MF radar height calibration using the MANTRA research balloon

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MANTRA.tex

Acknowledgements: We much appreciate the willingness of Dale Sommerfeldt and, in 1993, Kirk McDuffie, of Scientific Instrumentation Limited, Saskatoon, to share their balloon position data with us. A previous balloon (NASA) in 1988 was also seen by the MF radar, but the positions were by guess mostly from airport radars, and only every 1/2 hour at best; not good enough for a calibration.

1 Introduction

Radars make measurements at a series of height gates, each specified e.g. by its known time delay from the beginning of the Tx synch pulse. Since this delay includes time for the RF pulse (or, in some systems, the trigger pulse) to travel through cables to the Tx, thence to the Tx antenna, from the receiver antennas back to the receivers, and through to the receiver detector output, as well as the time we are interested in, viz. up to and down from the ionosphere, which is related to the height of reflection, some form of calibration is required. If the Tx and Rx were completely isolated (except for the synch pulse), it would be possible to look at the ground pulse - straight from the Tx to Rx antenna - and measure its delay relative to the Tx synch. In our case, the TX and Rx are located in the same building (and with our previous tube-Tx, the RF pulse was generated in the Rx building), and some of the RF power most certainly goes straight from Tx to Rx within the building; so the ground pulse method is not suitable.

A better method is to use a reflector at a known location. Since ground reflections occur at near ranges, and we don't routinely measure these ranges anyway (because there are no MF ionosphere echoes at the corresponding heights), the reflector must be located at a great distance. In routine operation our first height/range gate is at approximately 46 Km. Depending on the season and time of day, ionospheric echoes start to appear ~5-15 Km beyond this - which can obscure the wanted echo.

The reflector must also offer a large target to 135m wavelength, so it has to be big !

2 Parksite/Saskatoon MF radar data

The MF radar data comprise 5m records every 5m with *nominal* heights 49-142 step 3 Km. We are sure about the step, it is the conversion from nominal to real height that we want. The useful parameters for the purposes of height (and maybe phase) calibration are the mean signal strength (RMS amplitude over 5m), mean Doppler velocity (from the complex auto-correlation function averaged over all four Rx antennas), and mean angle-of-arrival (AOA) phase (i.e. zero lag cross correlation phase for pairs of receiving antennas). These parameters are extraneous to our usual measurement of horizontal wind (but it might be interesting to see if any *wind* vectors were produced- and consider their meaning in this extreme case of a single echo).

Data biases? - we know that the Doppler velocity is biased to lower speeds by Rx signal clipping - e.g. at 100% clipping the factor is 1.6. Angle of arrival phase is also affected this way, but only if the phase difference as seen **at the Rx outputs** is near zero — this is seldom the case. A more important question is: are the phase data biased by uncorrelated noise? I haven't investigated this yet.

3 Figures

Figure 1.

This figure is quite complicated (!). The 'X' denotes the MF radar. The analysis used MF Radar position (GPS position at door of Rx bldg.) 52.206666°N, -107.108333°E. [Re. accuracy of GPS, two measurements were made - see Park logbook - Jun29'93: 52°12'24"N, 107°07'03"W @ 519m above msl, and Feb22'94: 52°12'22"N, 107°07'00"W

@ 490m above msl; and another today, Nov19'98:52°12'34.4"N, 107°07'04.4"W, height was not available.]

Range and position calculations have been done in double precision.

A: marks the time scale, one tic per hour

B: shows the signal strength at the first 6 height gates, nominal 49-64 Km on time scale A - plotted at the centre time of the record using symbol '0' for 49Km, '1' for 52 Km etc.

C: shows the range of the balloon from the MF radar (calculated from balloon and MF radar GPS locations) on scale E by plotting symbol ':'

D: shows the theoretical Tx-RX gain in the direction of the balloon against time scale A, using symbol '@'. (E.g. if the balloon disappears, maybe it's sitting in a null of the Tx pattern.

