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Radio climatic conditions in the Svalbard area during the period from 30.08 to 05.09 1998.

Sofus Linge Lystad
Ola Guldberg
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Report nr. 3/99

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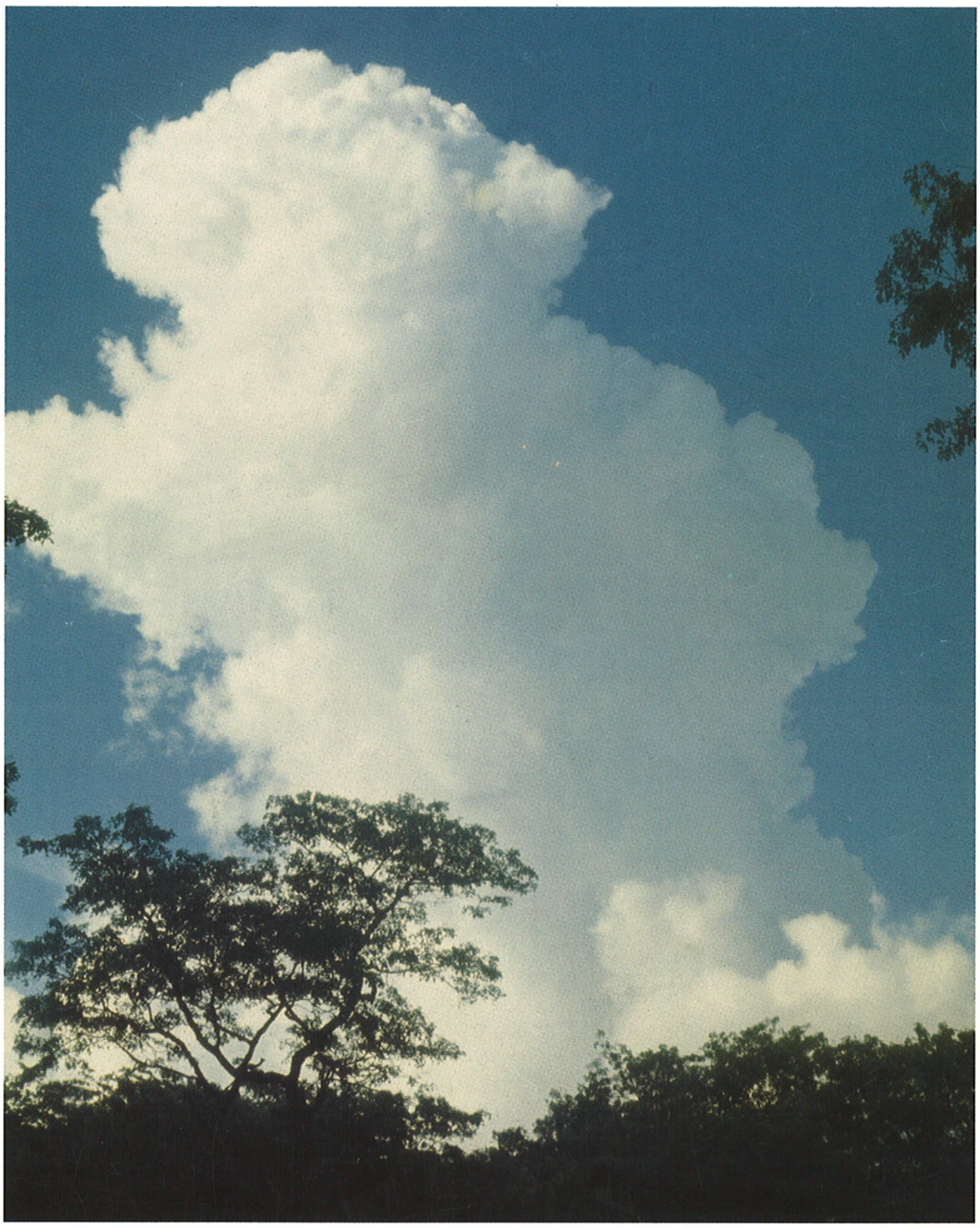

DNMI-REPORT

NORWEGIAN METEOROLOGICAL INSTITUTE
P.O. BOX 43 BLINDERN, N - 0313 OSLO
TELEPHONE: (+47) 22 96 30 00

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AUTHOR:

Sofus Linge Lystad
Ola Guldberg
Sigmund Bryntesen

PROJECT CONTRACTORS:

The Aircraft Accident Investigation board/Norway

Norwegian Meteorological Institute

SUMMARY:

As an effort to find an explanation of the Russian aircraft accident at Operafjellet near by Longyear in 1996, a test flight of a similar aircraft from the same Russian air company, Vnukovskie Avialinii, was set up in the period from the first of September to the fifth of September 1998. To monitor the radio climatic conditions in the area the Norwegian Air-craft Accident Investigation Board asked the Norwegian Meteorological Institute to perform necessary radio sonde ascents at Longear during the period. This report gives the results of the special radio sonde campaign, and compare the results to nearby standard radio sondes as well as a comparison of the results to the possible radio climatic conditions in 1996.

KEYWORDS:

1. Radio climatology, 2. Propagation of radiowaves, 3. Radio sondes

SIGNATURES:

Sofus Linge Lystad
SENIOR SCIENTIST

Bjørn Aune
HEAD OF DIVISION

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Acknowledgement

This campaign was initiated and funded by The Aircraft Accident Investigation board and the co-operation with this board has been a pleasure.

Among all other helpful persons at the airport at Longyearbyen we want to thank especially Mr. Arne Tollås and Mr. Snorre Stubmo for great help and solving nearly whatever practical problem we had in establishing the radio sonde stations and for communication equipment and transport.

We also are in great debt to Mr. Dirk Roehmermann at the Koldewey station of the Alfred Wegener Institute in Ny-Ålesund for providing us with the radio sonde ascents done at this site during the time of our work in Longyear and also for the 1996 observations.

Thanks go also to the Forecast division of the Norwegian Meteorological Institute for issuing special wind forecasts for the Svalbard area during our campaign.

Summary

During a 5 days radio sonde campaign (from 31 of August to 4 of September 1998) near by Longyear at Svalbard was launched 13 sondes to examine the radio climatic conditions in the landing route through Adventsdalen to Longeyear airport.

The obtained different refractivity profiles are examined as well as the distribution of the refractivity gradients.

Values from nearby radio sonde stations for the same period are also considered and the results are compared to the measurements done in Longyear. In addition profiles from this stations in 1996 are compared to the results obtained in 1998.

From the surface meteorological stations are computed surface refractivity both for 1996 and 1998 and the results are compared and discussed.

The statistical technique of Kolmogorov-Smirnov is then applied to give a statistical comparison of the computed refractivity profiles.

No elements of the theory of radio wave propagation are exposed in this report, for such material see for instance textbooks as [6] and [7] or reports as [1] and [4].

1.Background.

In the morning of the 29 of August 1996 a Russian Tupolev 154 aircraft of the Vnukovskic Avialinii hit the Opera mountain near by Longyearbyen airport at Svalbard under a landing approach with disastrous results. The Norwegian authorities represented by the «The Aircraft Accident Investigation board/Norway» (HSL) has in co-operation with the equivalent organisation in Russia tried to find the reason for this accident.

The Norwegian Meteorological Institute was contacted in the spring 1998 by HSL with the question if atmospheric conditions possibly could have been one of the reasons for wrong navigation with the respect to the ILS-system (Instrument Landing System) and therefore a fatal result.. The base in such a question is if the electromagnetic signals from an automatic landing-system has worked as expected in given atmospheric conditions.

The climate department of NMI has years of experience on radio climatology by a co-operation with the research unit of the Norwegian Telecommunication department, Telenor Research and Development. The work is mainly based on the description of the atmosphere done by the meteorological radio sondes on «line of sight» radio links, but also on general electromagnetic wave propagation through the atmosphere. This work has also been an international one, through the COST 235 project, where among others RAL (Rutherford Appleton Laboratories, UK) and CRC (Communication Research Centre, Canada) have been co-operative partners. From Russia the Radio Research & Development Institute (NIIR) has also participated in this project.

This knowledge was used in considering the existing observations from different radio sonde stations in the area and resulted in a report of the radio climatic conditions in the Svalbard area for the time of the accident [1]. The wish to combine this experience with a test flight of a Russian aircraft of the same type at Longyear airfield was expressed by HSL and agreed upon by NMI by offering two radio sonde stations, operating in Longyear at the time of the test flight.

2. Observation programme, objectives and set-up.

To experience the exact similar weather conditions in two different periods of time is more or less impossible. This is firstly due to the more or less chaotic behaviour of the atmospheric elements, but also to the complex interaction between the atmosphere and the «active underlying surface». A necessary but not at all sufficient condition is then to use the same period of time of the different years. In that case one can hope that differences in the yearly course between the atmosphere and the underlying surface may be minimised or at least reduced. Of the atmospheric state alone, nothing can be done. But again, this will also have its yearly course, and using the same approach (a similar yearly period of days of different years) again will maximise the chance of getting roughly the same weather conditions. Still this is more or less a case of hazard.

The main features exhibited as the most important radio climatological factors of the time of the accident was strong evaporation ducts in the nearby maritime area of Svalbard due to the «warm» sea waters of the late summer period. It was therefore suggested by the NMI that a possible test flight of the Tupolev aircraft should take place in late august, i.e. in the same period of the year as the accident took place. HSL agreed to this in an understanding with the Russian authorities. The date of the accident was the 29 of August 1996 and the period of the test flight and the necessary atmospheric measurements was then localised to the week no. 36, extending from 31 of August to the 6 of September 1998.

Due to practical considerations as available commercial flights from Norway to Longyearbyen and ample time to establish the necessary radio sonde equipment before the arrival of the Russian aircraft, it was decided that the personnel from NMI should leave Oslo the 30 of August. This ensured the arrival at Longyear the 31 of August with one day left for establishing the two radio sonde stations and be fully operative before the Tupolev aircraft had its scheduled arrival at the second of September. Test flights was scheduled on this day and if necessary also the following day,

Arriving at the Longyear airport on the 31 of August, we found a most helpful staff in the tower at the airport. Possible observation sites for the radio sondes was discussed as electricity and housing for the ground receiving devices was needed. Also, if possible some shelter for the inflated balloons just before launch. It was suggested that the facilities of «Nordlys observatoriet» at the site of the old airfield could be a suitable choice. In addition it was situated just in the flight path to Longyear airport. The use of this was confirmed by the authorities at «Nordlys observatoriet» in Tromsø and also at the local university authorities, UNIS, in Longyearbyen. We also got a car from the airport crew for our 250 kg of equipment and for transportation of the bottles of gas. To ensure continuos communication with the tower and mutual communication between LYR1 and LYR2 (see below) we also kindly were offered three sets of radio equipment that was of great help.

To get an idea of the spatial variation of the meteorological variables and then radio climatological conditions in the area it was determined to establish a second launching site for radiosondes. The second site was chosen at the ADV, a radio beacon some kilometres farther up in the Adventsdalen and still in the flight path to the airport, see map as figure 2.1. At the ADV site no ground receiving equipment's were placed, mainly because of the rather strong electromagnetic field radiated by the beacon. The two launching sites, temporarily got the identifications as LYR1 for the at «Nordlys observatoriet» and LYR2 for the ADV-site. Use of a GPS-position device gave the following co-ordinates for the sites:

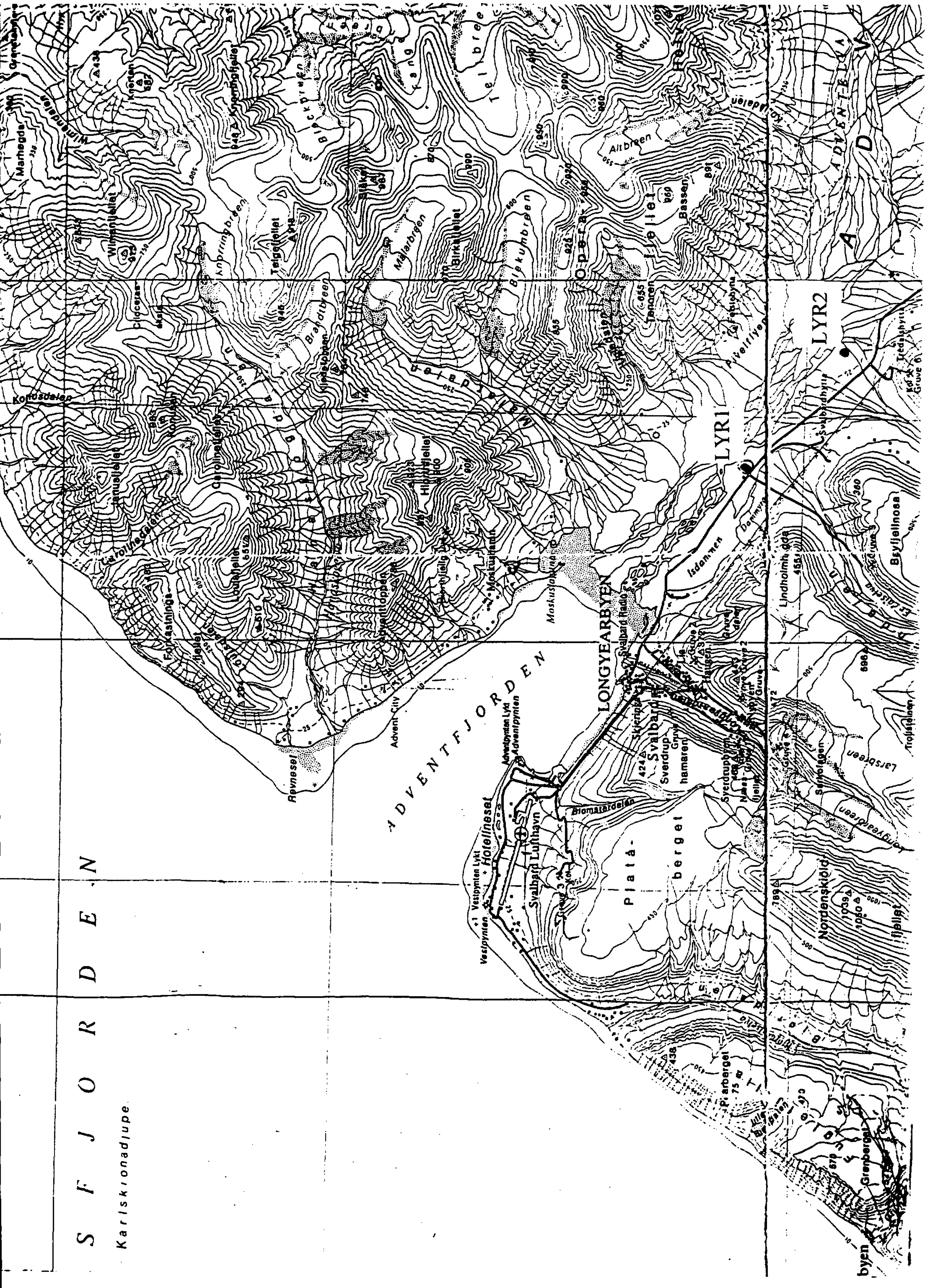
LYR1 : 78.12.09 LAT 15.49.50 LON 4 MASL
LYR2 : 78.10.30 LAT 16.00.08 LON 4 MASL

The procedure of launching two simultaneous radio sondes was after obtaining the car and the radio devices as follows: both radio sondes were made ready for launch at LYR1 and tuned by frequency to their own ground receiving station (the Digicora with wind handling and the PP15 with only the PTU, pressure, temperature and humidity values). The LYR2 (ADV)-sonde was used as an «old» Omega-sonde (the now closed down Omega navigating system) and then without position and no wind values, the LYR1 sonde was of the Loran navigation system type, giving also position and therefore the wind values. The balloon for the LYR1 sonde was then made ready and the radio sonde attached ready for launch. Sheltered by the building one man could then rather safely keep the inflated balloon with the radio sonde ready for launch. Then a not inflated balloon and a bottle of gas together with the ready made radio sonde was brought by car to the ADV-site. To secure continuos communication between this radio sonde and the ground equipment at LYR1, the radio sonde had to be held outside the car during the transport, a rather cold experience. Sheltered by the car and a small building at the ADV-site the other balloon was filled with gas and made ready with the radio sonde. By radio, both the airport crew (who gave permission to launch the radio sondes) and the two launching sites could communicate and ensure a simultaneous launch of the radio sondes.

In the afternoon of the 31 of August both the radio sonde stations were operative and one test launch, one single radio sonde received on both the Digicora and the PP15, was performed to ensure that both ground receiving devices was really operating and working without faults. The launch was performed successfully at standard WMO observation time, and the data from LYR1 was also submitted to the national meteorological service.

The procedures of two simultaneous sondes from LYR1 and LYR2 was tested the next day and resulted in unexpected problems; since also Ny-Ålesund (by the Alfred Wegener Institute) launches radio sondes of the same kind that we used (the Vaisala RS80) we got problems with the shearing of frequencies for the ground receiving equipment. A telephone call to this institute informed us that for the time being, not only the Ny-Ålesund used frequencies in the meteorological frequency band 400 to 408 MHz, but also the research vessel «Polarstern» from the same institution, was in the area and also performing radio soundings. A shearing of frequencies was easily agreed upon and the rest of the launches was performed with no problems, neither for us nor for the Alfred Wegener Institute. The first successful simultaneous radio soundings were performed at the hour 17, local time, and as proposed both stations were operative in the afternoon of the first of September.

Figure 2.1 Map of the Longyear area with the positions of the radio sonde stations LYR1 and LYR2



3. Observation results.

In the following we give the results from the observation campaign and, if possible, also compare the results with the data from the time of the accident. The data will thus consist of standard meteorological surface observations at possible hours 0, 6, 12, and 18 UTC , standard radio soundings at possible hours 0, and 12 UTC and the results of the radio soundings from our stations the LYR1 and LYR2 sites. In the following table 3.1 are given times for the various observations from those two stations, and in table 3.2 the observation hours for the stations Bjørnøya, Ny-Ålesund and Jan-Mayen.

Lyr1				Lyr2			
year	month	day	hour	year	month	day	hour
1998	08	31	18				
1998	09	01	18	1998	09	01	18
1998	09	01	24				
1998	09	02	04				
1998	09	02	08				
1998	09	02	12				
1998	09	02	18				
1998	09	03	04				
1998	09	03	06				
1998	09	03	12	1998	09	03	12
1998	09	04	12				

Table 3.1 Radio sonde ascents at LYR1 and LYR2.

Bjørnøya				Ny-Ålesund				Jan Mayen			
year	month	day	hour	year	month	day	hour	year	month	day	hour
1998	08	31	12	1198	08	31	12	1998	08	31	12
1998	08	31	24					1998	08	31	24
1998	09	01	12	1998	09	01	12	1998	09	01	12
1998	09	01	24					1998	09	01	24
1998	09	02	12	1998	09	02	12	1998	09	02	12
1998	09	02	24					1998	09	02	24
1998	09	03	12	1998	09	03	12	1998	09	03	12
1998	09	03	24	1998	09	03	24	1998	09	03	24
1998	09	04	12	1998	09	04	12	1998	09	04	12
1998	09	04	24	1998	09	04	23	1998	09	04	24

Table 3.2 Radio sonde ascents at Bjørnøya, Ny-Ålesund and Jan-Mayen.

From all radio sonde stations except Ny-Ålesund the «raw-data» exists, that is observations every 2 seconds during the ascent. From Ny-Ålesund we obtained data every 10 seconds, that gives an approximate height resolution of 50 m, whereas the 2 second data give the height resolution of every 10 m. It is here assumed an ascent rate of about 5 m/s as recommended for the meteorological services.

As seen from table 3.2 the standard observation hours are 12 and 24 in the day. It has been put forward that this hours represent either the most stable period of the atmosphere (hour 24) and at hour 12 most of the irregularities or layers in the atmosphere are driven aloft to heights not relevant for an investigation as this. The periods of shift from day to night or vice versa are then the most interesting, see for instance [2] or [3]. In the morning just before sunrise we have the possibility of formation of local inversions with definite layering of air near by ground. As the sun rises and the input of solar energy increases these layers may be driven to greater heights due to convective currents. We find clear evidence of this phenomenon in the ascents from LYR1 shown later on.

Since the accident also took place in the morning most of the soundings from LYR1 was performed in this part of the day, but as seen from table 3.1, soundings at the mandatory hours were done, mainly to have material for a comparison with the standard radio sondes from the nearby meteorological stations.

During our stay at Svalbard the «test aircraft» from the Norwegian Civil Air Administration visited the area to make measurements of the local ILS-system during the test flights of the Tupolev aircraft, and also in situations where the radio-soundings indicated ducting conditions in the area.

As shown in [1] a duct able to effectively catch waves with the wavelengths of that of an ILS-system must have a «depth» of at least 300 m besides being of ample intensity. We can state at once that even ducts were recorded during the campaign no one had the «right» combination of depth and strength or intensity to cause serious problems for the ILS-frequencies.

Another major difference between the radio climatic conditions in August/September of 1996 and that of the same period in 1998 is the lack of strong ground based or evaporation ducts, see the discussion below.

3.1 Radio sonde observations from Longyear.

From table 3.1 we find a total of 13 ascents performed from LYR1 and LYR2 during the campaign. This is by all means not a number necessarily to make a statistics for the radio climatic conditions of the Longyear area. But it can serve as a basis either to strengthen or to weaken some of the conjectures made in [1]. Further it can give some results in comparison with data from the ordinary radio sonde stations in the area and thus establish possible similarities between the stations.

Let us first start to examine the simultaneous ascents from LYR1 and LYR2, figures 3.1.1 to 3.1.4 (refractivity profiles and refractivity gradients). For this and all other figures we restrict the height interval from ground up to 2500 m to obtain maximum resolution in the range where the landing approach takes place. The full radio sonde ascent in the polar regions reaches normally up to about 35000 m.

As the air moves into the valley (Adventsdalen) and the land slightly rises when also the valley narrows, the air should be moved upwards due to continuity conditions. Existing layering of the atmosphere should then be found at slightly higher levels at LYR2 than observed at LYR1. This is well demonstrated in figure 3.1.1 showing the refractivity profiles in M-units for high noon (hour 12). The duct in approximate 1200 m level (LYR1, red line) is slightly moved upwards at LYR2 (blue line). Above approximately 1500 m the effect of the terrain is negligible and the two profiles are nearly identical. We can thus say that low lying atmospheric structures at the outlet of the valley can be moved upwards as the air mass moves into the valley. The conjecture of movements of strong evaporation ducts into the valley could therefore to some degree be justified.

