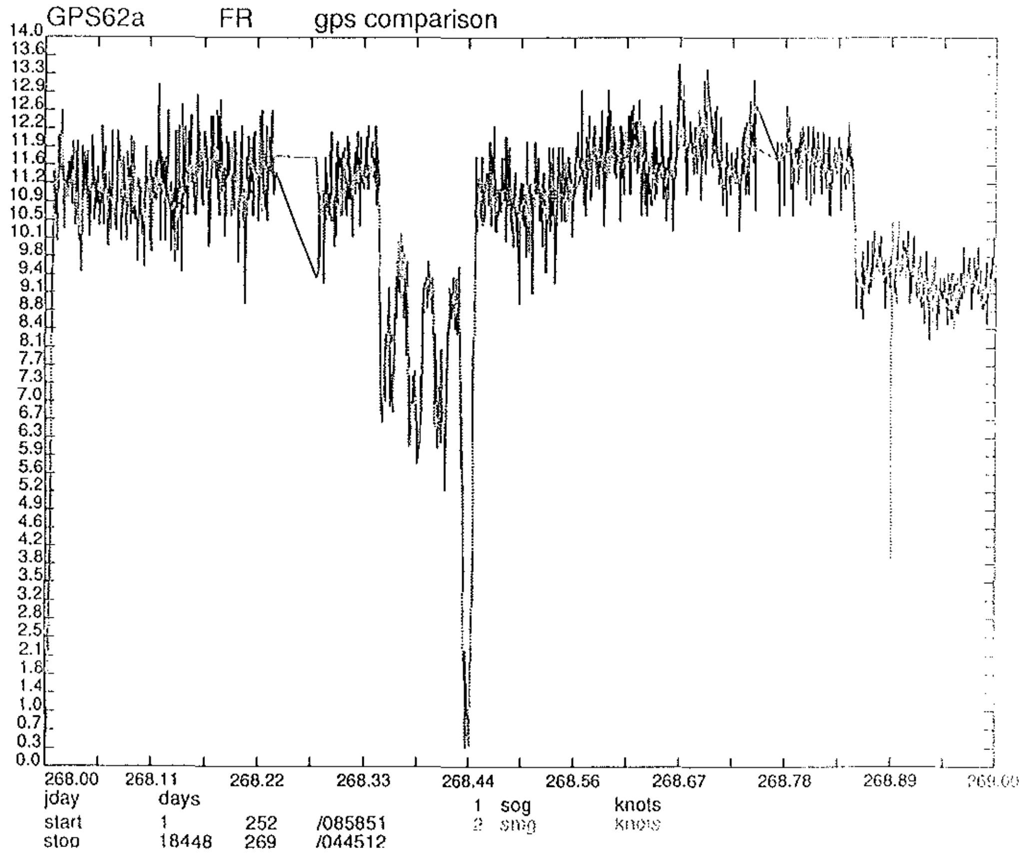


Figure 1.1a One minute values of ships' GPS ship's speed (smg) and Magnavox ship's speed (sog) for day 268.

Figure 1.1b Fifteen minute averages of smg and sog as in Figure 1.1a.

