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Meteorological Measurements under Temperature Inversion Conditions at the Tauhara Geothermal Power Station Site

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1.0 INTRODUCTION AND SUMMARY

Fletcher Challenge Limited, and the Oil and Gas Division of the Ministry of Energy, may develop a small (20 MWe) geothermal power station at Tauhara, near Taupo. The waste heat from the station will be rejected through mechanical draft evaporative cooling towers, and it is proposed that the exhaust gases remaining from the geothermal fluid will also be released into these towers. These exhaust gases will include hydrogen sulphide (H_2S), which can degrade local air quality if present in sufficiently high concentrations.

In March 1985 Meteorological Service staff carried out some computer modelling work, to predict the concentrations of hydrogen sulphide at various distances downwind of the proposed power station under various weather conditions (1). The highest concentrations of hydrogen sulphide at ground level which were predicted by the model occurred under low windspeed, temperature inversion conditions. Relatively large hydrogen sulphide concentrations might also occur at ground level if downwash occurs in the lee of the tower under windy conditions. The downwash situation cannot be simulated by the Meteorological Service model, and further advice on this is being sought from the Mitsubishi Corporation in Japan.

At a meeting with the Ministry of Works and the Developers a decision was made to investigate the local airflow under low windspeed, temperature inversion conditions. A particular aim was to check whether the low level drift of air was towards the inhabited areas of Taupo under such conditions. This report outlines these investigations, during which the vertical profiles of wind speed, wind direction and temperature near the site of the proposed power station were measured. It also includes some other information on the likely direction of drift of any pollutants from the proposed power station during such conditions, based on experience of local residents and observations of smoke plumes and fog drift made by Meteorological Service staff.

The field work on which the present report is based was carried out by the Meteorological Service between 15 and 26 July, 1985. Unfortunately the weather during this period was mostly unsuitable for the planned studies, and clear cool conditions with light winds and a temperature inversion only occurred during the early morning of 24 July. Thus the only wind and temperature profile data given in this report are for that morning. Our interpretation of this data was backed up by discussions with observant local people about winds and fog drift early in the morning following cold nights.

Although they are not included in this report, measurements were taken on other days as well. This was partly to provide meteorological information for the noise consultant, who was carrying out sound intensity measurements during part of the period. The information prepared for the noise consultant is contained in another report (2). The developers have also been given a compilation of all the measurements and observations made between 15 and 26 July (3).

Our observations during the early morning of July 24 showed a layer of cold air near the surface, which grew as deep as 100 metres as the night progressed, and within which the wind was often from between east and north. Since the sky had not cleared until about midnight, it is possible that on a cold winter night which stays clear from sunset to sunrise, the inversion and associated northeasterly quarter winds occur to a greater height than this. The modelling work (1) suggested that the plume centreline from the cooling towers would only rise to 60 to 80 metres above ground during these light wind temperature inversion conditions (also called "Pasquill Class F" conditions in the modelling report), so it appears that on such nights the plume from the power station will be carried towards inhabited parts of Taupo township for at least part of the time.

For the "standard" wind and temperature profiles used in the earlier modelling work (1), the greatest hydrogen sulphide concentrations predicted were 96 $\mu g/m^3$. The Health Department have sometimes used a guideline of 70 $\mu g/m^3$ (1 hour sample) as a guideline upper limit to hydrogen sulphide concentrations at ground level. (This guideline relates to odour, and is several orders of magnitude below concentrations at which any effects on human health occur). For the modelling work we assumed the largest emission rate from within a range of possible H_2S emission rates given to us by the Ministry of Works. Since our modelling report was written the DSIR have found the H2S emissions from the cooling towers at Tauhara are likely to be less than half those assumed in our calculations (letter to Mr J. Galloway, Ministry of Works and Development, from Mr W.A.J. Mahon, Geothermal Coordinator, Wairakei, 22 May 1985). Thus preliminary indications are that even under Pasquill Class F conditions the H_2S concentrations will be within the Health Department guidelines for one hour averaging time concentrations. To further investigate this point the Meteorological Service is currently modelling the dispersion from the cooling towers at Tauhara using the actual temperature, mixing ratio, and wind speed profiles found during the field work, in place of the "standard" profiles used in the earlier modelling work. A separate report will be provided at the completion of this work. Nevertheless it should be noted that such dispersion modelling gives only estimates, and model predictions are subject to uncertainties which cannot yet be fully quantified.

2.0 METHODS.

Measurements of wind speed, wind direction, wet bulb temperature and dry bulb temperature were made using a Tethersonde supported by a large tethered blimp-shaped balloon. The Tethersonde package transmits information back to a ground station over a radio link, and the information is recorded on cassette tape. The tapes were further analysed by computer back at the Meteorological Service Head Office, to produce plots showing the height variation of wind speed, wind direction, potential temperature and water vapour mixing ratio. (Some of these plots are included at the back of this report). Because of Civil Aviation Division restrictions the tethered balloon could only be flown up to 200 metres above ground. Information on temperature and mixing ratio above 200 metres was obtained from several Airsonde flights. (Airsondes are small instrument packages which use the same ground station as the Tethersonde but are flown under free balloons). The Tethersonde and Airsondes were flown from near the "tent site" marked on Figure 1. This was in farmland, approximately 400 m South of the corner of Centennial Drive and Aratiatia Road . This site was chosen since we understand a likely position for the power station is to the southwest of Fletchers' timber mill and wood panel factory (Figure 1), and this was the nearest we could get while still being reasonably unobtrusive from the road for security.

A Lambrecht clockwork anemometer was installed on a 6 metre high pipe mast, on a small ridge to the north-west of the tent site. This was run to provide comparisons between winds at the proposed power station site and winds at Taupo Airport (Figure 2). Also an acoustic sounder was set up at the Taupo Gun Club off Centennial Drive (Figure 2). We hoped this would provide information on the depth of temperature inversions. However, partly due to faults with the equipment, the sounder records were not very useful and will not be discussed further.

Further information on local airflows was obtained by observing the plume from the particle board mill, observing the movement of fog and smoke, and from discussions with Flight Service staff at Taupo Airport and a Taupo Borough Council officer.

3.0 OBSERVATIONS MADE ON 24 JULY.

3.1 Weather

As discussed in Section 1, the only time during the field trip for which clear sky, low windspeed conditions occurred at night was during the early morning of 24 July 1985. The results for this period are discussed in detail below.

The mean sea level pressure analysis ("weather map") for 0000 Hours NZ Standard Time on 24 July is shown as Figure 3. From this map one would have expected the winds over Taupo to be weak, and apart from any local influences to blow from the south west or west. Note that conditions were not ideal for formation of a strong nighttime temperature inversion at Taupo, since the most intense inversions probably form when there is an anticyclone over the North Island.

During the evening of 23 July it was overcast, with light rain at times up to at least 10 pm. However the sky cleared at some time before 1 am on 24 July, and it remained clear until stratocumulus cloud began to move in from the south about 7 am. From then until 9.30 am (when observations ceased) it remained partly cloudy. By 7 pm on 24 July the sky was totally cloud covered, and it commenced raining at 7.45 pm. The full weather log for July 24 is included as an Appendix.

3.2 Tethersonde and Airsonde Measurements

Figures 4 to 19 are profiles of wind, potential temperature, and mixing ratio measured with the Tethersonde, and Figure 20 is a profile of potential temperature and mixing ratio from an Airsonde. In these figures the wind direction is the direction from which the wind is blowing, and the mixing ratio denotes the number of grams of water vapour in one kilogram of air. The potential temperature in degrees Kelvin is related to the actual temperature T of the air in degrees Celsius as follows:

$$\frac{\theta}{(T + 273.16)} = \left(\frac{1000}{p}\right)^{k}$$

Where p is atmospheric pressure (in HectoPascals) and k=0.286.

Potential temperature is used in these plots rather than actual temperature, since its variation with height is a guide to the stability of the air (4). For air free of clouds or fog, vertical displacements tend to be damped when the potential temperature increases with height, so that pollutants do not spread very quickly in the vertical (this is called the stable situation). On the other hand the atmosphere is unstable to vertical displacements when the potential temperature decreases with height.

Figure 4 shows atmospheric profiles around 7.10 pm on 23 July. Note that the potential temperature and mixing ratio show little variation with height, the wind speed generally increases with height above the ground, and the wind direction changes by only about 20 - 30° between the surface and 200 metres. Such a profile is typical of "neutral stability" overcast conditions.

Figure 5 is the first Tethersonde profile for the morning of 24 July, at around 2.50 am. Note the beginning of a temperature inversion at the surface (potential temperature increasing with height). However as yet there is little change in wind direction with height, with the wind in the height range through which the power station plume is likely to be present blowing from the west, consistent with the earlier comments on the weather map.

As the morning progressed the wind near the surface backed to come from the southerly quarter (Figures 6, 7),although above about 20 metres it still blew from the west. By 4.15 am the the surface flow was from the southeast (Figure 8). Over the next hour (Figures 9,10) there were fluctuations in this behaviour, with the westerly flow reaching back down to the surface at times (Figure 10).

The behaviour of most interest commenced about 5.20 am (Figure 11). Note that the surface based inversion was by then much stronger and deeper than earlier in the morning, that there was a "nose" in the wind speed profile near the ground with a region of almost calm air up to about 40 metres above, and that the wind direction corresponding to this "nose" was from the east and clearly decoupled from the westerly flow aloft. This low level flow was caused by the drainage of cold, dense air towards lower terrain, and is of particular interest for its potential effect on power station emissions. The drainage flow became deeper and stronger as time progressed (Figures 12 - 15), and in this mature phase was generally from directions between north and east. The drainage flow was up to 100 metres deep at times (Figure 13), and the maximum speed within it reached just over 4 m/s (Figure 14).

However at 8 am the drainage wind speed dropped right back to near zero, and the wind varied through nearly 360° from near westerly just above the surface to westerly again at 40 metres (Figure 16). Following this the drainage wind built up again to 80 metres depth at 8.30 am (Figure 17), but by 9.15 it was only 40 metres deep (Figure 19). Note also that the air within which the drainage flow developed exhibited a stable potential temperature gradient up to at least 2000 metres (Figure 20).

In summary, the Tethersonde profiles showed that a cold air drainage flow from between east and north built up during the night. The height of this flow and the wind speed within it fluctuated, but wind speeds at the peak reached up to about 4.2 m/s at 20 metres height, and the layer was up to 100 metres deep at times.

3.3 Observations of Plumes and Fog.

The field team also observed the behaviour of the plume from the Fletchers Wood Panel factory, the movement of fog, and the behaviour of steam plumes near Wairakei, while they were carrying out their measurements. Details are given in the weather log (Appendix), and some night time photographs are also held on file by the Meteorological Service. In general, after 5.30 am low level fog and steam when present drifted towards Taupo, and for much of the time at least the lowest levels of the factory plume were caught within the northeasterly flow down towards Taupo (Figure 21 and Appendix). At 8am the factory plume was vertical, and after 8 am the plume penetrated the rather weak low level flow and was carried towards the NNE in the upper level wind.

3.4 Implications for Power Station Emissions.

The work done by the Meteorological Service in modelling the cooling tower plume (1) predicted that under temperature inversion (Pasquill Class E and F) conditions, the plume centreline above the point of maximum ground level concentration of hydrogen sulphide would be at 60 - 90 metres altitude, depending on the exact meteorological conditions assumed. Thus the Tethersonde data, and the other observations, suggest hydrogen sulphide within a cooling tower plume would have been caught in the drainage flow and carried towards Taupo for at least part of the early morning that was studied. As discussed within Section 1 it seems unlikely that resulting hydrogen sulphide concentrations in inhabited areas would be above Health Department 1 hour guideline concentrations. Some further modelling work is currently in progress to check this, using the actual wind, temperature and mixing ratio profiles measured during the field work.

4.0 COMPARISON OF WINDS BETWEEN TAUPO AIRPORT AND TAUHARA.

When light winds are present during the night and early morning at Taupo Airport they are predominantly from the northeasterly quarter (Table 2). (There are also a large number of "calms" recorded in Table 2. This is because the anemometer has a high starting threshold, of 3 to 4 knots). In our modelling report (1) we used this to tentatively suggest that the predominant winds at the proposed power station site for situations when moderate to strong surface based temperature inversions were present (Pasquill Class F) would also blow from the northeasterly quarter. However in our reports (1,5) we also warned there may be differences in wind direction between Taupo Airport and Tauhara , especially at low wind speeds, because of terrain differences.

While the Tethersonde profiles for 24 July were consistent with the north-easterly flow hypothesis, we also collected data from an anemometer mounted on a 6m pole at the field work site (Section 2) for comparison with Taupo Airport. Figure 22 shows wind directions at Taupo Airport and Tauhara for the 24 hour period commencing at noon on July 23, together with the wind speeds at Tauhara. It can be seen from this plot that for some of the time when wind speeds were low there were indeed differences between the wind directions recorded at Taupo Airport and Tauhara. However at the most interesting time when the wind at Tauhara was from the NE quarter during the morning of July 24, the wind at the airport was too light to move the anemometer.

Thus the results from the anemometer comparisons for the only period of marked cold air drainage flows were inconclusive. The full results of wind measurements at both sites during the total field work period are given in the separate volume of detailed data (3). In general when the winds were moderate or strong, and blowing continuously from a given direction, the wind directions at both sites were within 20 - 30°. However when wind directions were changing or wind speeds were light, there were some differences apparent between the two sites, although no consistent biases were discernable.

5.0 COMMENTS FROM LOCAL RESIDENTS.

The Meteorological Service field team discussed local weather patterns with Mr Carmichael, a Flight Service operator at Taupo Airport. When the field team staff were approaching Taupo at 5.45 pm on the evening of 15 July they saw a smoke layer about 30 m deep over the town, tending to move down towards the Lake. Mr Carmichael confirmed that the drift under light wind conditions, especially in the early morning, is generally similar to this.

On 28 June D. Wratt discussed local wind conditions with the landscape architect at the Lands and Surveys plant nursery near the wood panels factory. He also confirmed that on cool clear nights the winds tend to be down towards the Lake (ie from the NE quarter). He has observed this from watching the plume from the factory.

The field team also talked with Mr Miles, an inspector with the Taupo Borough Council. He said that under light wind conditions a notheasterly drift occurred from the Tauhara area, and that on many occasions (some documented in Health Section files at the Borough) material released into the atmosphere from the mill site has drifted down onto Taupo town.

6.0 CONCLUSIONS.

All of the evidence discussed in Sections 3 and 5 suggests that during the night and early morning under cool, clear, light wind conditions, the low level airflow near the proposed power station site at Tauhara is from the northeasterly quarter towards Taupo township. The Tethersonde profiles showed the depth of this flow fluctuated, but at times it reached 100 metres. Earlier dispersion modelling work suggested the cooling tower plume centreline would be between 60 and 80 metres high under such conditions, at the point of maximum ground level hydrogen sulphide concentration. Thus for at least some of the time, much of the cooling tower plume would be carried towards Taupo.