E: is the range scale for MF-balloon separation (used in plot C); in steps of 3Km to match the radar range resolution.

F: shows the position of the balloon - range (shown on scale I) vs azimuth (North is up) vs. UT (written beside the balloon track). These positions are found every minute by taking the median latitude and longitude of the raw GPS data (usually 12s time resolution, but there are some gaps, and some points are based on 1 raw GPS value). The earth is assumed spherical: Re = 6365Km.

G: shows the balloon radial velocity relative to the radar, based on differences in calculated range of adjacent one minute values, on time scale A

H: Δ shows the MF Doppler velocity on time scale A

I: shows the scale used in plotting the balloon track F, tics spaced 10 Km.

J: shows the scale for Doppler velocity and radial balloon velocity (+ve if away from radar): axis = 0, tics at 1,2,3,4,5,6 m/s.

Figure 2. This is a plot similar to Figure 1 for the '93 balloon There are 3 significant differences - one is that at that time the radar PRF and integration rate changed at 1500 and 0300 UT: 60Hz, 32 pulse integration at night and 7.5 Hz, 4 pulse integration in daytime. The big change in "signal" at these times is really just a change in S/N. In addition, the balloon echoes were strong enough that the Rx gain had to be changed at various time at all heights. This could - although it is not apparent - cause small jumps in the calculated/calibrated signal value. It is important that there not be a

gain change at the critical heights/times where we are looking for equal signal in two adjacent gates, and also that the gain should be the same in the two gates. I don't remember whether I checked this carefully ! The '98 data have only one gain change (which should also be avoided).

The final difference is that the "raw" balloon positions we got were one per minute.

Figure 3. This shows the first 6 MF gates' data overplotted on a zenith/azimuth plot (provided S/N, as measured by the fading rate according to auto correlation width, is sufficient). The number is the record number from 1200UT='0', and the line extending in or outward denotes the MF Doppler velocity (scale not shown).

The Rx antenna comprises an equilateral triangle of side 2λ (270m at 2.219MHz) with a fourth antenna in the centre of the triangle. For AOA we use pairs consisting of the centre and one outer antenna.

A 10d histogram of antenna phase differences is used for phase calibration, in which the assumption is made that the normal ionosphere is horizontally stratified. The calibration accuracy hard to estimate -i.e. we are trying to locate the peak position of a fairly wide and sometimes non-symmetrical histogram. I guess that the error is $\sim 1°$ in zenith angle. There are other minor corrections which should be put in for serious phase calibration - the height of the centre antenna is $\sim$8m lower than the three outer antennas. There could also be different temperature coefficients in the cable.

Since the closest antenna spacing is $\sim 1.15\lambda$, we cannot get an unambiguous AOA. [For that we would need $\frac{1}{2}\lambda$ spacing.]

Ambiguities are sorted as follows: the real phase path difference, $\Delta\phi$, for a pair of antennas (centre - outer) cannot be more than 416°. This means that each measured antenna-pair phase difference (between -180 and +180° by definition) will have one or two more possible values, which are found by adding and subtracting 360° and retaining those with phase magnitude less than 416°. Thus with three antenna pairs, we will have between 6 and 9 possible sets of AOA phases. This number can be further reduced by requiring that the phases add to (near) zero – which is the requirement for a plane phase front. We use the *normalized phase discrepancy* parameter

$$\mathrm{N}\phi\mathrm{D} = \frac{\mid \Sigma\Delta\phi \mid}{\Sigma \mid \Delta\phi \mid}$$

to choose good AOAs (at the moment we use $\mathrm{N}\phi\mathrm{D} < 0.3$? – but we should really be more critical since we know there is only one scatterer). A minor down side is that large zeniths will sneak through more easily because the denominator is larger. This pre-selection still leaves ambiguities, which are all plotted.

The dashed lines show where an antenna-pair phase will cross a +/- 180° boundary. If the phase corrections made to the measured phases (depend on horiz. stratified ionosphere calib. as mentioned before) are incorrect, then the positions of these lines will be slightly in error.