Next we examine the different refractivity profiles for LYR1. These are shown in figures 3.1.5 to 3.1.9 for the profiles and we pool together all ascents for each day on one figure. The profile of 31 of August at hour 18 is a nice example of a well mixed atmosphere with no layering at all. The first of September we observe a duct structure in about 1200 m level. The structure are weak at 18 hour but evolves to a well defined duct about midnight. Small irregularities are also observed at 18 hour in 1700 m and just above 2000 m but these are both weak and also very narrow structures. At the second of September we have four profiles, two in the morning, one at high noon and one in the afternoon. The morning profiles show that the duct from the midnight has moved down to a lesser height, now about 1000 m, lowest at four o'clock and rise a little at 8 hour. Both depth and intensity are more or less unchanged. Energetic mixing of the atmosphere in the middle of the day diminish the duct structure at noon and we observe that at hour 17 the whole structure has disappeared.

For the third of September we have 3 profiles and again we find ducts in the 1200 m level for both early morning, and afternoon and also for noon but this structure is not so clear as the others. Ducts have therefore regenerated during the late afternoon of the day before and perhaps evolved during the night. Following the theory the duct structures are most pronounced in the morning as well as the afternoon. Also in the height levels between 1500m and 1700m we find a duct moving down during the day. Another structure appears just below 2500 m.

The fourth of September, the last day of the radio sonde campaign, was launched only one balloon, giving a refractivity profile at noon, hour 12. The pronounced duct structures between 1000m and 1200m have disappeared, leaving only a very weak non-ducting structure in approximately 1200 m. However the structure below 2500 m has evolved a little and represent here the only observed duct in this profile below 2500 m.

In figures 3.1.10 to 3.1.14 are shown the refractivity gradients in M-units pr km for the profiles discussed above. From this figures it is easy to identify the ducts as dM/dz for this case is less than zero. The value of the negative gradient may also roughly indicate the intensity of the duct and we find the «most negative» value for the duct in the profile for 3 September at hour 4 in the height level of about 1700 m but again, none of these ducts have the necessary depth to effectively trap the waves from the ILS system.

Since the gradients in some way a accentuate the pictures of the layers in the air we can also use these to look for evaporation or surface based ducts. We find no ducts of that kind, but at both the 3 as well as the 4 of September rather strong super refractive structures evolve in the bottom layer, see also the results from Ny-Ålesund.