It has been noted that while the modelling work predicted some of the highest ground level hydrogen sulphide concentrations would occur under such "Pasquill Class F" conditions, these predictions for 1 hour average concentrations were still below Health Department guidelines. The guidelines are based on odour nuisance and are several orders of magnitude above the concentrations at which effects on human health have been discerned. This modelling work was based on "standard" profiles of wind, humidity and temperature, and the work is currently being repeated using the actual height profiles obtained from the field measurements. It must also be pointed out that dispersion modelling results are estimates, and they are subject to uncertainties which cannot yet be fully quantified.

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Flight	Date	Release time (NZST)	Surface Pressure (HectoPascals)
Tethersonde 7	23/7/85	1845	957.9
Tethersonde 8	24/7/85	0247	958.6
Tethersonde 9	24/7/85	0326	958.7
Tethersonde 10	24/7/85	0414	958.5
Tethersonde 11	24/7/85	0504	958.5
Tethersonde 12	24/7/85	0553	958.6
Tethersonde 13	24/7/85	0645	959.1
Tethersonde 14	24/7/85	0755	959.7
Tethersonde 15	24/7/85	0840	960.0
Airsonde 7	24/7/85	0932	960.2

Table 1: Information for Tethersonde and Airsonde releases. Using the pressure information it is possible to calculate actual temperature given the potential temperature and height from the figures.

RELATIVE WIND FREQUENCIES

TAUPO AIRPORT JAN 1982 TO DEC 1984

ALL SEASONS COMBINED

SPEED (KNOTS)	1 - 5				6 - 10				11 - 20			
TIME OF DAY	N	M	A	E	N	M	A	E	N	M	A	E
DIRECTION												
350-010	22	20	7	17	43	37	29	42	9	14	13	11
020-040	55	31	6	41	55	36	37	76	18	23	26	21
050-070	36	16	3	25	20	12	8	32	2	7	5	4
080-100	25	15	1	17	39	23	22	59	3	6	17	15
110-130	27	14	3	12	30	35	25	41	7	19	39	19
140-160	15	11	2	11	13	13	14	15	2	7	8	4
170-190	7	10	7	6	8	10	10	10	2	4	7	1
200-220	4	16	24	6	6	21	42	9	5	7	12	8
230-250	4	31	42	8	20	58	123	25	59	59	65	48
260-280	5	16	21	8	39	54	74	72	57	61	132	108
290-310	6	12	7	7	24	19	23	29	5	11	20	11
320-340	10	14	12	10	23	27	34	33	8	16	25	8
CALM	274	201	41	119								

SPEED (KNOTS)	21 - 30				31 - 40				OVER 40				TOTAL			
TIME OF DAY	N	M	A	E	N	M	A	E	N	M	A	E	N	M	A	E
DIRECTION																
350-010													74	70	49	70
020-040	1	1											129	91	70	138
050-070													57	35	17	61
080-100													67	45	40	91
110-130		1	1	1									65	70	69	74
140-160													30	31	24	31
170-190													16	23	24	17
200-220			1										16	45	79	24
230-250	5	6	5	5									88	155	235	85
260-280	3	4	6	4									105	135	232	193
290-310	1												37	43	50	47
320-340													41	57	70	50
CALM													274	201	41	119

TOTAL OBS USED N = 6224. M = 6311. A = 6407. E = 6353.

VALUES ARE %*10 OF TOTALS FOR TIME OF DAY
N = FREQ FOR HOURS 0000-0500 NZST
M = FREQ FOR HOURS 0600-1100 NZST
A = FREQ FOR HOURS 1200-1700 NZST
E = FREQ FOR HOURS 1800-2300 NZST

Table 2: Wind analysis for Taupo Airport

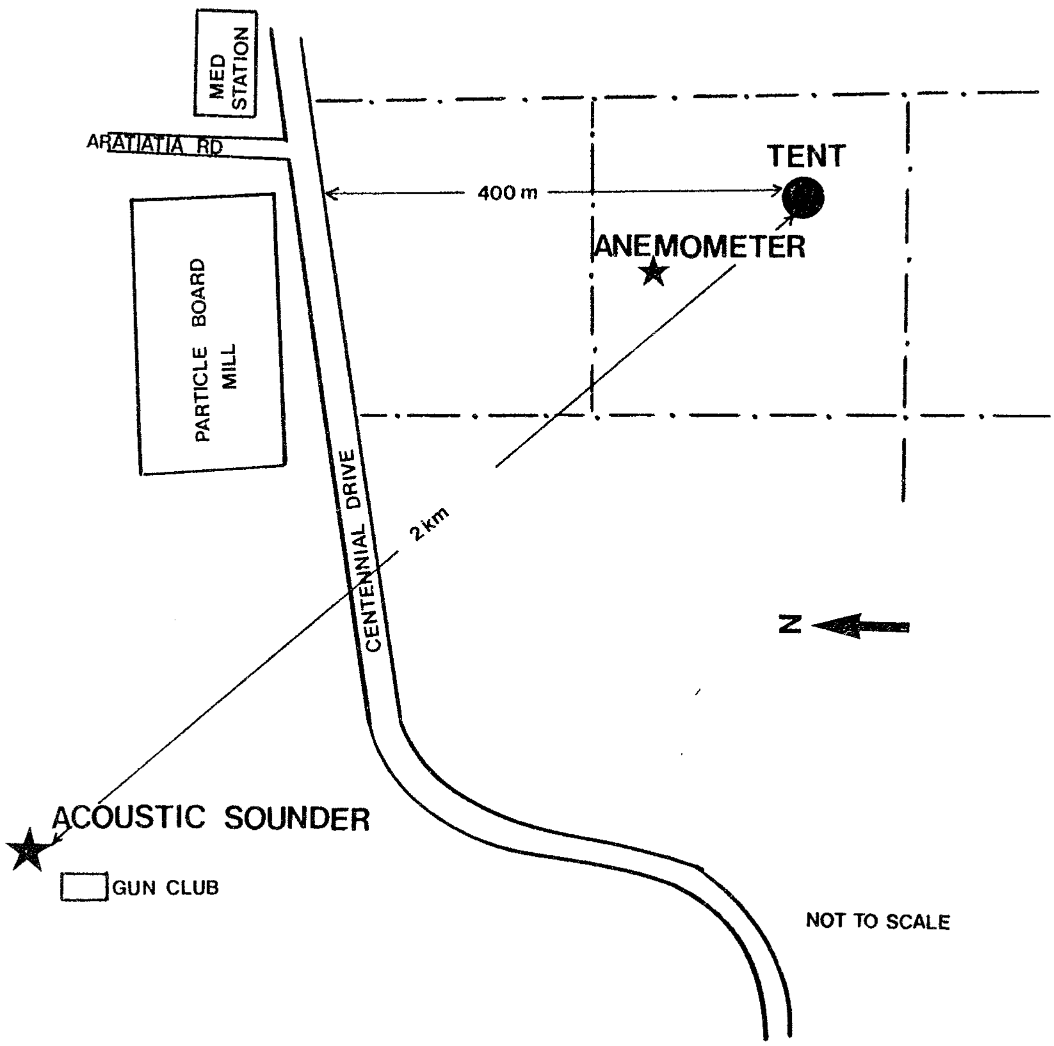


Figure 1: Locations for experimental work. The Tethersonde and Airsonde were flown from near the tent site

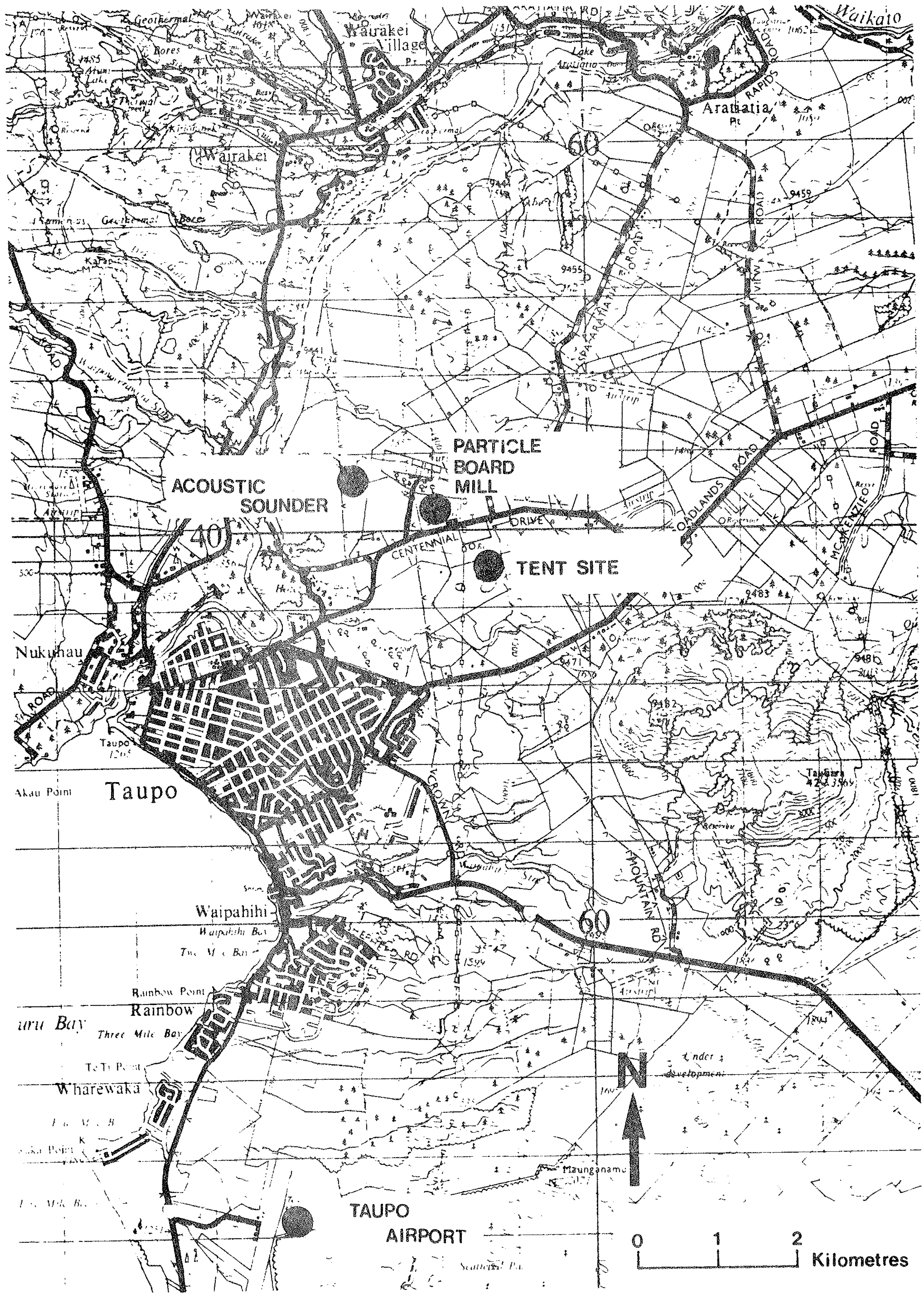


Figure 2: Map of the Taupo area, showing locations mentioned in report

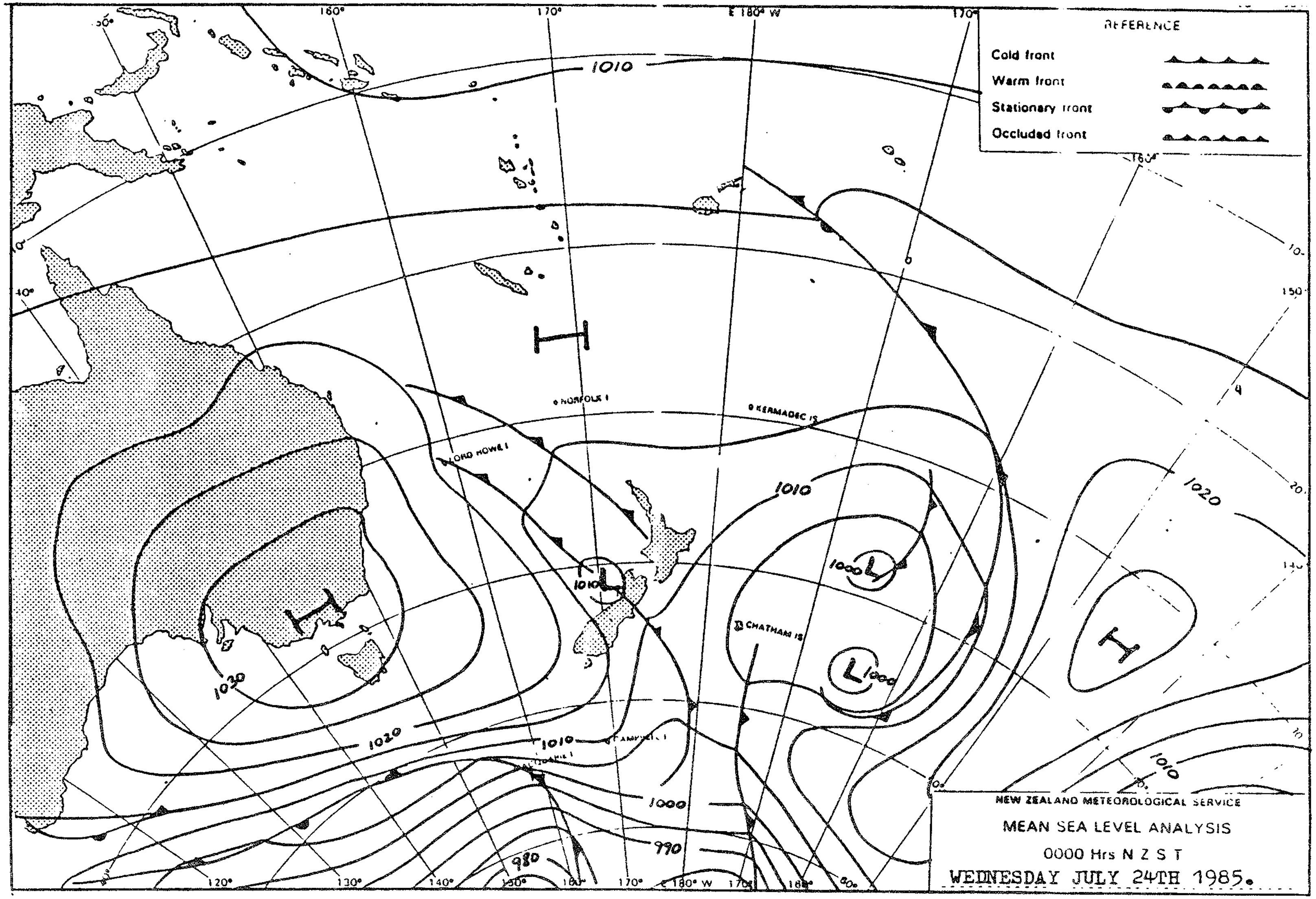
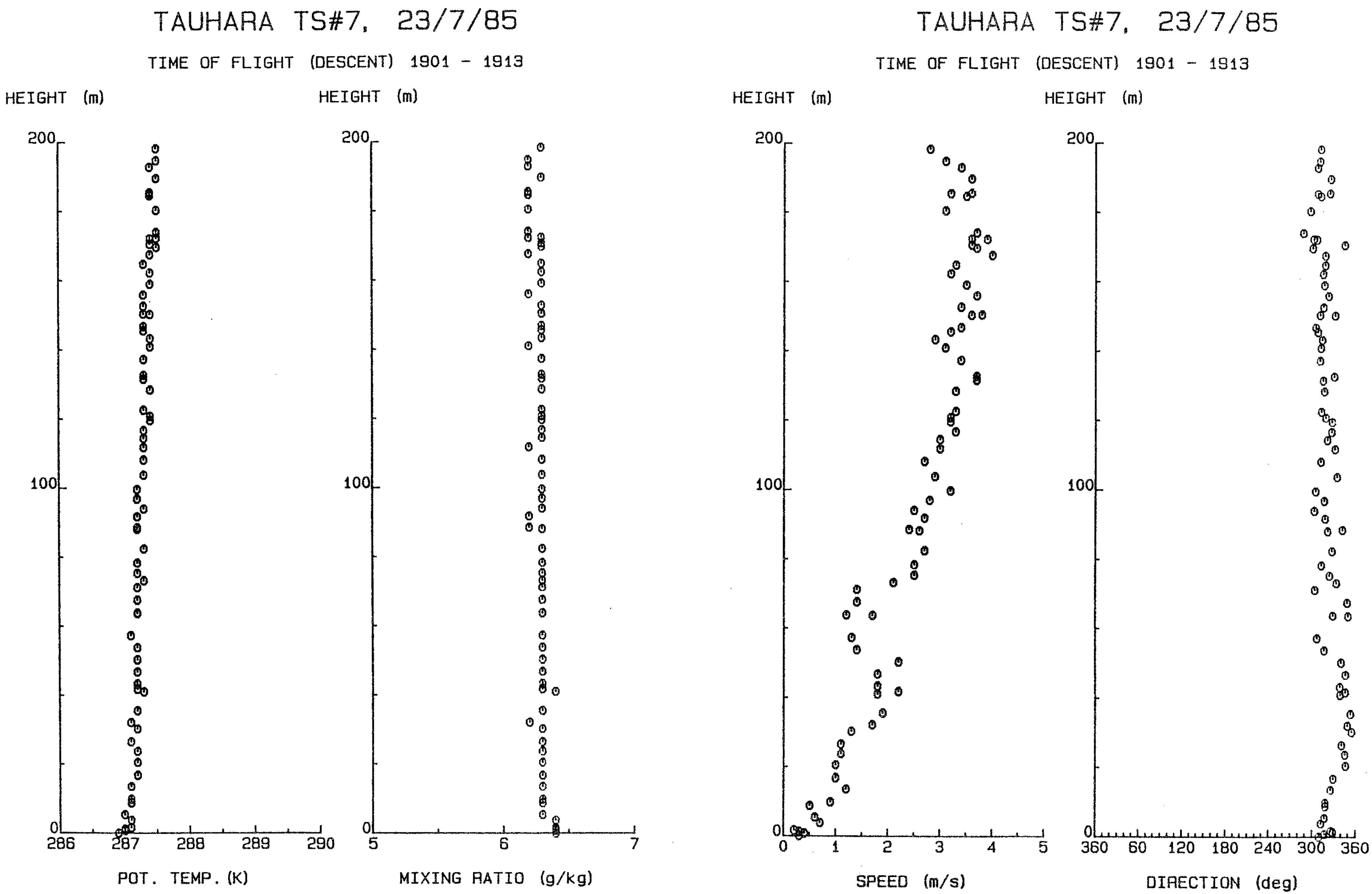