Figure 4.

As in Figure 3, but range gates are separated; 'nkm' means nominal height/range.

Figure 5. This shows accurate nominal height/range positions of peak signals vs. time. (parabolic fit to three adjacent gates of the 5m signal-height dB profiles) The balloon echo is clearly visible at the lowest ranges. It is a puzzle why we couldn't see it before ~1300 UT, where the range is *decreasing* with time - although nighttime interference might have covered up the echo.

A "problem" with the MF system is that we do not measure absolute signal - just signal to noise - because the Rx gains are set according to the *integrated* coherent signal, which even if the noise is 100% clipped, still looks reasonable after heavy integration (and so the Rx gain is not reduced by the system).

Also (Figure 1) the GPS locations seem to be strange before ~1530UT — so we can't tell where the balloon really is, and whether we should have been able to see it.

Another puzzle is how the balloon escaped by us to the east without us catching sight of it again - the plot for the next day didn't show any sign of it (although that might again be blamed on night time interference).

4 Height Calibration:

This is the whole purpose of this experiment! One way is to look for max. signal at a particular gate and assume that the balloon is dead centre in the gate at this time – the problem with this method is that because the Tx pattern is non-uniform (and very non uniform in places!), trends could be superimposed on the signal variations, thus shifting the peak in time.

A better method is to find times when the signal is equal in adjacent range gates and look up the *real* balloon range on curve C, scale E. These results can be measured directly on Figure 1 by drawing a smooth curve through the signals at each height/range gate, and looking for crossings.

As mentioned previously, we must avoid possible signal calibration jumps caused by changing Rx gains.

5 Tentative Conclusion

At the moment the conclusion is that the height calibration has not changed significantly since the 1993. This is nonsense because we know that the Tx pulse occurs later relative to the synch - since it is now a formed quasi-Gaussian rather than square/trapeziodal, as it was with the old tube Tx used for the '93 balloon measurements. As well, climatological (zero crossing of 10d average zonal mean wind) before/after comparisons indicate a 2-3 Km change in the sense we expect. In '98 there were about 6 suitable times for calibration - the corrections to nominal height varied from 4-9Km; quite a wide range. The '93 balloon produced values all near $\sim$5.5 Km.

The path of the '98 balloon is less satisfactory compared with the '93 and the time sequences of MF signal strengths look somewhat irregular, even though there were very few gain changes in '98.