Figure 3.1.1 Refractivity profiles from LYR1 and LYR2

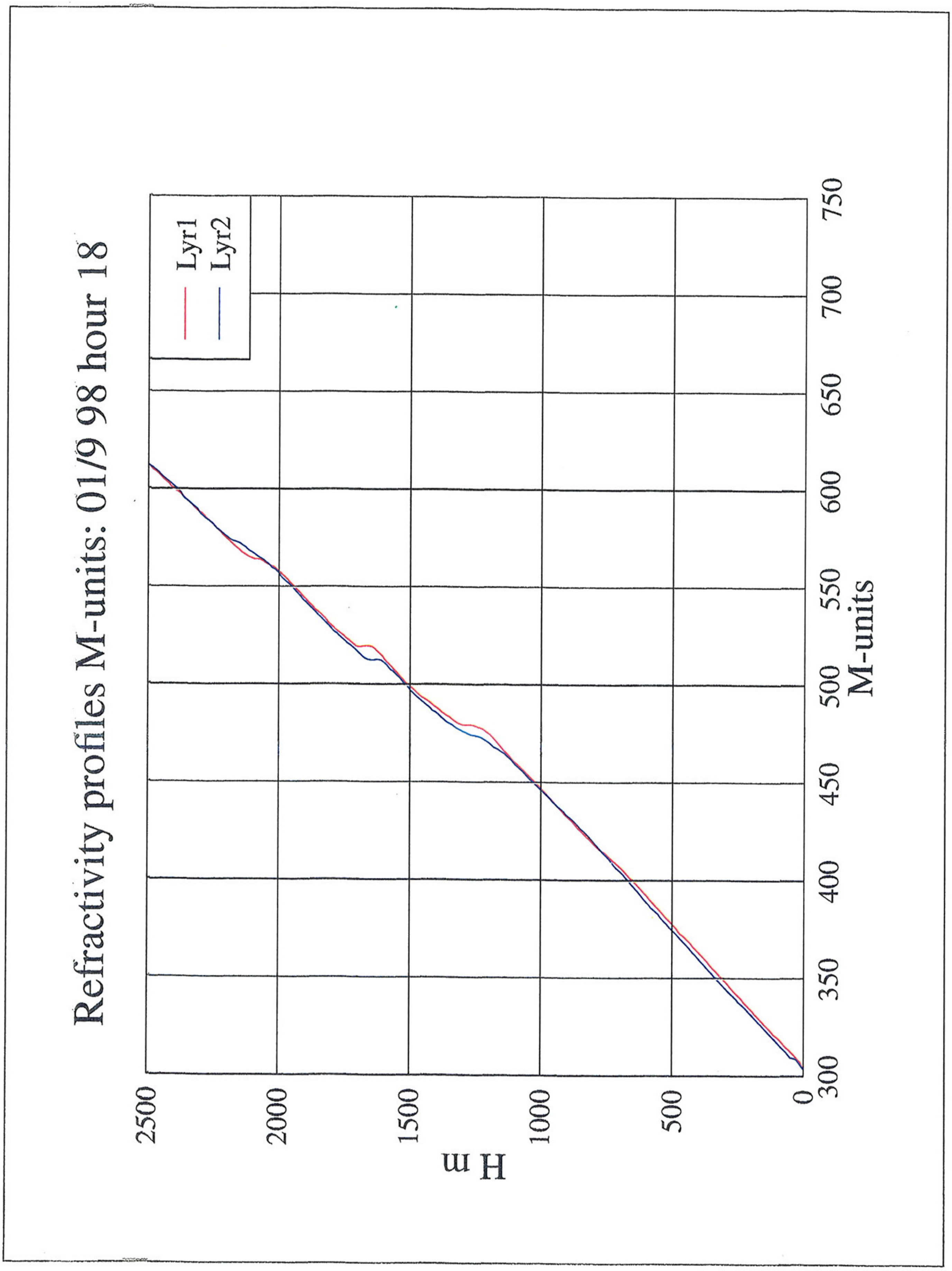


Figure 3.1.2 Refractivity gradients from LYR1 and LYR2

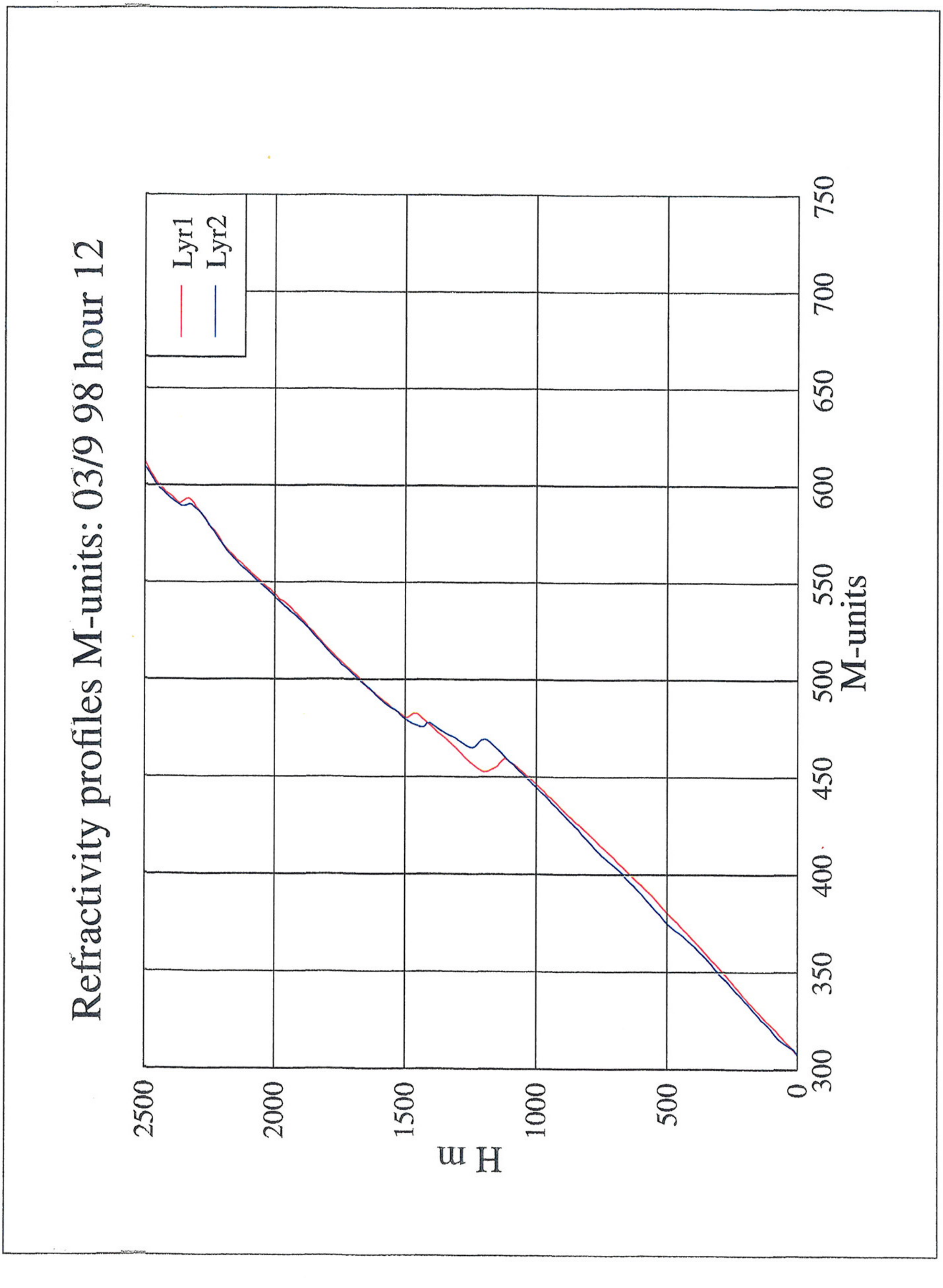


Figure 3.1.3 Refractivity profiles from LYR1 and LYR2

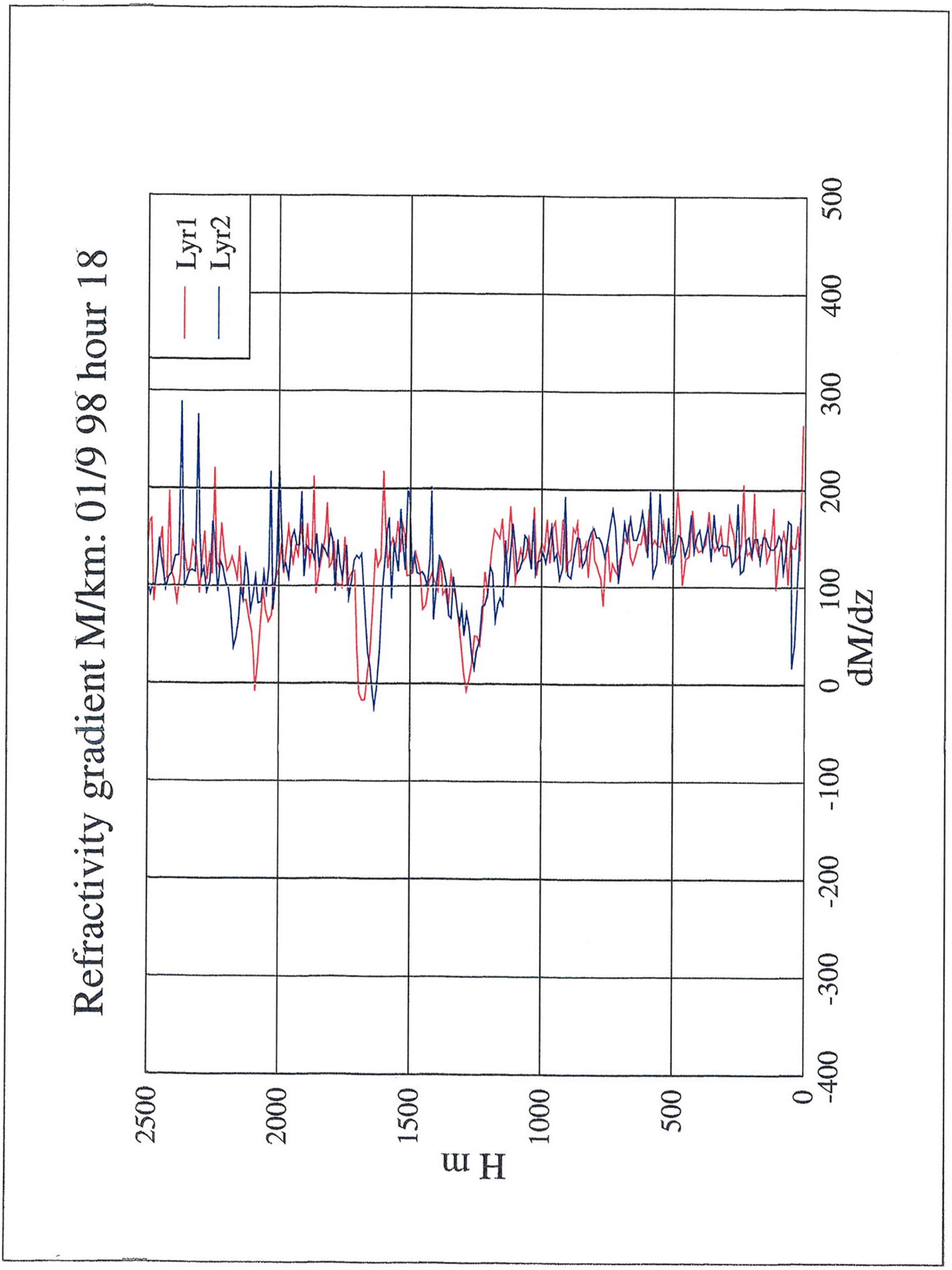


Figure 3.1.4 Refractivity gradients from LYR1 and LYR2

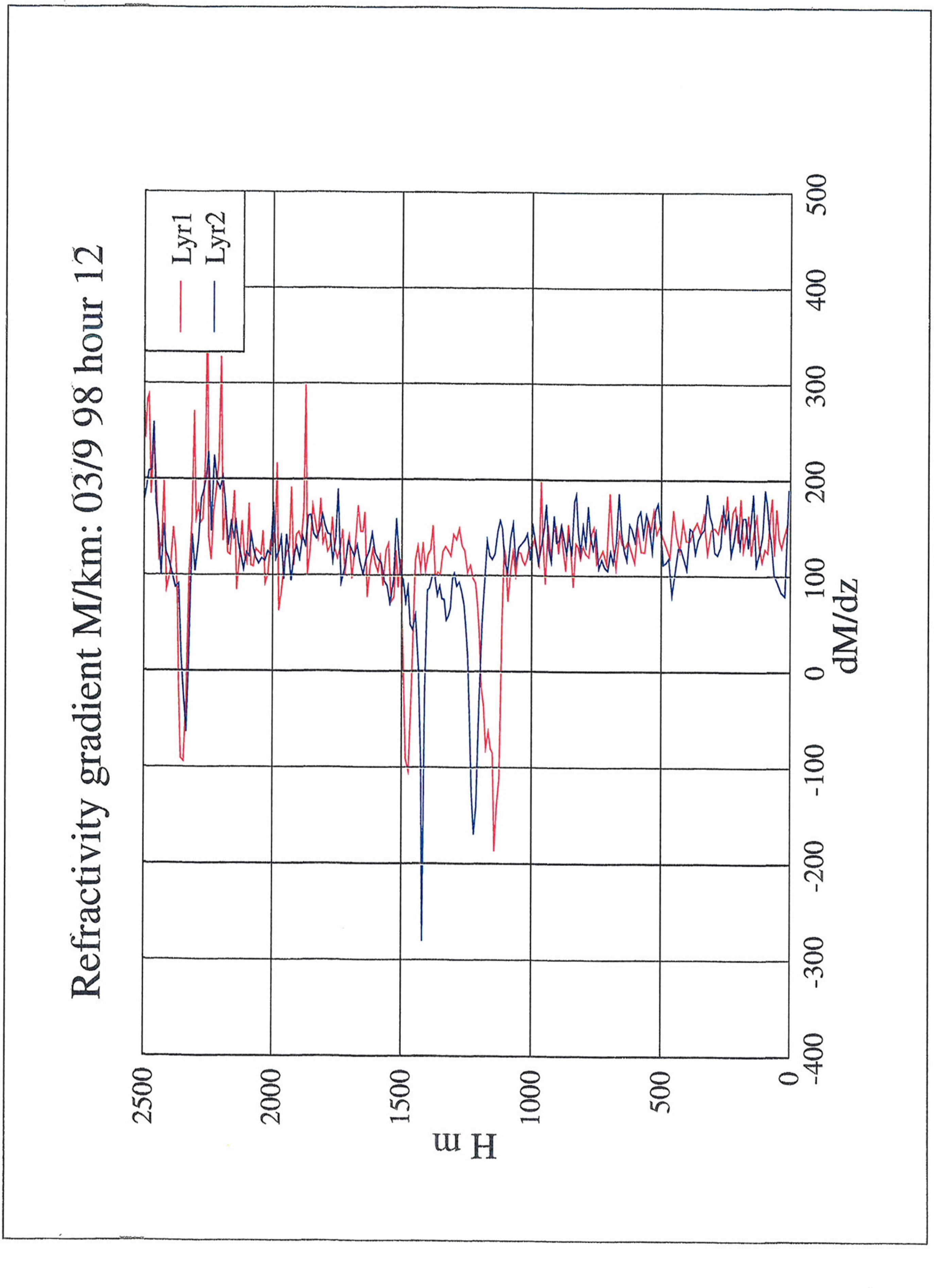


Figure 3.1.5 Refractivity profiles from LYR1

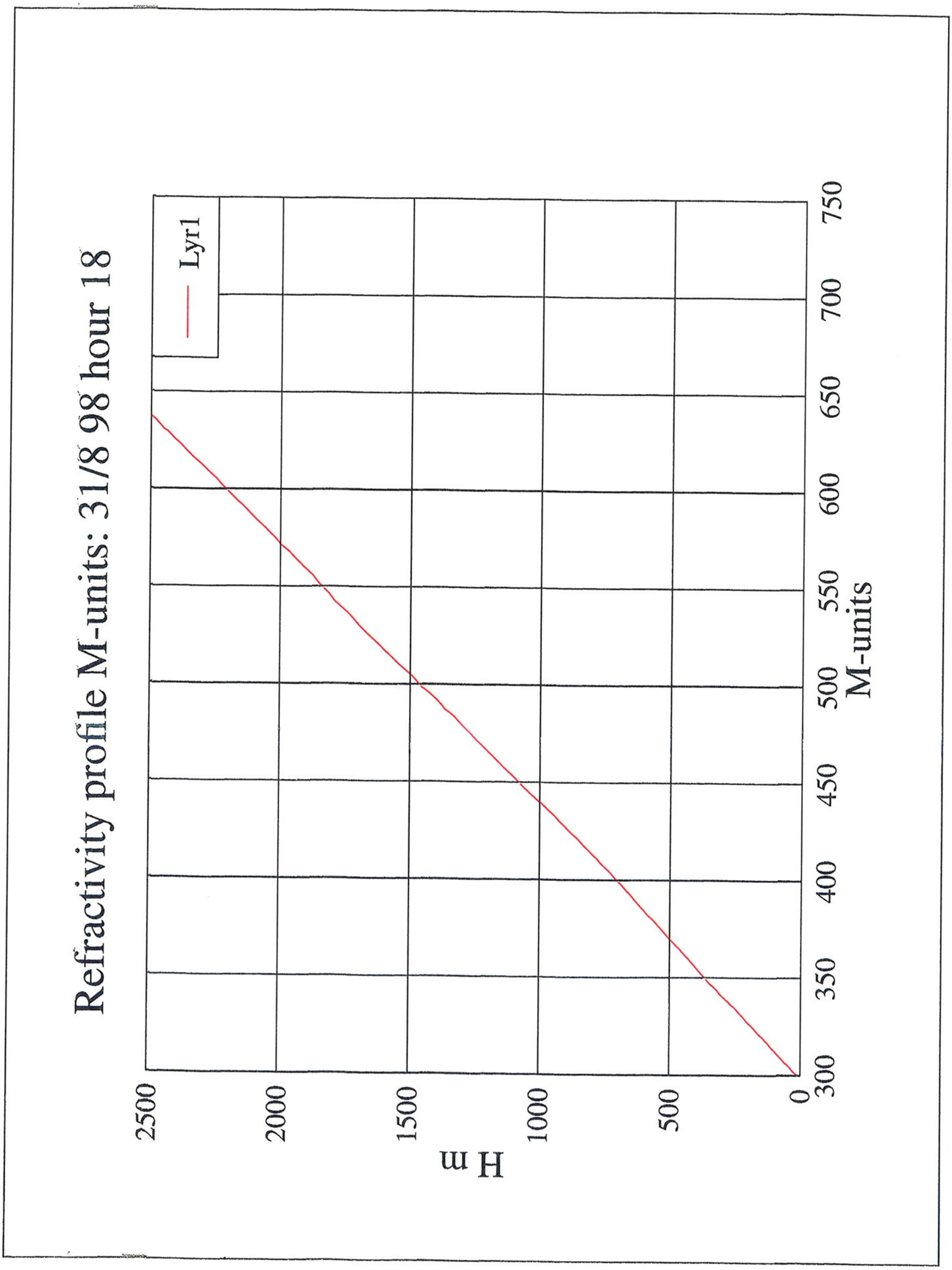


Figure 3.1.6 Refractivity profiles from LYR1

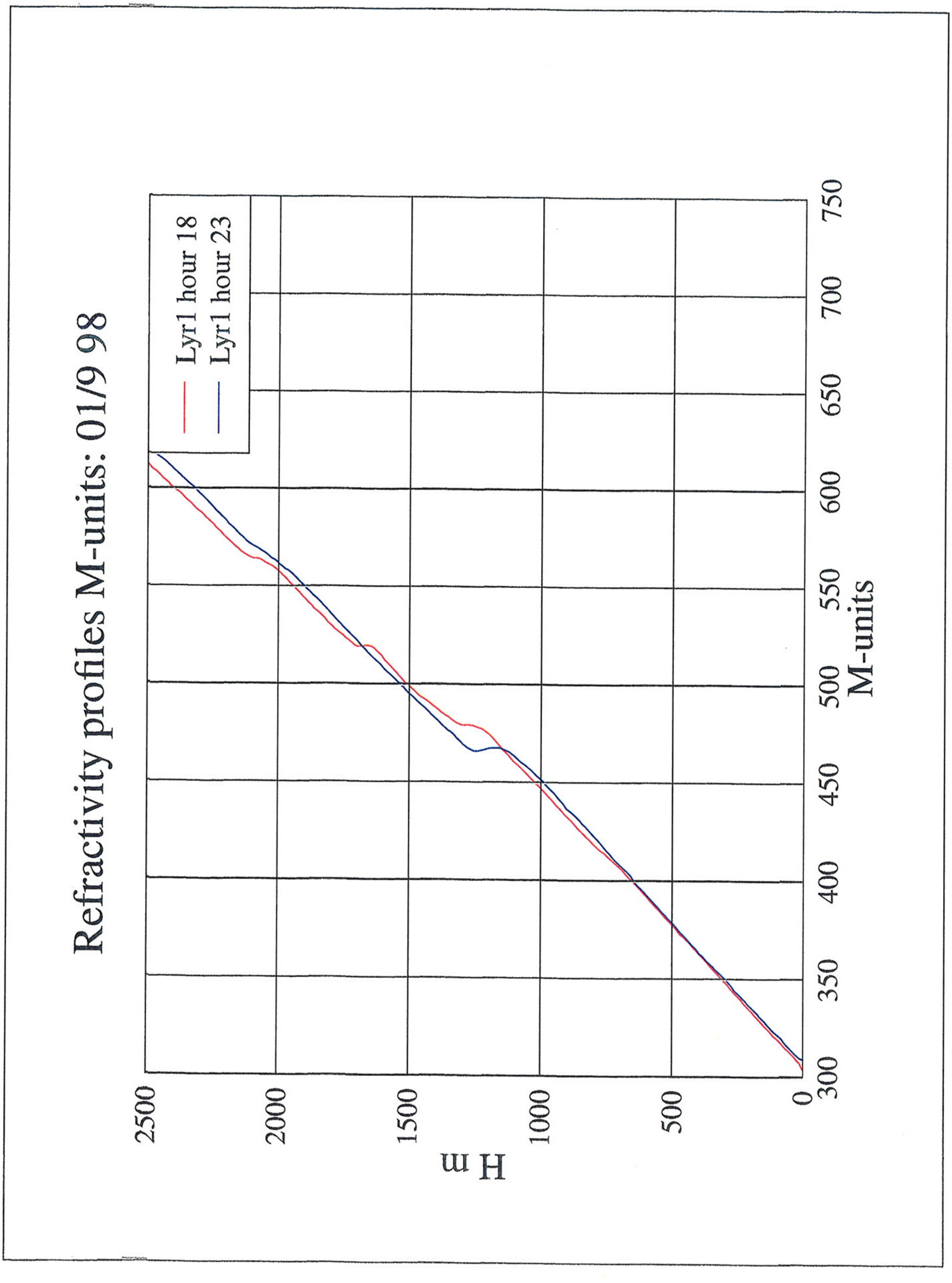


Figure 3.1.7 Refractivity profiles from LYR1

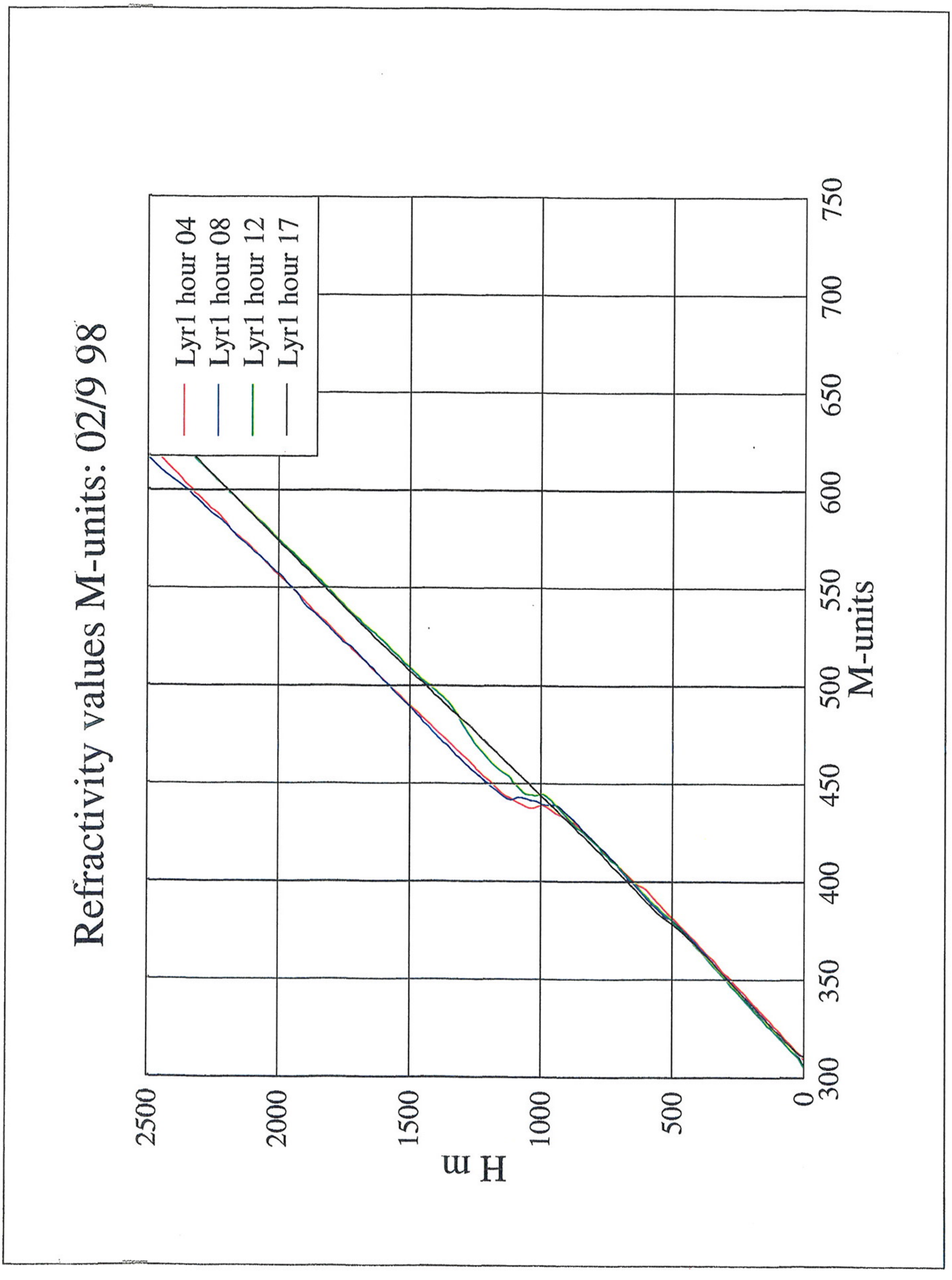


Figure 3.1.8 Refractivity profiles from LYR1

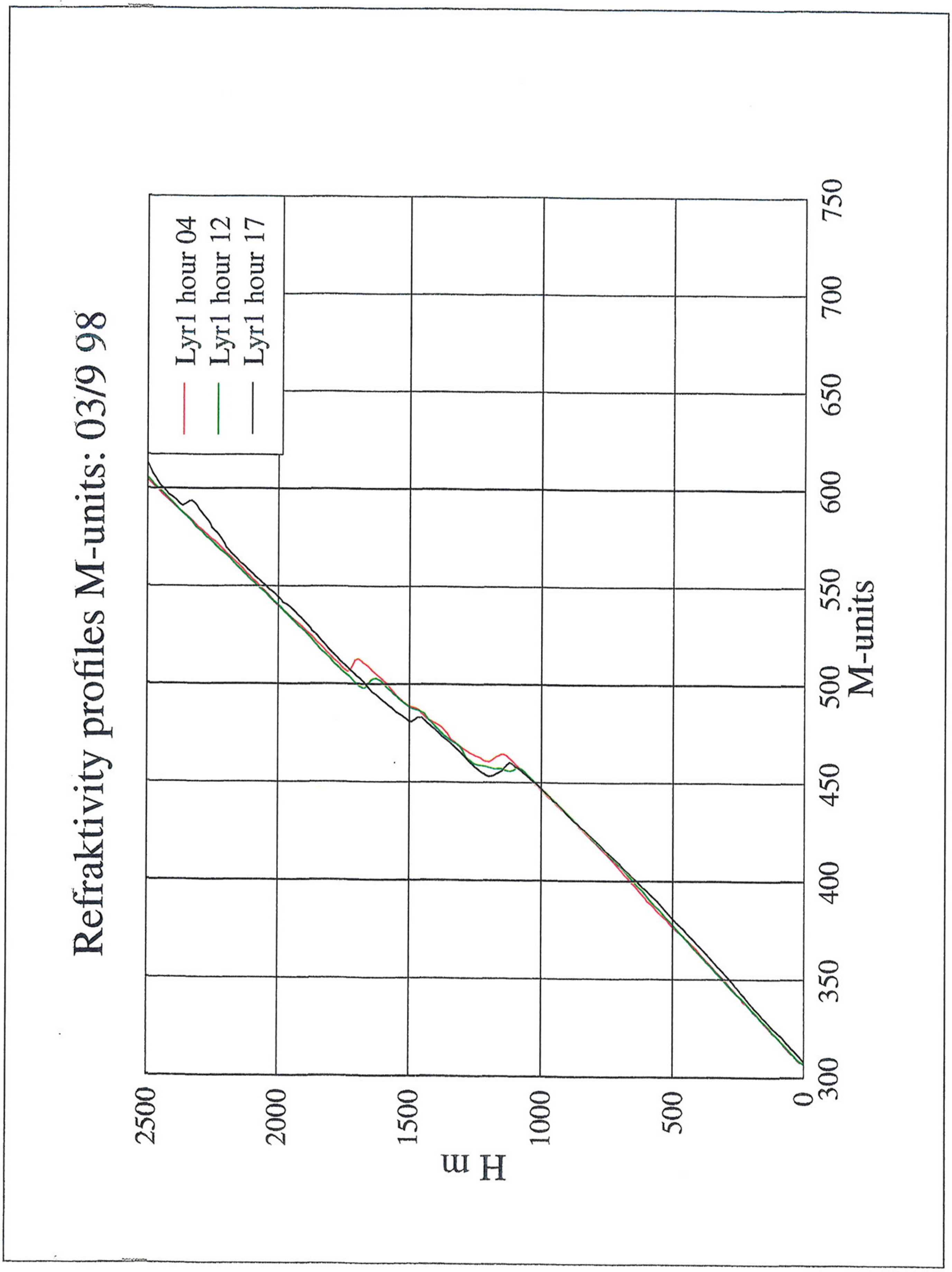


Figure 3.1.9 Refractivity profiles from LYR1

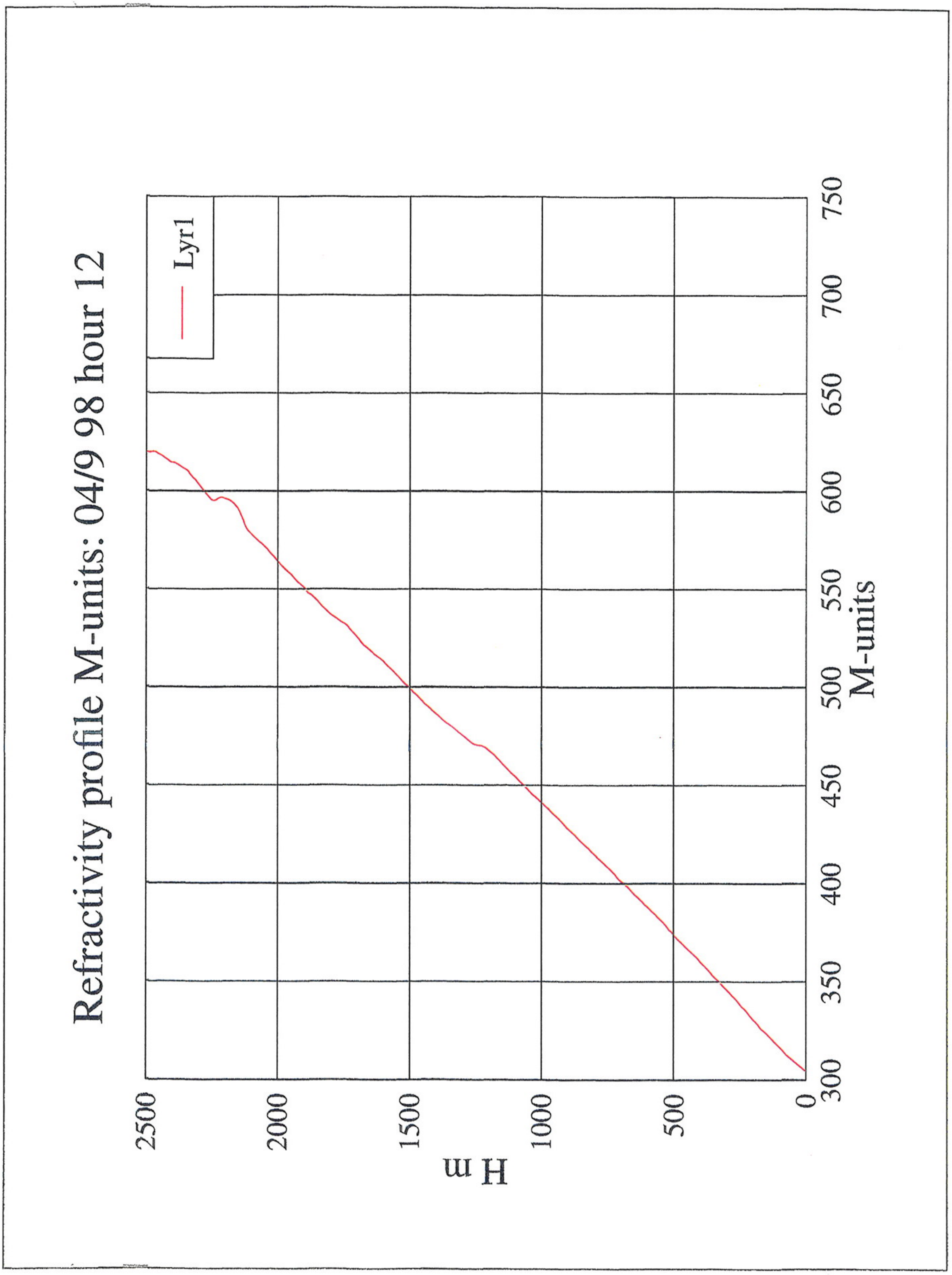


Figure 3.1.10 Refractivity gradients from LYR1

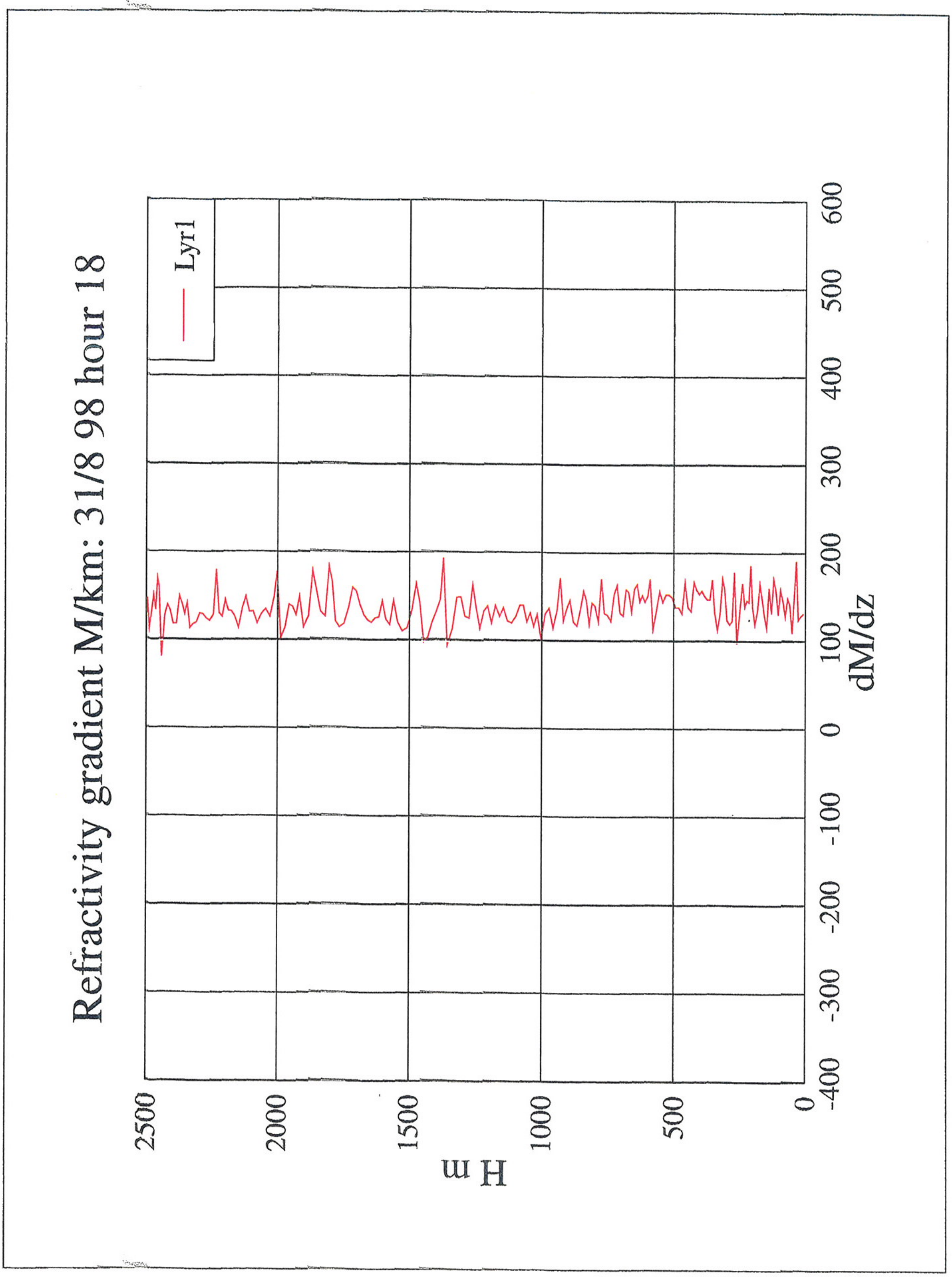


Figure 3.1.11 Refractivity gradients from LYR1

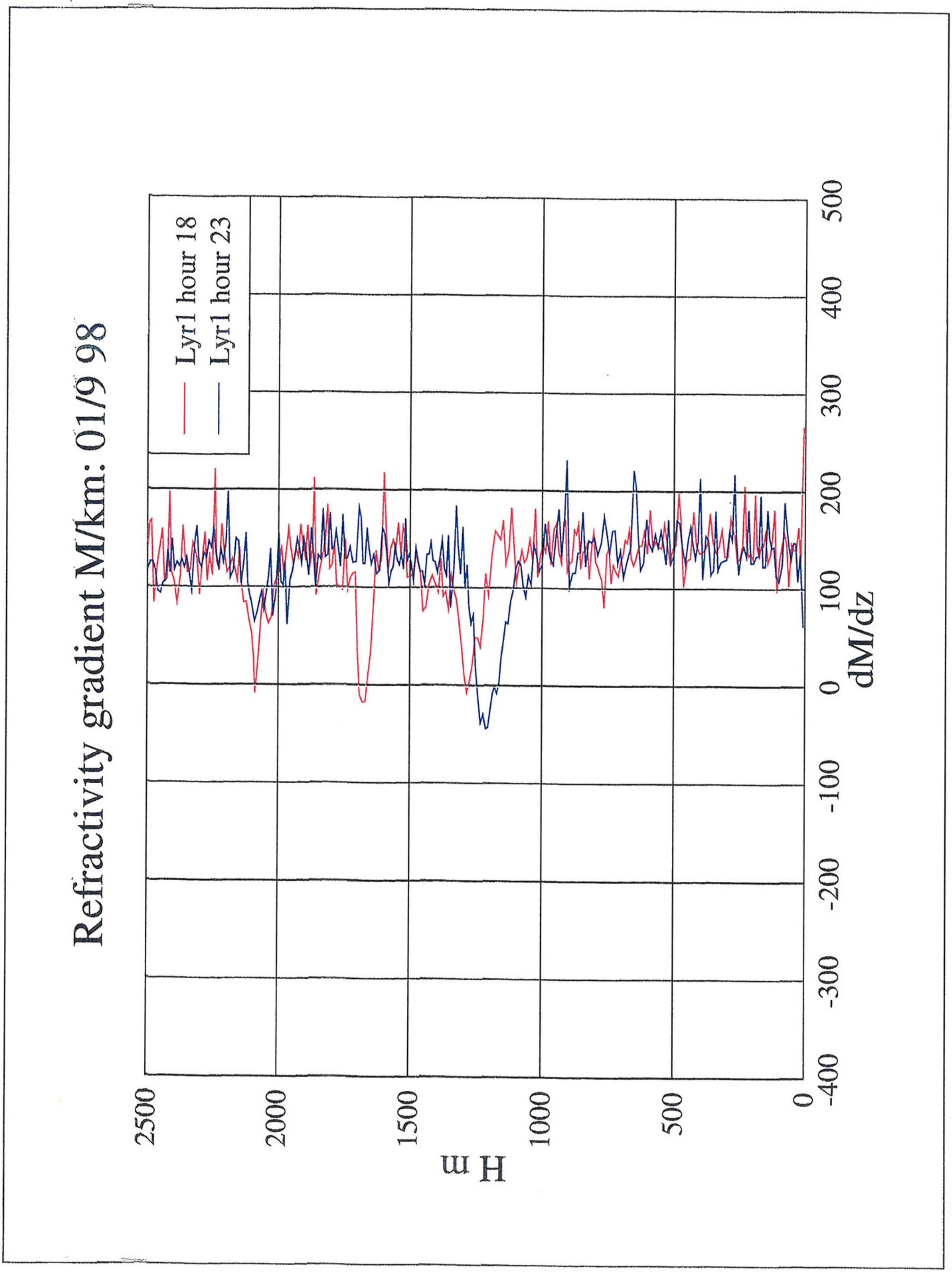


Figure 3.1.12 Refractivity gradients from LYR1

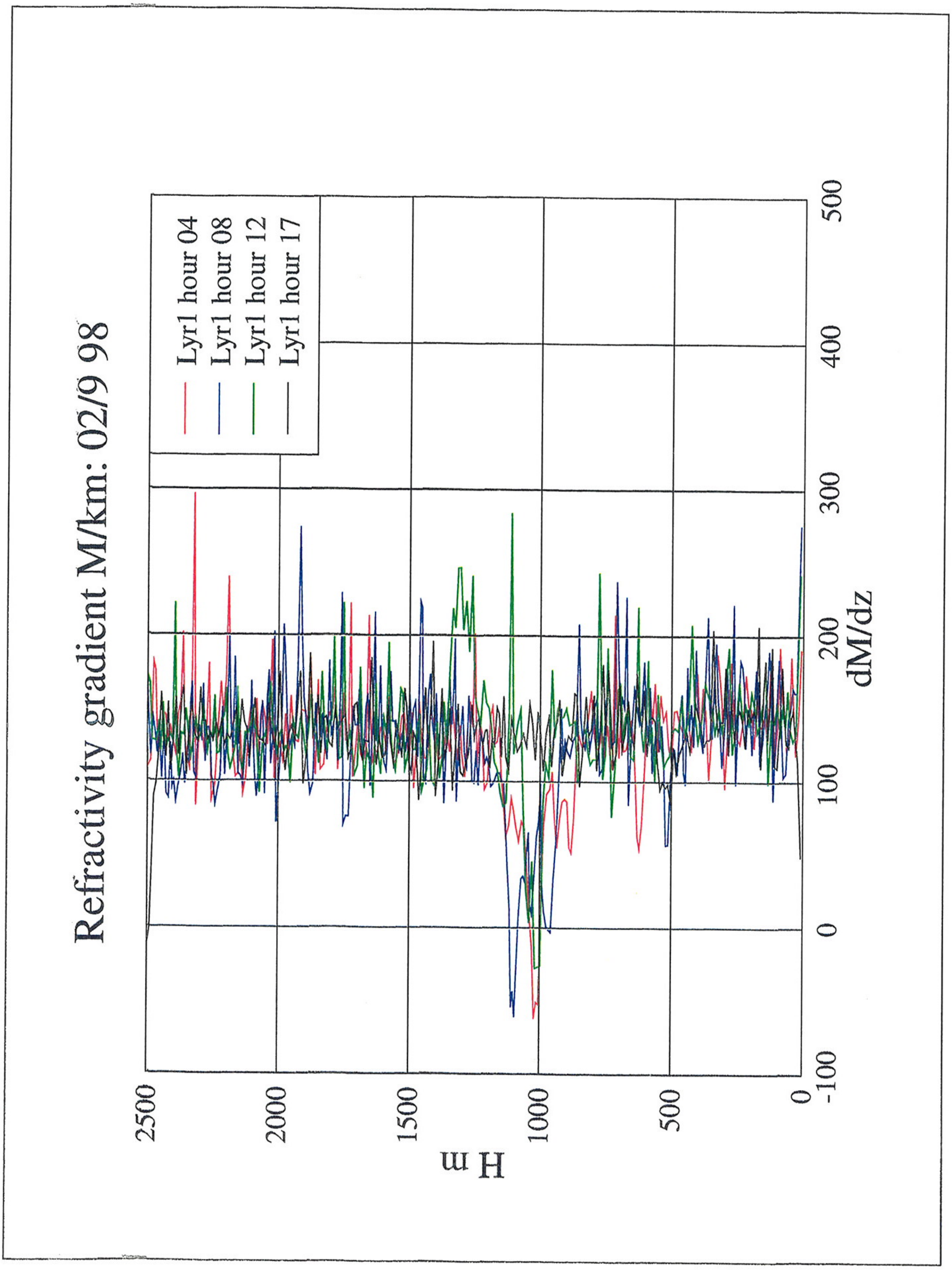


Figure 3.1.13 Refractivity gradients from LYR1

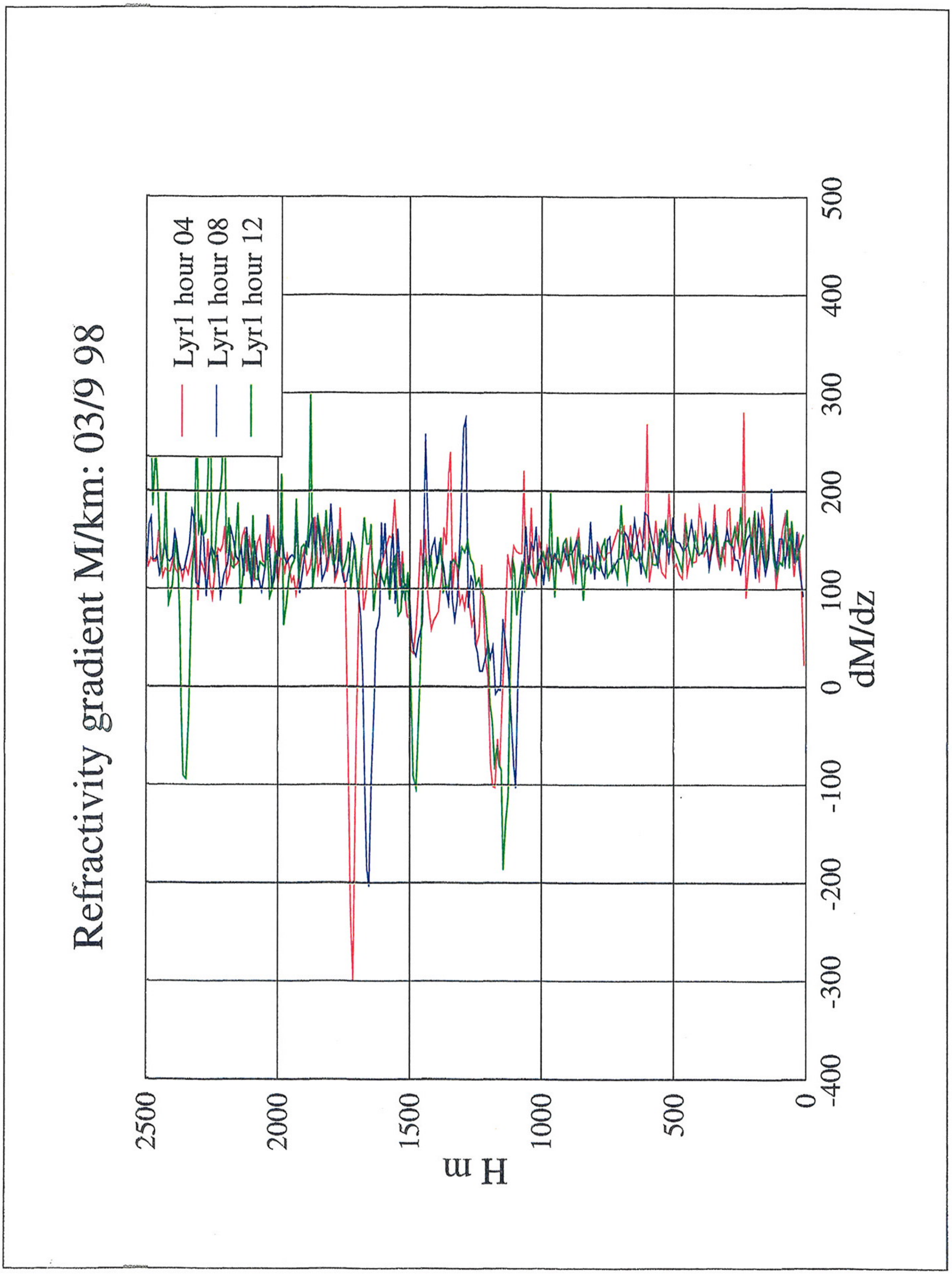


Figure 3.1.14 Refractivity gradients from LYR1

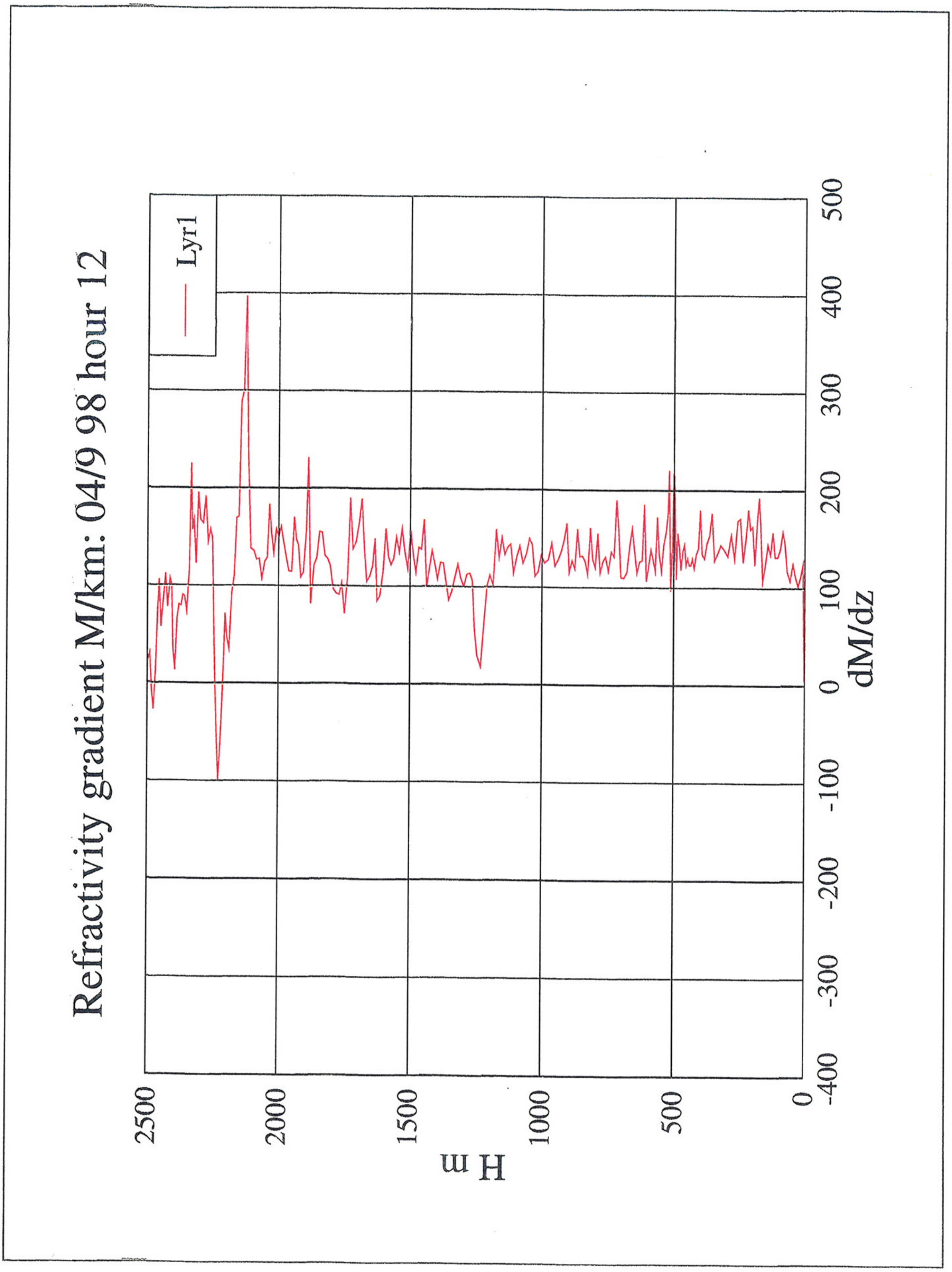


Figure 3.3.1 Refractivity profiles from Ny-Ålesund