Figure 3: Mean sea level analysis for 00 Hours NZST, 24 July 1985



<u>Figure 4</u>: Tethersonde profiles, 1901-1913, 23/7/85

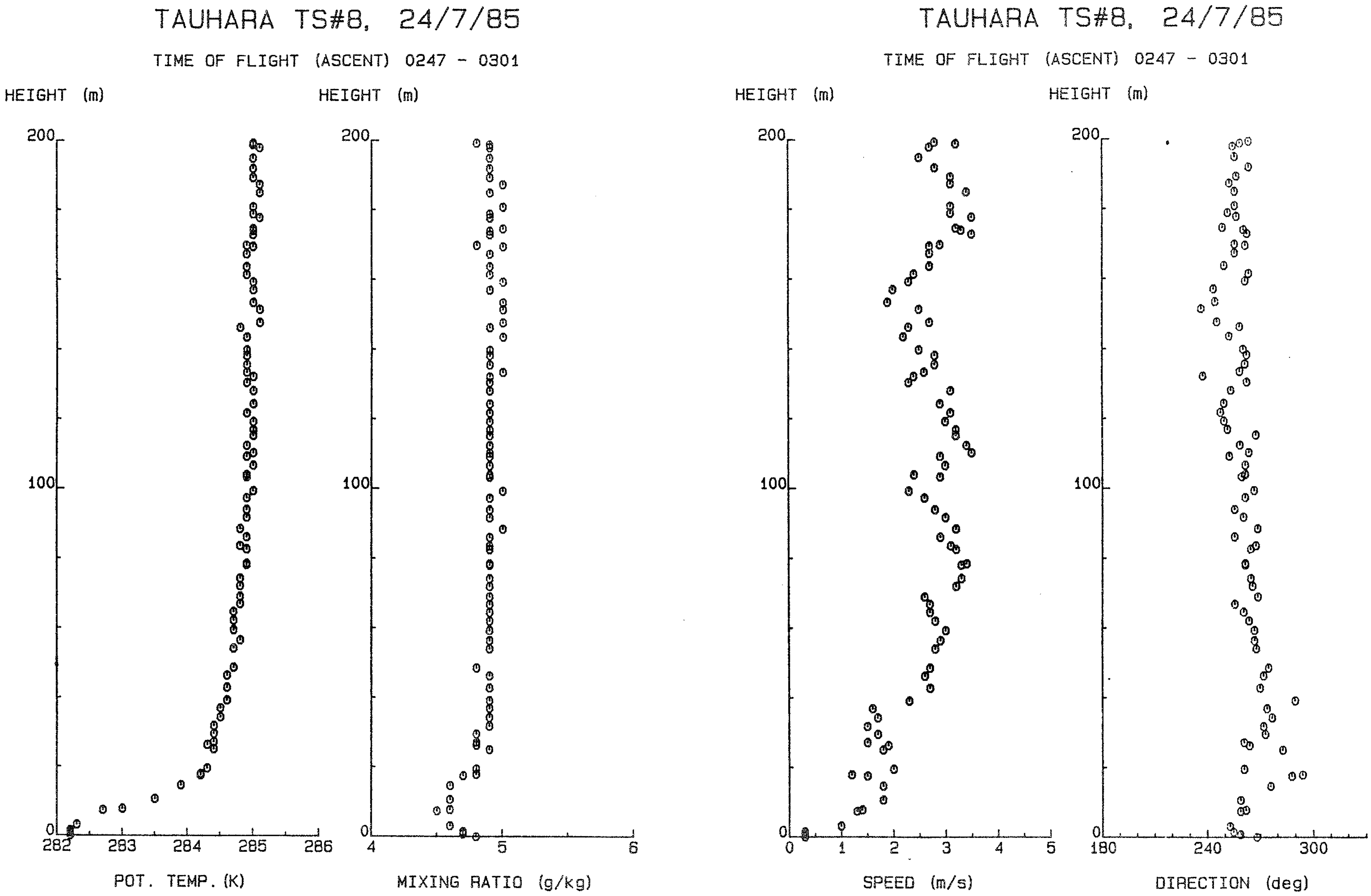


Figure 5: Tethersonde profiles, 0247-0301, 24/7/85

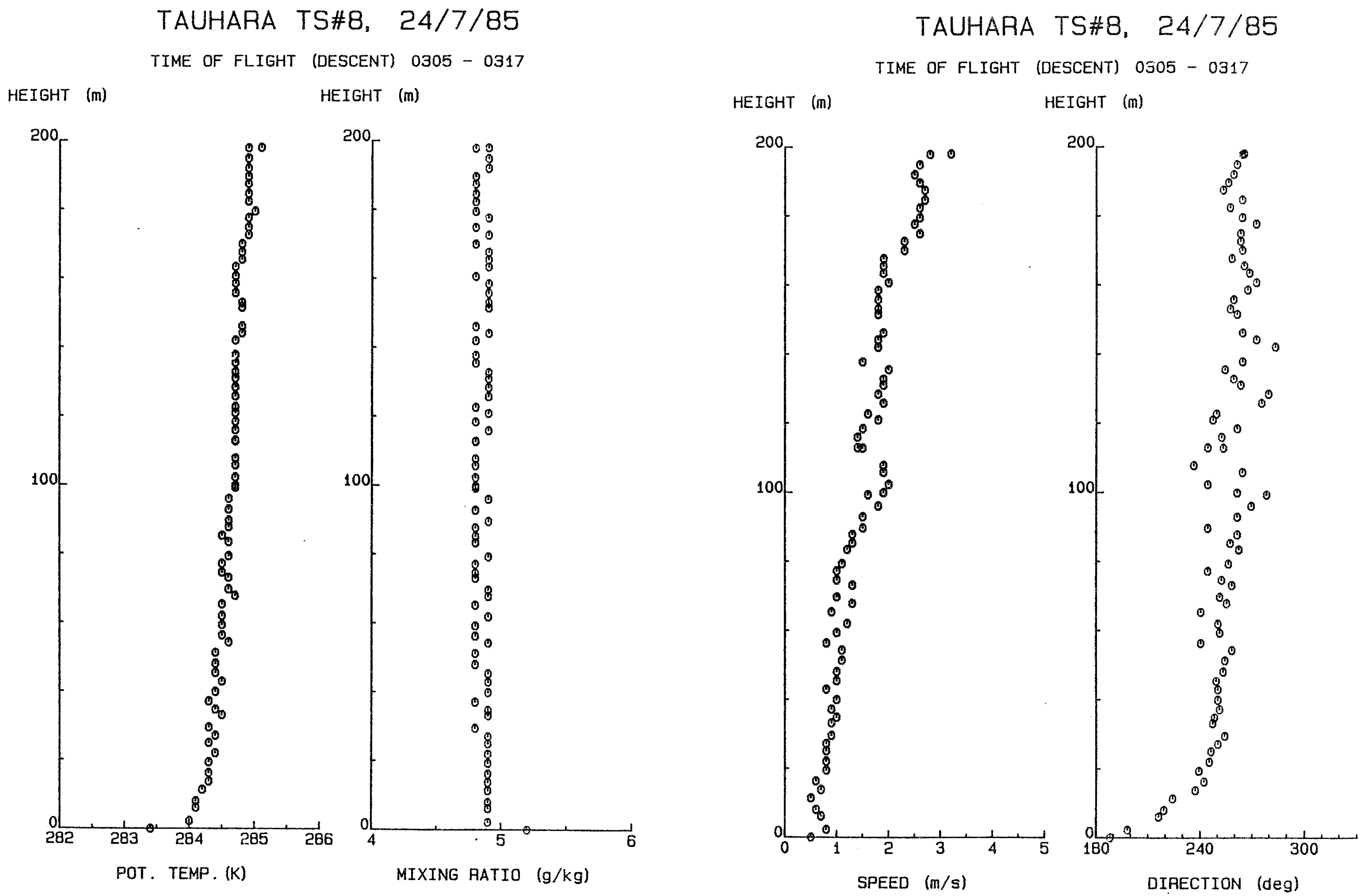
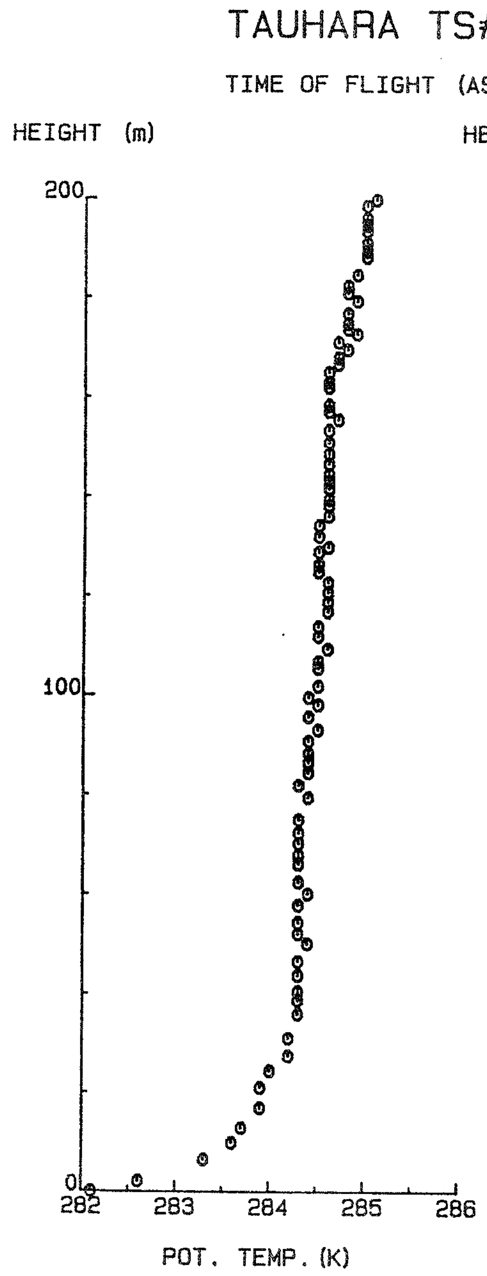