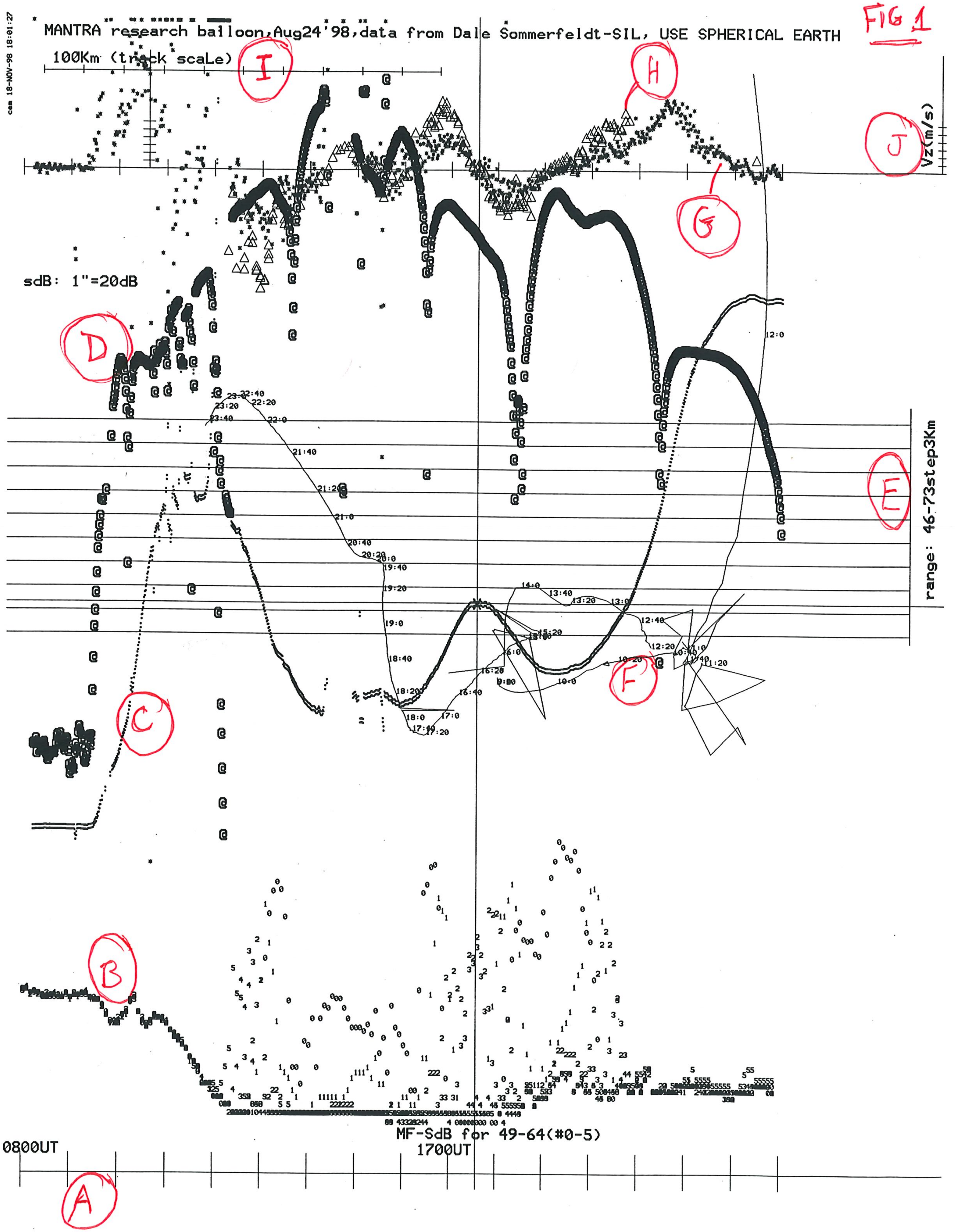
6 Further analysis to do:

- Check into time and heights of Rx gain changes in both '93 and '98. Is there any significant error(s) – should we discard some of the signal crossings because of nearby gain changes ?