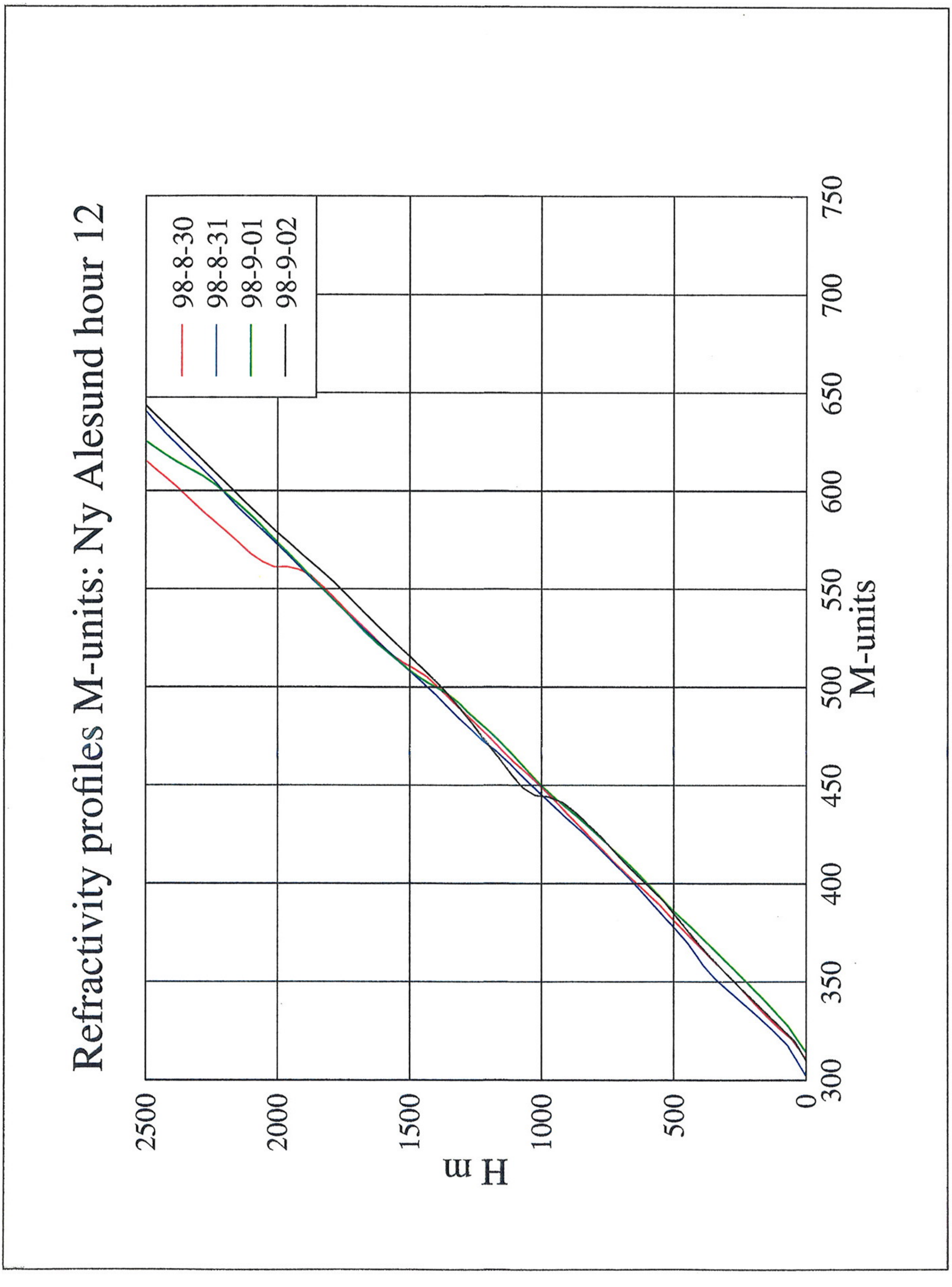


Figure 3.3.1 Refractivity profiles from Ny-Ålesund

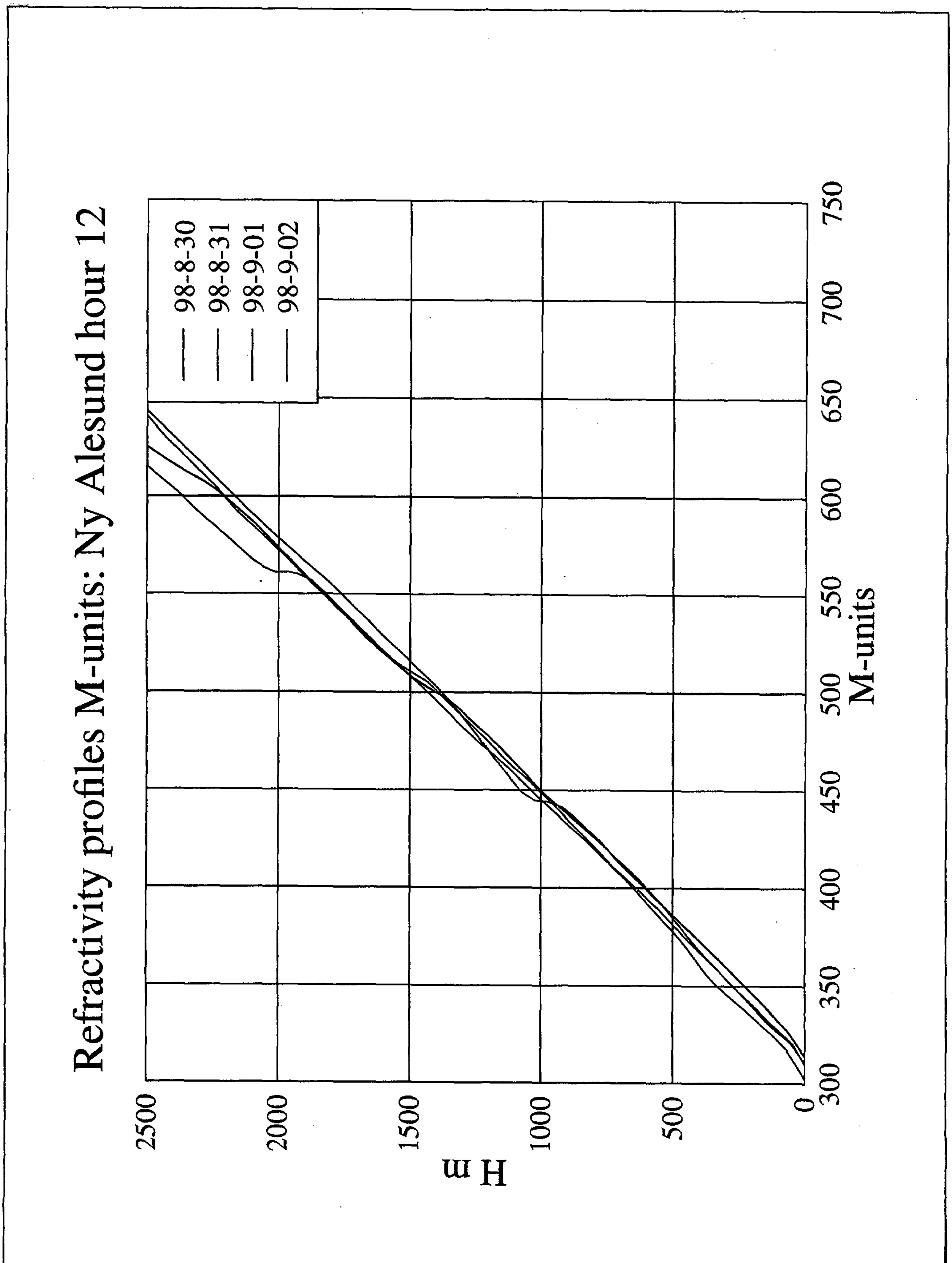


Figure 3.3.2 Refractivity gradients from Ny-Ålesund

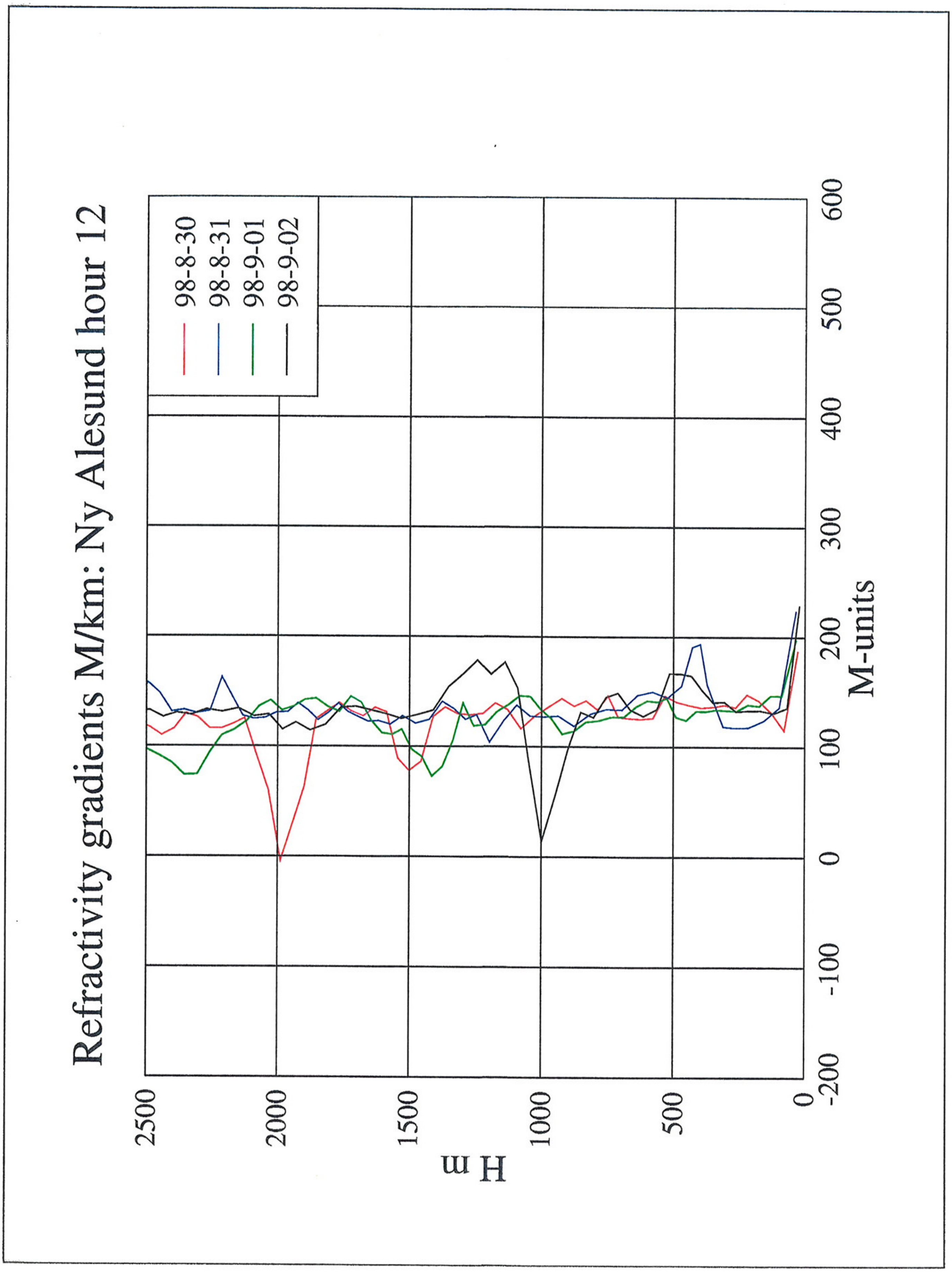


Figure 3.3.3 Refractivity profiles from Ny-Ålesund

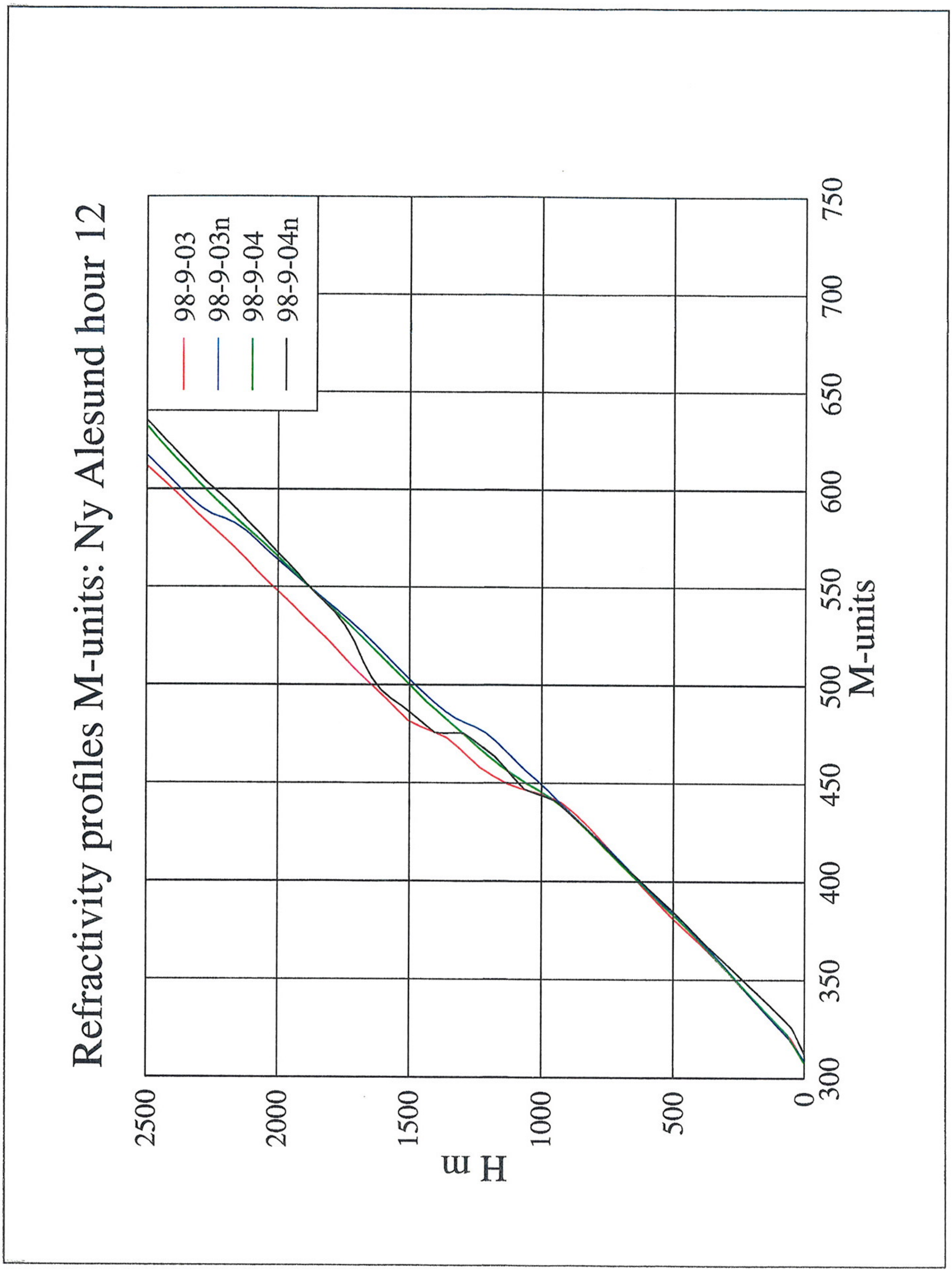
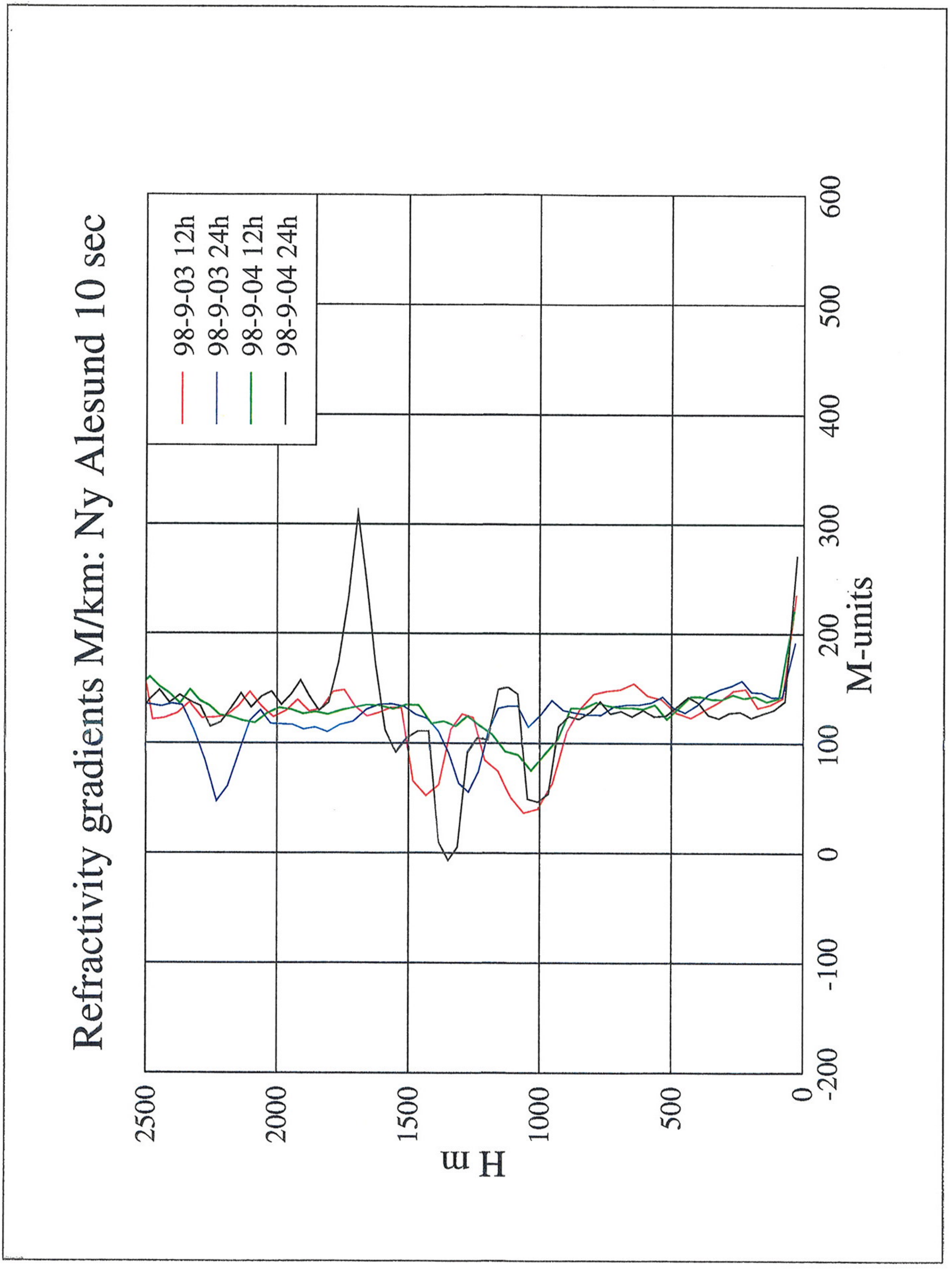


Figure 3.3.4 Refractivity gradients from Ny-Ålesund



3.3 Radio sonde observations from Bjørnøya.

Looking at the standard 2 sec ascents for Bjørnøya we can make figures 3.3.1 to 3.3.5 for the refractivity profiles and figures 3.3.6 to 3.3.10 for the refractivity gradients. when collecting both the noon and night ascent for one day in the same picture. We observe the following; for the 31 of August a weak duct in the 500m level at noon and a well developed duct in the 1400 m level at night. However, for both hours well established evaporation ducts exist, strongest at night with a gradient of about -600 M/km. For the first of September we find a most regular profile at noon except for again the surfacebased evaporation duct with a gradient of about - 250 M/km. At night the same day naturally the surfacebased duct evolves and we have now a gradient for the refractivity of about -450 M/km. In addition is created a duct structure in 750 m level with also several superrefractive structures between this level and the 1200 m level.

The 2 of September the evaporation ducts still exists both for day and night, with gradients strongest in the night of about -320 M/km. The value of the day is slightly less and amounts to nearly -200 M/km. In the day we observe that the duct structure from the night before still exists but has moved down a 100 m and the gradient has diminished to -150 M/km. In addition is created a superrefractive structure just below 1000 m. At we find a narrow duct in 1800 m, and several strong superrefractive layers between 1000 m and 1500 m.

The 3 of September the evaporation ducts still exists here both for noon and night, but weaker with the greatest gradient value at night of about -140 M/km. A permanent duct structure exists in the 1250 m layer both at noon and night. Subrefractive structures exist in the 900 to 1300 m layer at noon, moving up at night to about 1200 to 1300 m level. At the fourth of the September we find at noon still a well developed duct in the 1200 m level and the narrow surfacebased duct has reduced to a subrefractive structure. This structure evolves at night to a real surface duct, the gradient in the lowest layer is then -300 M/km, whereas the duct encountered at noon moves down and weakens to a subrefractive structure at about 1100 m.