Figure 6: Tethersonde profiles, 0305-0317, 24/7/85



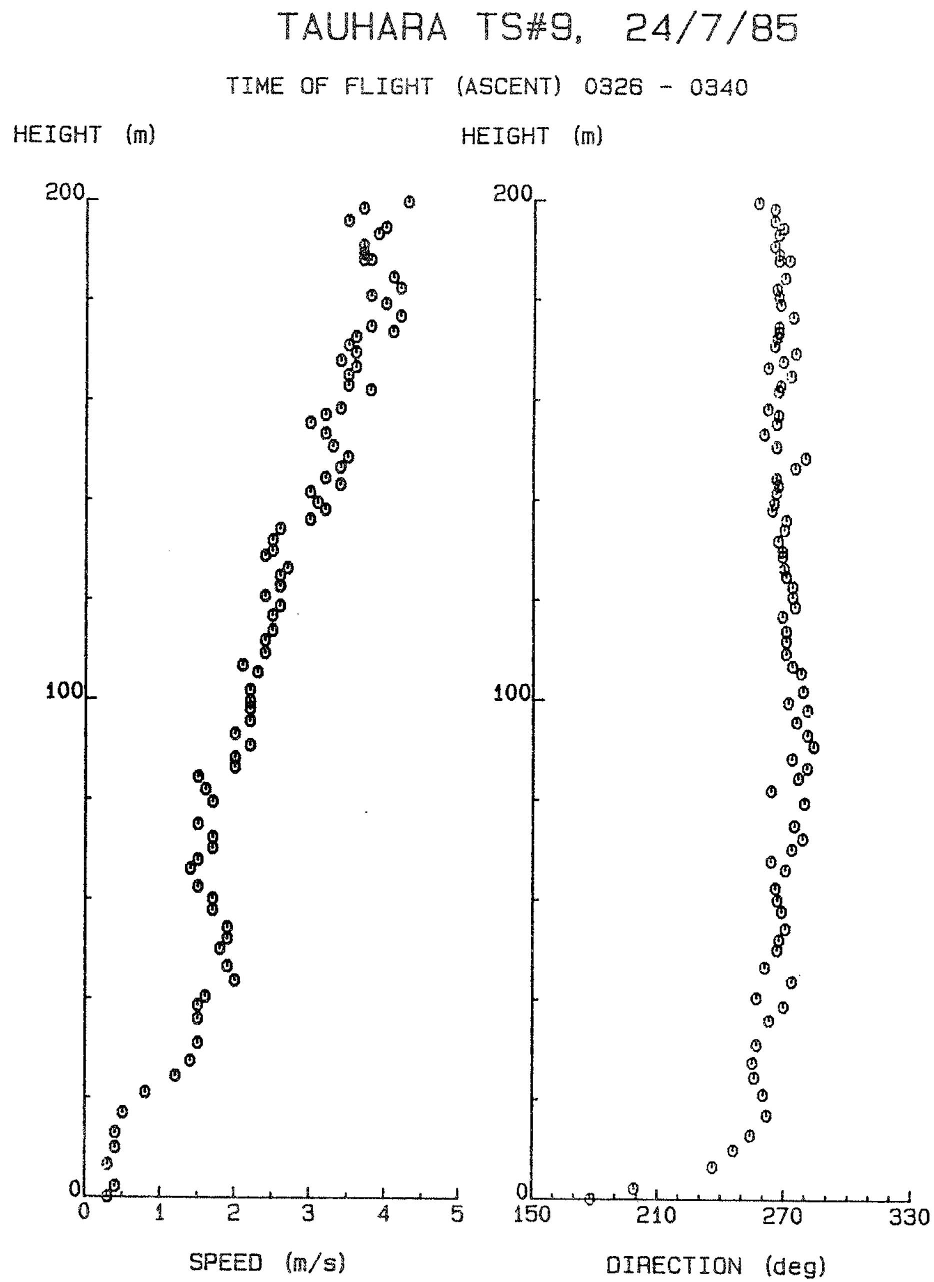


Figure 7: Tethersonde profiles, 0326-0340, 24/7/85

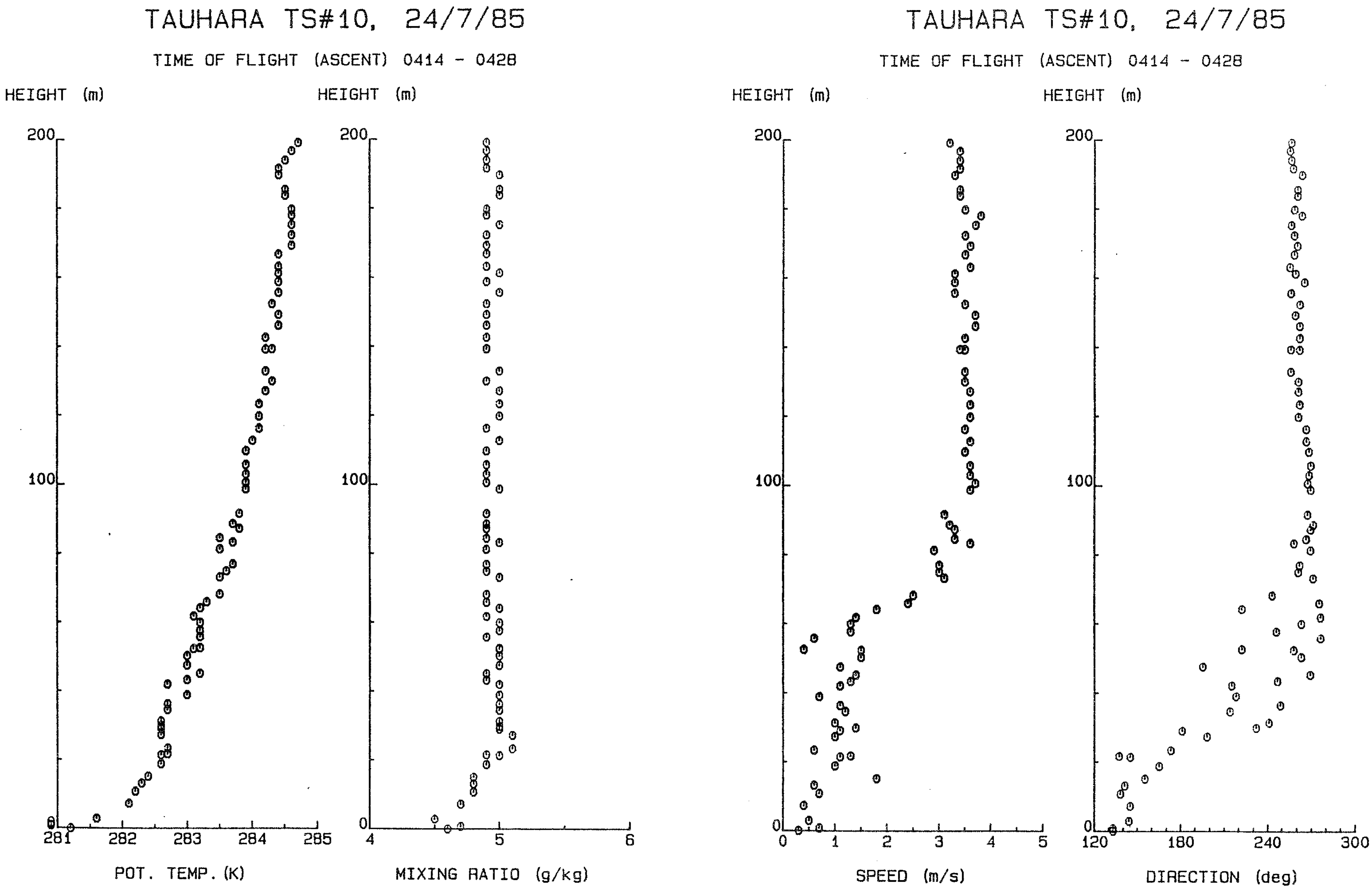


Figure 8: Tethersonde profiles, 0414-0428, 24/7/85

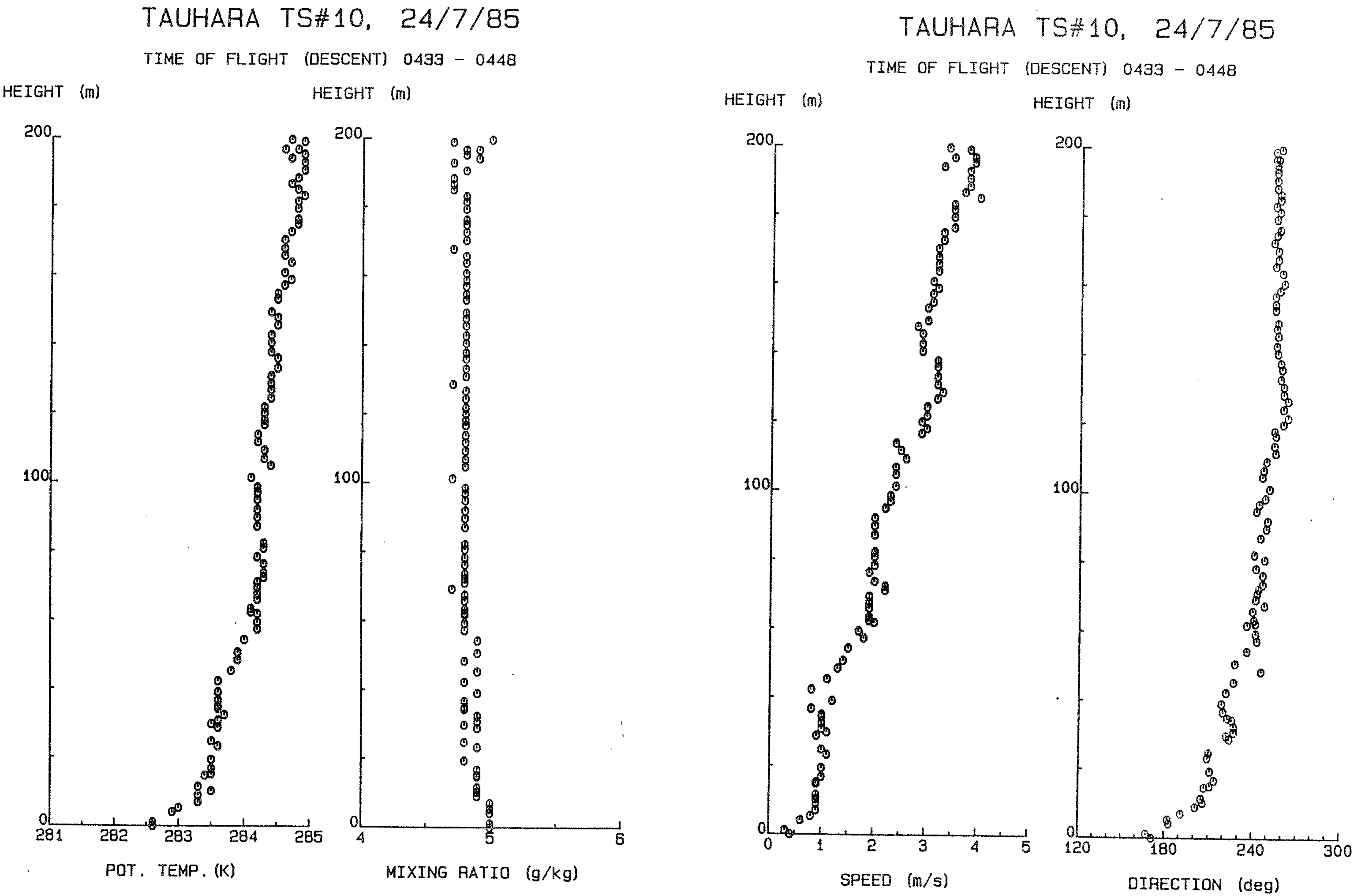


Figure 9: Tethersonde profiles, 0433-0448, 24/7/85