a



b

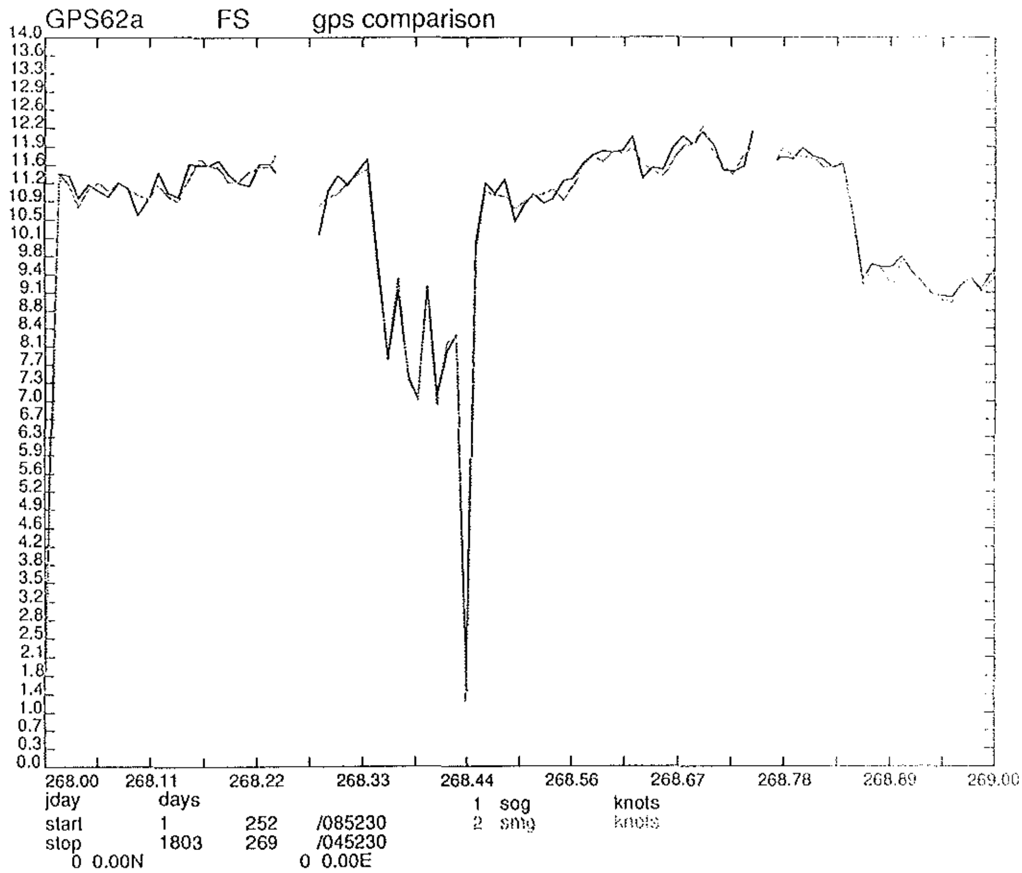
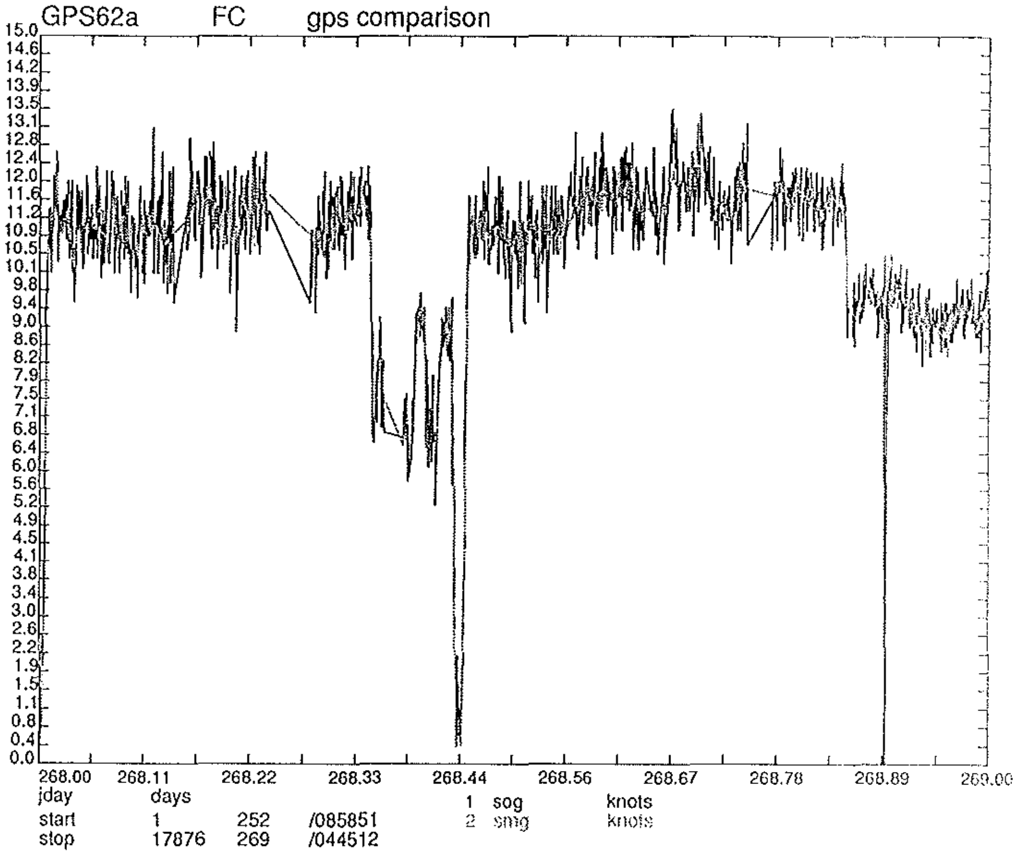


Figure 1.2a One minute values of smg and sog following selection for satellite tracking mode and 'acceleration' editing.

Figure 1.2b Fifteen minute averages of smg and sog as in Figure 1.2a.

