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MET.O.15 INTERNAL REPORT

No 17

AN ASSESSMENT OF THE PERFORMANCE OF THE NAVAID DROPSONDE

by

P Ryder

April 1979

Cloud Physics Branch (Met.O.15)

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An Assessment of the performance of the NAVAID dropsonde

BY P. Ryder

Introduction

MRCP 309 (April 1972) described our intentions to develop a wind finding dropsonde for use from the Met Research Flight C130 aircraft. During the intervening period a major effort has been expended by Met O 15 and MRF on the design, construction and testing of such devices and the necessary ancillary equipment. It is not the purpose of this report to set out a detailed description of that development programme and all of the results obtained from it. However following clearance of the dropsonde ejector on the aircraft during 1978, data which allow some assessment of the end product are becoming available. These are discussed below following a brief description of the sonde system and a review of the design objectives of the project.

The NAVAID dropsonde

The dropsonde is designed to be ejected from the MRF C130 and, whilst descending by parachute, to transmit information to the aircraft from which ambient atmospheric temperature, humidity, pressure and wind can be derived. A schematic diagram of the sonde is shown in figure 1(a) and (b).

Lateral position, from which lateral movement and hence wind can be inferred, is derived from the retransmission of NAVigation AID (Loran C) signals received at the sonde. A detailed account of the principles of this technique has been given in MRCP 309 and Ryder (1974), (1976), but in essence the difference in time of arrival of signals from two separate but coherent transmitters defines a locus or 'line of position'. In practice this is essentially a vertical plane, except close to either transmitter. Two such time differences obtained from signals from at least three transmitters create intersecting lines of position and hence effectively define a unique plan position. The advantage of the technique for sonde wind finding arises from the fact that such a position can be extracted provided only that time differences are preserved without distortion.

In particular any common signal path such as that between a moving aircraft and sonde is unimportant.

The sonde contains a Loran C receiving antenna formed from a single wire attached to a parachute shroud line and a Loran C (100 KHz) receiver. The signal from this is used to frequency modulate a UHF carrier. The sonde body forms a dipole to transmit this carrier.

Atmospheric temperature, humidity and pressure are measured by suitably exposed transducers on the sonde. A thermistor is used for temperature; a carbon hygristor for humidity (see MRCP 386, Oct 1975) and a National Semiconductor integrated circuit LX1602 A for pressure. The output 'signals' of these devices are converted to frequencies in the range 50 to 1800 Hz, which are then time multiplexed with housekeeping data and used to modulate the UHF carrier. Each transmitter is crystal controlled at one of five separate frequencies in the 400 MHz band.

The sonde also contains necessary control equipment to deploy the parachute and turn on the transmitter several seconds after ejection.

The aircraft equipment consists of a pressurised ejector in the C130 ramp door, signal conditioning and data logging equipment and a pre-ejection, calibration rig. Signals from up to five sondes, each at a different UHF frequency, are received at a single broad band aircraft antenna which serves five independent crystal controlled receivers. Loran C and thermodynamic data are extracted from each of these sources. The latter are stored on magnetic tape as digitised samples of the individual element frequencies. Data from which time differences are calculated, are extracted from zero crossings of chosen cycles of the pulsed 100 KHz waveform generated by the Loran C system. These are also stored on magnetic tape. Loran signals are received directly at the aircraft and during the development of the NAVAID sonde system, have been used extensively to provide post flight trajectory data for the C130. An example of this incidental use of the system is shown in figure 2. The main reason for providing this 'local' source of Loran C signals however, is to provide a suitable starting point for acquisition of the required sonde Loran C zero crossings after ejection.

Each sonde is tested before ejection through use of an umbilical connection to a special purpose test rig. This also provides a single point calibration at aircraft cabin pressure for each sonde pressure element shortly before ejection. The same rig is used in the laboratory when the individual sonde transducers are exercised in an environmental chamber. Data from such experiments are used to define transducer transfer functions.

System requirements

It was shown in MRCP 309 that the RMS error in vertical velocity which might be inferred from the equation of continuity and measurements of horizontal wind velocity at grid points separated by distances of the order of 25 Km, was approximately 2 cms^{-1} if the horizontal winds were known to $\pm$ 0.4 ms^{-1}. Previous Scillonia experiments had shown that estimation of vertical velocity of this magnitude, with a vertical resolution of 500 m or so, would allow useful investigations of mesoscale structure in warm frontal zones for example. Figure 3 shows the accuracy likely to be achieved by the use of Loran C in the North Atlantic for this purpose. The diagram was based upon surface experiments designed to study Loran C phase stability and whilst every effort was made to take account of all likely sources of error, verification of the predictions requires experiments of the type reported below.

The accuracy required of the individual sonde measurements of pressure, temperature and humidity was not well defined in MRCP 309. There is a natural desire to measure these parameters as accurately as possible but this must be tempered with an awareness that the lack of representivity of spot measurements is likely to provide a practical limit to usefulness. Because the sonde could provide an excellent, perhaps unique opportunity, to study the latter problem there was a natural tendency to err in the direction of maximum, reasonably achieved accuracy. Absolute RMS errors of $\pm$ 0.2°C for temperature, $\pm$ 5% RH for humidity (perhaps better than this close to 100% RH - see MRCP 386) and $\pm$ 1 to 2 mb pressure became accepted as sensible targets during the development programme. Of course it was expected that differential errors between separate estimates of these parameters during a single sonde descent might reasonably be expected to be less than the figures quoted. The importance of the response times of the temperature and humidity transducers were always recognised. In practice the ability of the transducers to 'forget' their recent exposure to aircraft cabin temperature and humidity following ejection into an environment at -50°C and 5% RH, became a significant constraint.

Trial results - wind finding

Several trials of the sonde and aircraft equipment have taken place at MOD test ranges around UK. These have pointed to some defeciences in sonde design and operational procedures. The problems have tended to be in areas which are not amenable to laboratory evaluation and have been such as to affect reliability rather than quality of performance. Thus the deployment of the parachute and Loran C antenna, the acquisition and tracking of the optimum points in the Loran C waveform have all presented difficulties. In fact it remains to be demonstrated that these have been entirelyovercome. Nevertheless data which allow assessment of the quality of performance have been obtained at both Aberporth and

Benbecula (see figure 3).

Three sondes were dropped at Aberporth on 28 July 1978 to test the ability of the system to accept data from more than one sonde at a time. Of course only one of these could be tracked by the single high quality radar which was available there. In the Aberporth region the intersecting lines of position (LOPs) created by transmissions from Loran C transmitters at Ejde, Sandur and Sylt form parallelograms as sketched in figure 4. The component of motion perpendicular to a given set of LOPs can be inferred from the rate of change of the time differences which define those lines. Thus the Ejde-Sylt time difference can be used to calculate the wind speed perpendicular to 32^{o}. Similarily the Ejde-Sandur time difference provides an estimate of the component perpendicular to -18^{o}. These components are compared for sonde A001 with their equivalent radar estimates in figures 5(a) and (b). When viewed in this way the great importance of LOP geometery is isolated and emphasised. Each component is derived from the rate of change of time difference assessed over 60 seconds centered on the time of the estimate. This is calculated by fitting a straight line by the least squares method to 60 one second time differences obtained from each source. The error bars are assigned from the standard estimate of the error in the time difference gradient implied by the individual departures from the straight line; they are a measure of 'goodness of fit'. Conversion from rate of change of time difference to rate of change of distance (i.e. wind component) is achieved by use of the LOP scale factors. These are simply the perpendicular distances between LOPs separated by unit time difference. As might be expected from figure 4, the small scale factor for the Ejde-Sylt time difference allows a good estimate of the wind component perpendicular to 32^{o} (parallel to 122^{o}); Fig. 5(a) confirms this. Note that the RMS difference between radar and Loran C estimates of the wind component is 0.3 ms^{-1}, which is in good agreement with the error predicted from goodness of fit ($\pm$ 0.2 to 0.3 ms^{-1}). The large scale factor, in the Aberporth area which applies to the Ejde-Sandur time difference, produces much larger errors between radar and Loran C estimates for that wind component (ie parallel to 72^{o}), but again the RMS differences are comparable to the goodness of fit estimates (ie 1.2 ms^{-1} cf $\pm$ 0.6 to 1.0 ms^{-1}). Of course this latter error dominates the estimation of the <u>total</u> wind vector error, which is close to that predicted in figure 3 for the Aberporth area. The results have further significance however, because they demonstrate that where the geometery and scale factors are favourable, low wind errors are achieved.

In an analysis of the algorithm which is used to track the individual Loran C signal zero crossings from which time differences are derived, Ryder (1976) has pointed out that the response can be oscillatory if the signal to noise ratio becomes very low. Accordingly the signal to noise ratio (SNR) for each transmission is also shown in figure 5. An oscillatory response is not expected at the values indicated but there is an obvious correlation between low SNRs at about 1505 and the increased component errors at that time.

On 28 February 1979 six sondes were dropped in the vicinity of Benbecula, S Uist. Five of these were tracked by radar at ranges of between 20 and 30 km. The radar used was a Cossor WF4 (353) with angular and range resolution of 0.1^{o} and 25 m respectively. These figures imply a wind finding accuracy of the order of 1 ms^{-1}. This is confirmed in figure 6, which shows the variation of vertical velocity derived by radar for one sonde; others are similar.

Figure 7 shows the Loran C LOP geometery in the vicinity of Benbecula. This is a considerable improvement on that at Aberporth; which is reflected in the wind errors predicted for this area in figure 3 of course. Unfortunately two techniques for optimising transfer of Loran C signal tracking between aircarft and sonde were not used on this occasion. This resulted in poor Loran signal to noise ratios on all but one of the sondes; good thermodynamic data were obtained from all. The radar and Loran C derived wind components perpendicular to the LOPs are shown in figure 9(a) and (b) for this good SNR sonde, serial A021. Note that errors derived as before from goodness of fit are of the order of 0.1 to 0.3 ms^{-1} as predicted by figure 3. However there is some disagreement between the radar and Loran estimates outside these limits. These are compatible with the estimated accuracy of the radar and of a nature which suggests that the radar may be smoothing out some of the wind variation. There is further circumstantial evidence for this view, in that the strong shear observed at about 14:08:20 coincides with a temperature inversion at 840 mb, see figures 12 and 13.

Figures 9(a) and (b) show a similar comparison between radar and Loran C derived components for sonde C007 at Benbecula, again on 28 February 1979. The effect of poor signal to noise ratios is clearly discernable. The results suggest that the onset of oscillatory response occurs between SNR = -6 to -8 dB.

<u>Trial results</u> - <u>pressure measurement</u>

The accuracy of the pressure element can be investigated by using the estimated surface pressure, radar derived sonde height and the sonde measurement of temperature. From these data and the hydrostatic equation the variation of pressure with time can be estimated for comparison with that measured at the sonde. Several such comparisons have been made. The results are summarised in Table 1. On most occasions differences between individual measurements of pressure are less than 2 mb. Sonde C007 is unusual in that a constant difference of ~ 6 mb is observed. The reason for this is unknown. It was always expected that the absolute measurement of pressure would be difficult. It is for this reason that each sonde undergoes a single pressure calibration before ejection. Fortunately experience suggests that a further check may be possible. Thus the loss of signal indicates entry of the sonde into the sea with a resolution of ± 0.2 sec allowing estimation of the surface pressure to ± 0.2 mb. Provided that the surface pressure can be inferred from some other source, gross errors at least, should be avoided.

Trial results - Temperature and Humidity measurement

Figure 10(a) shows the superposition of temperature and humidity measurements made on four sondes which were dropped over the Aberporth range on 28 May 1978. The individual profiles are shown in figures 10(b),(c),(d) and (e). The first sonde, A003 was ejected at 12.54.21Z; the last, D001, entered the sea at 13.52.40Z. The data sets are the individual samples of temperature and humidity plotted as a function of indicated pressure. Gaps result from signal fades and some defeciences in the synchronisation software which have now been corrected. Several features are worthy of note. Thus there is good agreement between the temperature profiles throughout with excellent comparability in the lower atmosphere. There is also very good correlation between small scale features detected in the humidity profiles. On close inspection many of these are seen to be linked to small changes in temperature lapse rate - see for example figure 10(d). Note also the rapid moistening in the vicinity of 500 mb at -28°C, a cloud layer from about 680 to 760 mb and a very rapid drying out below the inversion. Clearly the latter represents a division between two air masses.

It is difficult to demonstrate that the design criteria have been met but clearly self-consistency amongst the sonde data sets is of a high order. Special Aberporth radiosonde ascents made at 1130Z and 1400Z are shown in figure 11 for comparison with sonde C003.

Figure 12 shows the temperature and humidity profile measured on sonde A021 at Benbecula on 28 February 1979. This is plotted as a conventional tephigram in figure 13 where it is compared with the mid-day Stornoway ascent. Apparently on this occasion the aircraft was just above a tropopause. Despite the temperature difference of some 70°C between the aircraft cabin and external environment it is clear that the sonde transducers rapidly took up the environmental conditions. Lower in the atmosphere considerable structure can be seen again. Transit through at least one layer of cloud in the vicinity of 840 to 900 mb demonstrates the ability of the humidity element to dry out below cloud and no sign of a significant wet bulb effect can be seen in the temperature profile.