-

——————the end——————

FIG 1


cem 18-NOV-98 18:01:27
MANTRA research balloon,Aug24'98,data from Dale Sommerfeldt-SIL, USE SPHERICAL EARTH
100Km (track scaLe)
sdB: 1"=20dB
Vz(m/s)
range: 46-73step3Km
MF-SdB for 49-64(#0-5)
0800UT
1700UT
A
B
C
D
E
F
G
H
I
J
22:40
23:20
23:40
22:20
22:0
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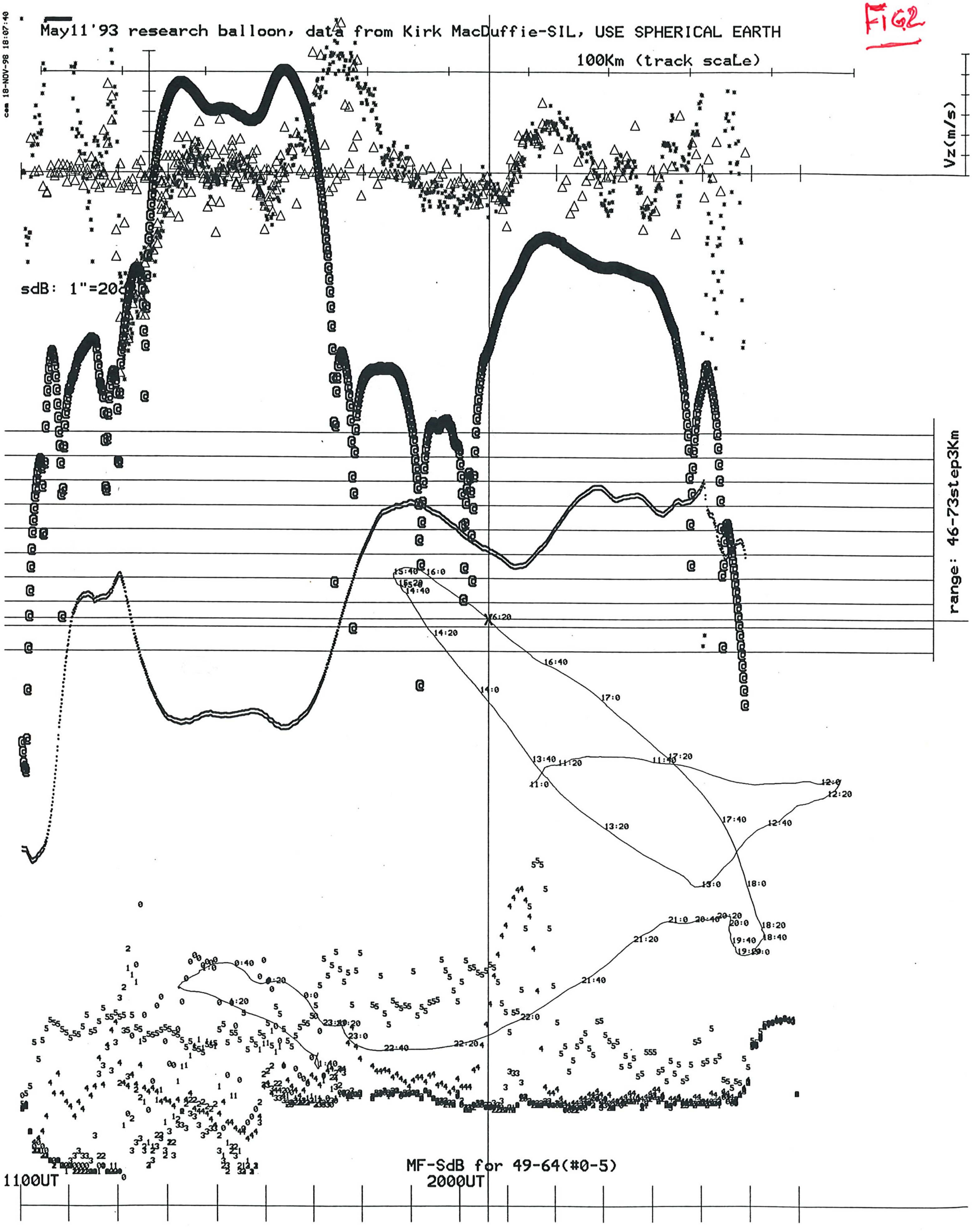
11:20
10:20
10:0