a



b

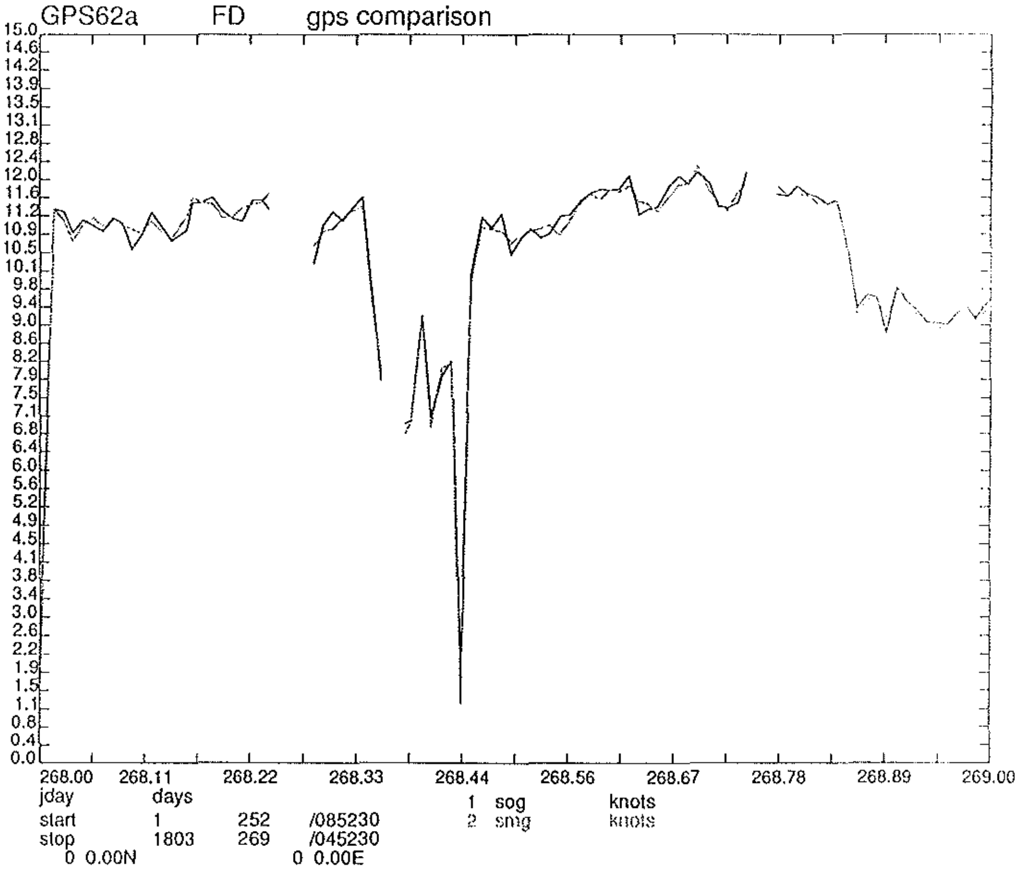


Figure 1.3a One minute values of smg and sog as in Figure 1.2a but with addition editing on theoretical hdop value.

Figure 1.3b Fifteen minute averages of smg and sog as in Figure 1.3a.

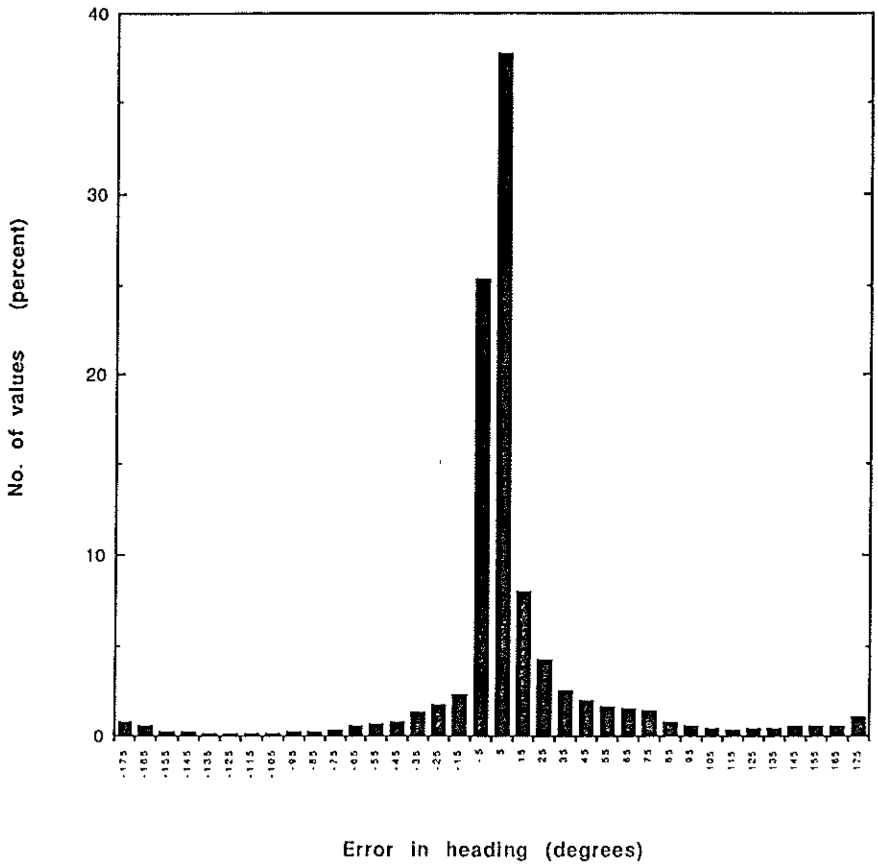
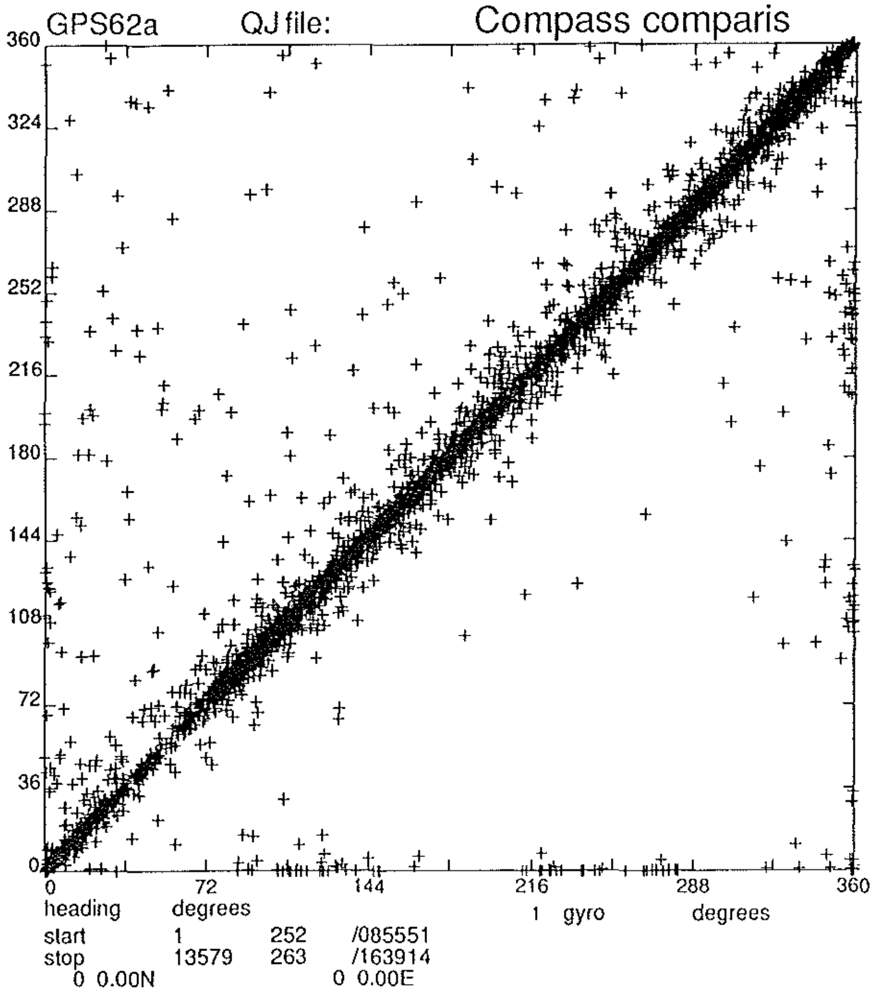