Conclusion

Whilst it cannot be claimed on the basis of evidence presented here that the performance of the dropsonde meets our original aspirations in all respects, the indications are that a good approximation to the design requirement will be achieved. The major task ahead is to achieve and maintain the required standards of reliability.

Acknowledgements

As stated in the introduction the development of the dropsonde facility represents the results of the combined efforts of many of the present and past staff of Met O 15 and MRF. Mr A. F. Lewis, Mr W. M. Longworth. Mr E. Stirland and Mr G. Watts from Met O 15, and Dr D.G. James and Mr J. Sears of MRF have made major contributions.

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Table 1 **Pressure Comparisons**

Sonde No. A.003 Date 28/4/78 Aberporth

Sonde Launch Time: 13:54:21

Time	Sonde Pressure	Radar Pressure	Difference	Time	Sonde Pressure	Radar Pressure	Difference
488.4	1006.7	1008.8	-2.1	208.6	679.4	678.4	1.0
458.6	971.1	973.9	-2.8	198.6	668.7	667.6	1.1
448.6	958.9	961.3	-2.4	188.6	657.7	656.5	1.2
438.6	946.6	949.1	-2.5	178.6	647.0	645.5	1.5
428.6	934.2	936.7	-2.5	168.6	636.0	634.6	1.4
418.6	922.0	924.8	-2.8	158.6	625.2	623.6	1.6
408.6	909.8	912.0	-2.2	148.6	614.6	612.7	1.9
398.6	897.6	900.1	-2.5	138.6	604.0	602.2	1.8
388.6	885.6	887.1	-1.5	128.6	593.4	591.3	2.1
378.6	873.5	875.1	-1.6	118.6	583.0	580.9	2.1
368.6	861.7	863.2	-1.5	108.6	572.5	570.4	2.1
358.6	849.9	851.2	-1.3	98.6	562.2	559.9	2.3
348.6	838.1	839.8	-1.7	88.6	552.0	549.5	2.5
338.6	826.3	827.8	-1.5	78.6	541.7	539.1	2.6
328.6	814.7	815.7	-1.0	68.6	531.6	528.8	2.8
318.6	803.2	804.1	-0.9	58.6	521.4	518.6	2.8
308.6	791.7	792.3	-0.6	48.6	511.4	508.5	2.9
298.6	780.0	780.8	-0.8	38.6	501.5	498.5	3.0
288.6	768.7	769.1	-0.4	28.6	492.0	488.0	4.0
278.6	757.3	757.6	-0.3	18.6	482.0	477.9	4.1
268.6	745.9	746.0	-0.1				
258.6	734.7	734.5	0.2				
248.6	723.5	723.2	0.3				
238.6	712.4	712.0	0.4				
228.6	701.4	700.7	0.7				
218.6	690.4	689.7	0.7				

Sonde No B.009 Date 28/4/78 Aberporth

Sonde Launch Time: 14:17:19

Time	Sonde Pressure	Radar Pressure	Difference	Time	Sonde Pressure	Radar Pressure	Difference
505.3	1007.9	1008.8	-0.9	253.8	714.2	715.2	-1.0
483.8	981.7	983.3	-1.6	243.8	703.4	704.3	-0.9
473.8	969.2	971.3	-2.1	233.8	692.8	693.2	-0.4
463.8	956.8	958.9	-2.1	223.8	681.9	682.4	-0.5
453.8	944.6	946.9	-2.3	213.8	671.2	671.6	-0.4
443.8	932.4	934.6	-2.2	203.8	660.8	661.0	-0.2
433.8	920.2	922.3	-2.1	193.8	650.3	650.3	0.0
423.8	908.1	910.3	-2.2	183.8	639.9	640.0	-0.1
413.8	896.1	897.8	-1.7	173.8	629.5	629.6	-0.1
403.8	884.2	886.3	-2.1	163.8	619.4	619.3	0.1
393.8	872.5	874.2	-1.7	153.8	609.3	609.3	0.0
383.8	860.7	862.5	-1.8	143.8	599.0	599.0	0.0
373.8	849.2	850.8	-1.6	133.8	588.9	588.9	0.0
363.8	837.5	839.0	-1.5	123.8	579.1	578.8	0.3
353.8	826.0	827.4	-1.4	113.8	568.9	568.6	0.3
343.8	814.5	816.1	-1.6	103.8	559.0	558.8	0.2
333.8	803.2	804.6	-1.4	93.8	549.3	549.1	0.2
323.8	792.0	793.2	-1.2	83.8	539.3	539.1	0.2
313.8	780.6	781.9	-1.3	73.8	529.6	529.3	0.3
303.8	769.5	770.7	-1.2	63.8	519.9	519.7	0.2
293.8	758.3	759.5	-1.2	53.8	510.3	510.2	0.1
283.8	747.4	748.3	-0.9	43.8	500.7	500.2	0.5
273.8	736.2	737.3	-1.1	33.8	491.0	490.9	0.1
263.8	725.3	726.1	-0.8				

Sonde No C.002 Date 28/4/78 Aberporth

Sonde Launch Time: 14:31:18

Time	Sonde Pressure	Radar Pressure	Difference	Time	Sonde Pressure	Radar Pressure	Difference
493.9	1008.8	1008.8	0.0	236.7	705.5	704.2	1.3
476.7	987.6	987.8	-0.2	226.7	694.2	692.9	1.3
466.7	975.0	974.9	0.1	216.7	683.0	681.6	1.4
456.7	962.6	962.7	-0.1	206.7	671.9	670.6	1.3
446.7	950.5	950.3	0.2	196.7	661.1	659.7	1.4
436.7	938.2	937.8	0.4	186.7	650.1	648.7	1.4
426.7	926.2	926.4	-0.2	176.7	639.4	638.3	1.1
416.7	914.3	913.7	0.6	166.7	628.8	627.4	1.4
406.7	902.3	902.2	0.1	156.7	618.2	616.8	1.4
396.7	890.3	889.6	0.7	146.7	607.5	606.0	1.5
386.7	878.5	878.3	0.2	136.7	597.0	595.6	1.4
376.7	866.6	865.9	0.7	126.7	586.5	585.2	1.3
366.7	854.6	854.0	0.6	116.7	576.2	574.6	1.6
356.7	842.9	842.2	0.7	106.7	565.9	564.5	1.4
346.7	831.1	830.4	0.7	96.7	555.7	554.3	1.4
336.7	819.4	818.8	0.6	86.7	545.5	544.2	1.3
326.7	807.8	807.0	0.8	76.7	535.4	533.9	1.5
316.7	796.2	795.5	0.7	66.7	525.3	523.9	1.4
306.7	784.7	784.0	0.7	56.7	515.3	514.1	1.2
296.7	773.2	772.5	0.7	46.7	505.4	504.2	1.2
286.7	761.8	760.9	0.9	36.7	495.6	494.3	1.3
276.7	750.3	749.3	1.0	26.7	485.8	484.0	1.8
266.7	738.9	738.1	0.8				
256.7	727.7	726.6	1.1				
246.7	716.5	715.5	1.0				

Sonde No. D.001 Date 28/4/78 Aberporth

Sonde Launch Time: 14:43:18

Time	Sonde Pressure	Radar Pressure	Difference	Time	Sonde Pressure	Radar Pressure	Difference
501.6	1007.0	1008.8	-1.8	242.2	703.1	704.2	-1.1
482.2	983.3	986.9	-3.6	232.2	691.9	693.1	-1.2
472.2	971.3	973.7	-2.4	222.2	681.3	682.0	-0.7
462.2	959.1	961.7	-2.6	212.2	670.3	671.3	-1.0
452.2	946.8	949.7	-2.9	202.2	659.5	660.4	-0.9
442.2	935.1	937.1	-2.0	192.2	648.7	649.7	-1.0
432.2	922.6	925.0	-2.4	182.2	638.1	638.7	-0.6
422.2	910.8	913.4	-2.6	172.2	627.6	628.4	-0.8
412.2	898.6	901.3	-2.7	162.2	616.8	617.8	-1.0
402.2	887.1	889.1	-2.0	152.2	606.4	607.6	-1.2
392.2	875.2	877.1	-1.9	142.2	596.5	597.1	-0.6
382.2	863.2	865.5	-2.3	132.2	586.0	586.9	-0.9
372.2	851.4	853.8	-2.4	122.2	576.1	576.7	-0.6
362.2	839.9	842.1	-2.2	112.2	566.0	566.7	-0.7
352.2	828.1	830.2	-2.1	102.2	556.1	556.8	-0.7
342.2	816.8	818.5	-1.7	92.2	546.3	546.9	-0.6
332.2	804.9	806.7	-1.8	82.2	536.6	537.2	-0.6
322.2	793.2	795.1	-1.9	72.2	527.0	527.6	-0.6
312.2	781.9	783.3	-1.4	62.2	517.3	517.8	-0.5
302.2	770.1	771.9	-1.8	52.2	507.7	508.0	-0.3
292.2	759.2	760.5	-1.3	42.2	498.0	498.7	-0.7
282.2	747.8	749.5	-1.7	32.2	488.4	488.8	-0.4
272.2	736.5	737.9	-1.4	22.2	478.2	478.9	-0.7
262.2	725.4	726.7	-1.3				
252.2	713.9	715.4	-1.5				

Sonde No. C.007 Date 28/2/79 Benbecula

Sonde Launch Time: 13:40:45

Time	Sonde Pressure	Radar Pressure	Difference	Time	Sonde Pressure	Radar Pressure	Difference
664.0	996.2	990.5	5.7	370.0	652.2	646.3	5.9
625.0	948.6	943.7	4.9	355.0	636.1	630.4	5.7
610.0	930.2	924.2	6.0	340.0	620.3	614.3	6.0
595.0	910.2	905.5	4.7	325.0	604.2	598.5	5.7
580.0	891.8	887.6	4.2	310.0	588.3	582.6	5.7
565.0	874.7	869.3	5.4	295.0	572.7	567.0	5.7
550.0	857.5	851.5	6.0	280.0	557.0	551.2	5.8
535.0	839.7	834.4	5.3	265.0	541.2	535.5	5.7
520.0	822.7	816.7	6.0	250.0	526.2	520.1	6.1
505.0	804.9	799.7	5.2	235.0	511.4	505.0	6.4
490.0	787.7	782.2	5.5	220.0	496.9	490.3	6.6
475.0	770.3	764.6	5.7	205.0	482.7	475.8	6.9
460.0	752.9	747.1	5.8	190.0	468.1	461.3	6.8
445.0	735.7	729.7	6.0	175.0	454.1	446.9	7.2
430.0	718.6	712.7	5.9	160.0	439.7	432.4	7.3
415.0	701.7	695.5	6.2	145.0	425.7	417.9	7.8
400.0	684.9	679.1	5.8	130.0	411.9	403.2	8.7
385.0	668.7	662.6	6.1				

Sonde No. A.021 Date 28/2/79 Benbecula

Sonde Launch Time: 14:06:11

Time	Sonde Pressure	Radar Pressure	Difference	Time	Sonde Pressure	Radar Pressure	Difference
671.3	992.8	990.4	2.4	400.0	676.6	674.1	2.5
640.0	953.7	954.9	-1.2	385.0	659.1	656.9	2.2
625.0	935.1	938.3	-3.2	370.0	641.9	639.6	2.3
610.0	916.4	917.9	-1.5	355.0	625.9	623.5	2.4
595.0	897.9	896.0	1.9	340.0	609.9	607.3	2.6
580.0	879.8	877.3	2.5	325.0	594.4	591.9	2.5
565.0	862.0	860.1	1.9	310.0	579.0	576.5	2.5
550.0	845.0	843.4	1.6	295.0	564.0	561.2	2.8
535.0	827.9	827.1	0.8	280.0	549.2	546.1	3.1
520.0	810.9	810.7	0.2	265.0	534.7	531.3	3.4
505.0	793.4	793.7	-0.3	250.0	520.2	516.9	3.3
490.0	776.3	775.3	1.0	235.0	505.9	502.6	3.3
475.0	758.5	758.8	-0.3	220.0	491.4	488.4	3.0
460.0	741.5	740.8	0.7	205.0	476.7	473.7	3.0
445.0	725.7	724.5	1.2	190.0	461.9	459.0	2.9
430.0	710.0	708.3	1.7	175.0	447.1	444.4	2.7
415.0	693.3	690.8	2.5				