Figure 3.3.1 Refractivity profiles from Bjørnøya

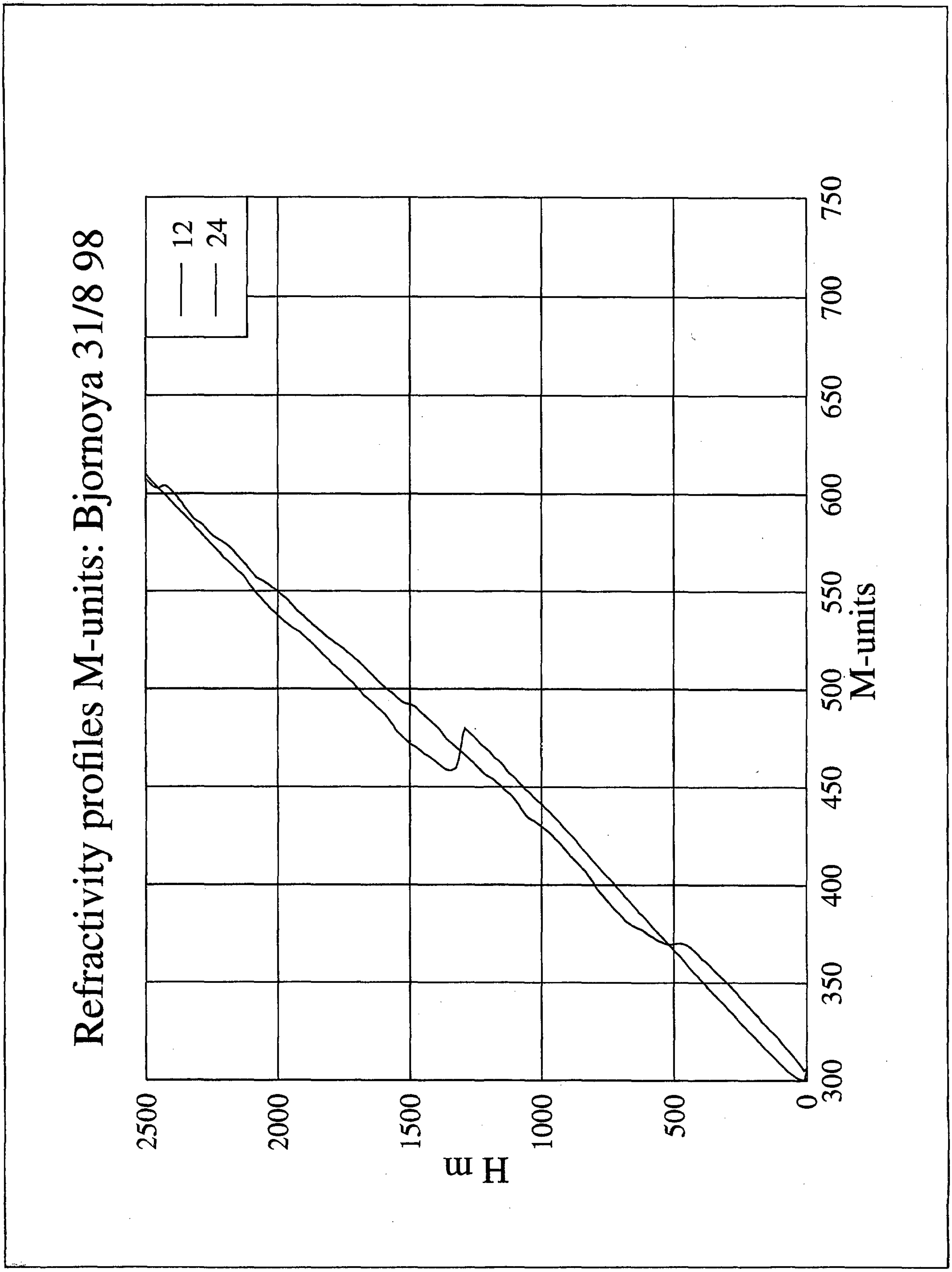


Figure 3.3.2 Refractivity profiles from Bjørnøya

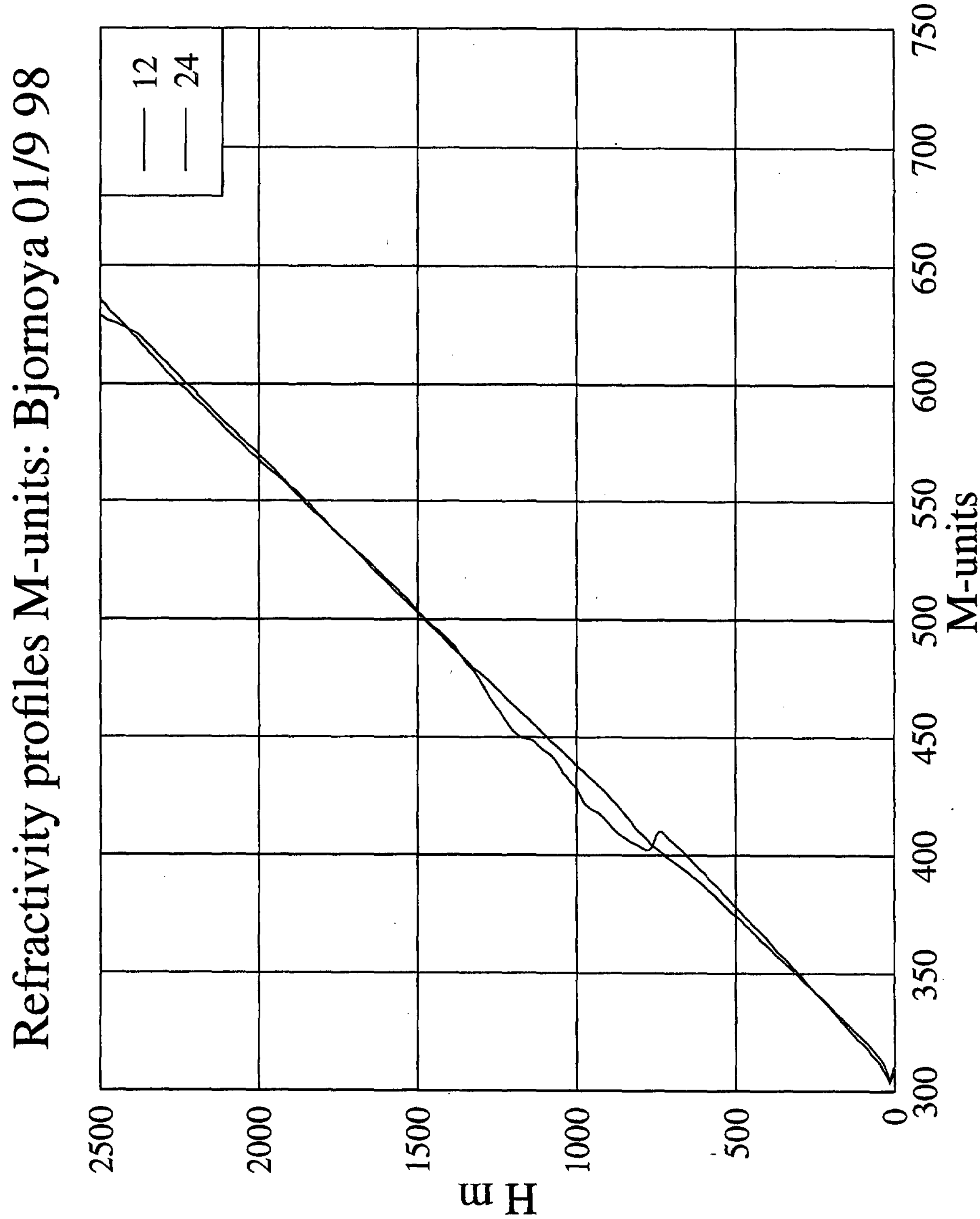


Figure 3.3.3 Refractivity profiles from Bjørnøya

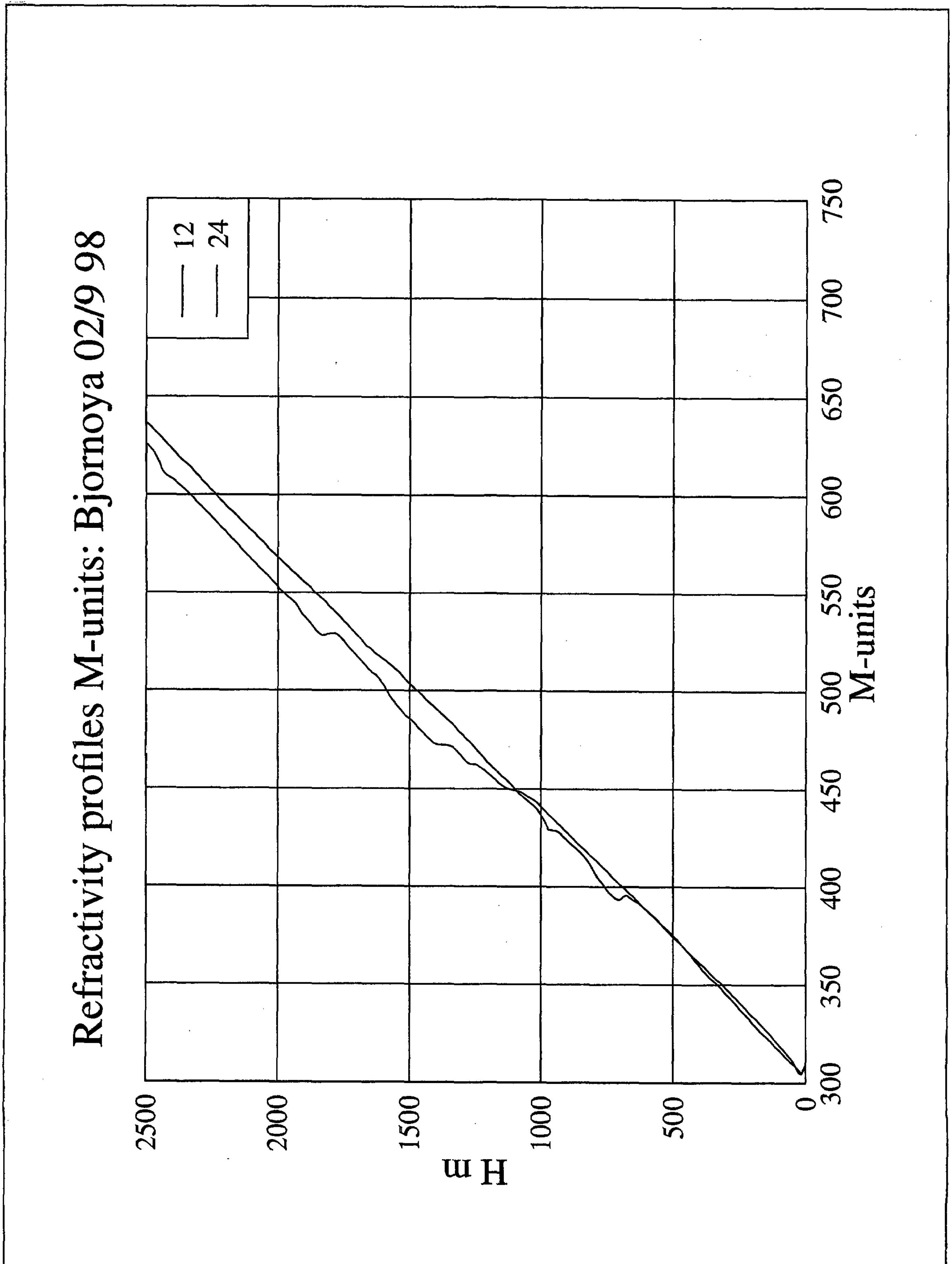


Figure 3.3.4 Refractivity profiles from Bjørnøya

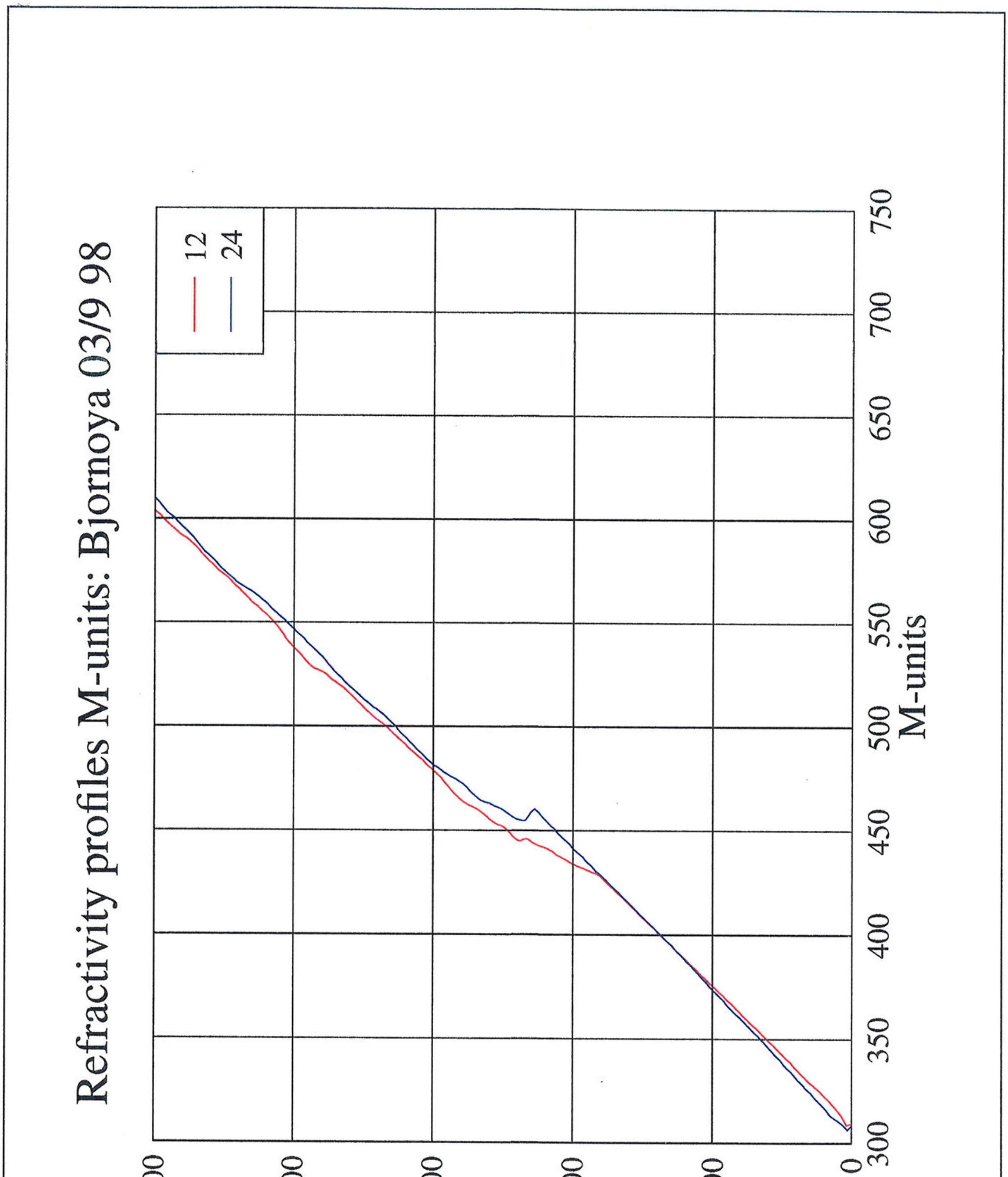


Figure 3.3.5 Refractivity profiles from Bjørnøya

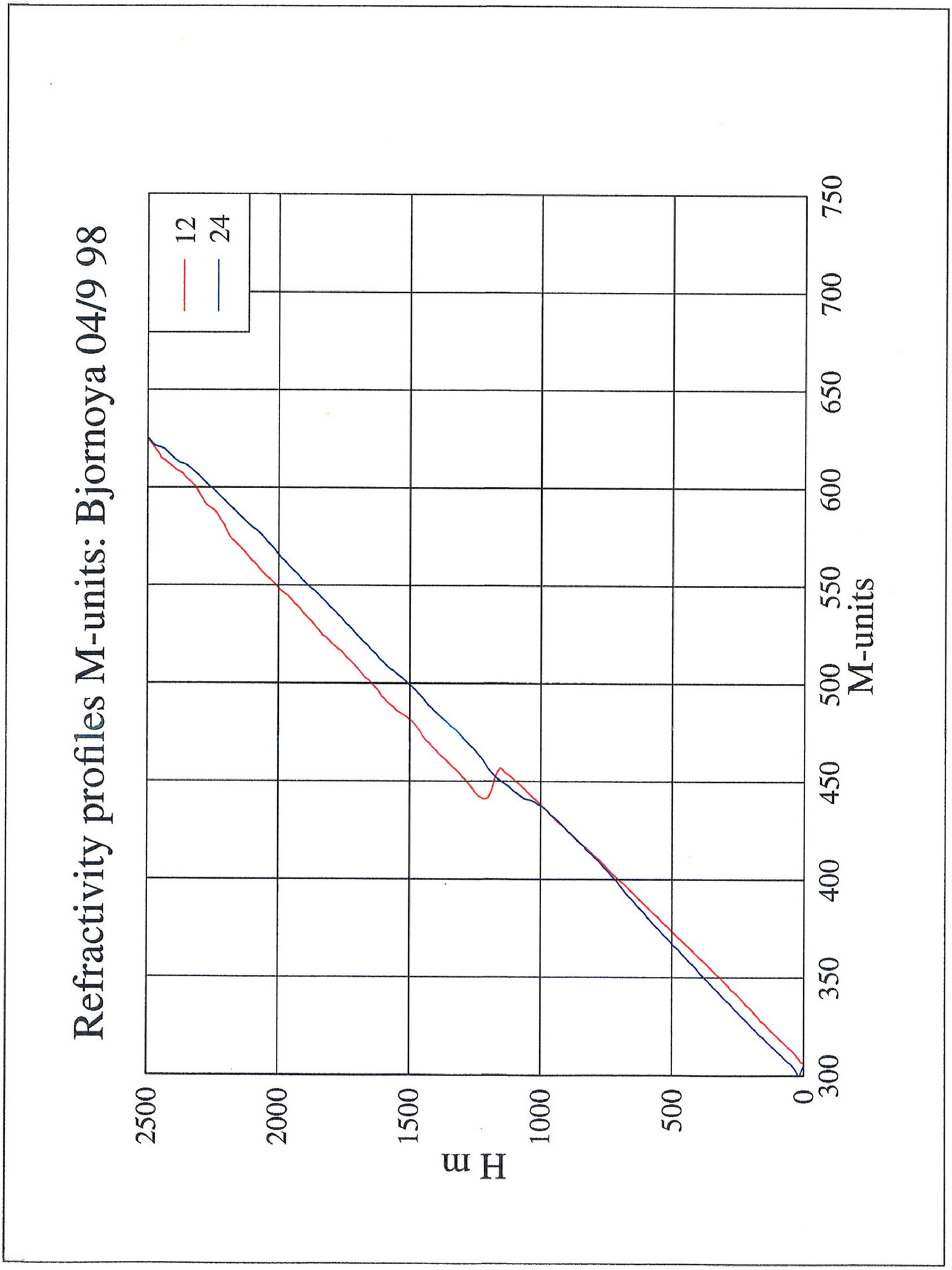


Figure 3.3.6 Refractivity gradients from Bjørnøya

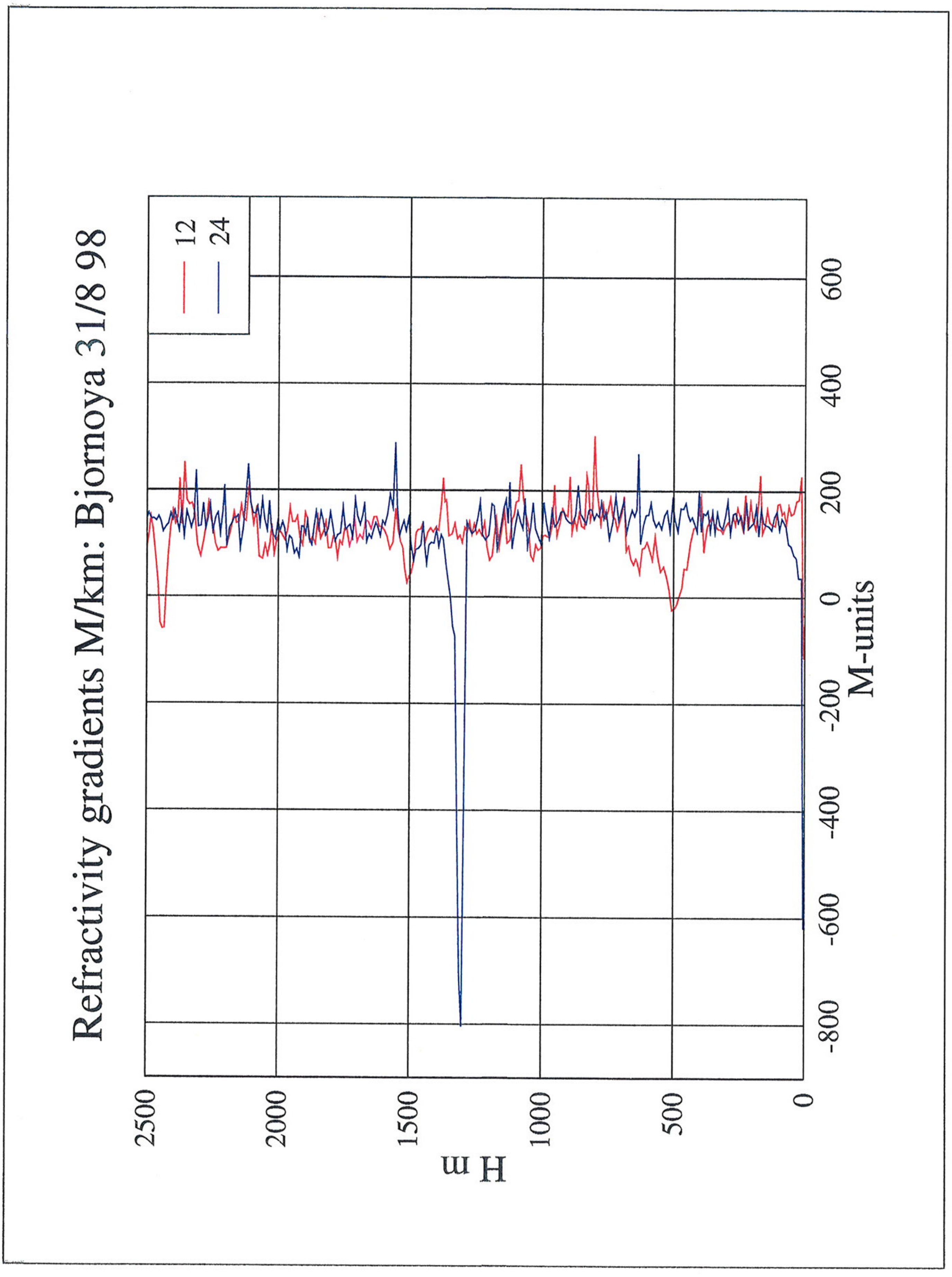


Figure 3.3.7 Refractivity gradients from Bjørnøya

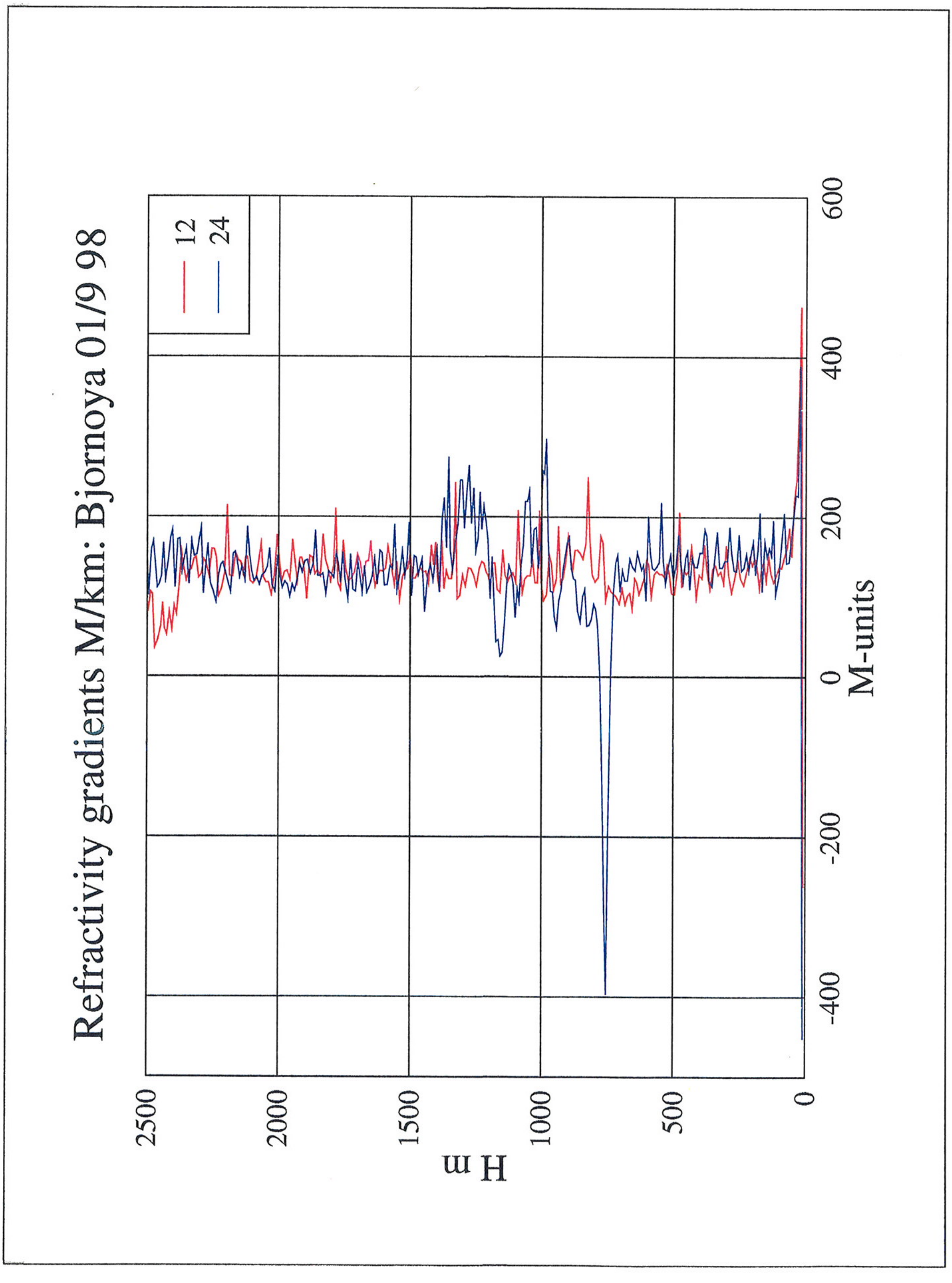


Figure 3.3.8 Refractivity gradients from Bjørnøya

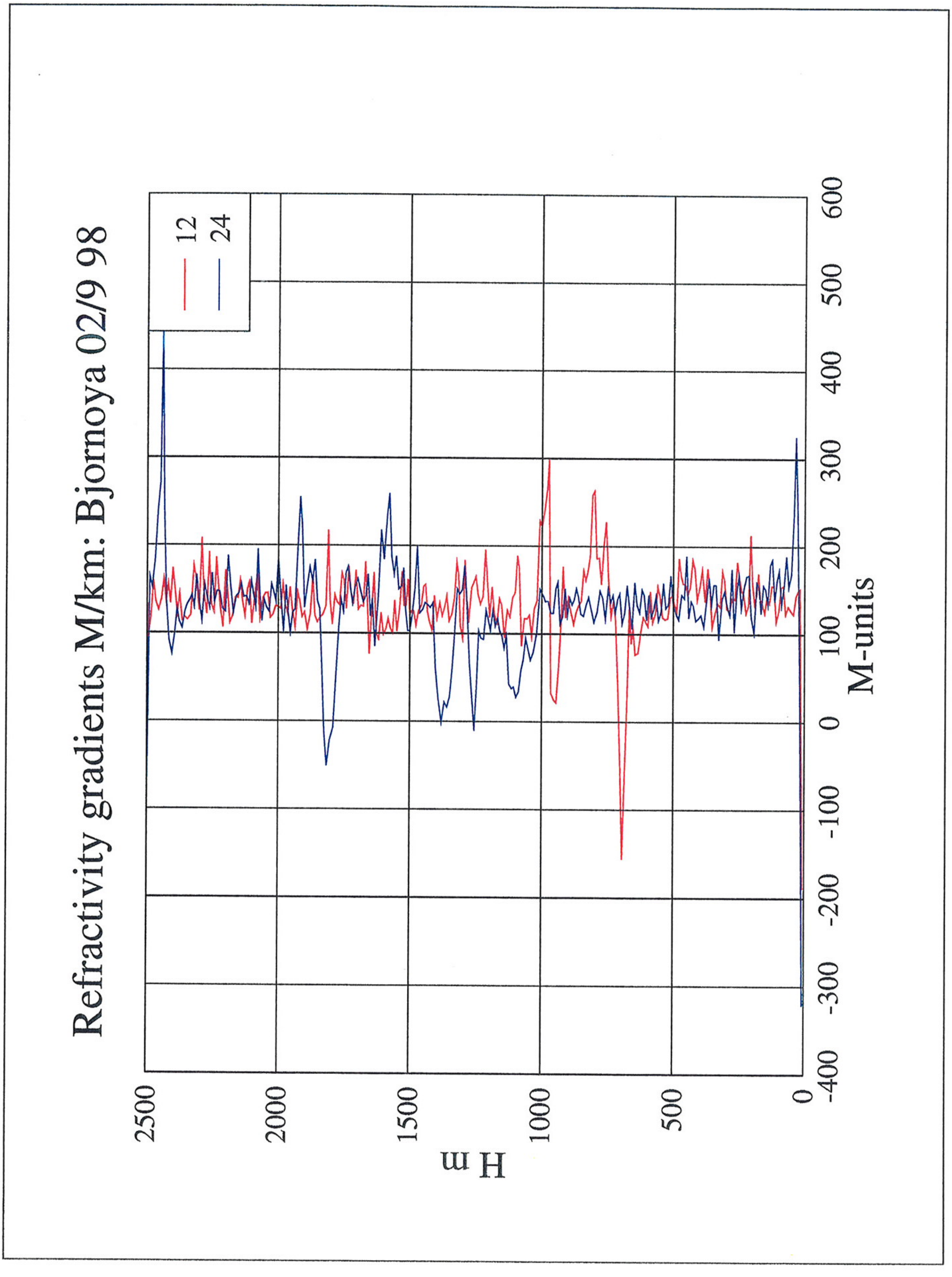


Figure 3.3.9 Refractivity gradients from Bjørnøya

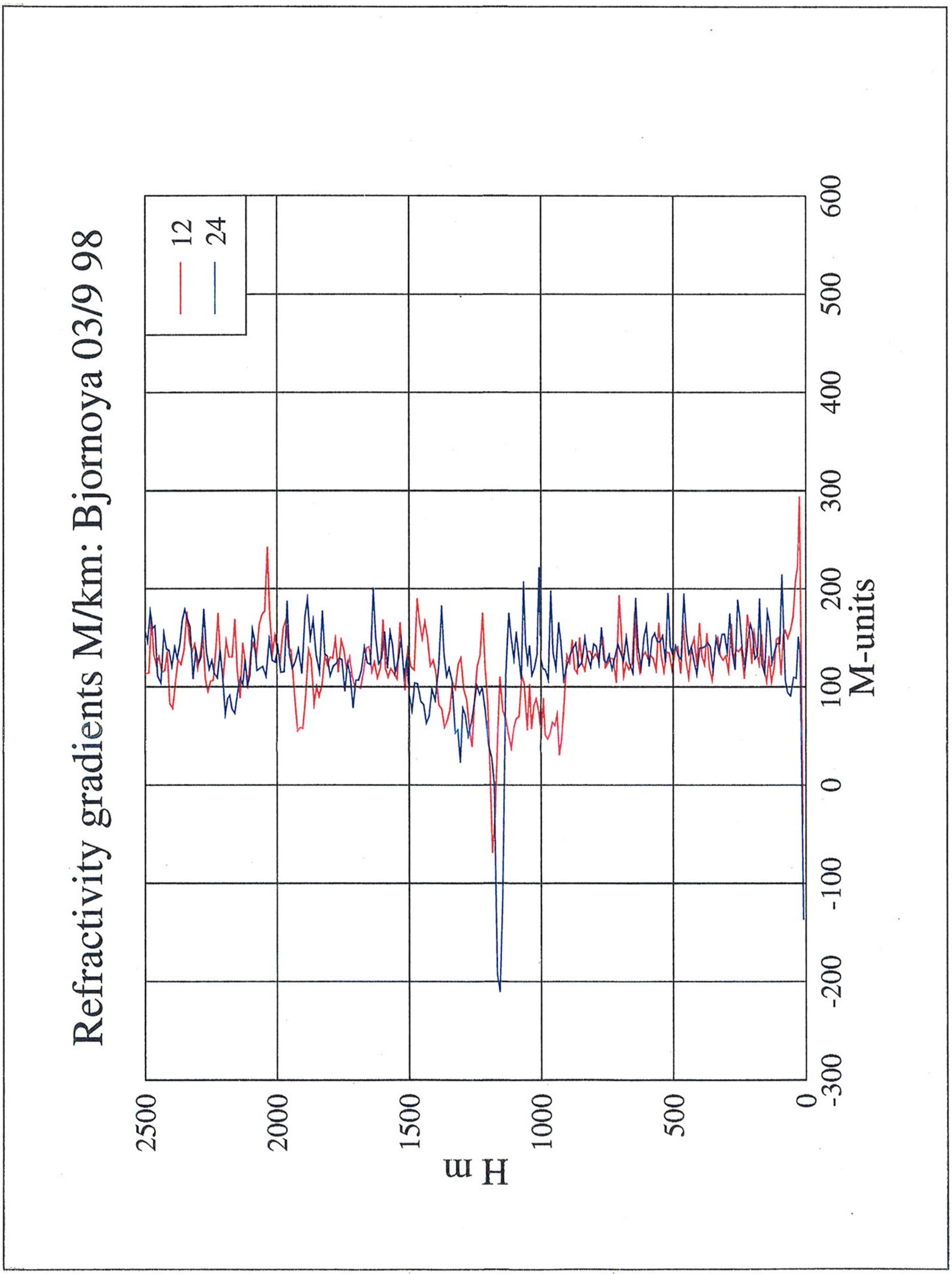
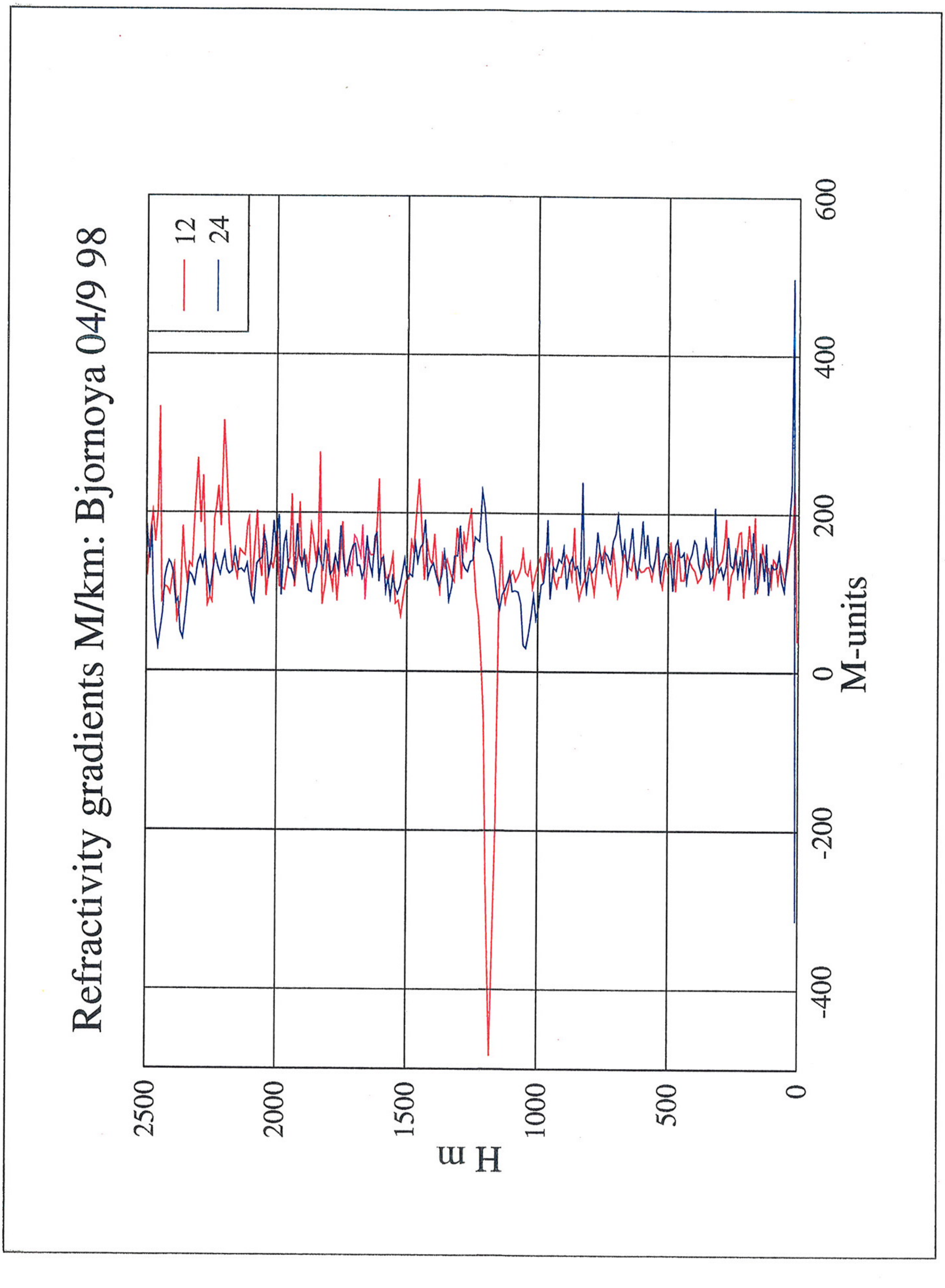


Figure 3.3.10 Refractivity gradients from Bjørnøya



3.4 Radio sonde observations from Jan-Mayen.

From the ascents done at Jan-Mayen we recollect the following facts: for the 31 of August we find at night a narrow but strong surfacebased duct, the gradient is -420 M/km. Further a wide super refractive structure appears just below 500 m as well as a narrow just about a duct near by 2000 m. The previous day ascent reveals duct structures at 1200 m, 1400 m and 2300 m and a wide super refractive structure around 1500 m.