Figure 2.1 Error in the 'heading' variable due to the use of the EM-log values to provide a "pseudo-heading value". The histogram shows the percentage of occasions when the heading would have been changed by the amount shown.

a



b

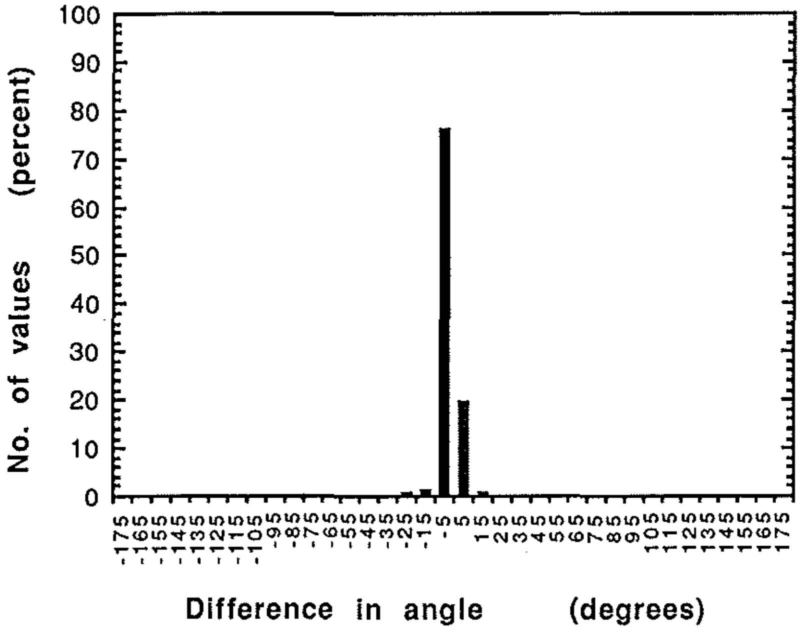
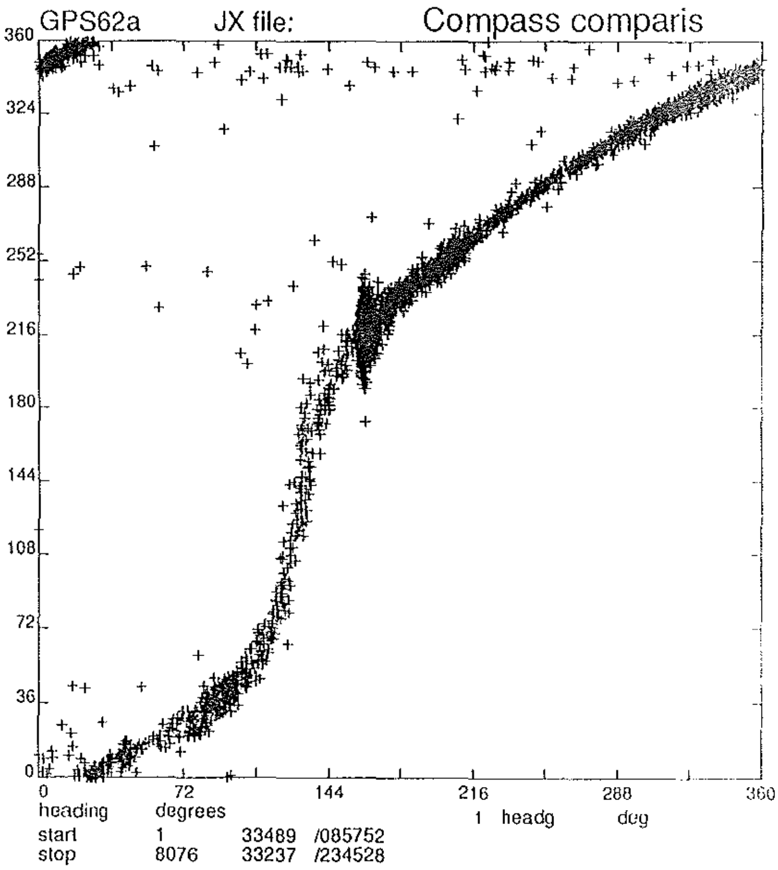


Figure 2.2a Comparison of the 'heading' value used in these comparisons and the MultiMet logged gyro values.