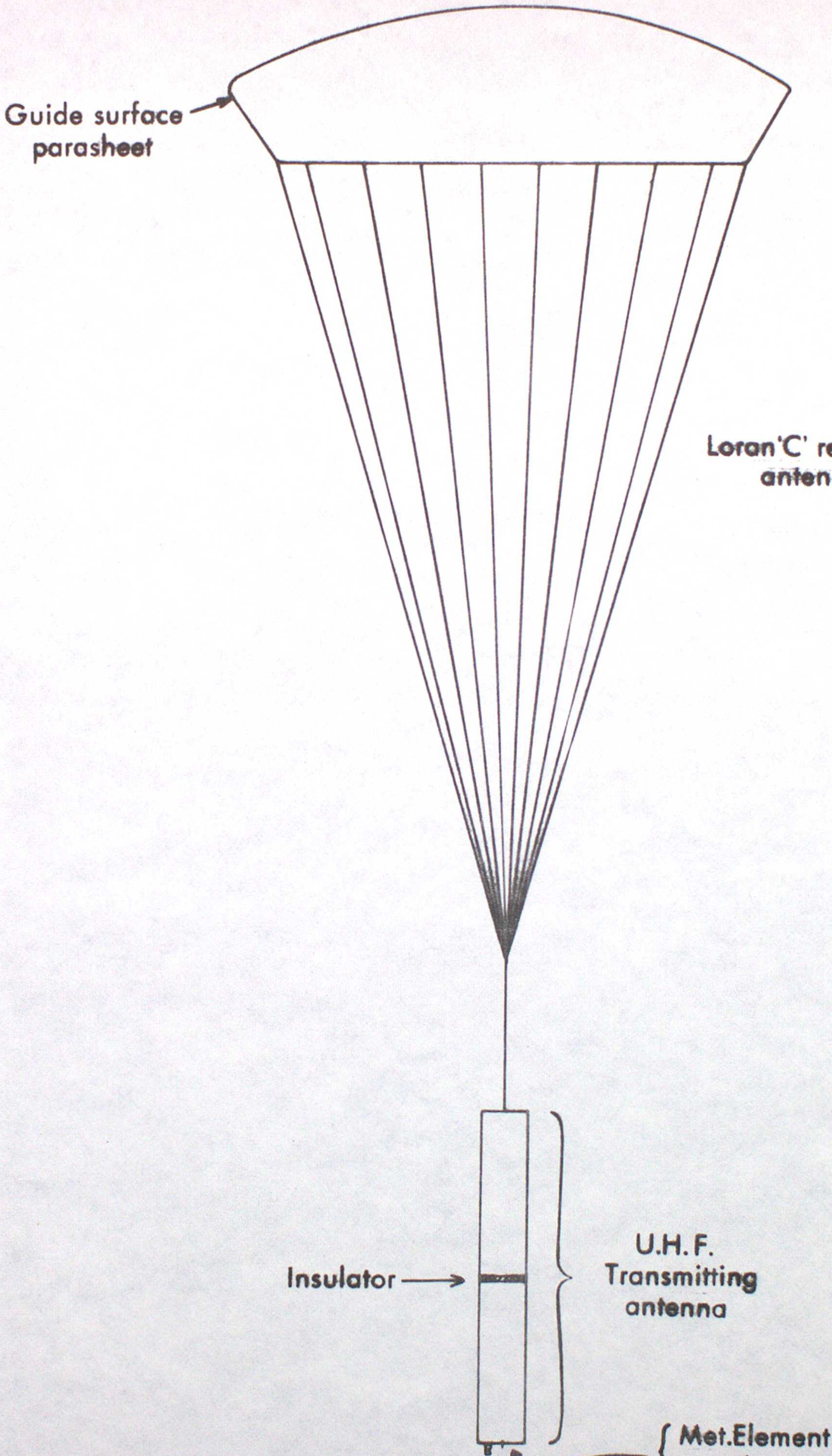


Fig.1 Navaid dropsonde.
(a). General arrangement

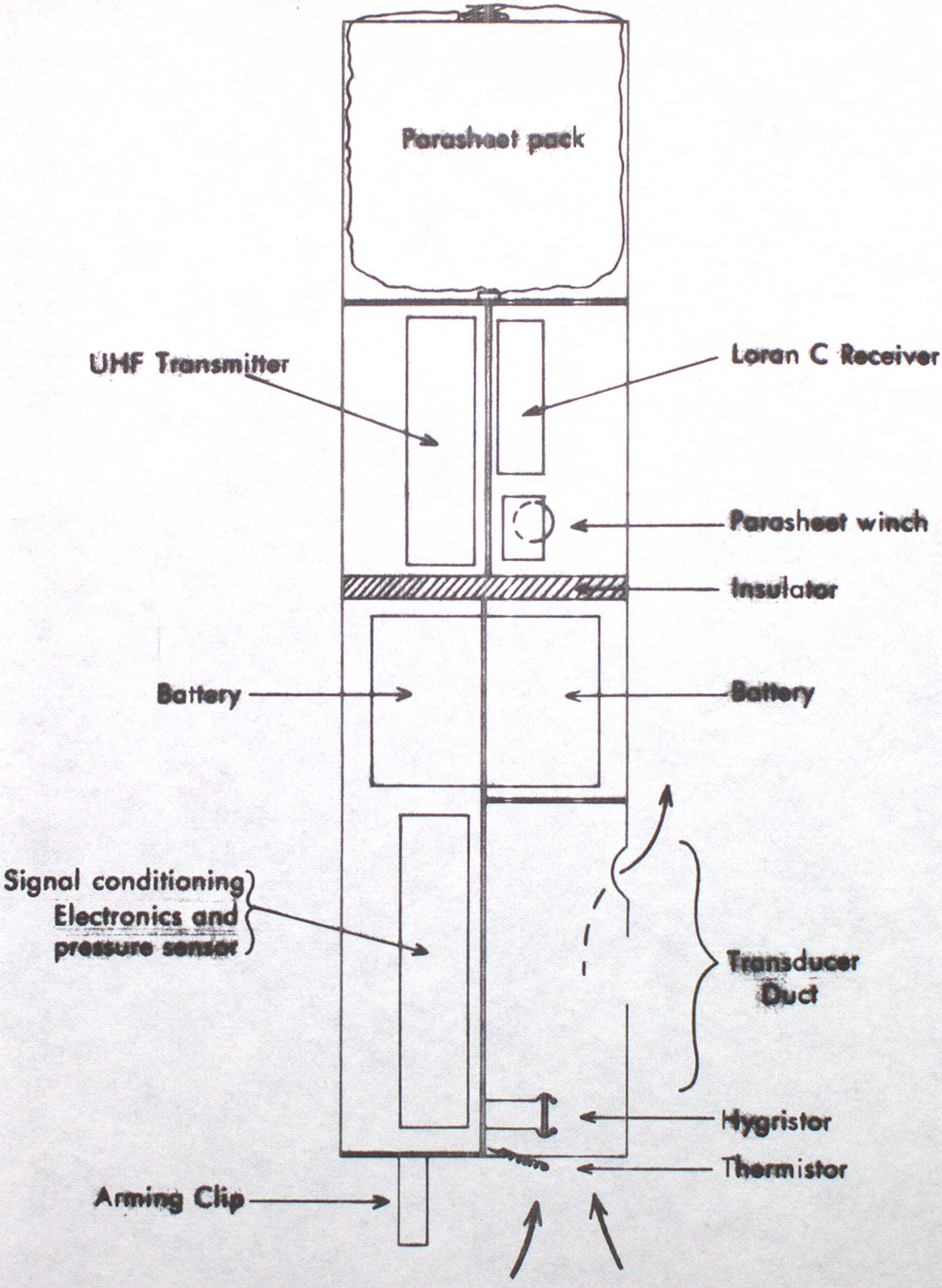
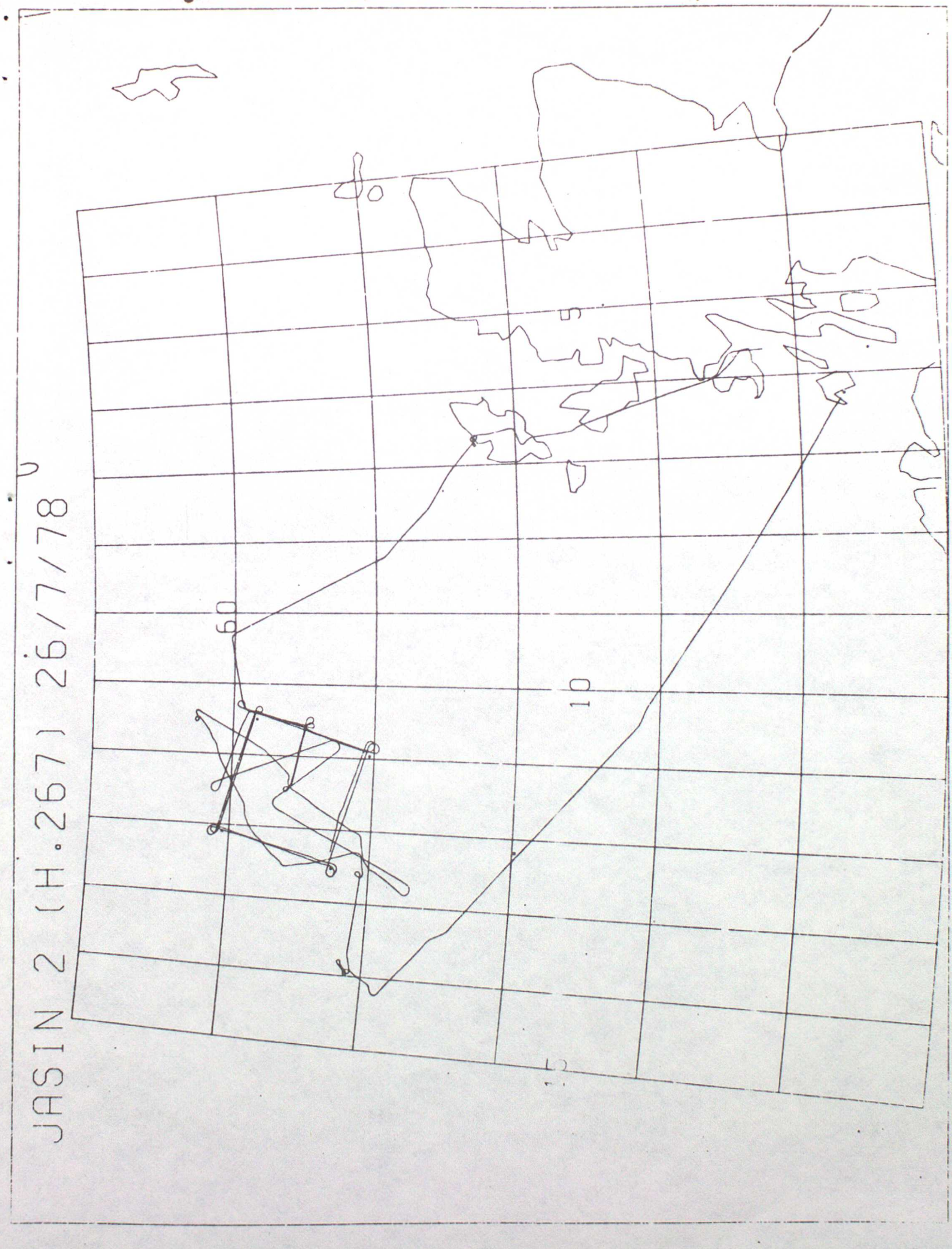