At the first of September we find that the evaporation ducts have disappeared, reduced to a super refractive structure at noon. At the same time we see ducts in the 800 to 900 m level and a narrow duct at 1200 m. Small and narrow super refractive structures exist from below 2000 m and up to 2500 m. At night the structures around 1000 m evolve to narrow ducts in 1100 m, 1200 m and 1900 m. We find also an extreme layering of the atmosphere between 2200 m and 2500 m with a shift between ducts, super refractive and subrefractive layers. The most extreme thin duct has a gradient of -250 M/km in 2300 m level.

The second of September we recognise a stable, both day and night, well developed duct just below 1000 m. The gradient is around -600 M/km for both hours, greatest negative for the night. Surfacebased ducts are non-existing, only a super refractive structure at night. At noon we find a super refractive layer in the 1800 m level. The 3 of September the atmosphere at Jan- Mayen are more or less well mixed, only at night we recognise a thin duct in 700 m level.

At the 4 of September we find a strong subrefractive layer near by ground, with a gradient of nearly 500 M/km, this evolves back at night to a real duct with a gradient of about -100 M/km. A small duct structure appears in the day at the 2200 m level, from the night ascent we recognise a super refractive structure about 1100 m.

For all hours the profiles are shown in figures 3.4.1 to 3.4.5 and the gradients in figures 3.4.6 to 3.4.10.