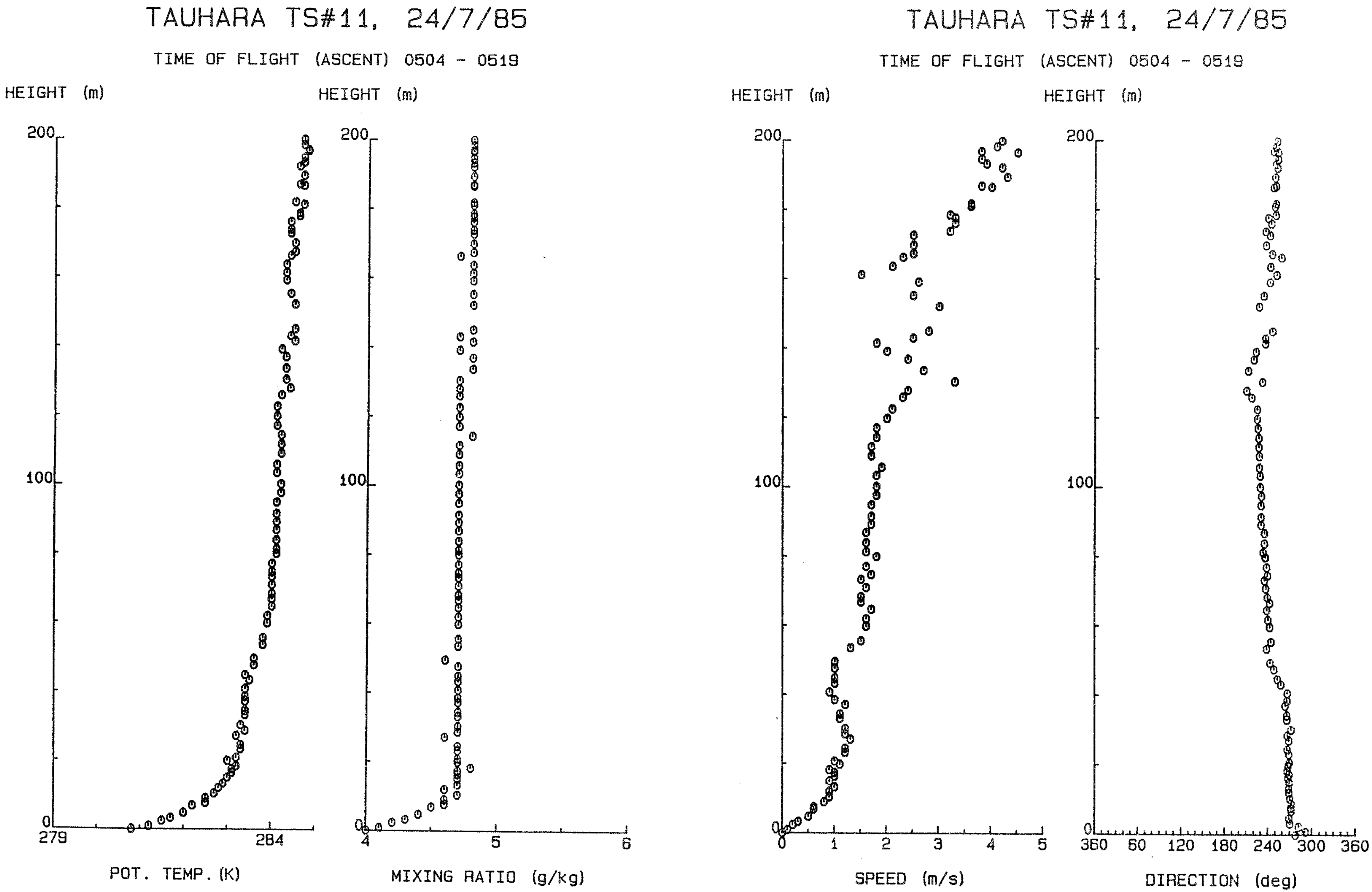


Figure 10: Tethersonde profiles, 0504-0519, 24/7/85

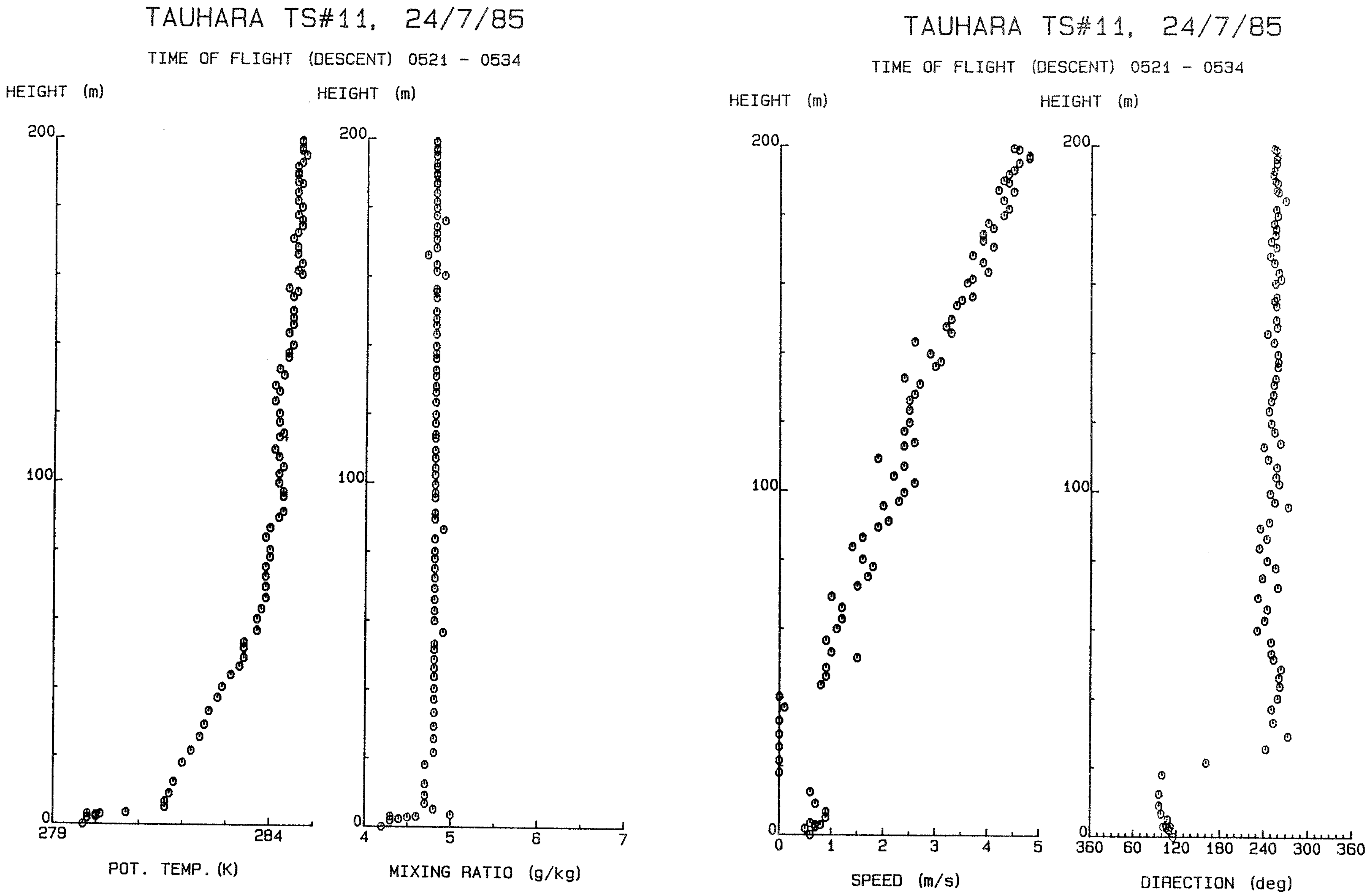
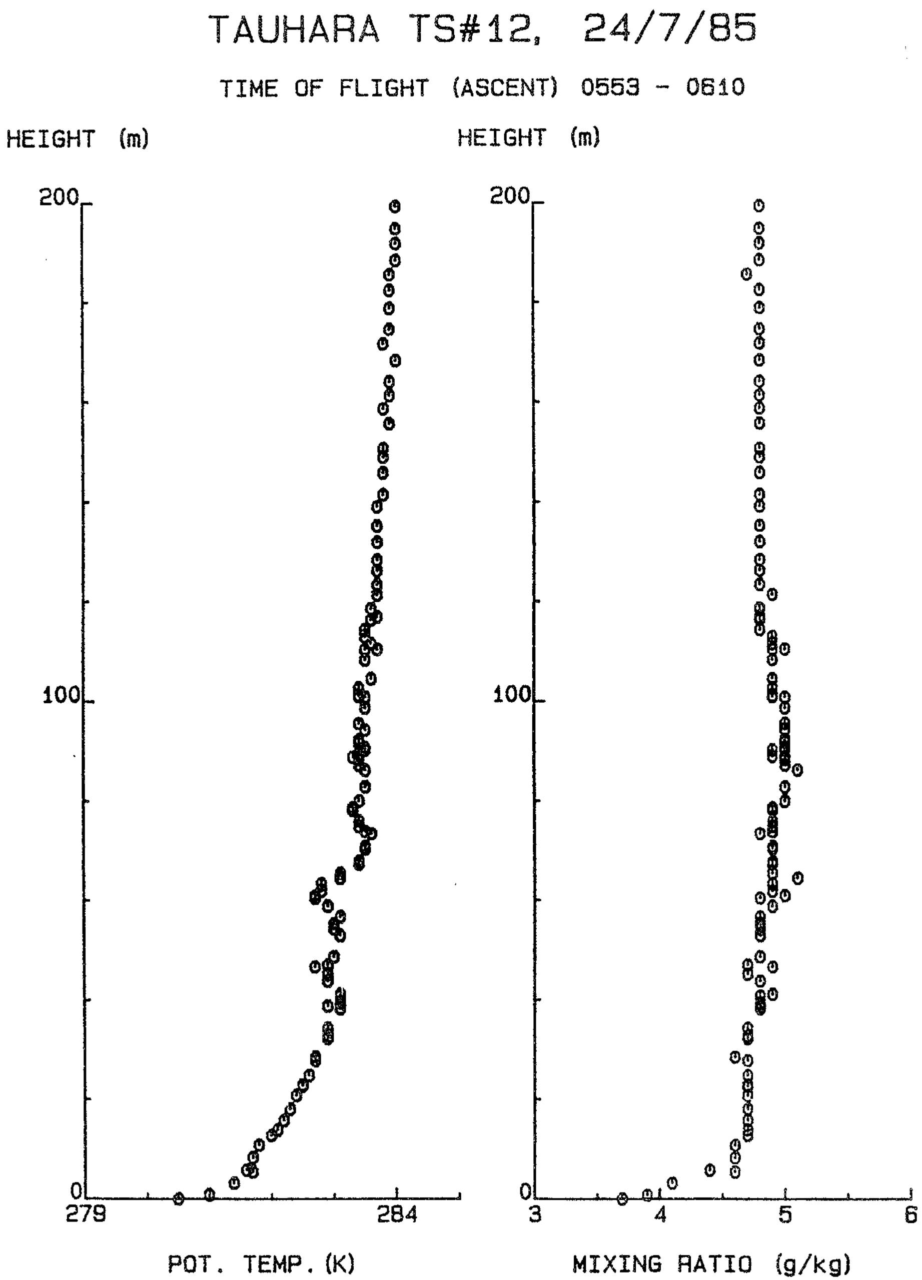


Figure 11: Tethersonde profiles, 0521-0534, 24/7/85



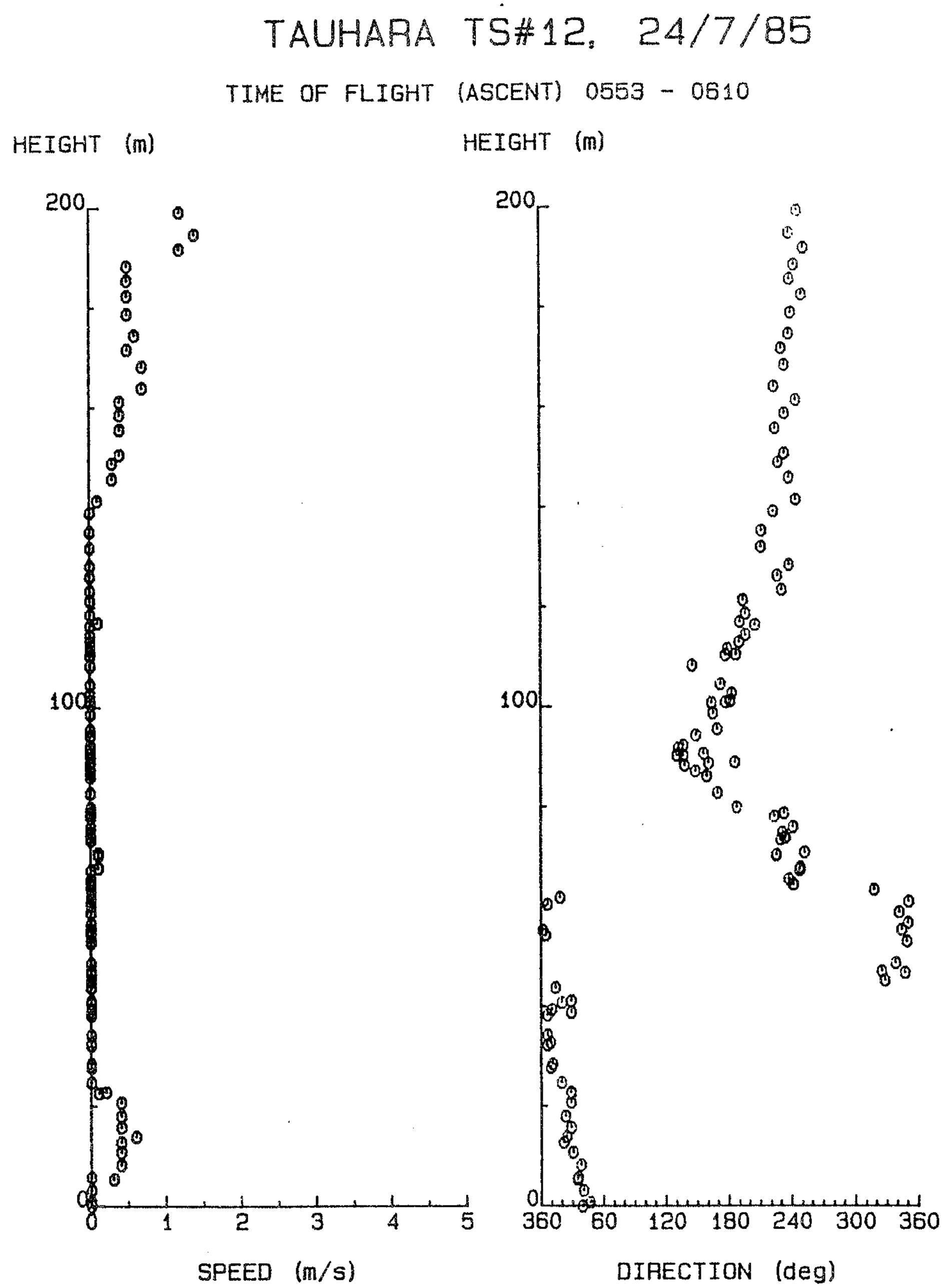
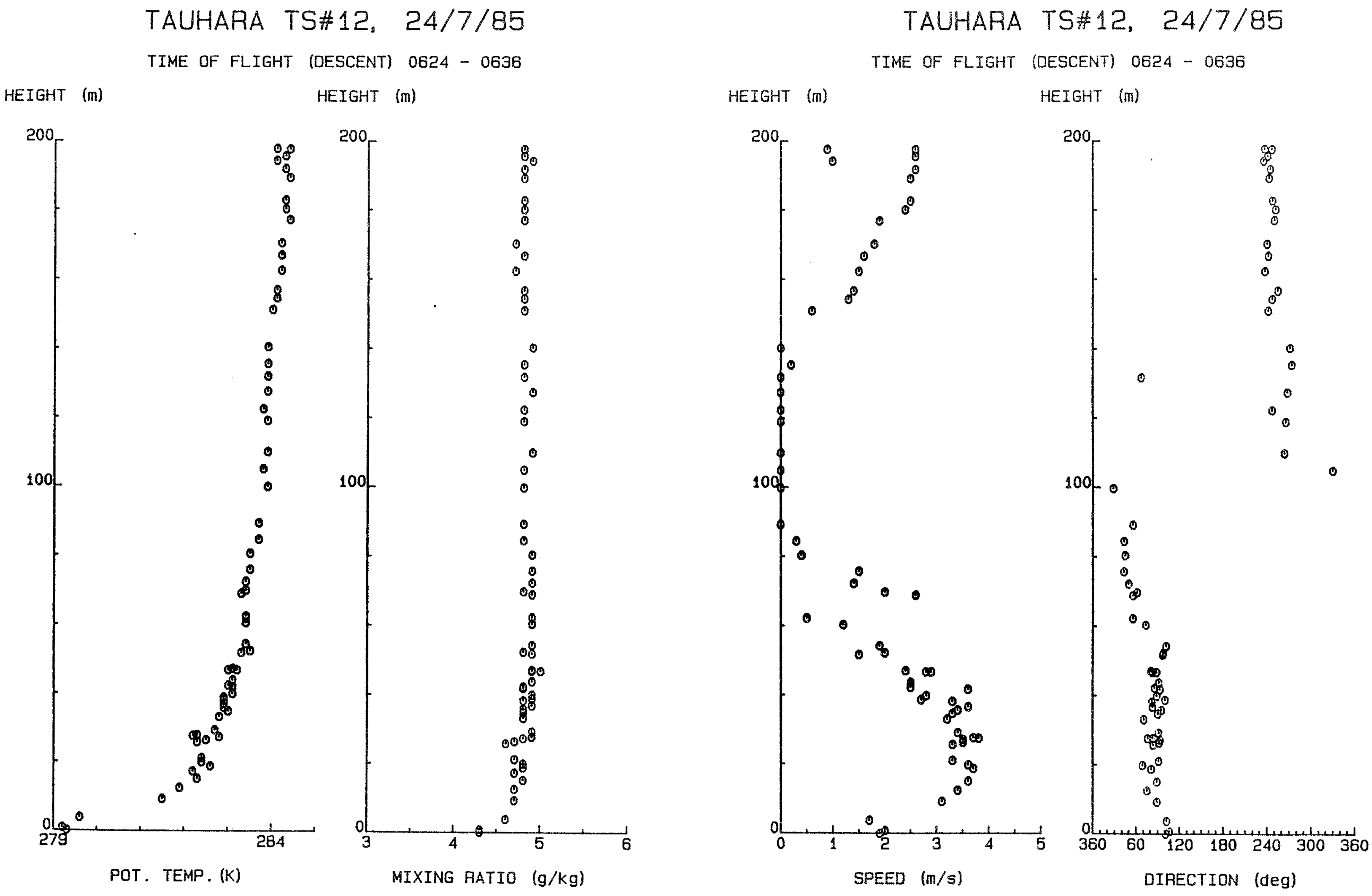