Figure 1(b) Navaid dropsonde
schematic diagram of sub-assemblies

Figure 2. Use of Loran C to calculate aircraft trajectories



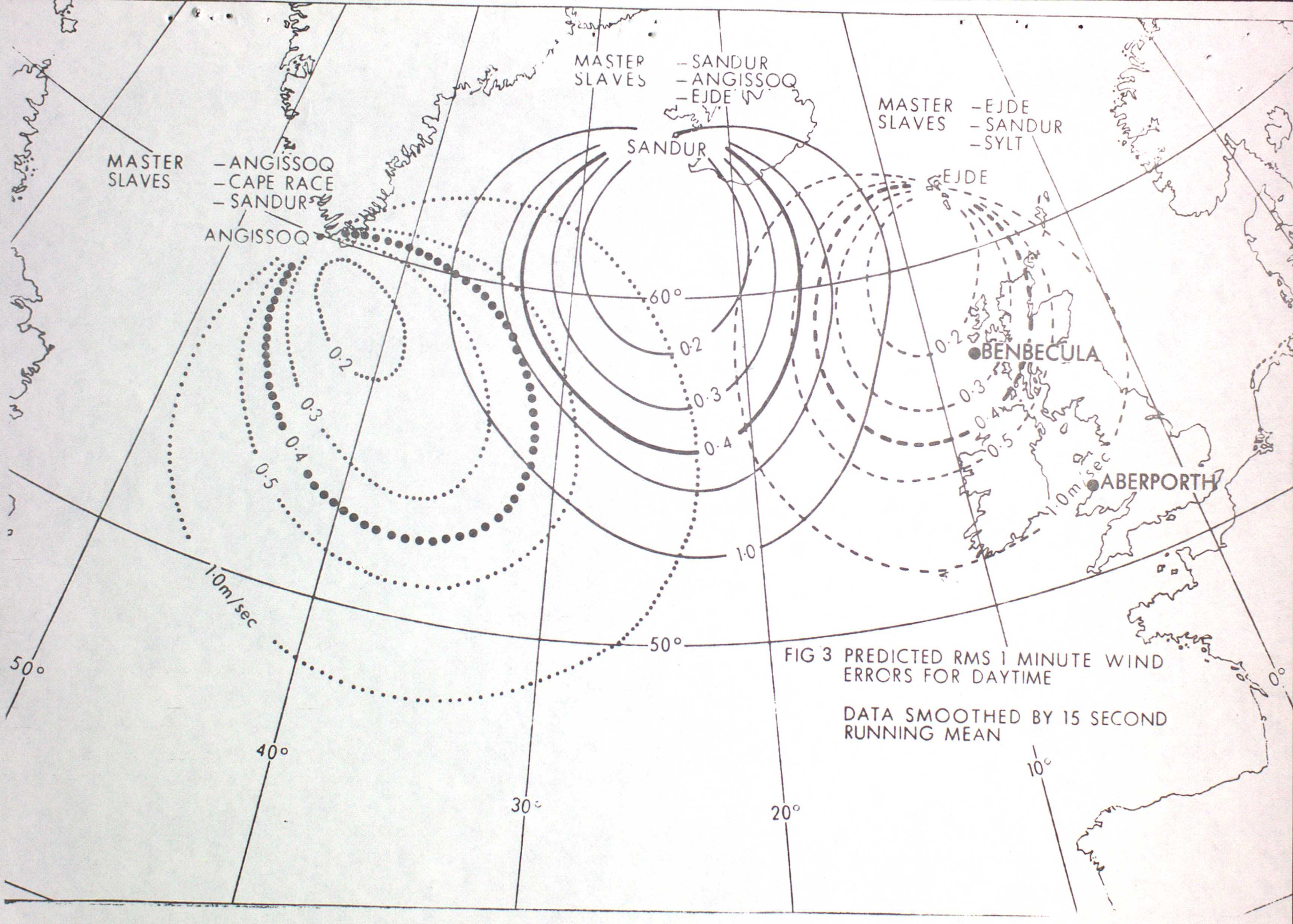


FIG 3 PREDICTED RMS 1 MINUTE WIND ERRORS FOR DAYTIME

DATA SMOOTHED BY 15 SECOND RUNNING MEAN

Figure 4
LOP Geometry in the vicinity of Aberporth

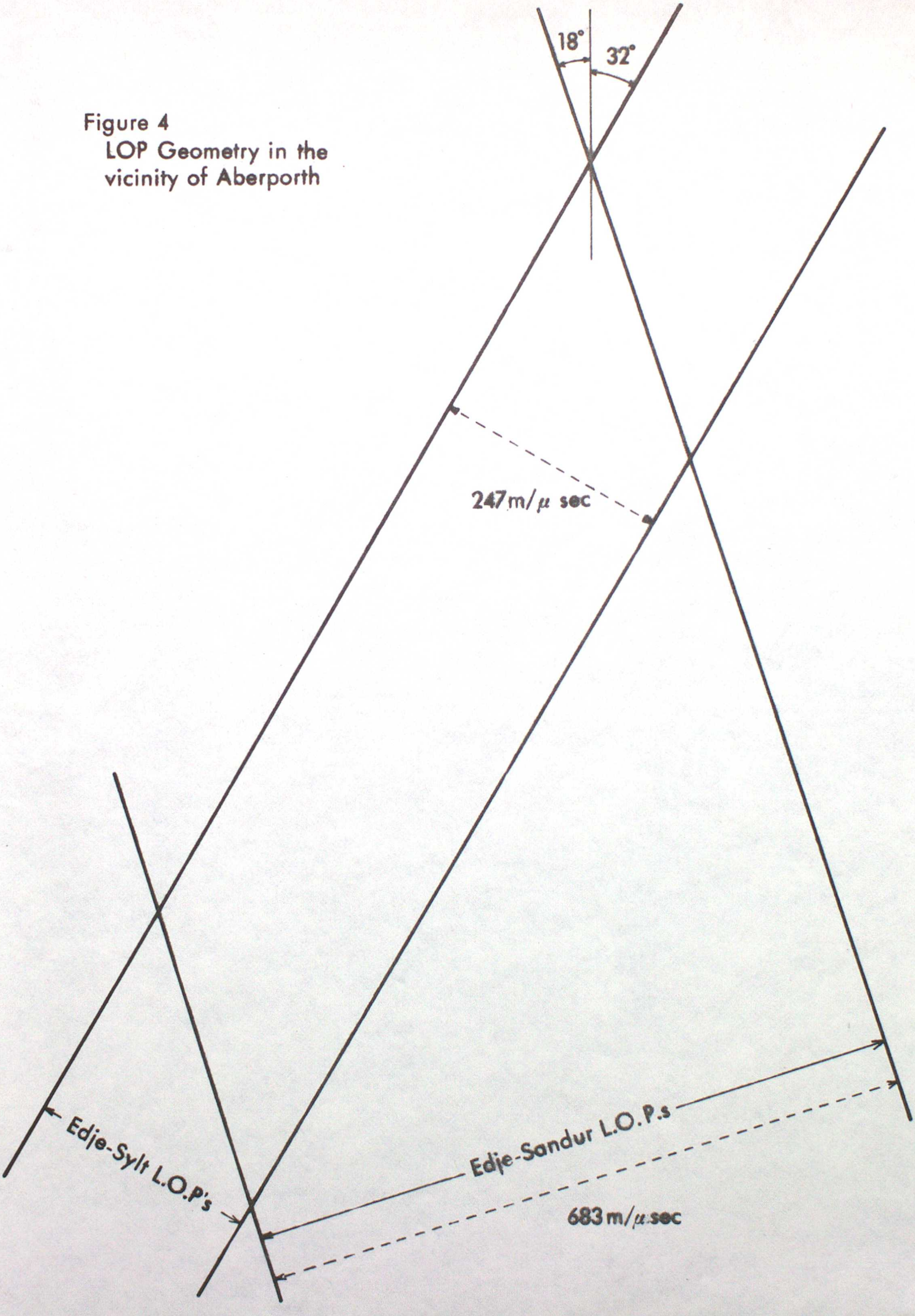