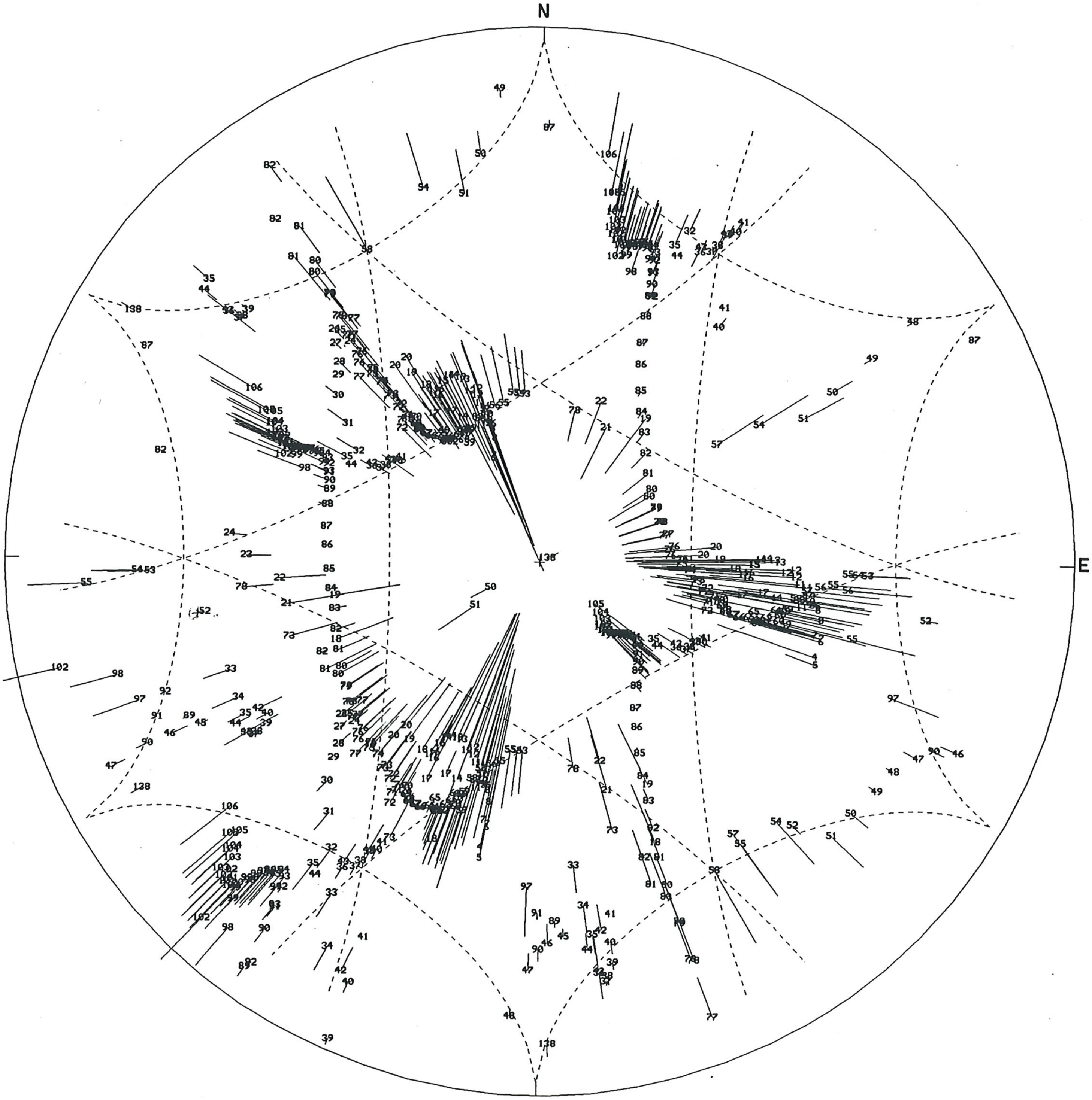
FIG2


cem 18-NOV-98 18:07:40
May11'93 research balloon, data from Kirk MacDuffie-SIL, USE SPHERICAL EARTH
100Km (track scaLe)
Vz(m/s)
sdB: 1"=20dB
range: 46-73step3Km
MF-SdB for 49-64(#0-5)
1100UT
2000UT

cem 18-NOV-98 18:43:18

ALL hts 49-64nKm,98:236 UT 12- 23(fazcor= 170. 170. 156.), '0'=1200UT, Lines=Vrad