Figure 2.2b Histogram of the differences between the 'heading' value used in these comparisons and the MultiMet logged gyro values.

a



b

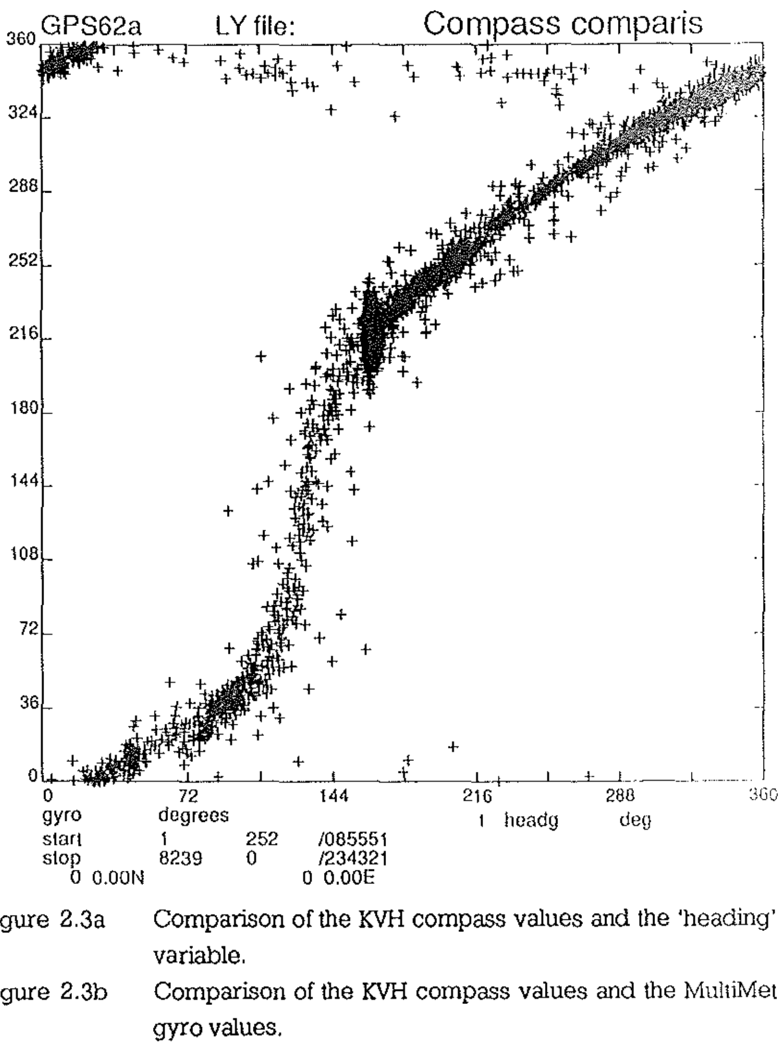


Figure 2.3a Comparison of the KVH compass values and the 'heading' variable.

Figure 2.3b Comparison of the KVH compass values and the MultiMet gyro values.