Figure 5(a) Aberporth Sonde A 001 18 July 1978

Wind component parallel to 122°

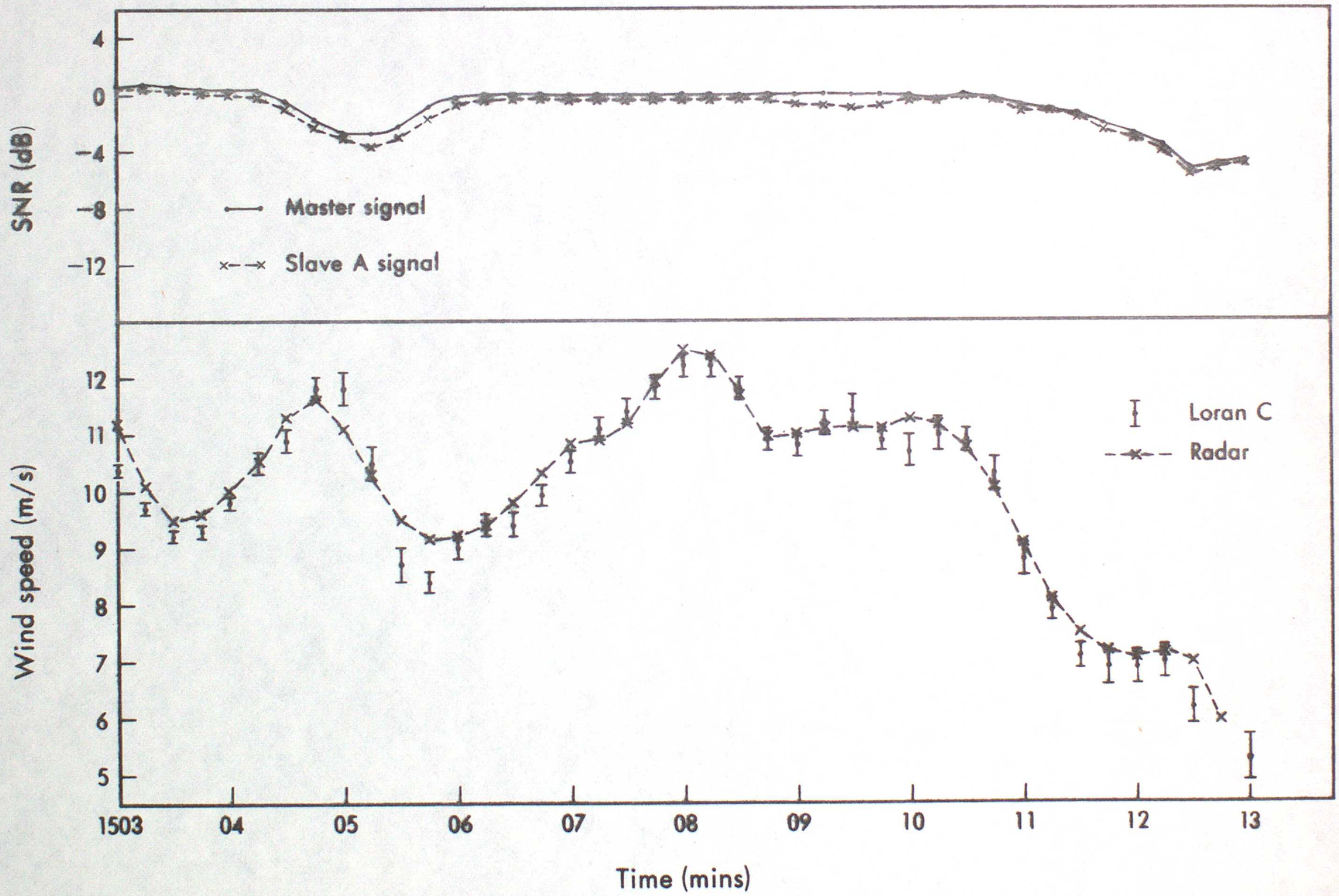


Figure 5(b) Aberporth Sonde A 001 18 July 1978

Wind component parallel to 72°

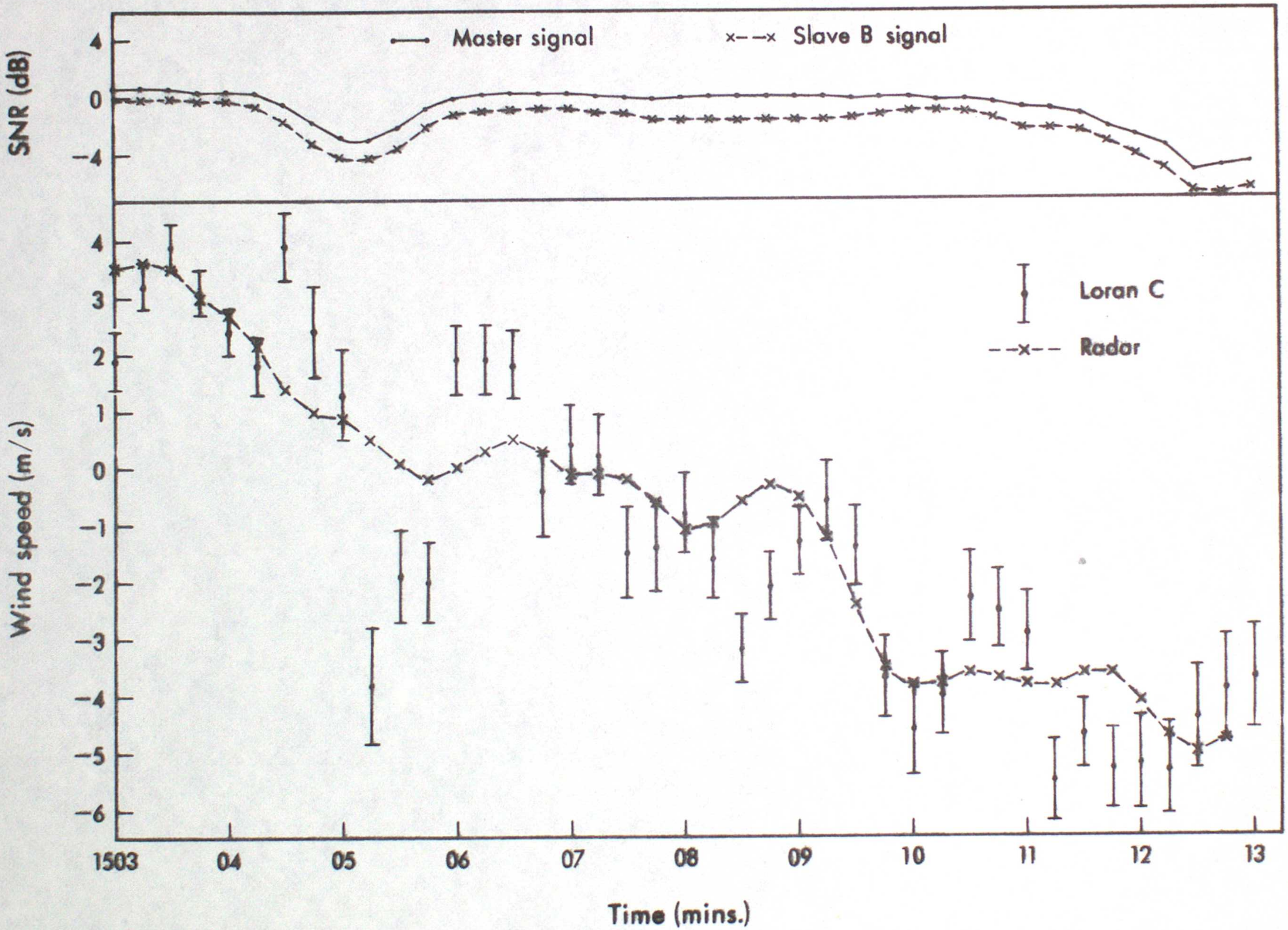


Figure 6 Benbecula Sonde A 021 28 February 1979

Vertical velocity from radar

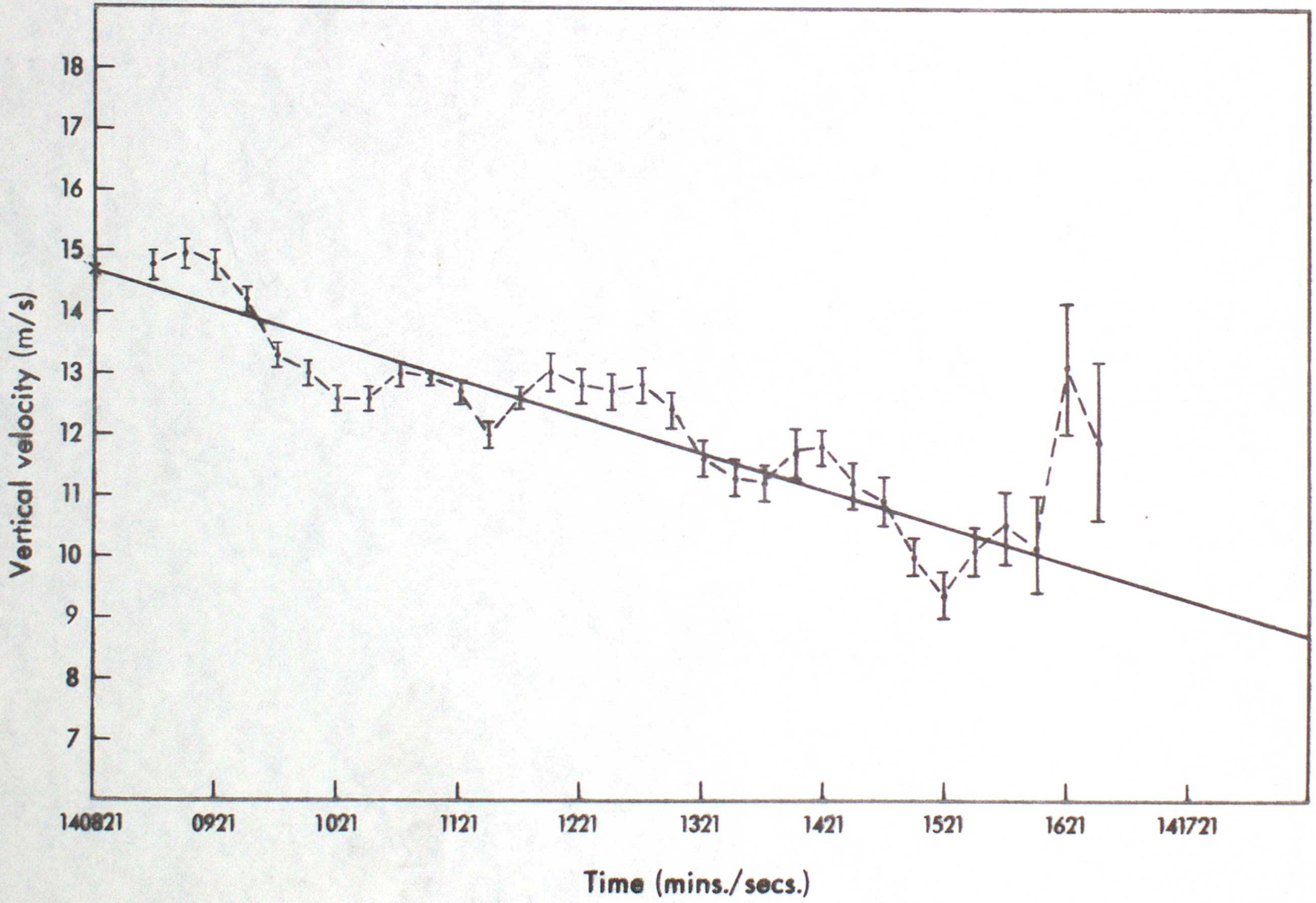


Figure.7.