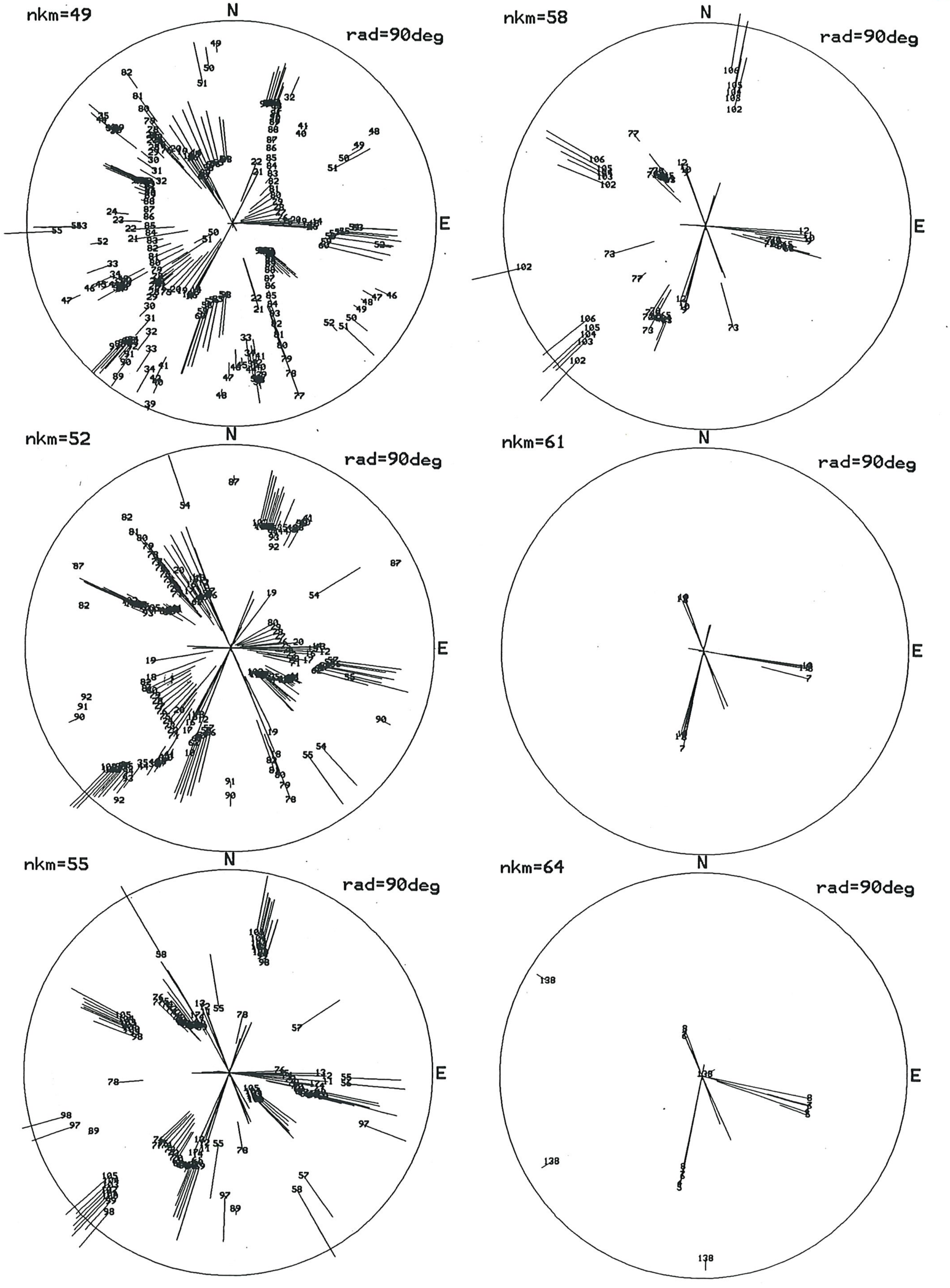
Fig 3



cem 18-NOV-98 18:43:16

Aug 24,1998 BaLLoon: pLot aLL AOA possibs.;'0'=1200UT,aro or Lin=rad.veL

Fig. 4



Heights (nomkm!) for max("-"m

Fig 5