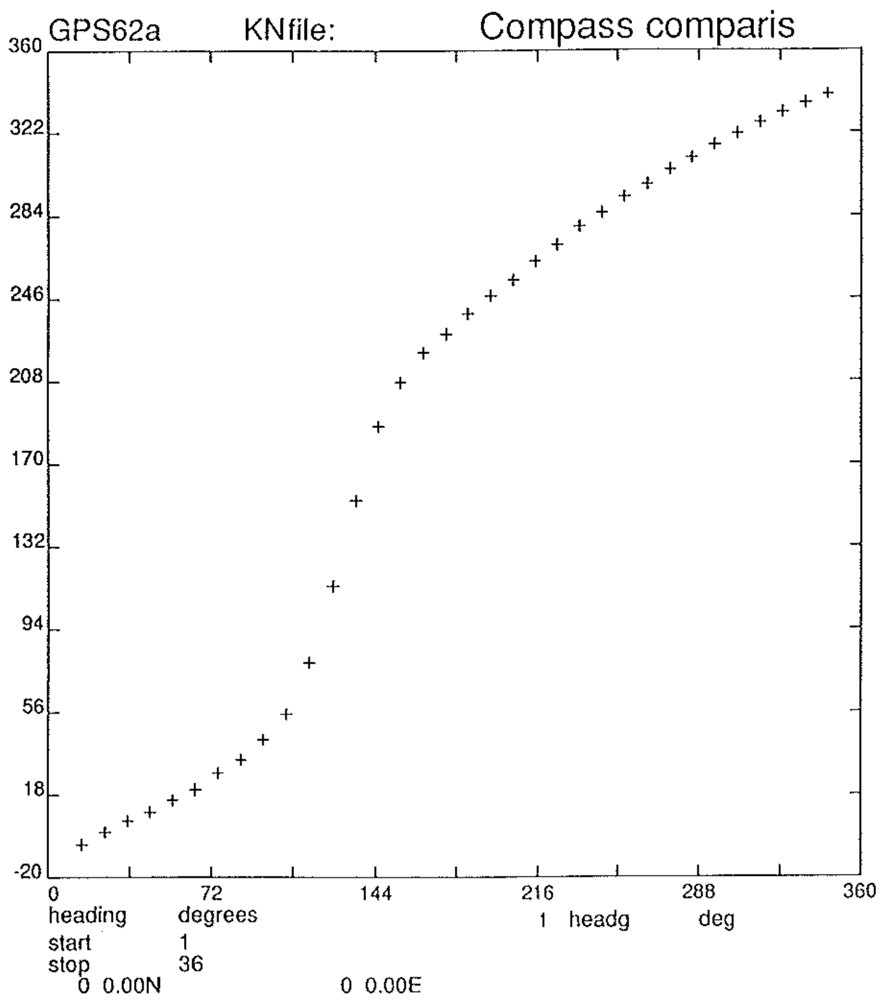
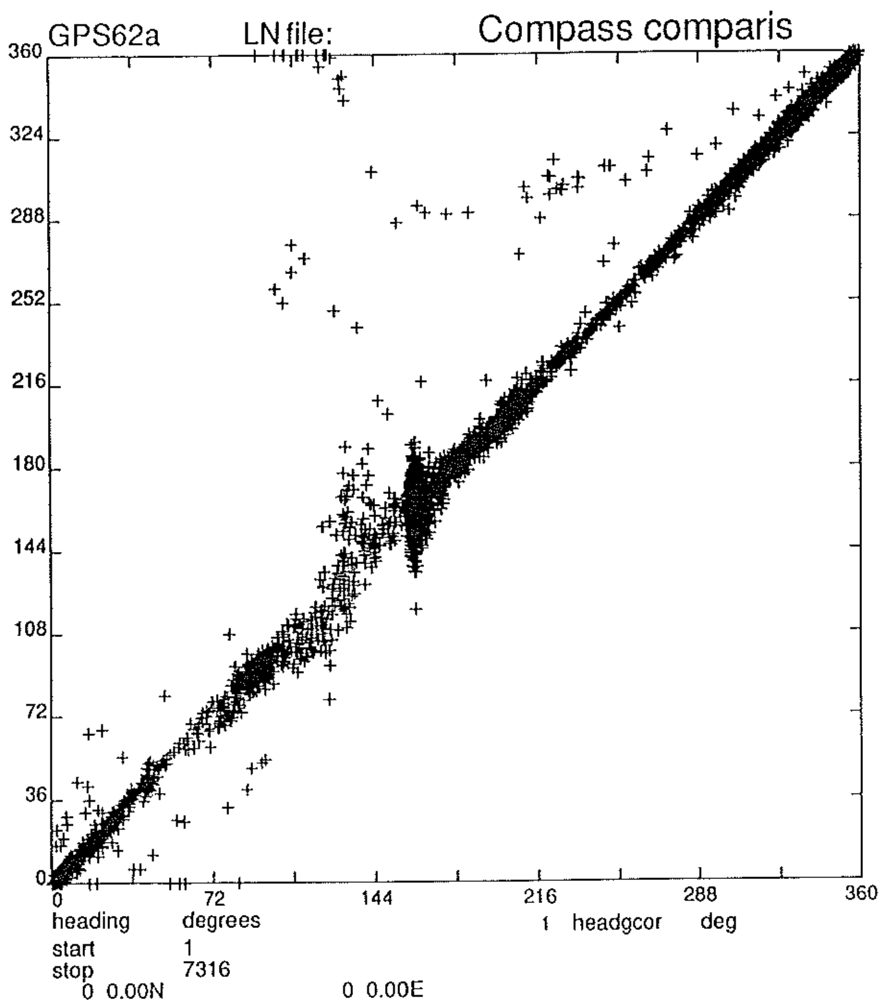


Figure 2.4 The mean comparison between the KVH compass values and the 'heading' variable.

a



b

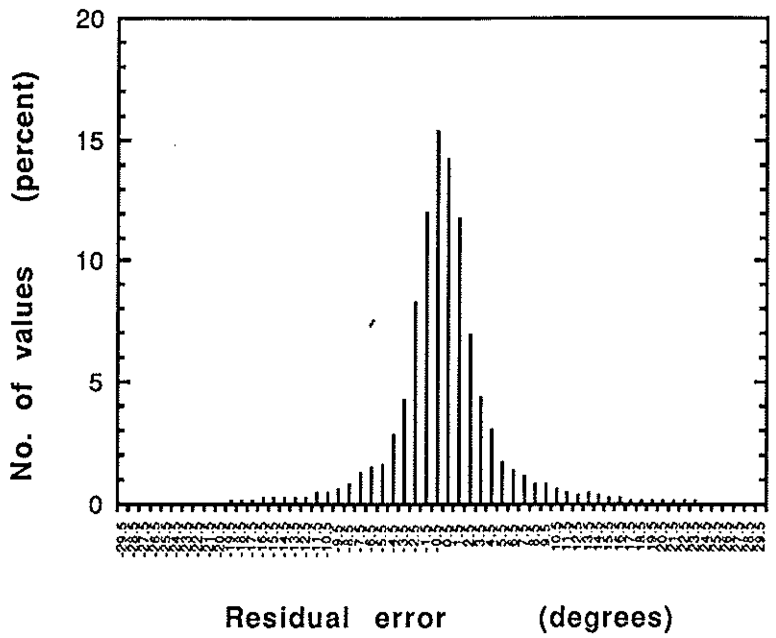


Figure 2.5a Comparison of the corrected KVH compass values and the 'heading' variable.