LOP geometry in the vicinity of Benbecula

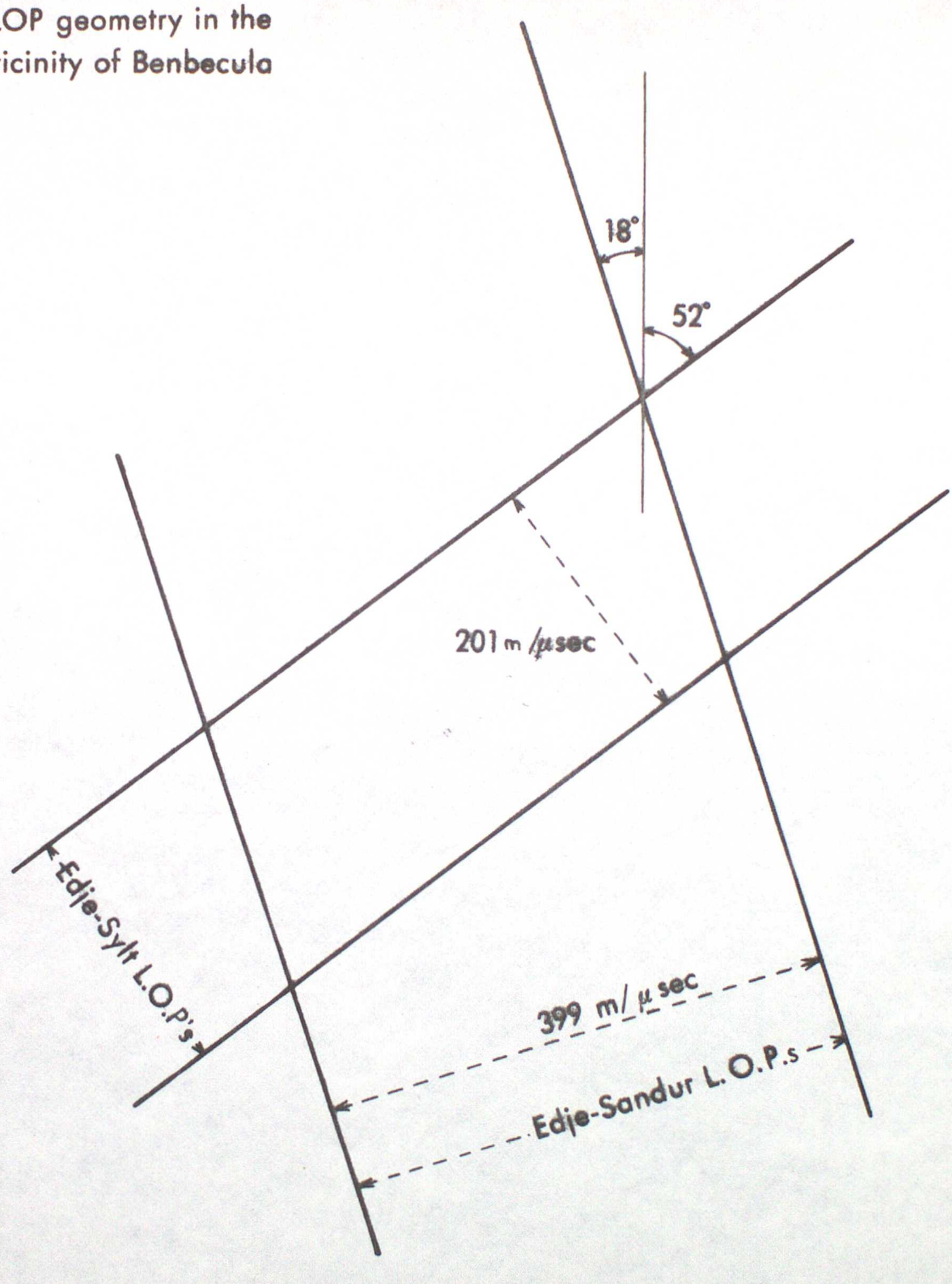


Figure 8(a) Benbecula Sonde A 021 28 February 1979

Wind component parallel to 142°

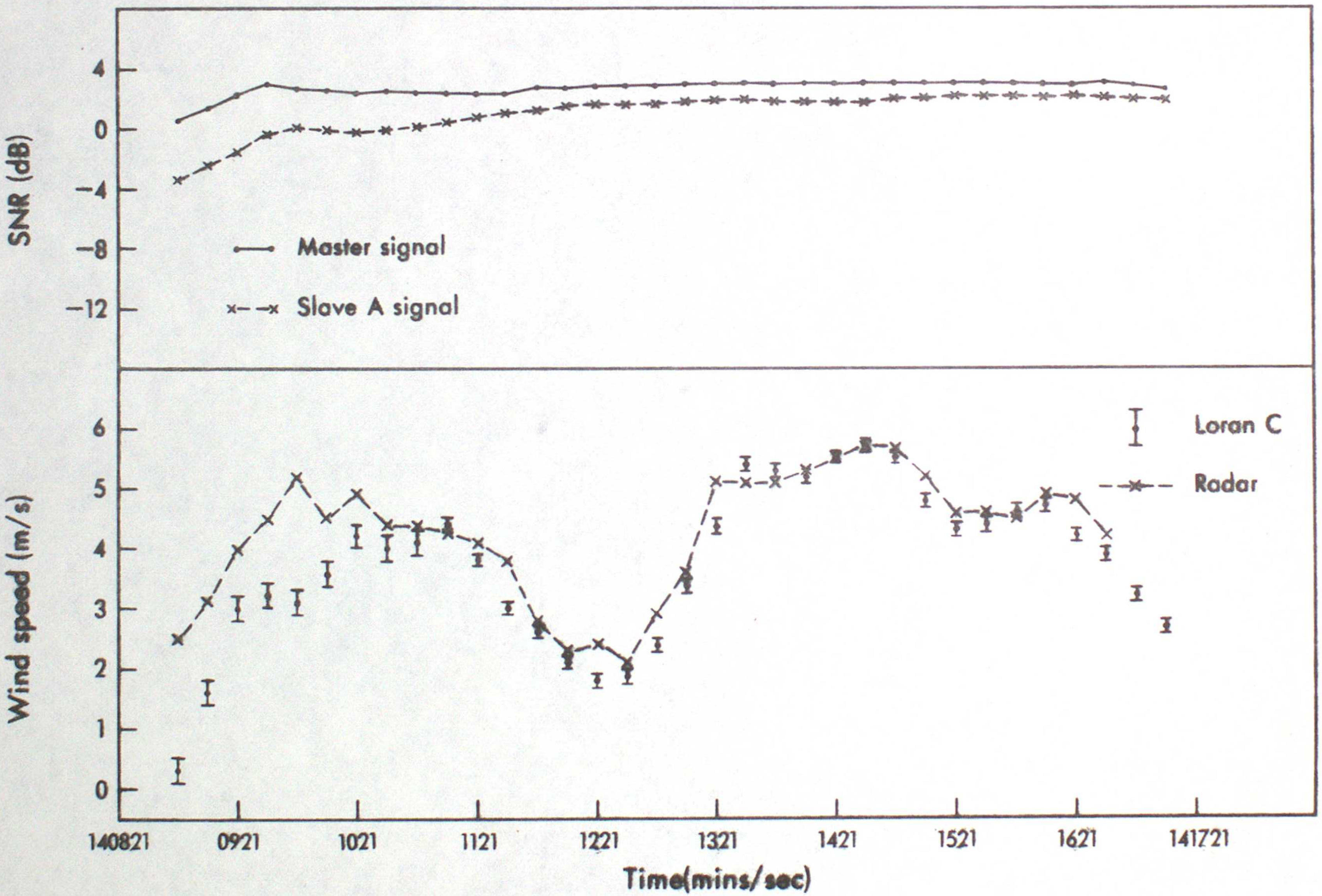


Figure 8(b) Benbecula Sonde A 021 28 February 1979

Wind component parallel to 72°

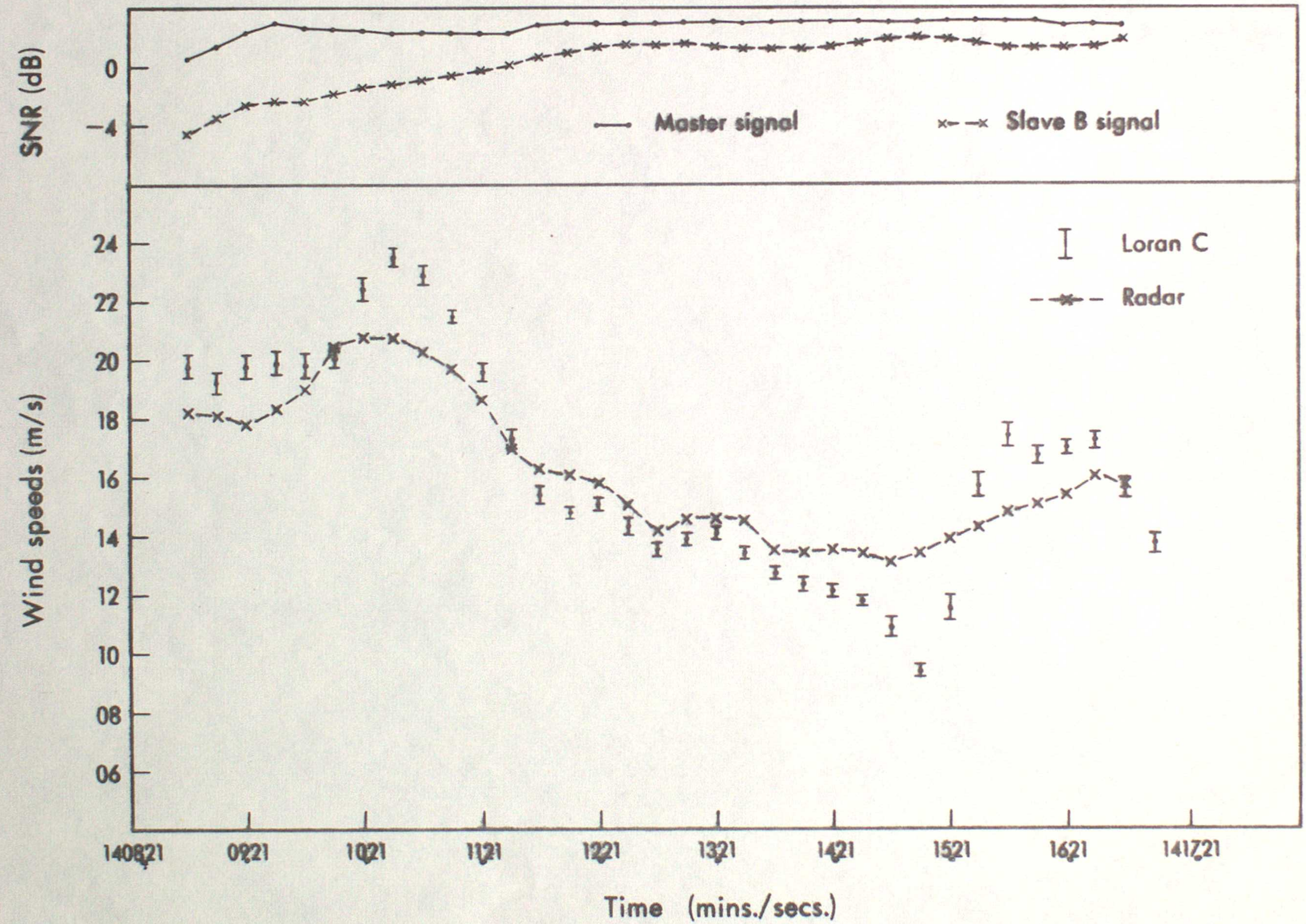


Figure 9(a) Benbecula Sonde C 007 28 February 1979

Wind component parallel to 142°

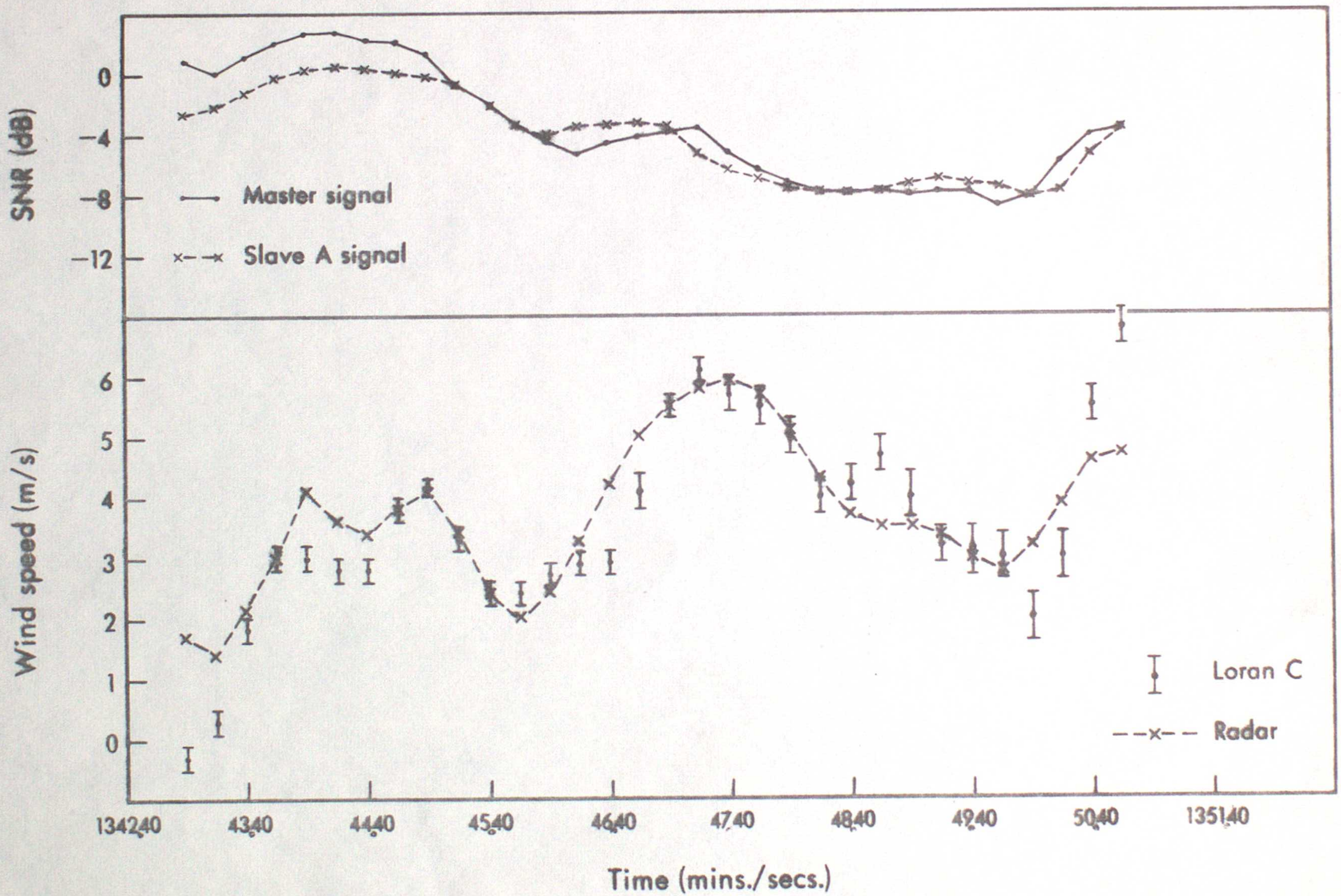
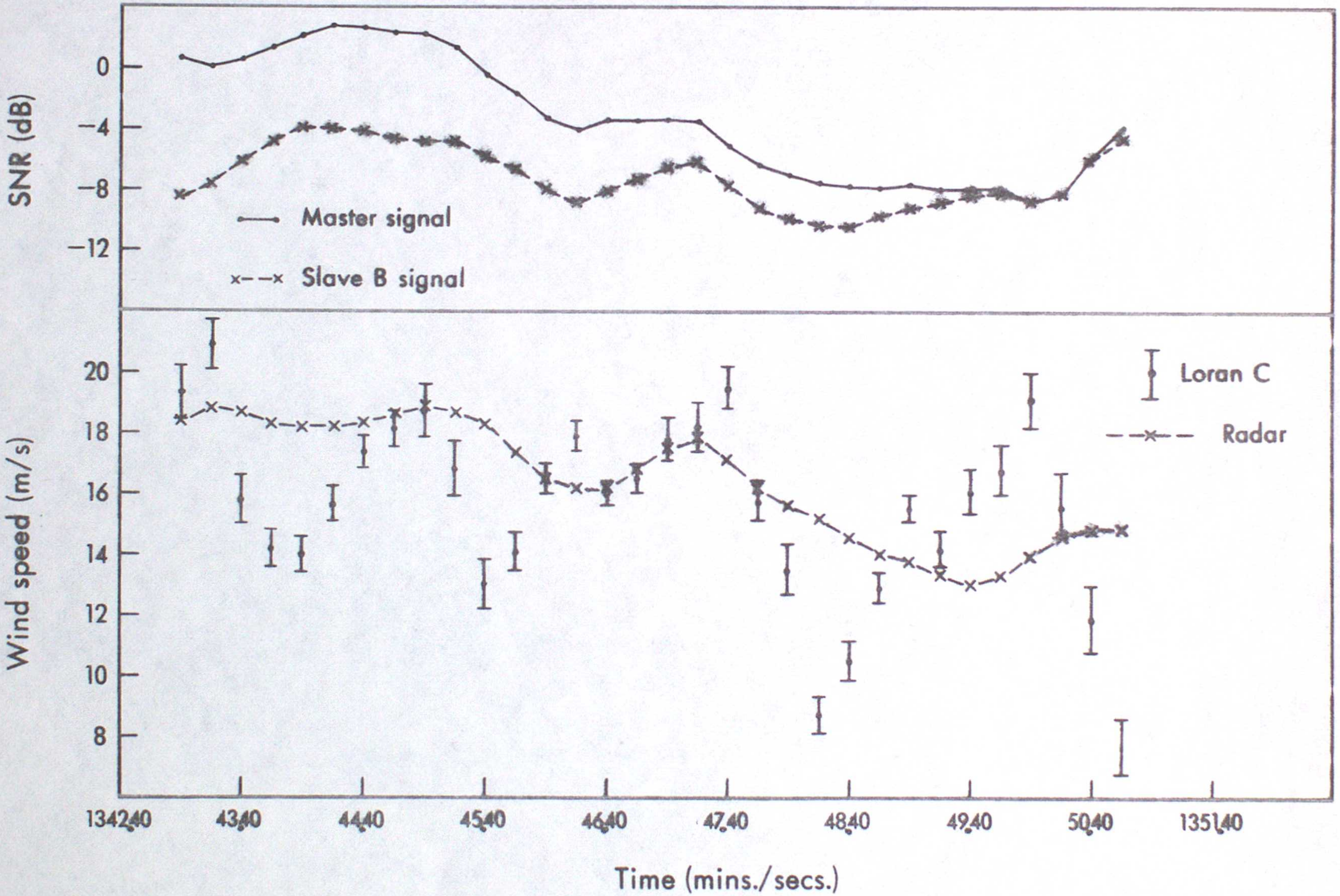