Figure 12: Tethersonde profiles, 0553-0610, 24/7/85



<u>Figure 13</u>: Tethersonde profiles, 0624-0636, 24/7/85

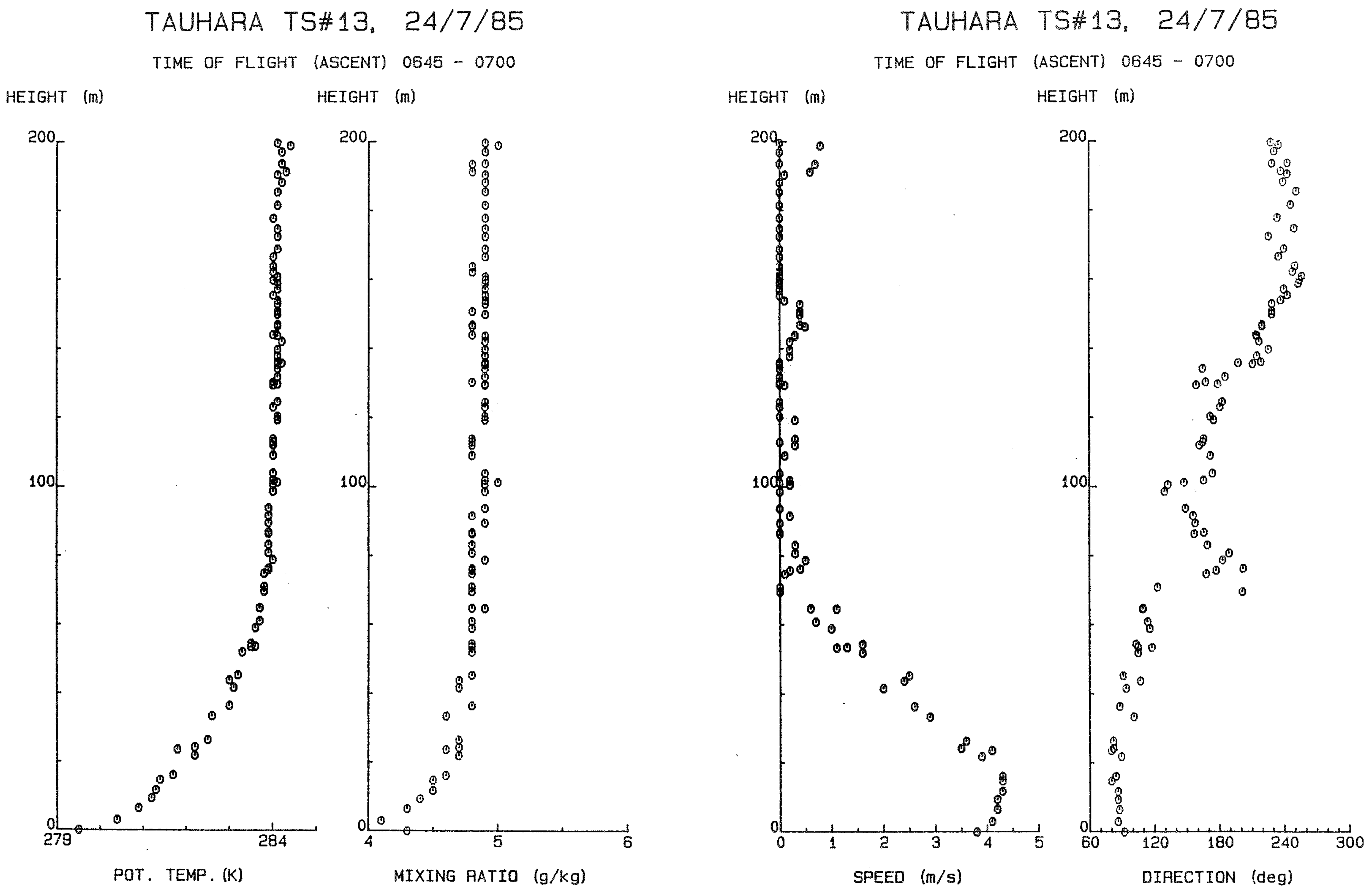
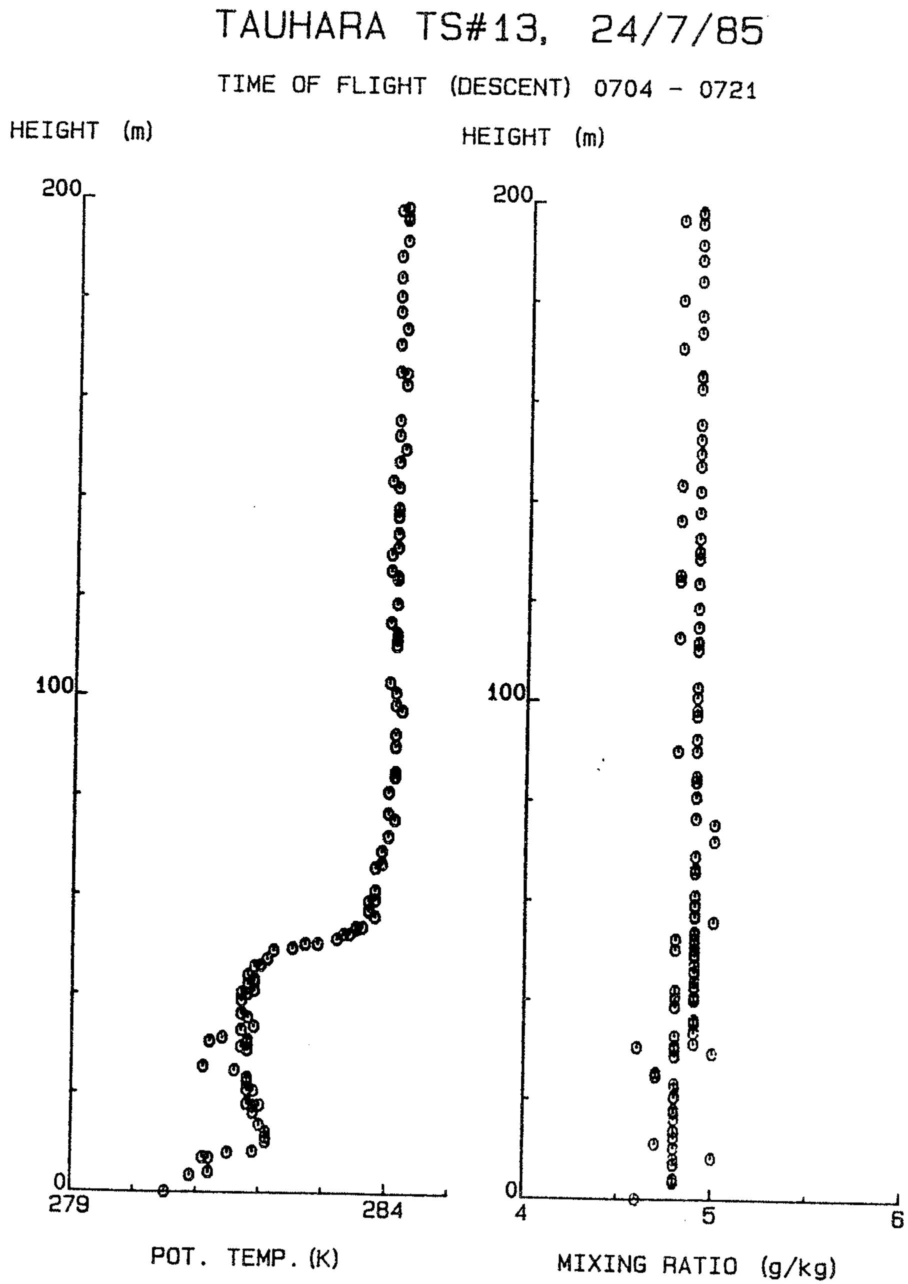