Figure 2.5b Histogram of the residual errors after correcting the KVH compass values.

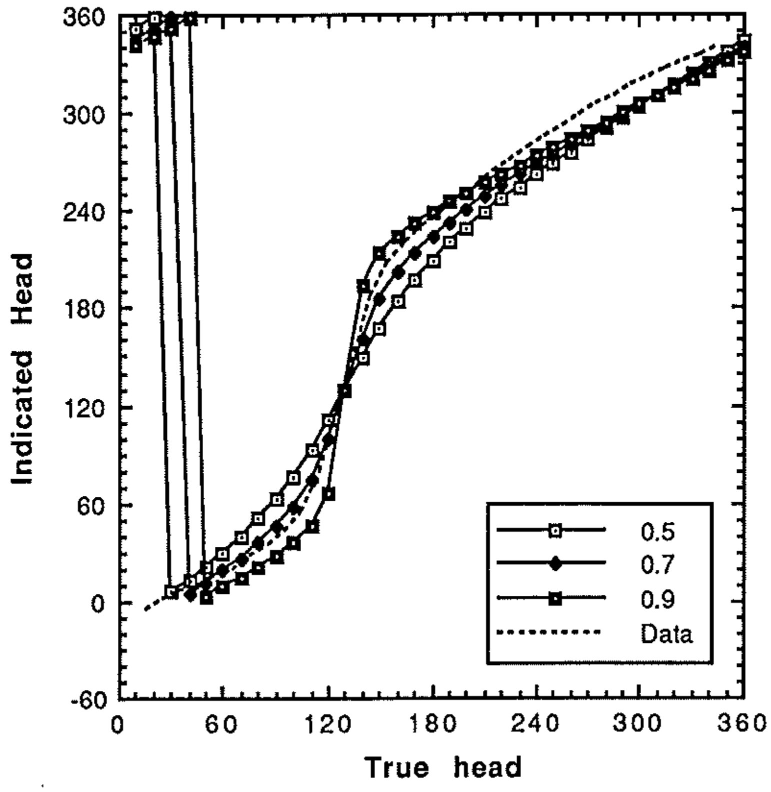


Figure 2.6. The expected error curves for cases where the ship's magnetic field is 0.5, 0.7, and 0.9 of the earth's magnetic field. The data from the KVH compass are also shown.