Figure 9(b) Benbecula Sonde C 007 28 February 1979

Wind component parallel to 72°



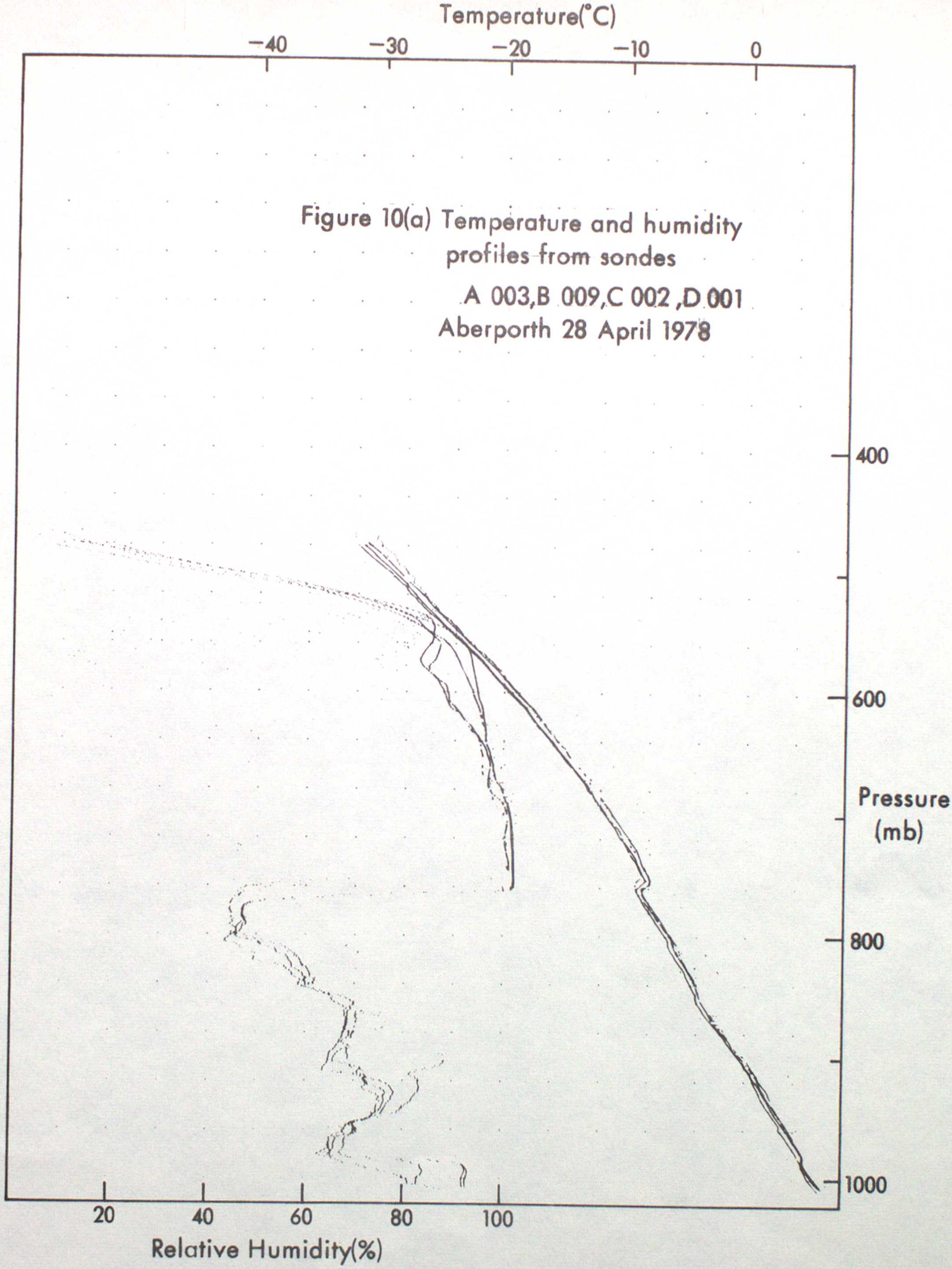


Figure 10(a) Temperature and humidity profiles from sondes A 003, B 009, C 002, D 001 Aberporth 28 April 1978

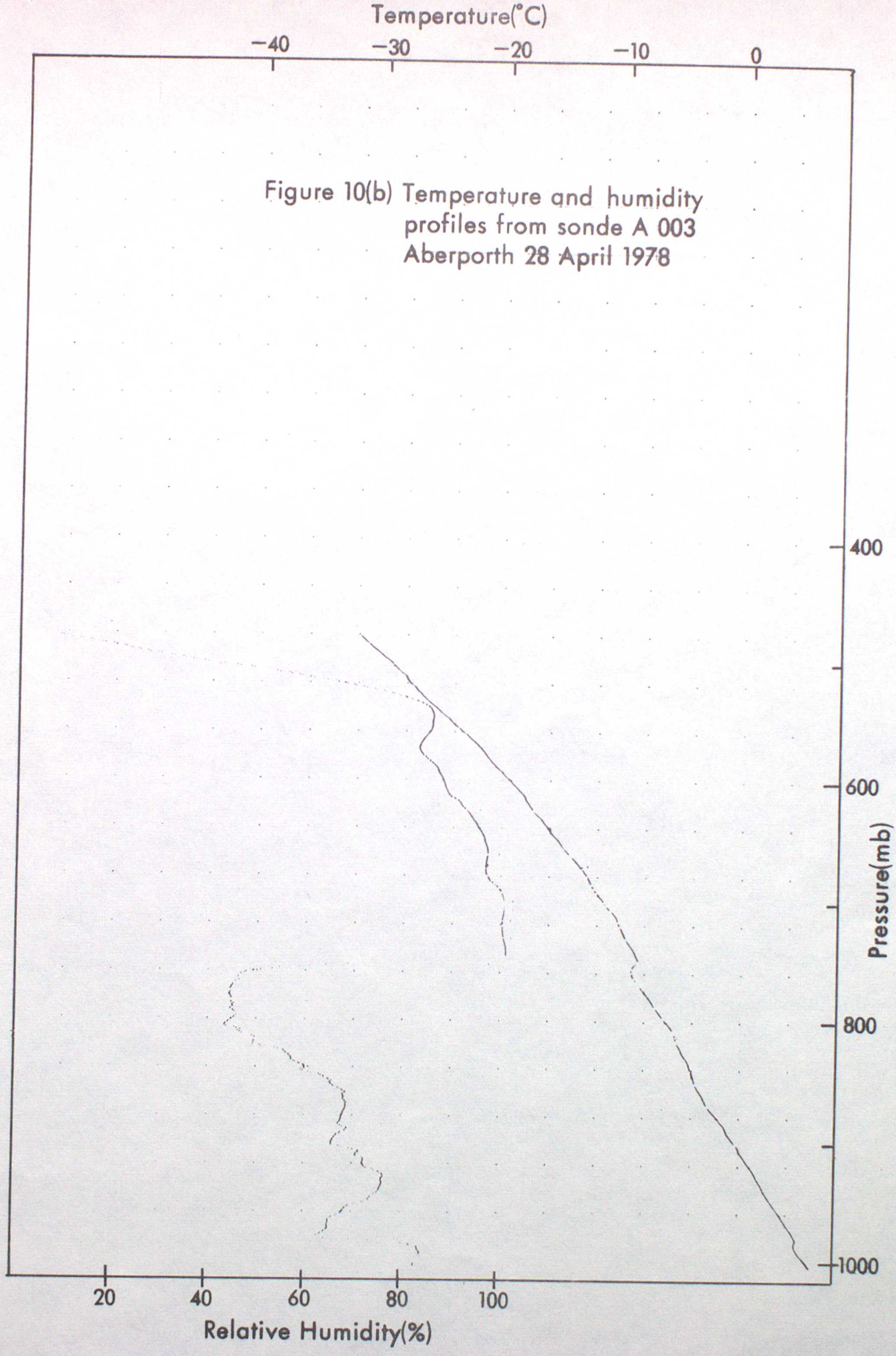


Figure 10(b) Temperature and humidity profiles from sonde A 003 Aberporth 28 April 1978

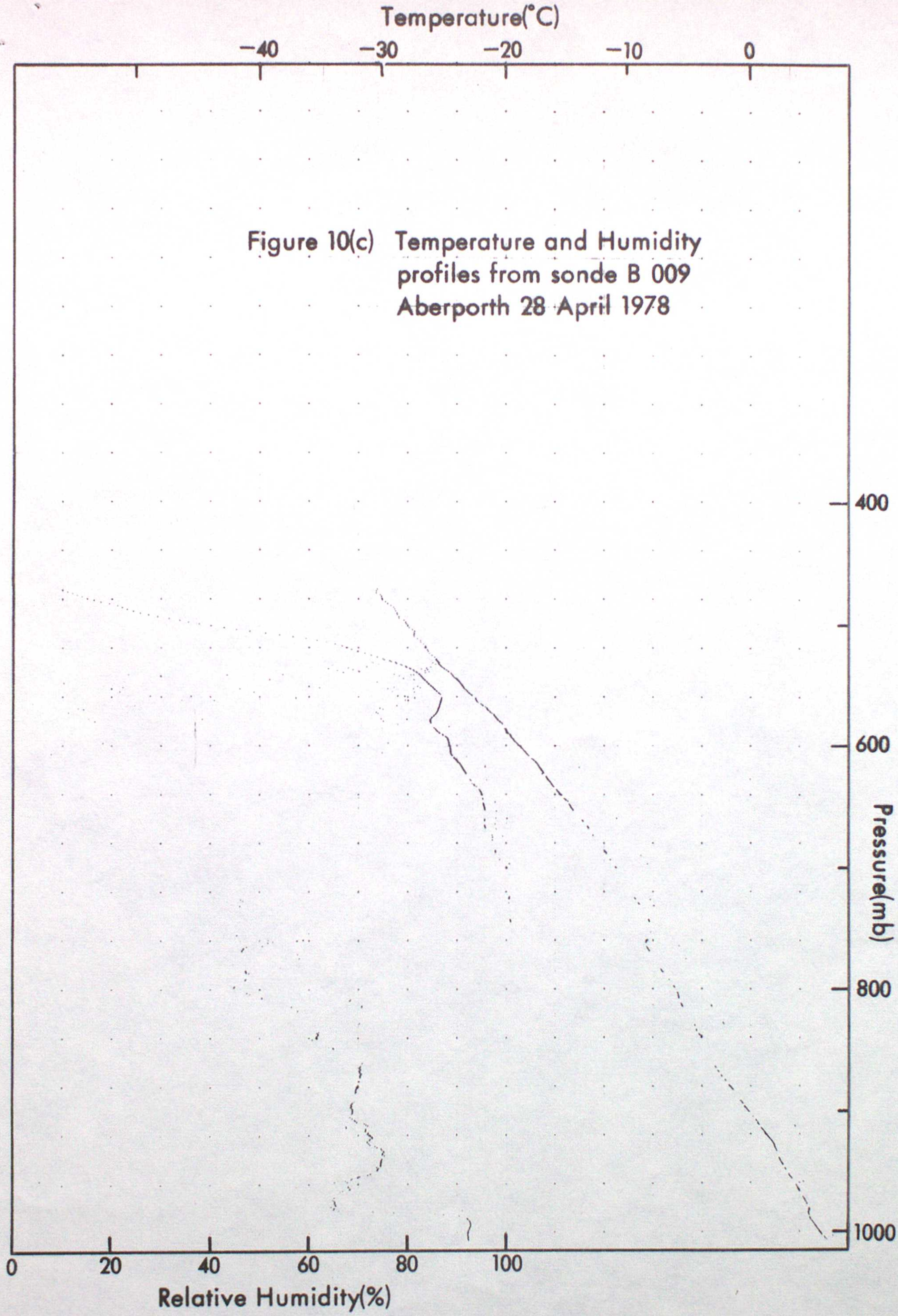


Figure 10(c) Temperature and Humidity profiles from sonde B 009 Aberporth 28 April 1978

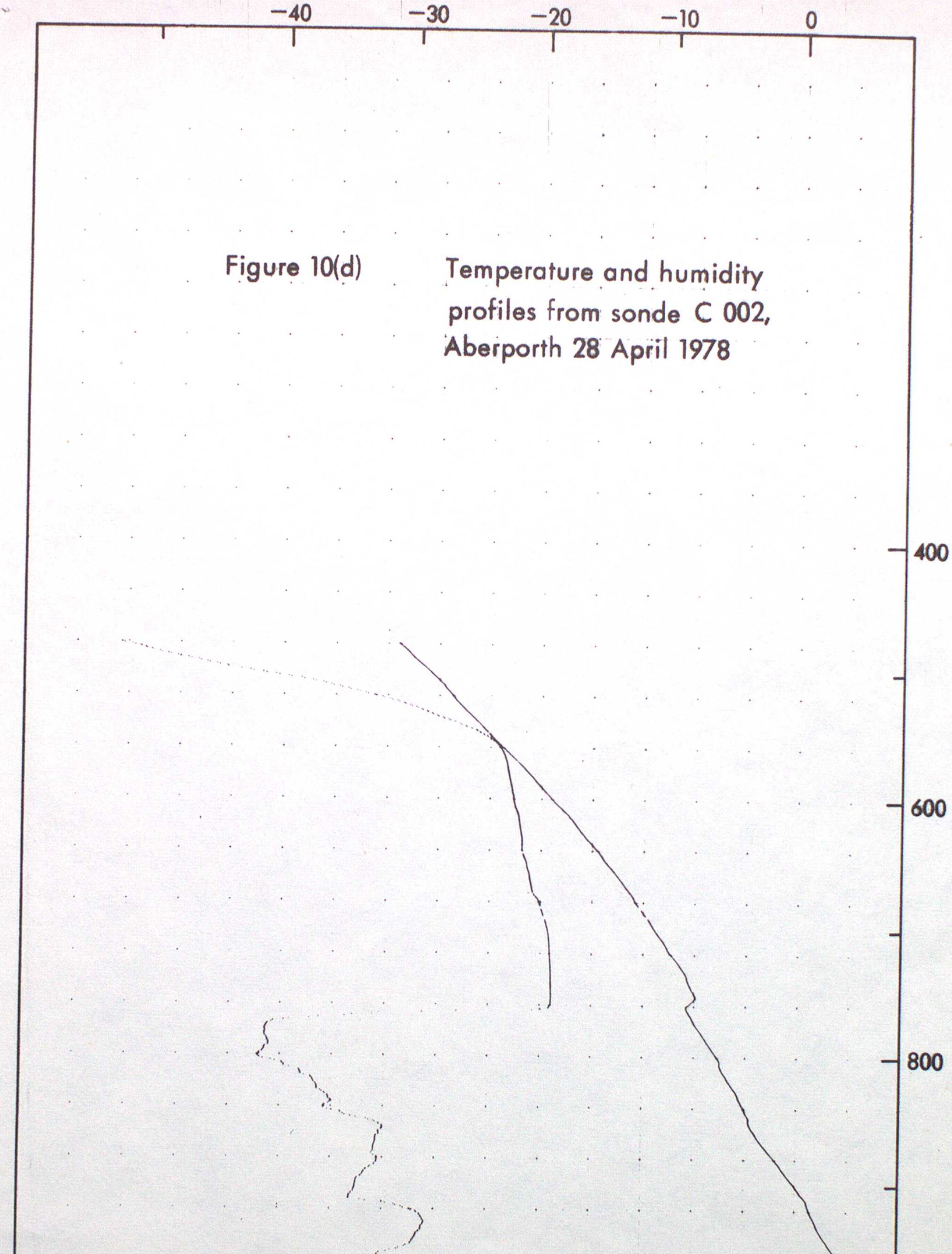


Figure 10(d) Temperature and humidity profiles from sonde C 002, Aberporth 28 April 1978