Figure 14: Tethersonde profiles, 0645-0700, 24/7/85



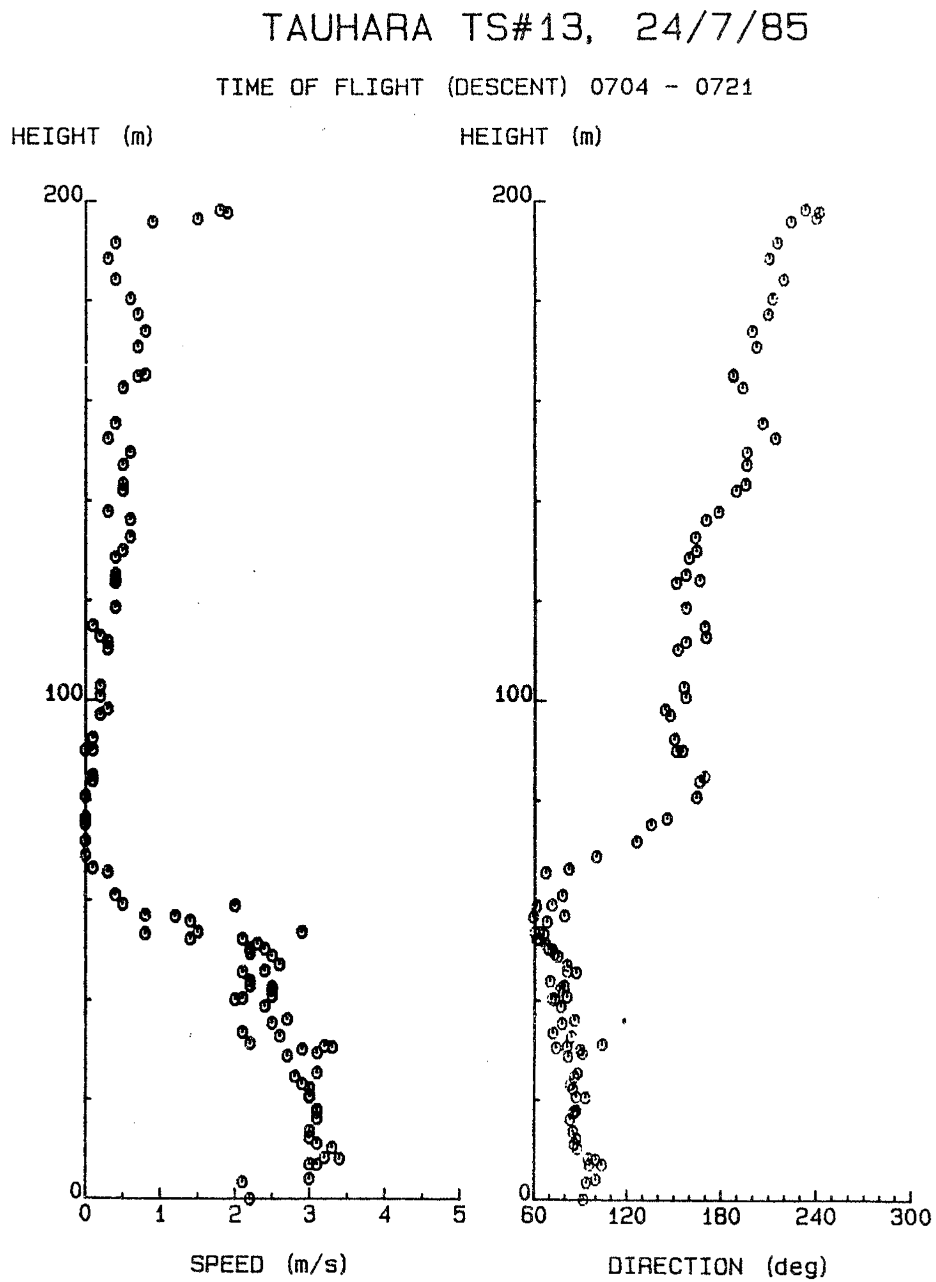


Figure 15: Tethersonde profiles, 0704-0721, 24/7/85

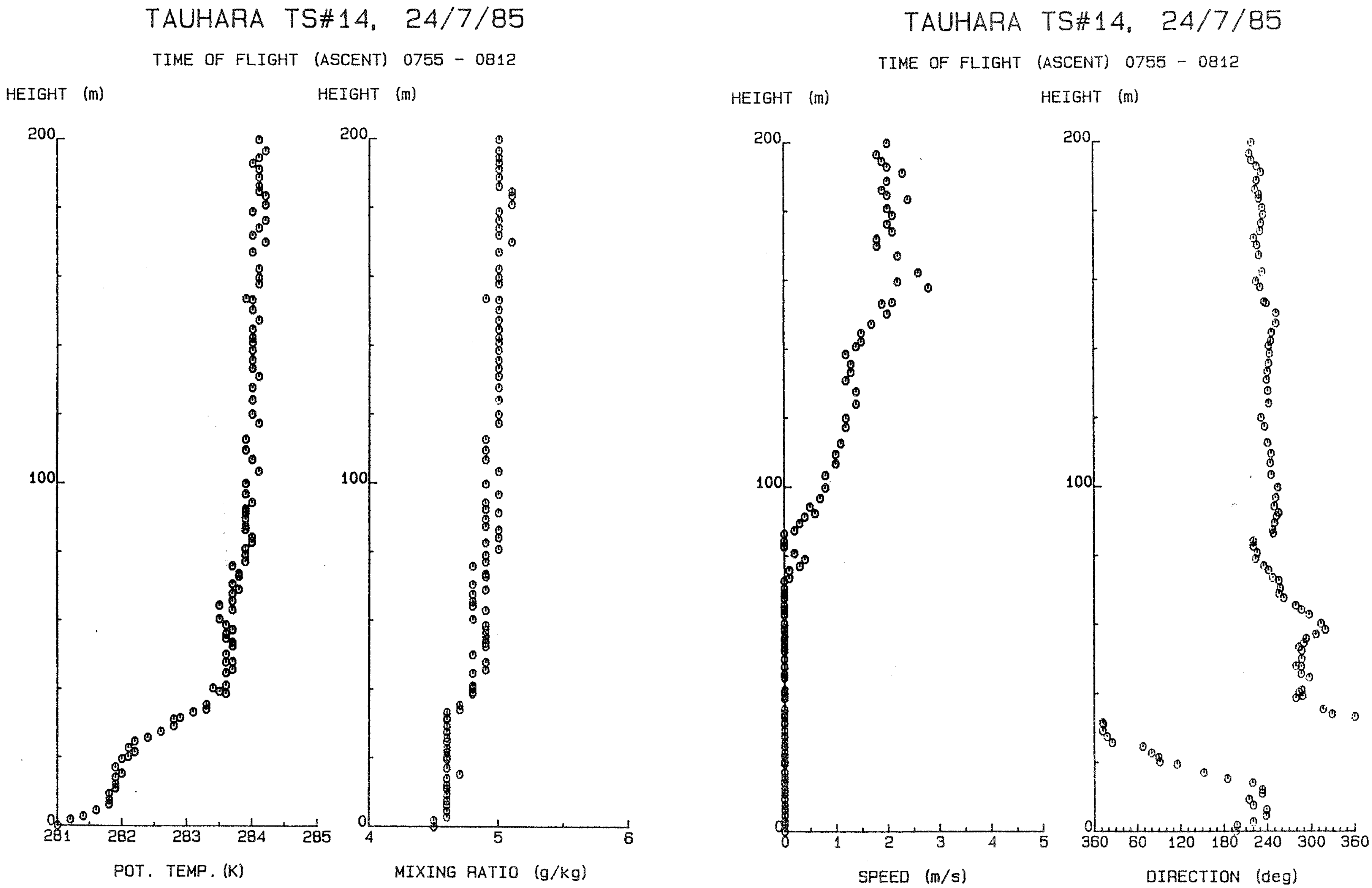


Figure 16: Tethersonde profiles, 0755-0812, 24/7/85

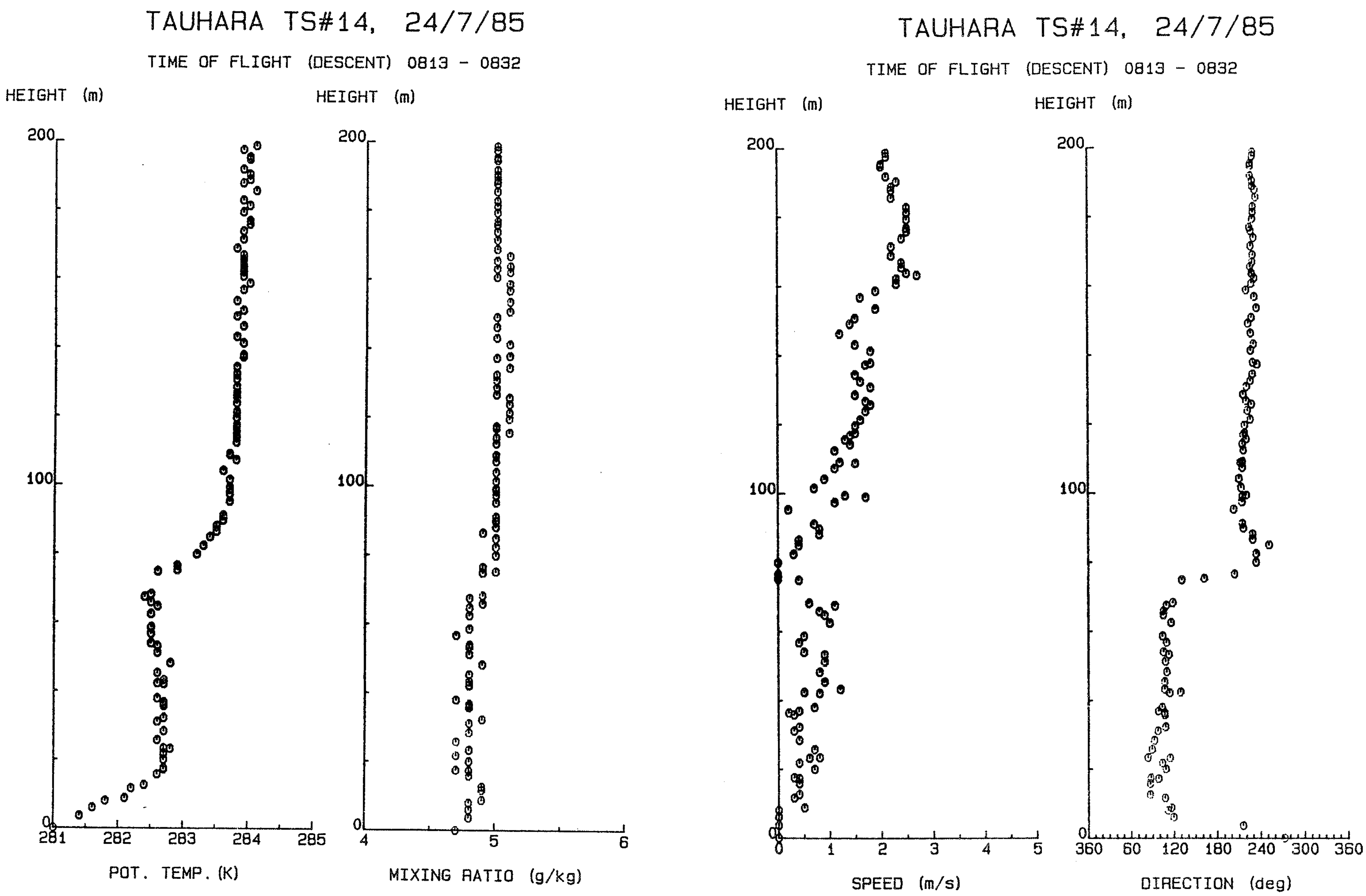


Figure 17: Tethersonde profiles 0813-0832, 24/7/85

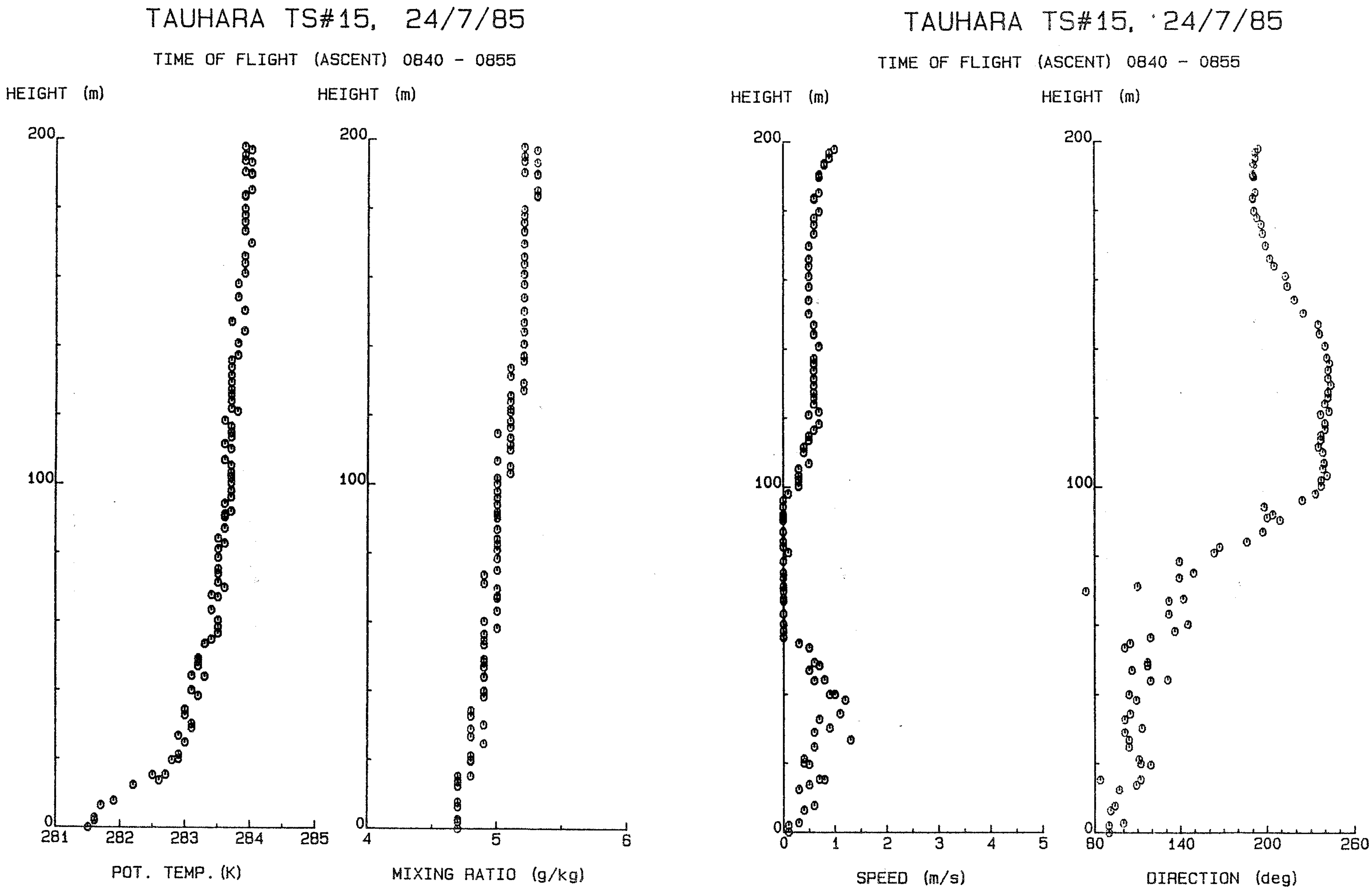
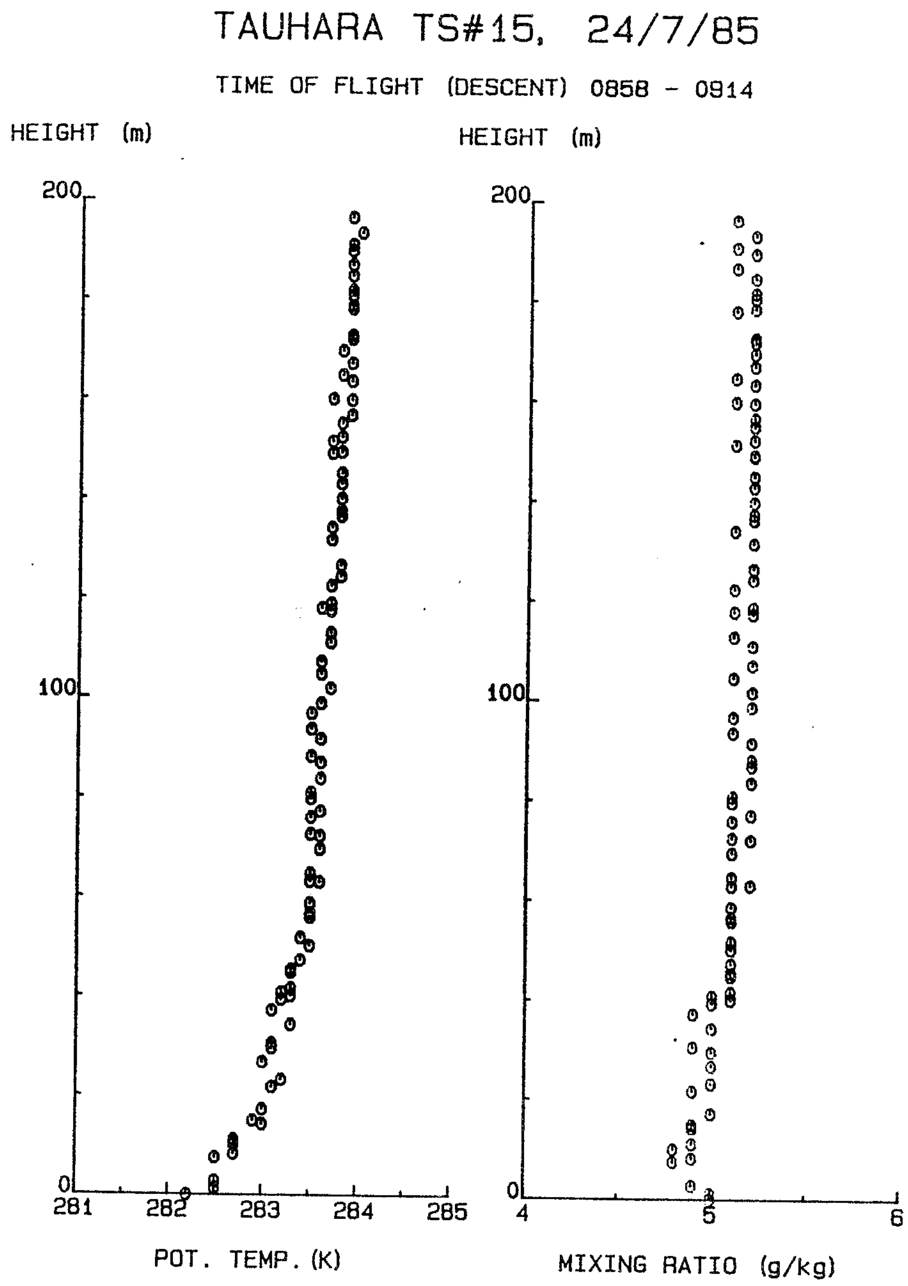