APPENDIX 2 - LISTING OF PROGRAM GPSREAD

```
C......program to read in gps and compass data and to code the mode
C......of the data (navigation, tracking etc)
C
      program gpsread
      implicit real*8 (A-H,O-Z,a-h,o-z)
C
#include 'datadf.h'
#include 'psio.h'
C
      character*154 BUFF
      character*3 CNAV,CTRK,CSTS,CIAC,CACQ,CIDL
      character*80 FLNAMS(6)
      real*8 jstart,jday
C
      character*8 PROG
      dimension DATA(IRECXX,12)
      character*8 fields(12),units(12)
C
      data PROG/'gpsread'/
C
C.....set up data description
      data INSTMT/'GPS     '/,DATNAM/'GPS62a  '/
      data PLATYP/'Ship    '/,PLTNUM/'62a     '/,PLTNAM/'Darwin  '/
      data fields/'jday    ','lati    ','long    ','headg   '
     &,'mode    ','sat t/v ','edop    ','ndop    ','vdop    ',
     &'hdop    ','cog     ','sog     '/
      data units/'days    ','deg n   ','deg e   ','deg     '
     &,'        ',5*'        ','deg     ','knots   '/
      COMMON/IOFILS/FLNAMS
      NUMWRD=IRECXX
C
C.....put field names and units into arrays FLDNAM & FLDUNT
      do 40 i=1,8
       FLDNAM(i)=fields(i)
       FLDUNT(i)=units(i)
   40 continue
C
C.....initialise
      call PROGHD(PROG)
C
C.....open file
      call OPENOT(IODISK)
      if(IODISK.EQ.-999) stop 'no output file'
C
C.....open input file
      call OPENSQ(INDISK)
      if(INDISK.EQ.-999) stop 'no input file'
C
C.....find day from file name
      read(FLNAMS(INDISK-IFDIS),1020)jd,jh,jm
 1020 format(1X,I3,2I2)
      jstart=jd+(jh+(jm/60.))/24.
C
C.....set up flags
      CNAV="NAV"
```

```
      CTRK="TRK"
      CSTS="STS"
      CIAC="IAC"
      CACQ="ACQ"
      CIDL="IDL"
C
C.....assign flags
      NOFLDS=8
      NORECS=0
        IEND=0
  110        READ(INDISK,1070,END=20) BUFF
 1070 format(A154)
             IFLAG=-1
             IF(BUFF(31:33).EQ.CNAV)then
               IFLAG=0
                 else if(BUFF(31:33).EQ.CTRK)then
                   IFLAG=1
                 else if(BUFF(31:33).EQ.CSTS)then
                   IFLAG=2
                 else if(BUFF(31:33).EQ.CIAC)then
                   IFLAG=3
                 else if(BUFF(31:33).EQ.CACQ)then
                   IFLAG=4
                 else if(BUFF(31:33).EQ.CIDL)then
                   IFLAG=5
             endif
      if(IFLAG.LT.0)goto 110
      NORECS=NORECS+1
C
C.....read in data
      read(BUFF,1010,err=500)ih,im,is,alatdeg,alatmin,alondeg,alonmin,
     &DATA(NORECS,4),ivis,itrak,DATA(NORECS,7),DATA(NORECS,8)
 1010 FORMAT(3I2,F2.0,F6.3,1X,F3.0,F6.3,1X,F5.2,3X,2I1,4F5.2,2F5.1)
      DATA(NORECS,5)=IFLAG
C.....calc day from jd + ih,im,is
      day=jd+(ih+(im/60.)+(is/3600.))/24.
C.....check for change of day
      IF(day.LT.JSTART)then
      jd=jd+1
      day=day+1
      endif
      DATA(NORECS,1)=day
      JSTART=day
C
C.....calc lats and longs
      DATA(NORECS,2)=alatdeg+alatmin/60.
      DATA(NORECS,3)=alondeg+alonmin/60.
      DATA(NORECS,3)=-DATA(NORECS,3)
      DATA(NORECS,4)=10.*trak+1.*vis
C
C.....check if file is too big (limit IRECXX lines)
      IF(NORECS.LT.IRECXX) goto 110
      write(IOITT,1030)
 1030 format('warning - too many records in file')
      stop
C
C.....error message for bad record, print then carry on
  500 write(IOITT,1040) BUFF
 1040 format('bad record'/A154)
      goto 110
C
```

```
   20 do 35 I=1,NOFLDS
          call OTDATA(IODISK,I,1,NORECS,DATA(1,I),NOFLDS,NORECS)
   35 continue
C
C.....tidy up
      do 50 I=1,NOFLDS
   50 ABSENT(I)=-999.0
C
      do 60 I=1,NOFLDS
   60 call UPRLWR(IODISK,I,1,NORECS,ALRLIM(I),UPRLIM(I),ABSENT(I),
     &NOFLDS,NORECS)
C
      CALL PFINIS(IODISK,PROG,
     & MAGIC,NOFLDS,NORECS,NROWS,NPLANE,ICENT,IYMD,IHMS,
     & FLDNAM,FLDUNT,ALRLIM,UPRLIM,ABSENT,
     & ALAT,ALONG,DEPTHI,DEPTHW,OPWRIT,RAWDAT,PIPEFL,ARCHIV,VERS,
     & DATNAM,PREFIL,POSTFL,PLATYP,PLTNUM,RECINT,PLTNAM,INSTMT,COMENT)
C
      STOP
      END
```

APPENDIX 3 - EXAMPLE OF UNIX SCRIPT TO QUALITY CONTROL GPS DATA

```
#!/bin/csh

# Script to edit pstar format output of program gpsread ( Appendix 1)
# to remove data associated with large ship's accelerations

# read in input file name and store as infile

echo "input filename"
set infile = $<

# datpik is used to select only data recorded during 'navigation mode'

datpik<<!
${infile}
${infile}pik
1
5 0 0
0/
/
!

if($status>0) then
echo "problem with datpik $infile"
exit
endif

# pcopya is used to duplicate two variables
# both are overwritten by fdiff later
# the second sog time difference is for filtering

pcopya<<!
${infile}pik
```

```
n
${infile}pik2
1~12,12,12/
/
/
!

if($status>0) then
echo "problem with pcopya $infile"
exit
endif

# fdiff finds the difference between consecutive values of a varible
# two new varibles are created, each containing the 'first difference'
# of the ship's speed

fdiff<<!
${infile}pik2
y
12 13
12 14/
sogdif
sogdifav
!

if($status>0) then
echo "problem with fdiff $infile"
exit
endif

# pcopya is used to remove the first datacycle as pfiltr will not accept
# absent data

pcopya<<!
${infile}pik2
y
/
2,/
/
!

if($status>0) then
echo "problem with pcopya2 $infile"
exit
endif

# the 'first difference' of ship's speed is averaged using a five point
# running mean

pfiltr<<!
${infile}pik2
${infile}pikdiffilt
14/
2
/
!

if($status>0) then
echo "problem with pfilt $infile"
exit
endif
```

```
# the 'first difference' and it's running mean are subtracted from each
other
# to create sogdifmn

parith<<!
${infile}pikdiffilt
${infile}pikdiffiltdif
/
2 13 14
0/
sogdifmn
knots
!

if($status>0) then
echo "problem with parith $infile"
exit
endif

# data are deleted for data cycles with a sogdifmn greater than +/- 2
knots/s

datpik<<!
${infile}pikdiffiltdif
${infile}pikdiffiltdifpik
2
19 -2 2
0/
/
!

if($status>0) then
echo "problem with datpik $infile"
exit
endif

# the remaining data are averaged over a fifteen minute period

pavrge<<!
${infile}pikdiffiltdif
${infile}pikdiffiltdifav
1 0 900 0
!

if($status>0) then
echo "problem with pavrge $infile"
exit
endif
```