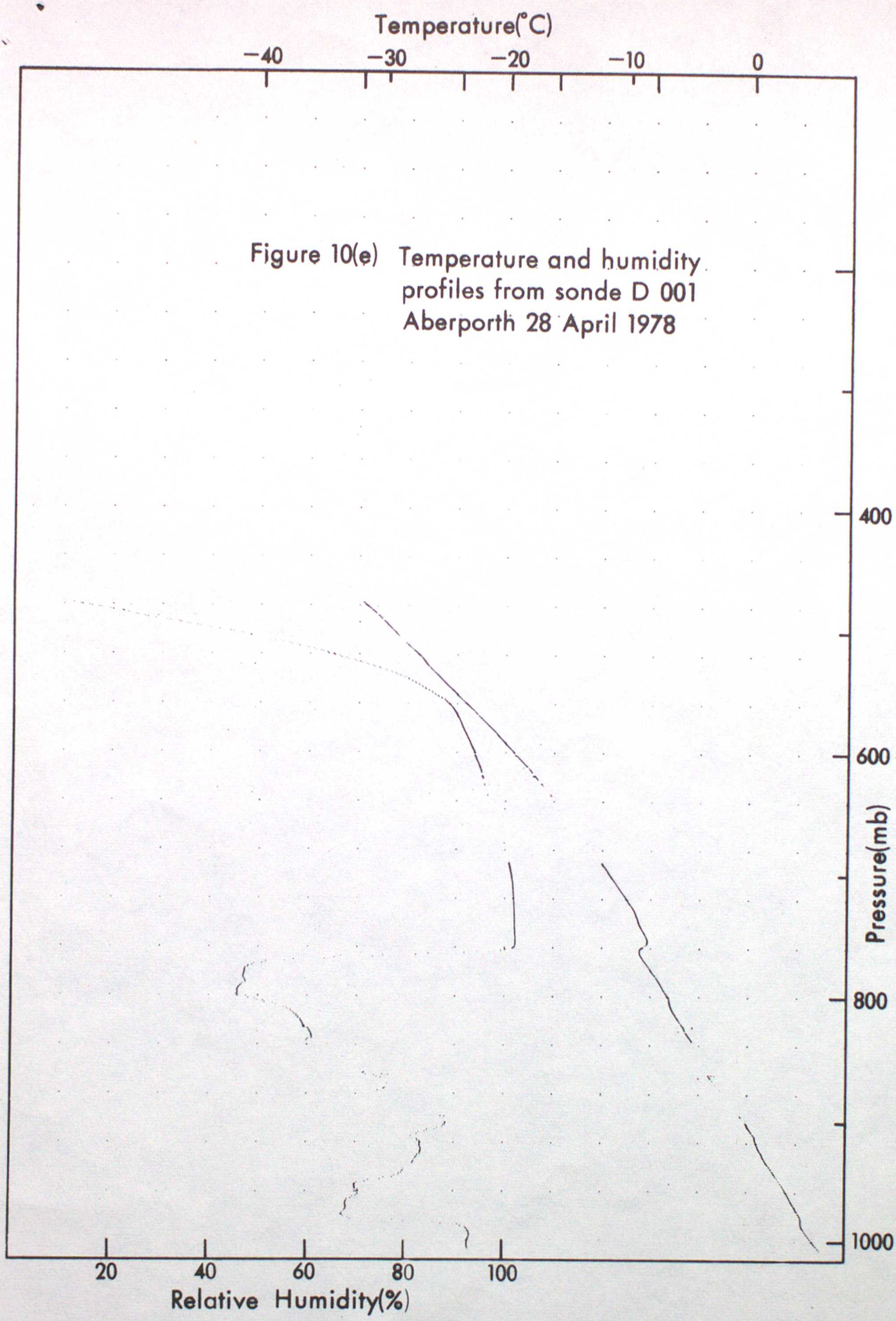


Figure 10(e) Temperature and humidity profiles from sonde D 001 Aberporth 28 April 1978

Comparison between Aberporth Radiosonde ascents and data from sonde D 001 released over Aberporth range.

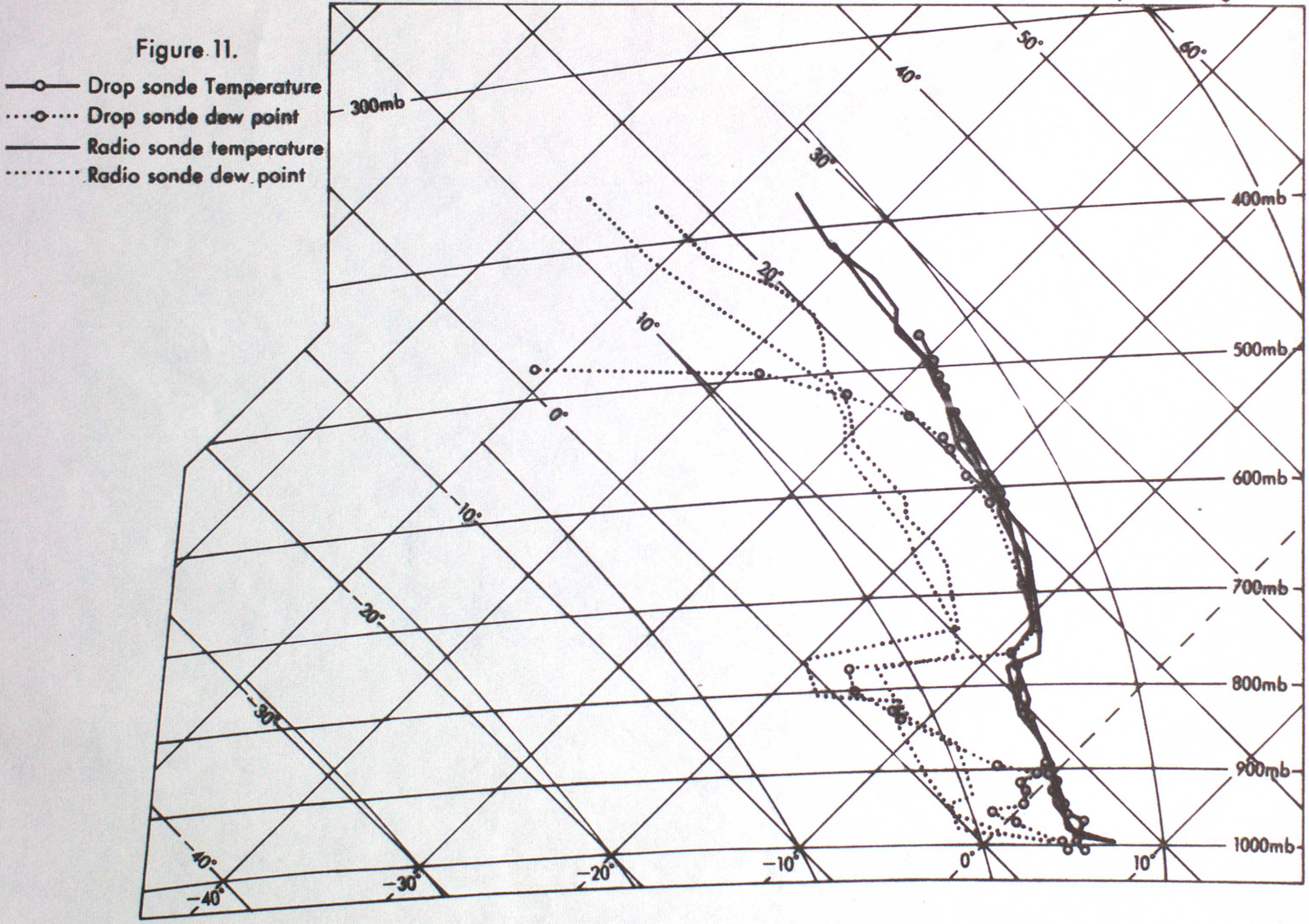


Figure 11.

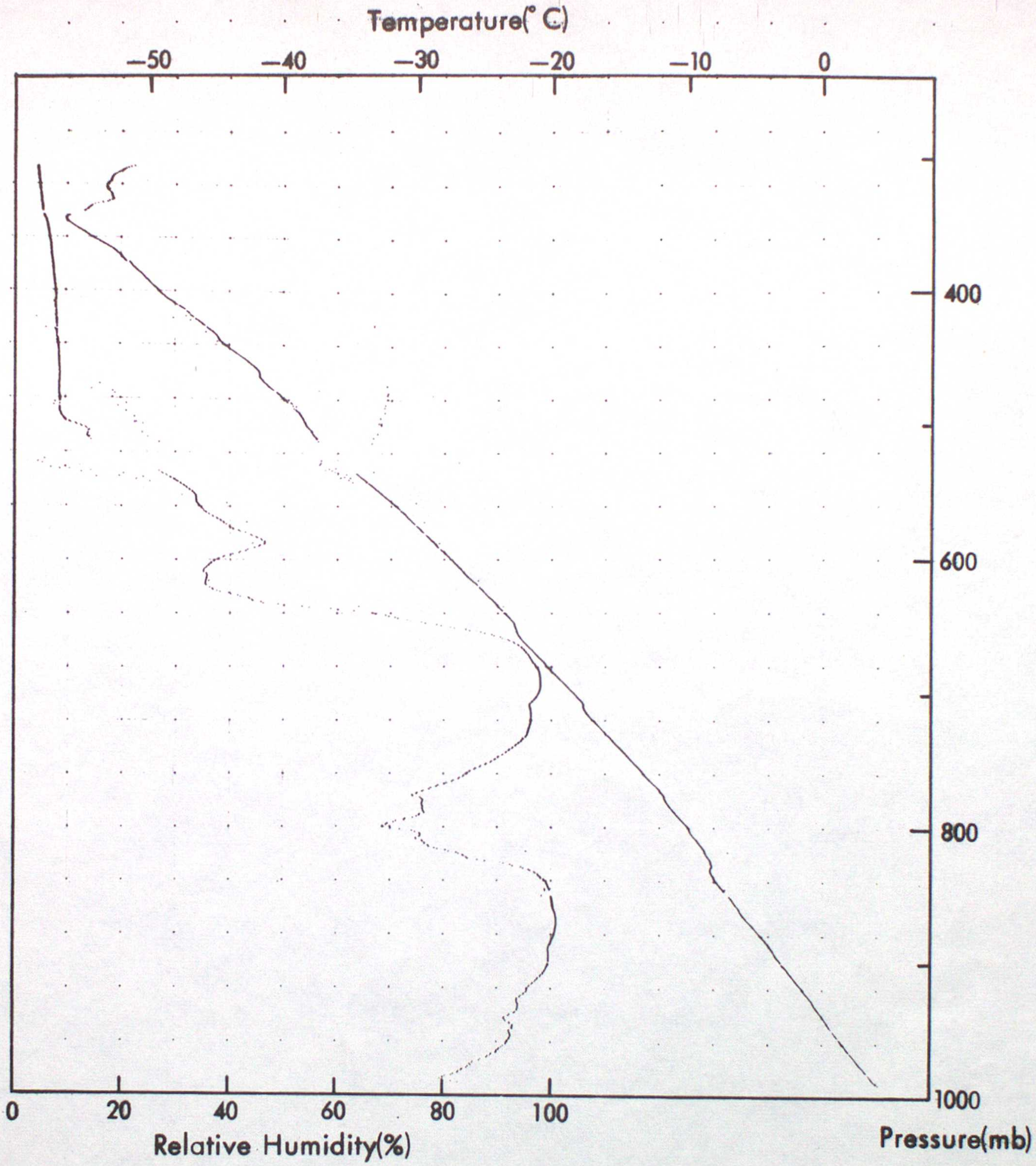


Figure 12 Temperature and humidity profile
Sonde A 021,Benbecula 28 Feb 1979

Figure 13 Comparison of the A 021 dropsonde at Benbecula with Stornoway radiosonde.

28 February 1979