Figure 18: Tethersonde profiles, 0840-0855, 24/7/85



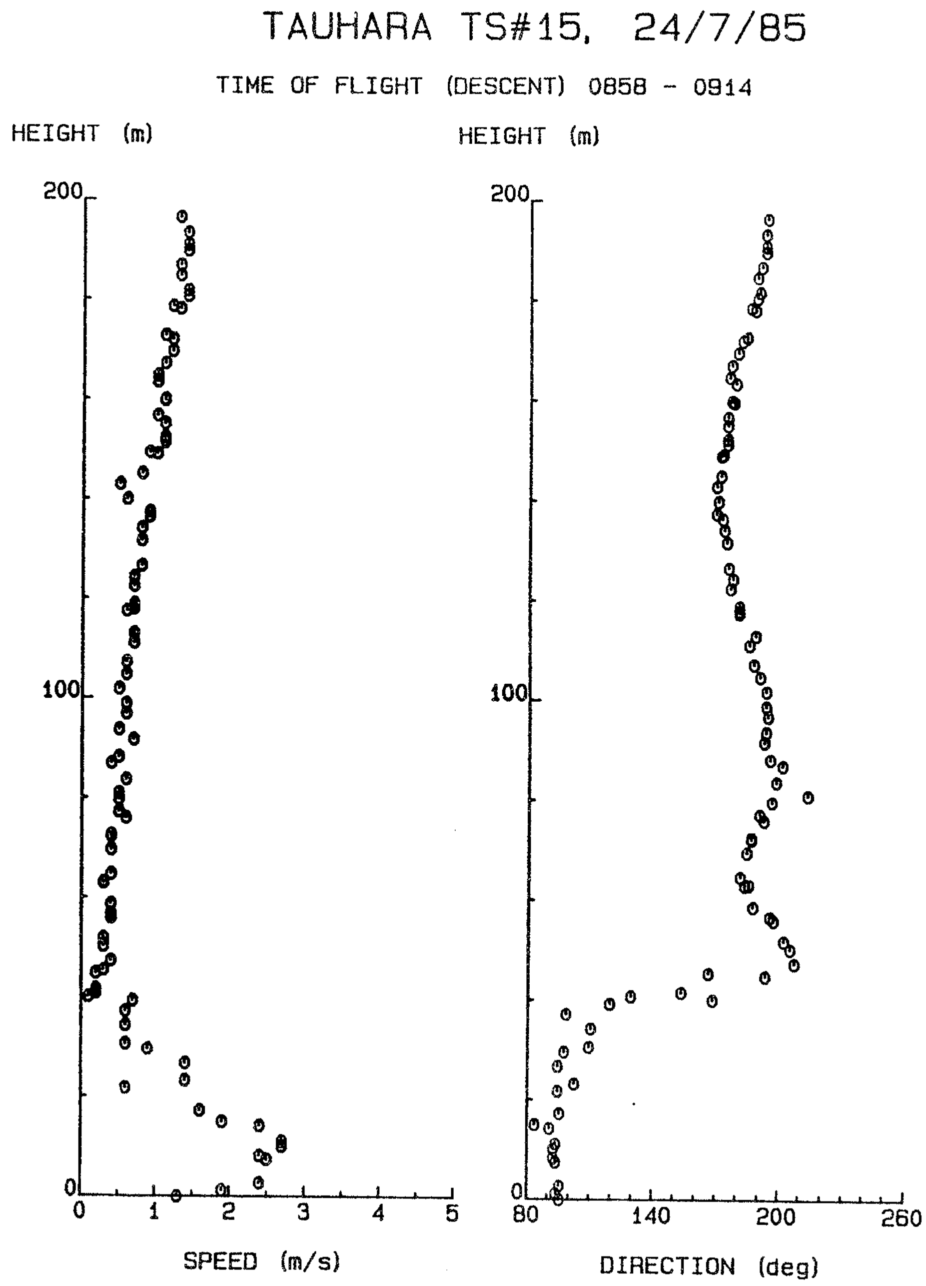


Figure 19: Tethersonde profiles, 0858-0914, 24/7/85

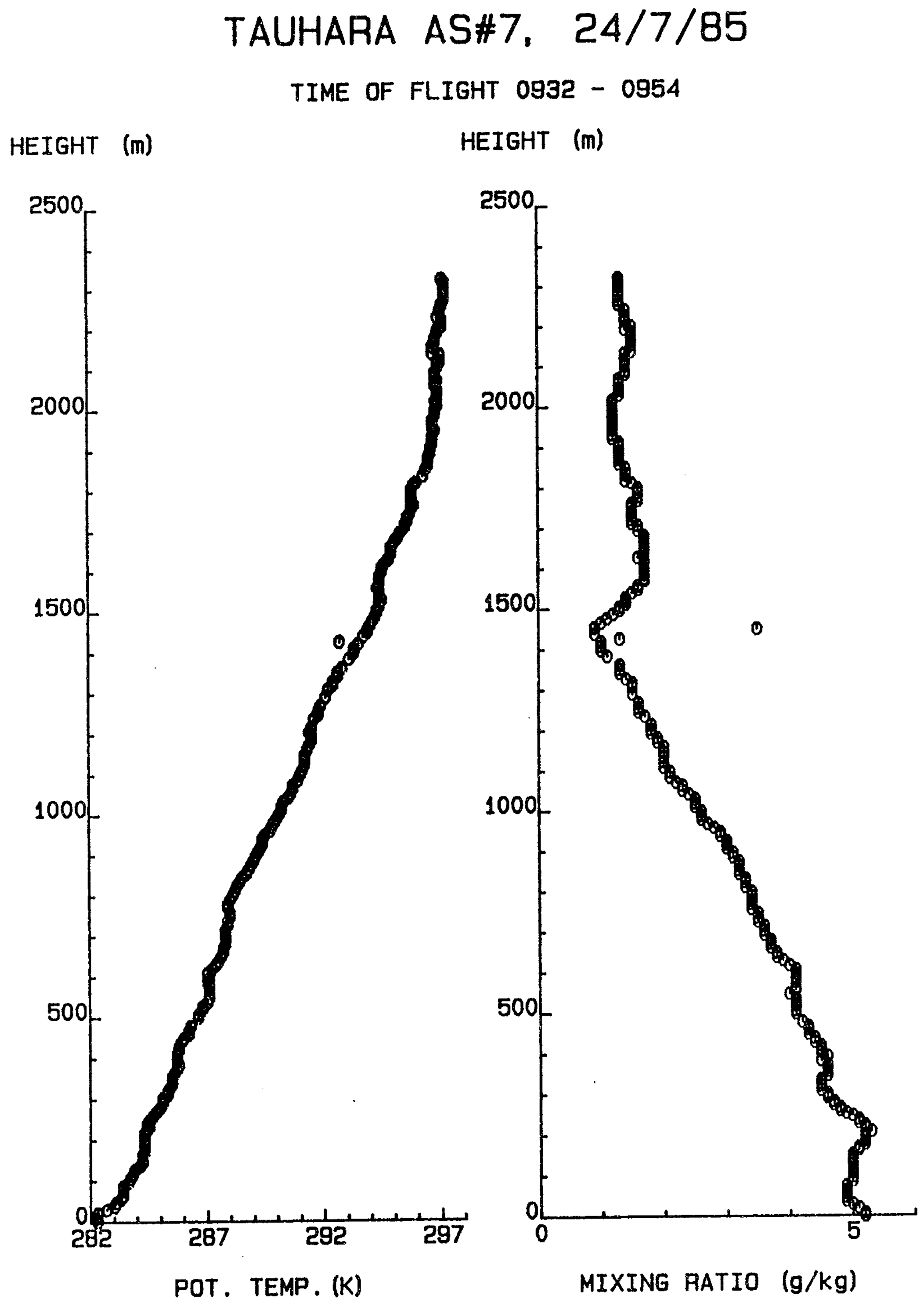


Figure 20: Airsonde profiles, 0932-0954, 24/7/85

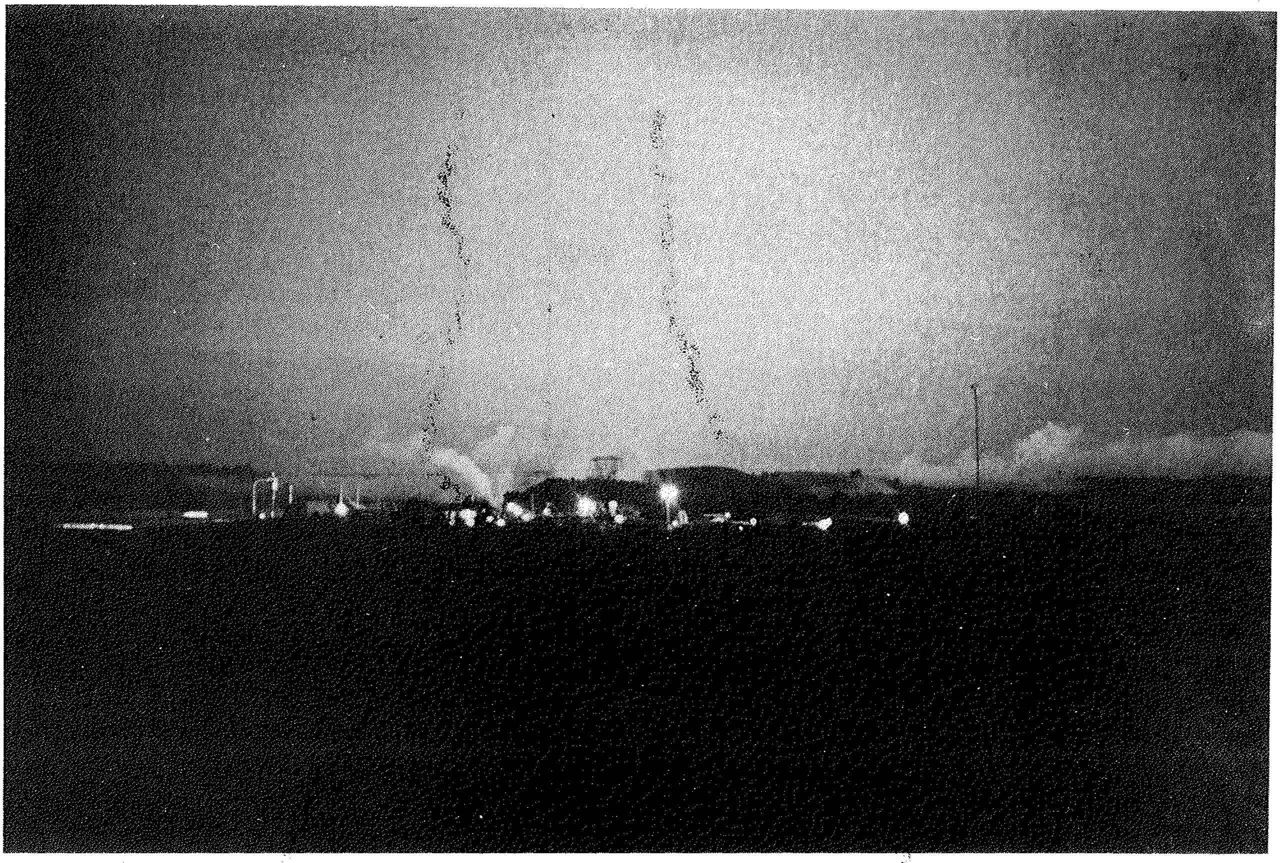


Figure 21: Photograph taken from near tent site, 0624 NZST, 24 July 1985. Note plume from wallboards factory (slightly left of centre) is caught within the airflow from the NE quarter. (Refer also to Figure 13).

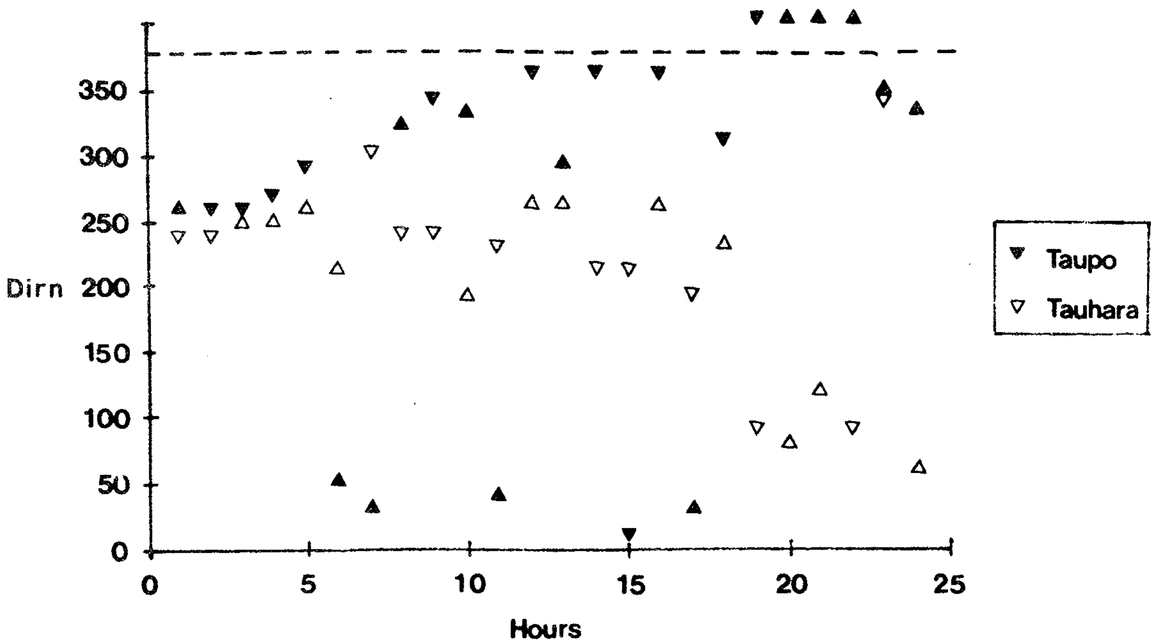


Figure 22(a): Wind directions from anemometers at Taupo Airport and Tauhara, 23-24 July 1985. The direction given for hour 1 is the average from 1200 to 1300 NZST on July 23. The points above the dotted line were recorded as calms (no direction).

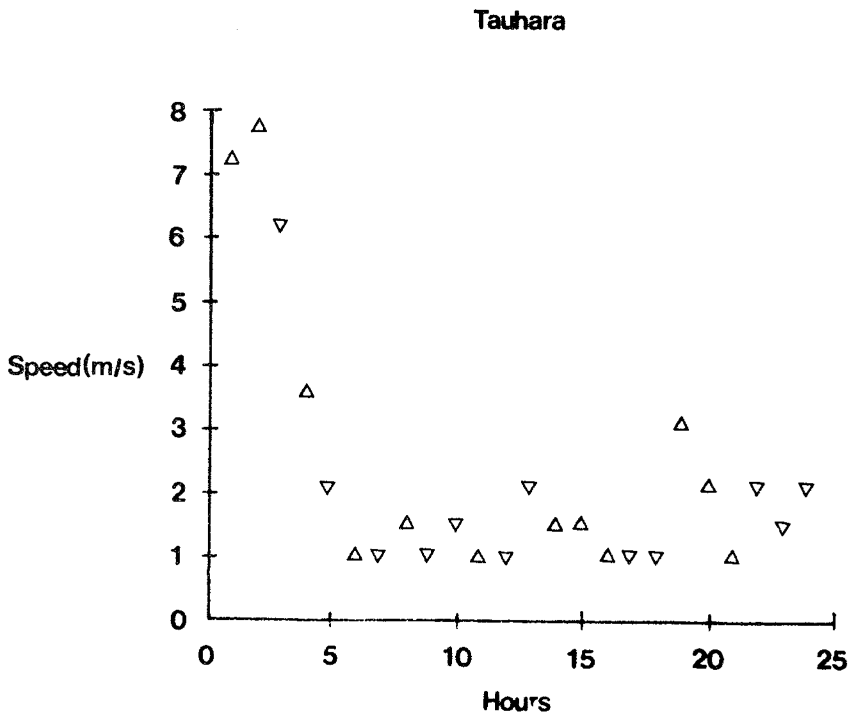


Figure 22(b): Wind speeds at Tauhara, 23-24 July 1985

APPENDIX

Tauhara: Weather Log 24 July 1985

0115 NZST	Calm, clear
0230 NZST	Calm, clear. Mill plume from SSW
0300 NZST	Steam plumes from AC Baths and Tauhara from soutn, although AC Bath plumes perhaps tending to drift towards Taupo i.e. from NE
0306 NZST	AC Baths and Tauhara plumes drifting from NNE. Mill still from S
0330 NZST	Calm, nil cloud Mill plume from SW AC Baths from ENE
0400 NZST	Calm, nil cloud
0500 NZST	Calm, nil cloud. Mill plume vertical for 50 m, then from SW
0552 NZST	Mill plume lowest 30 m drifting from NE. Above this drift still from SSW
0604 NZST	AC Baths plume from NE. Noticeable pooling of smoke, steam/fog over Taupo. Lowest layers of mill plume drifting considerable distance downwind in NE flow towards Taupo
0636 NZST	Steam from Wairakei etc pouring down valley and river towards S
0645 NZST	E 6kts 1/8 Sc to E-SSE-S. 1/8 Ci to N. Low land to N and W filled with fog/steam. Thin layer fog/steam/smoke over Taupo
0700 NZST	Distinct edge of Sc sheet moving in rapidly from S
0800 NZST	Calm 3/8 Sc 1000 moving from S 3/8 Ac 14000 moving from WNW 7/8 Ci 25000 moving from WNW

	Mill plume vertical. Fog in river valley and at Taupo moving from NE. Wairakei and Craters of Moon plumes from SSW
0820 NZST	Valley fog still flowing rapidly down towards Taupo
	Smoke from domestic fire near NZE substation also flowing downslope close to ground. Fog in Taupo area drifting from NE
0858 NZST	Smoke from mill plume observed impinging on hill slope about 1 km north of mill
0910 NZST	Mill smoke plume visible as blue streak extending many km NNE - as far as eye could see
0930 NZST	E 1kt $^1/8$ Sc 1000, $^2/8$ Ac 14000, $^5/8$ Ci 25000
1800 NZST	ENE 4kts $^5/8$ Sc 3000, $^7/8$ Ac 12000
1900 NZST	NNW 1kts $^1/8$ Sc 3000, $^8/8$ As 10000
	Rain commenced 1945 NZST
2230 NZST	$^8/8$ As. Light southerly. Intermittent light rain.