Figure 3.4.1 Refractivity profiles from Jan-Mayen

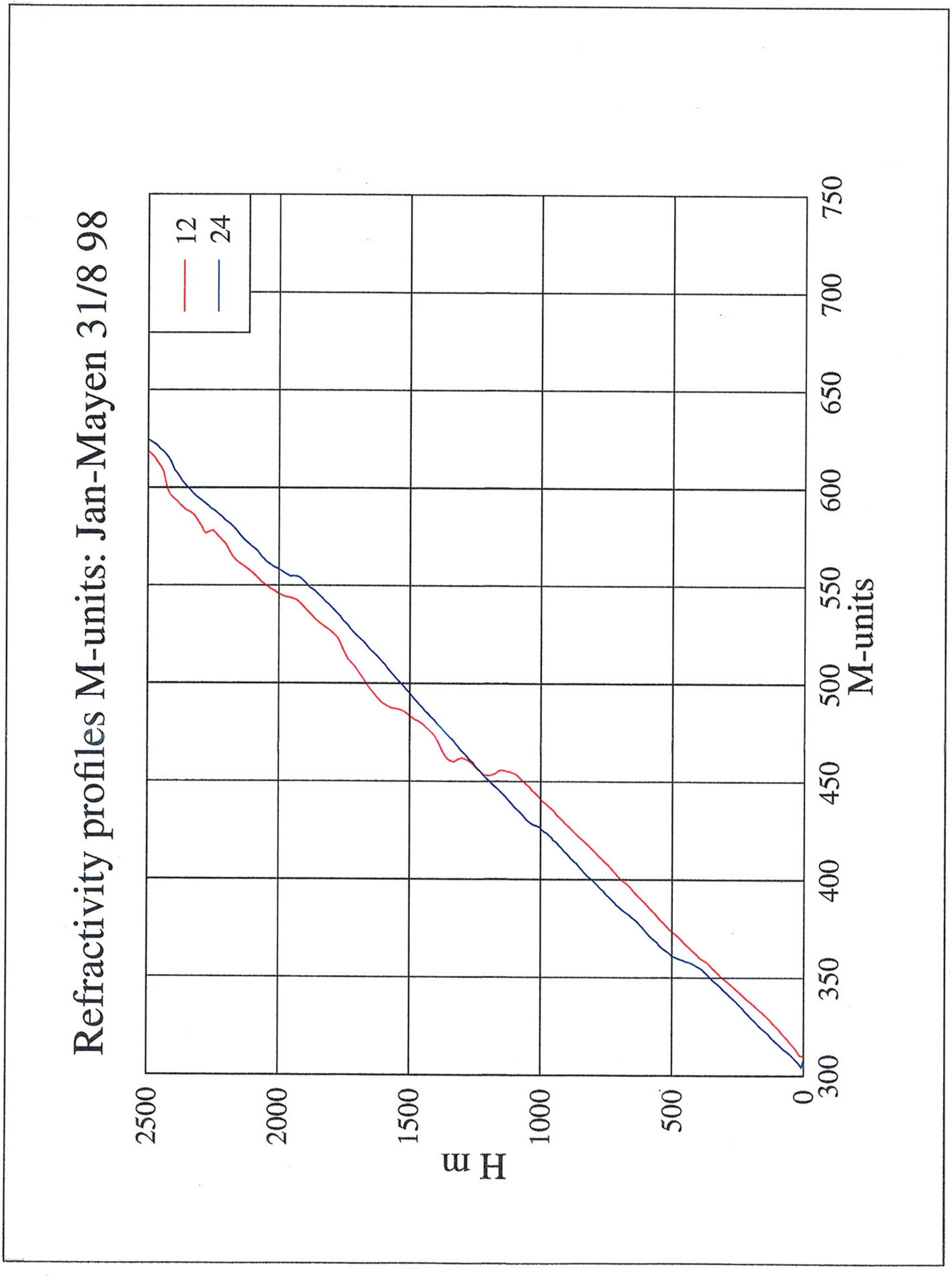


Figure 3.4.2 Refractivity profiles from Jan-Mayen

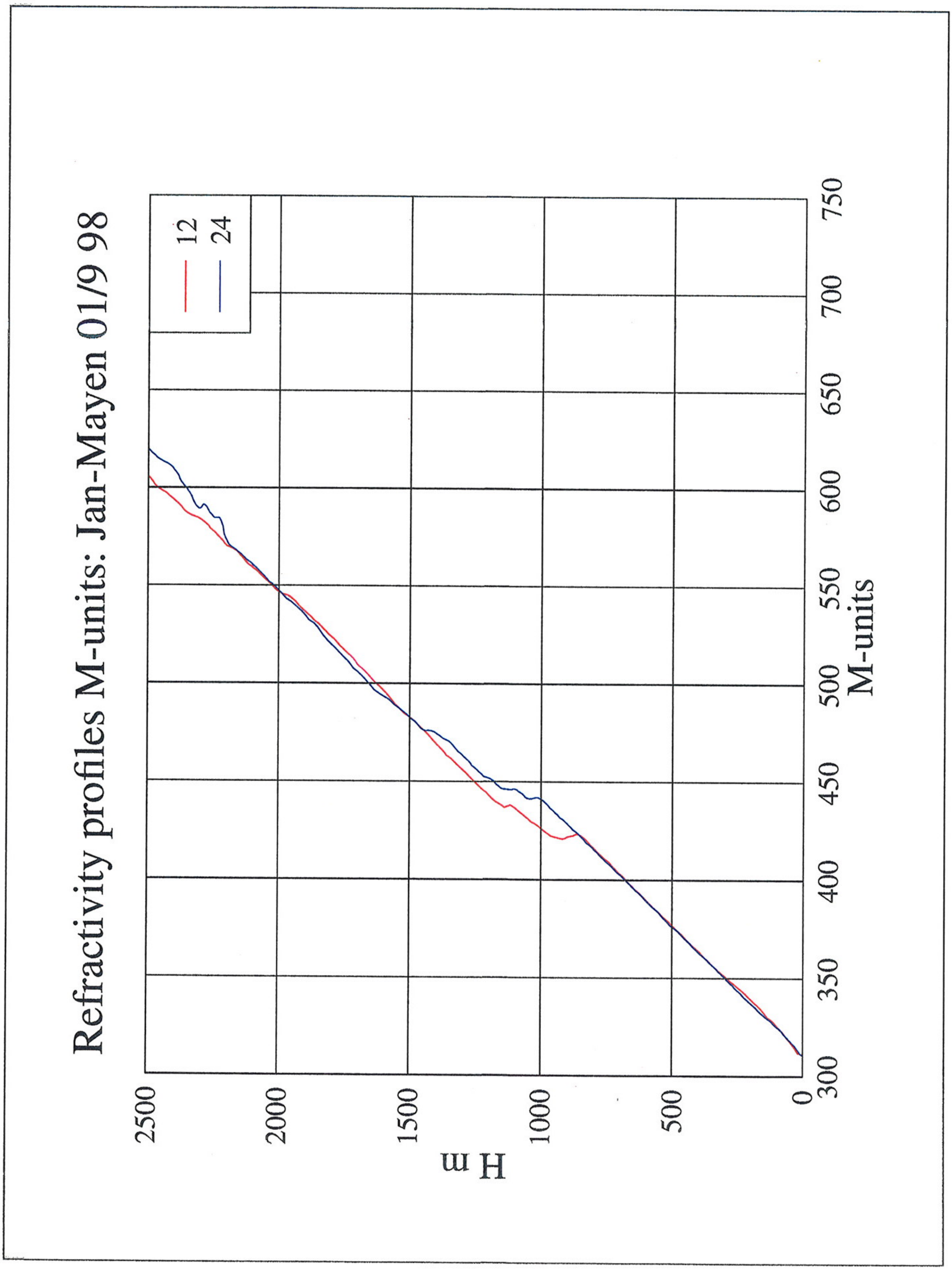


Figure 3.4.3 Refractivity profiles from Jan-Mayen

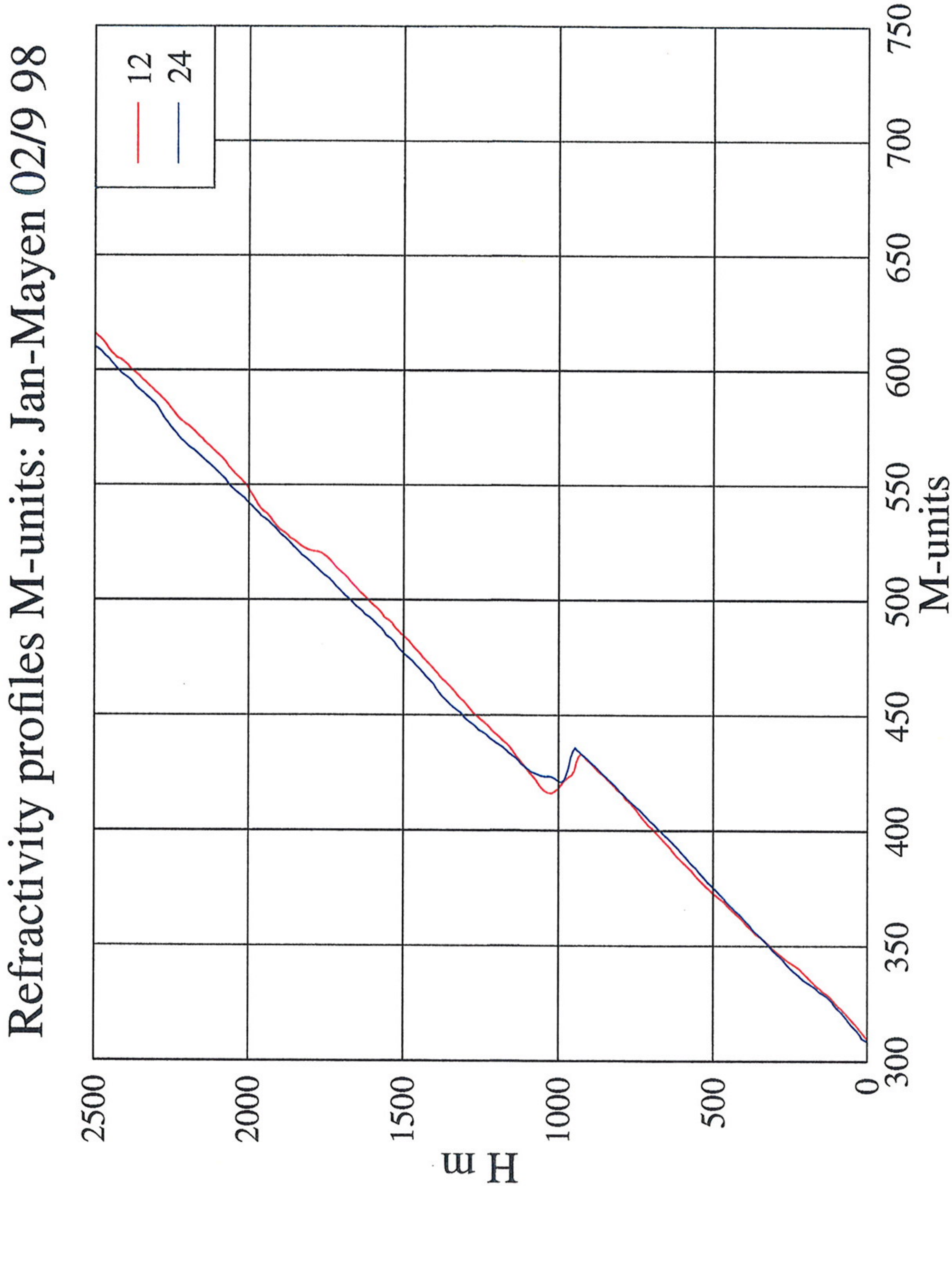


Figure 3.4.4 Refractivity profiles from Jan-Mayen

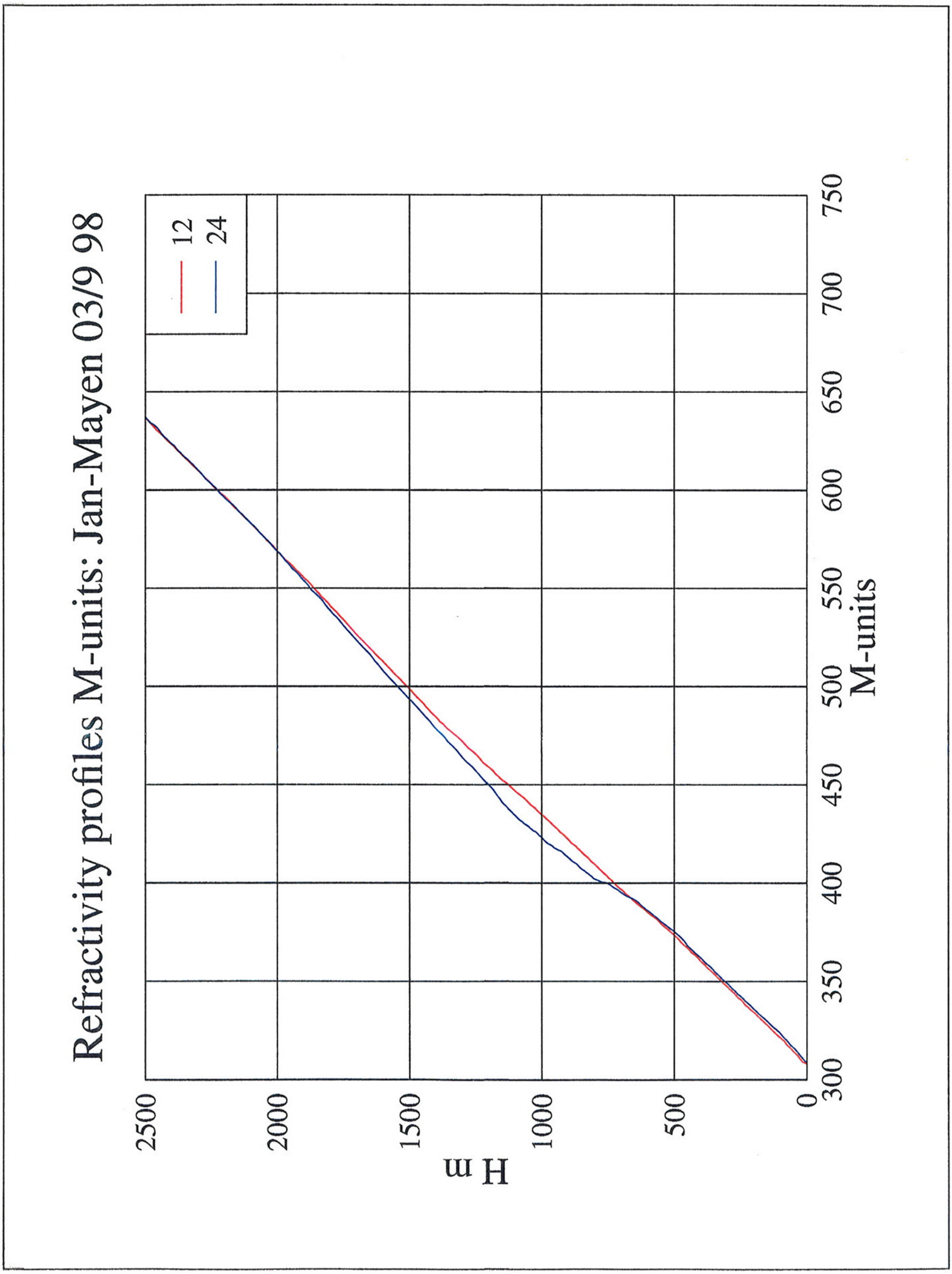


Figure 3.4.5 Refractivity profiles from Jan-Mayen

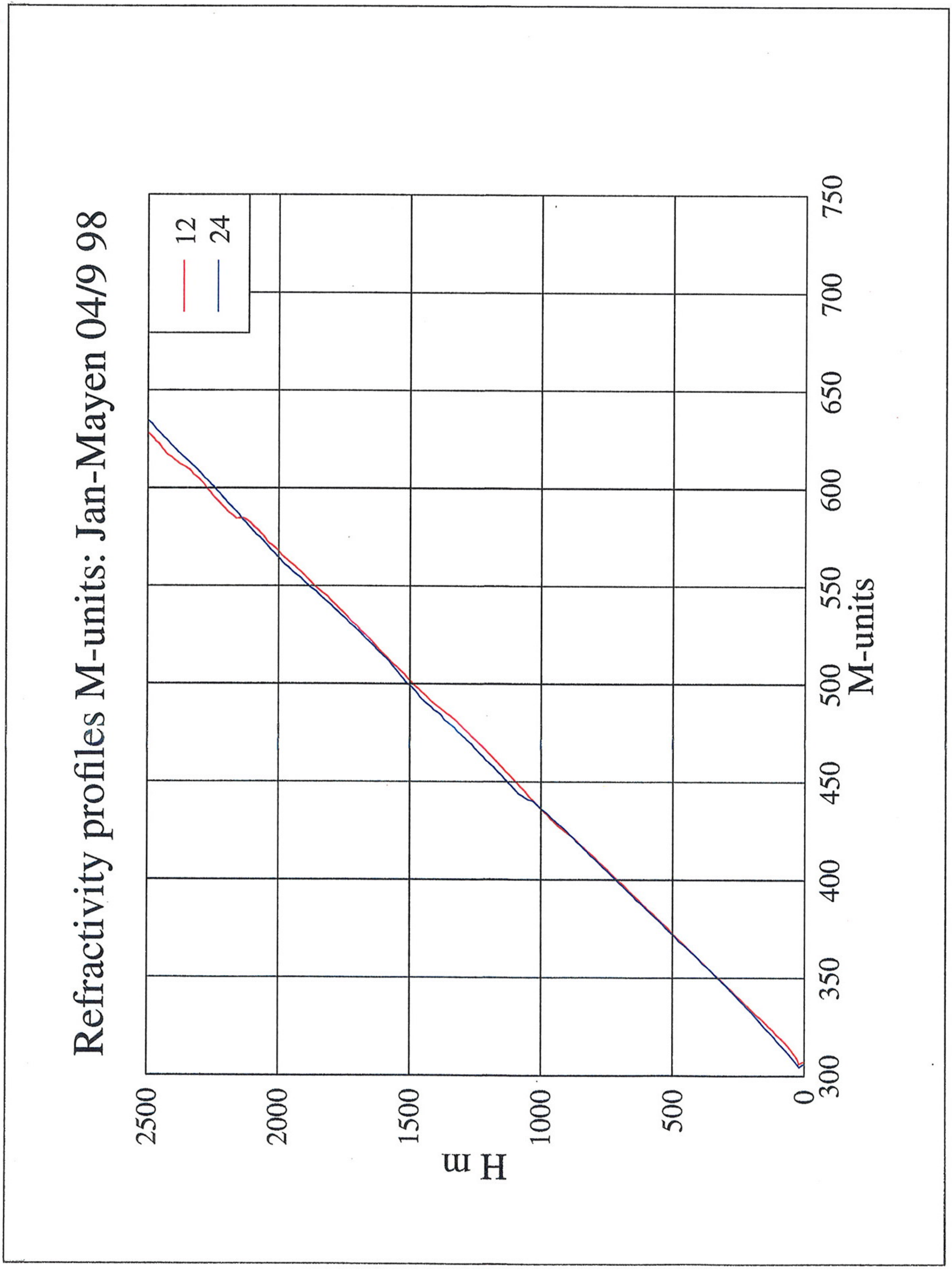


Figure 3.4.6 Refractivity gradients from Jan-Mayen

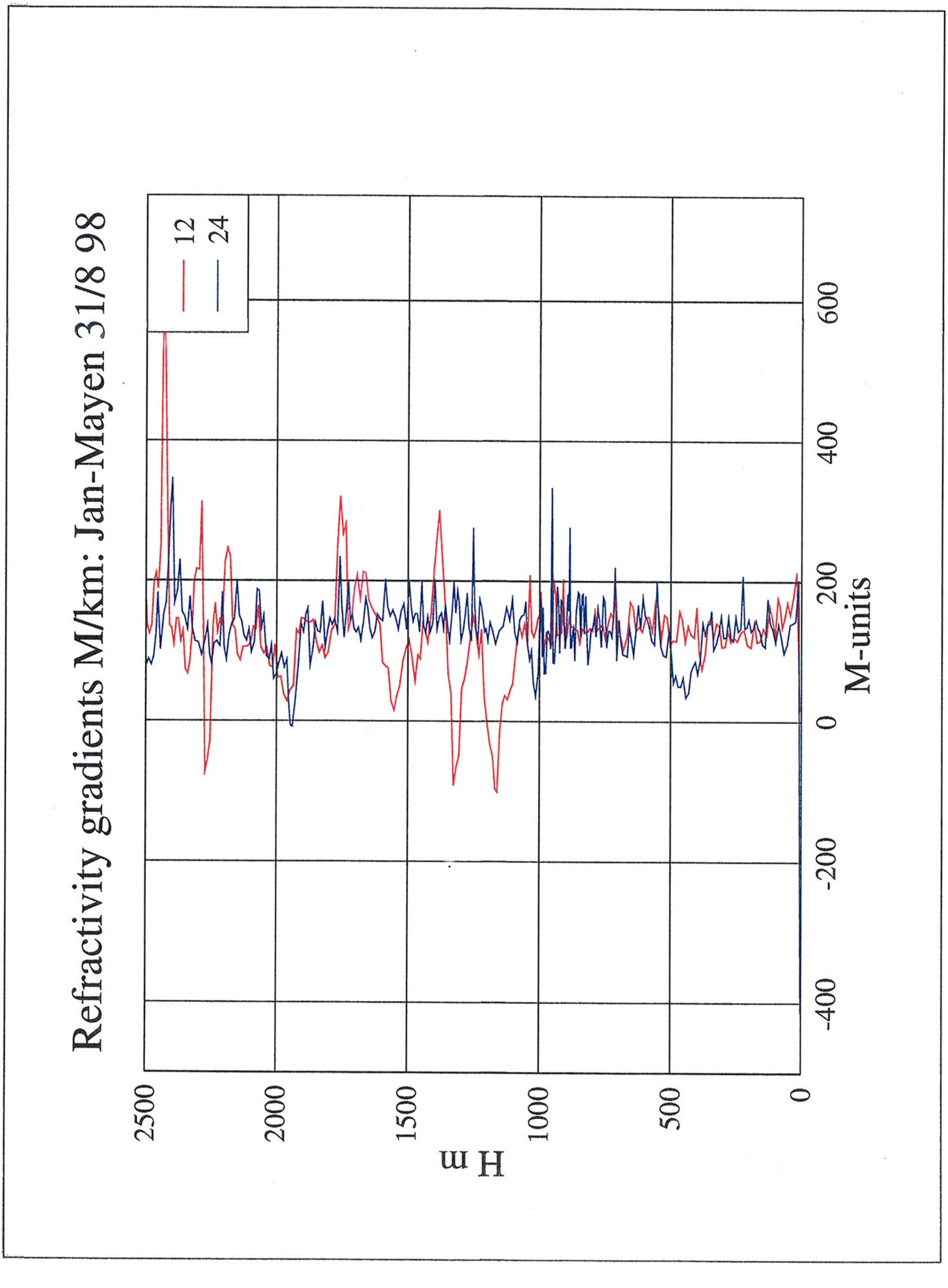


Figure 3.4.7 Refractivity gradients from Jan-Mayen

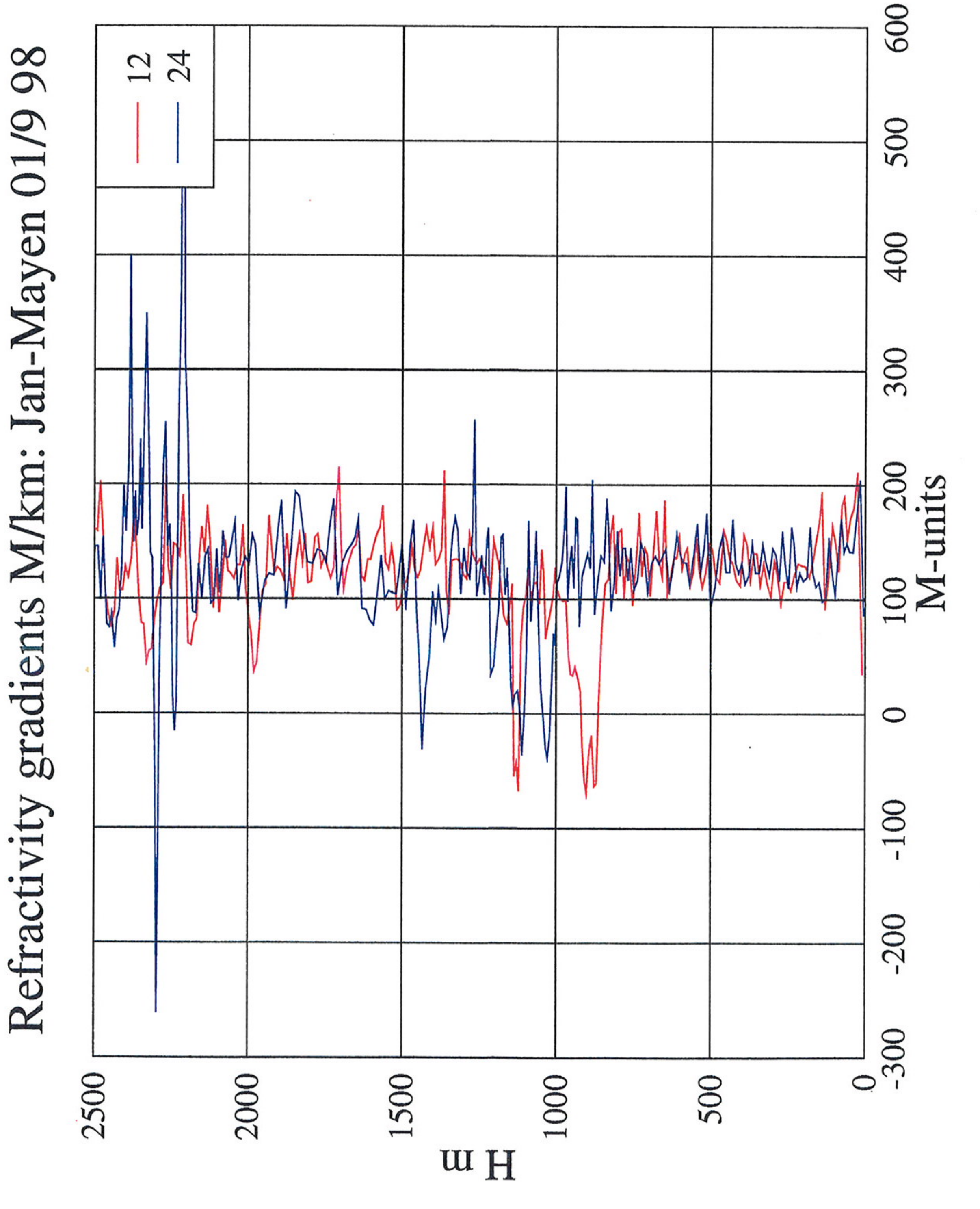


Figure 3.4.8 Refractivity gradients from Jan-Mayen

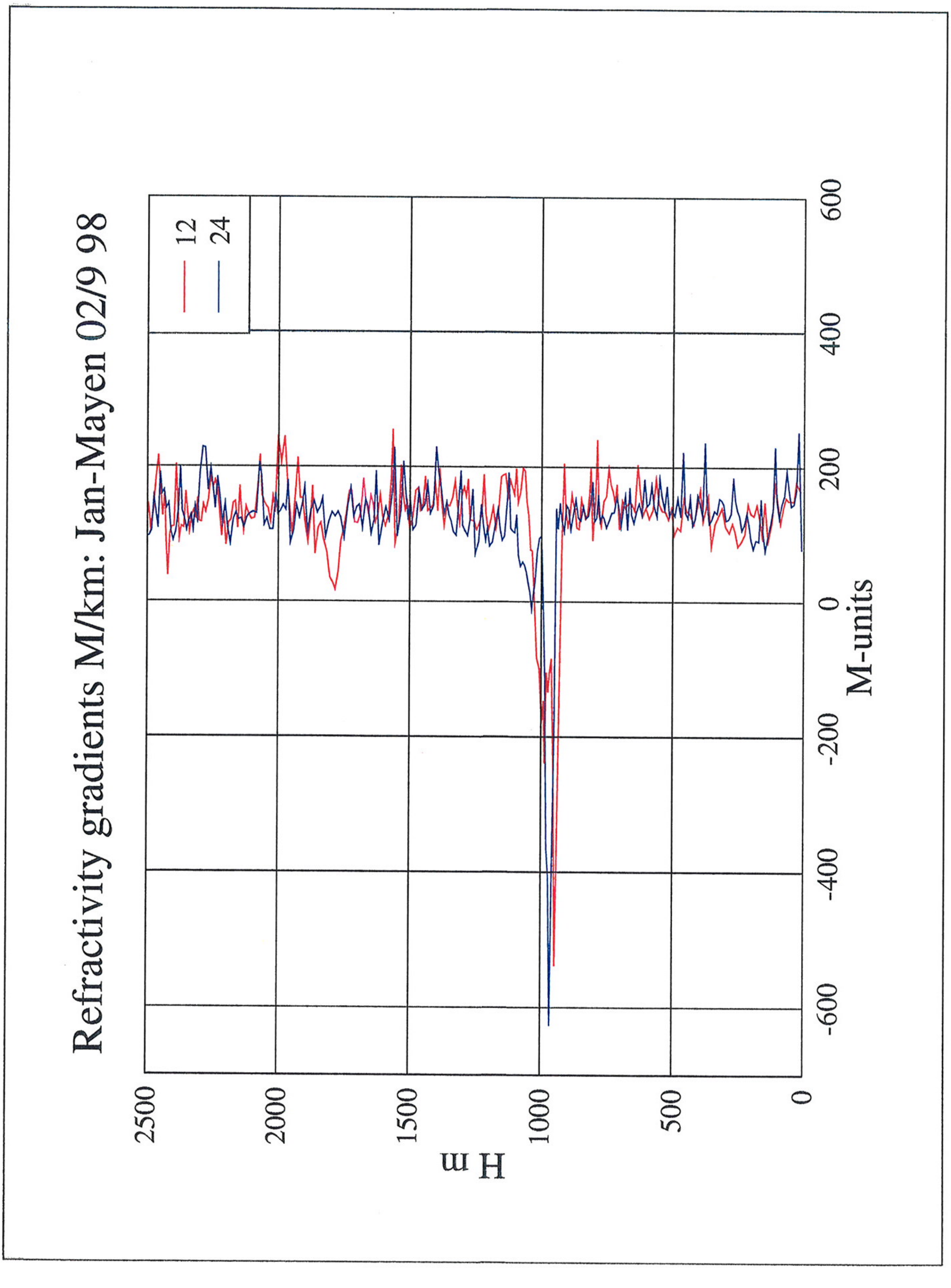


Figure 3.4.9 Refractivity gradients from Jan-Mayen

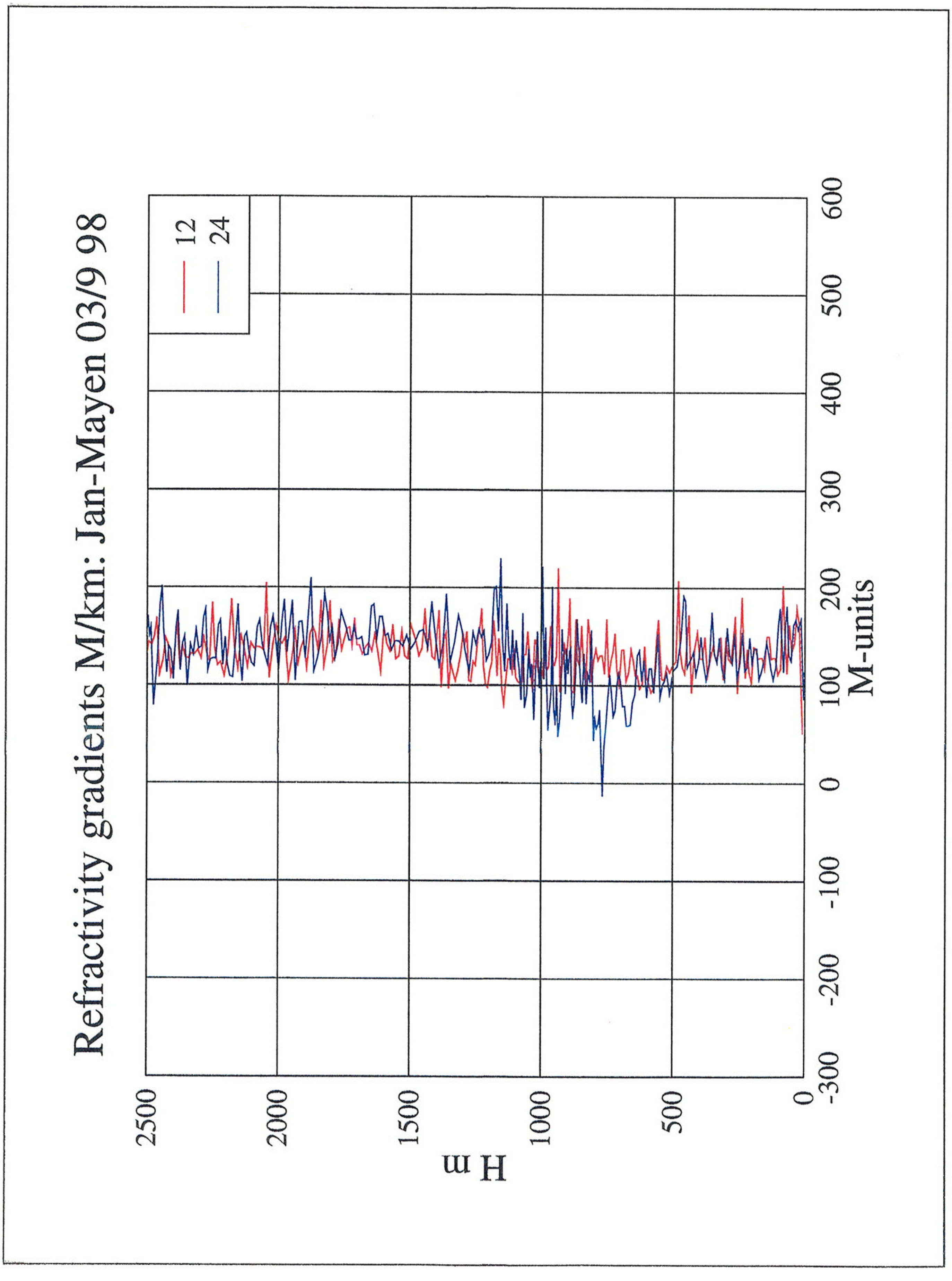
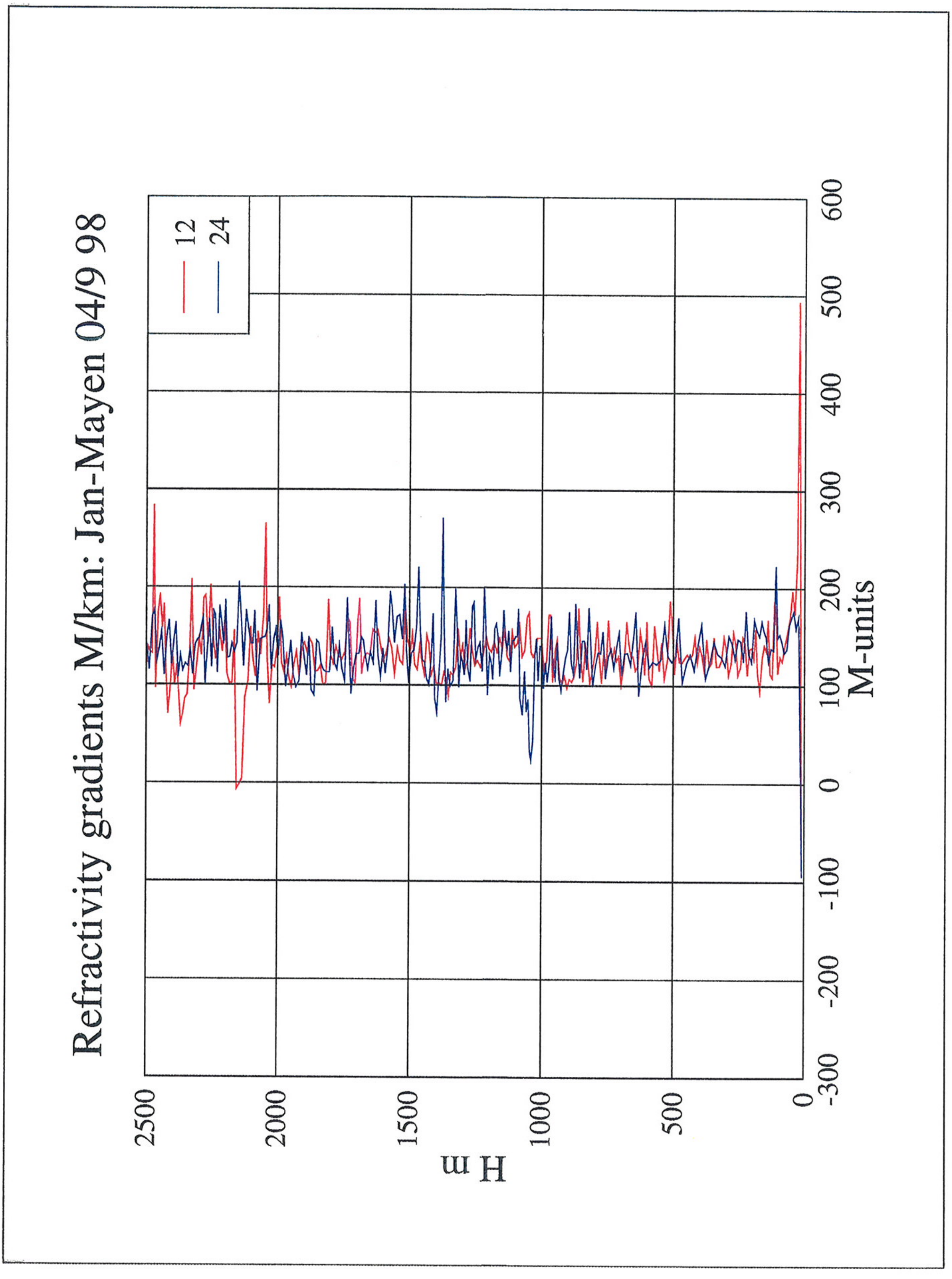


Figure 3.4.10 Refractivity gradients from Jan-Mayen



3.5 Surface observations.

The surface network of meteorological stations make observations at least 3 times a day, at major stations at least 4 times, hours 0, 6, 12 and 18. At these stations pressure, temperature and humidity observations are included in the total observation programme. Data from such stations make it possible to compute what is known as «surface refractivity» or the refractive index near to ground. From [4] we have long-term monthly means with standard deviation for this quantity computed for the period 1981-1990. In the table is the refractivity split in its dry term and wet term, the sum gives the total refractivity, Dry and wet terms are explained in for instance [1] or [4] and the idea here is only to point out that it is the wet (humidity dependent) part that have the greatest standard deviation and therefore contributes most to the changes in the refractivity values. The following discussion only relates to the total refractivity.

station	refractivity	month			
		August		September	
		mean	std	mean	std
Bjørnøya	dry	281.6	1.8	282.4	1.3
	wet	38.0	2.9	34.0	4.1
	total	319.6	2.4	316.4	3.1
Longyear	dry	280.4	1.4	284.9	2.3
	wet	31.6	2.6	24.1	4.3
	total	312.0	2.2	309.0	2.6
Ny-Ålesund	dry	282.4	1.5	286.3	2.6
	wet	32.5	1.8	24.3	4.8
	total	314.9	1.7	310.8	2.5
Jan-Mayen	dry	280.5	1.7	282.5	1.4
	wet	38.6	4.3	31.7	3.8
	total	319.0	3.1	314.2	2.8

Table 3.5.1 Long-term values of surface refractivity.

From the table we can make a mean of the two monthly values for each station and then make a grand mean of these values, this value 314.2 N- or M-units (at ground these are identical). Estimation of a standard deviation of about 2.5 units is reasonable and thus we obtain the values for the «normal surface refractivity» in the range 309 to 320 units for the area covered by the stations and for the period covered by August and September.

Next we compute the surface refractivity four times a day from the data obtained from the same meteorological stations in 1996 and 1998. The result is shown in figure 3.5.1 for 1996 and 3.5.2 for 1998 respectively. The «day-numbering» has to be understood in the following manner: The span 100 to 103 covers the four values for 25/8, the next four (104 to 107) cover the day 29/8 and so on until 144 to 147 covering the day 5/9.

In figure 3.5.3 is shown the means for the stations for both years, perhaps a more readable picture. Looking back to the long-term values we find that 1996 in the period 25/8 to 5/9 is quite normal but that 1998 for the same period is much above normal, in fact apparently more than three standard deviations. This may be a result of the guess for the standard deviation. that should have been given a slightly higher value. But we can conclude that for the surface refractivity and that should be the «ground point» of the tropospheric refractivity profiles, that for the short 12 day period 25/8 to 5/9 there is a significant difference between the years 1998 and 1996, the latter being the «most normal».

The latitude for the above stations are in ascending order: Jan-Mayen (70° 56'), Bjørnøya (74° 31'), Longyear (78° 15') and Ny-Ålesund (78° 55'). Normal surface refractivity near by sea level is shown to decrease with increasing latitude [4] this is also more or less the fact in 1998. In 1996 however, Jan-Mayen, the southern most station shows up with the least refractivity values, this could in spite of the normal «area mean» indicate more adverse refractivity conditions in 1996.

Figure 3.5.1 Surface refractivity 25.8.1996 to 5.9.1996 for Bjørnøya, Longyear, Ny-Ålesund and Jan-Mayen (see text for legend)

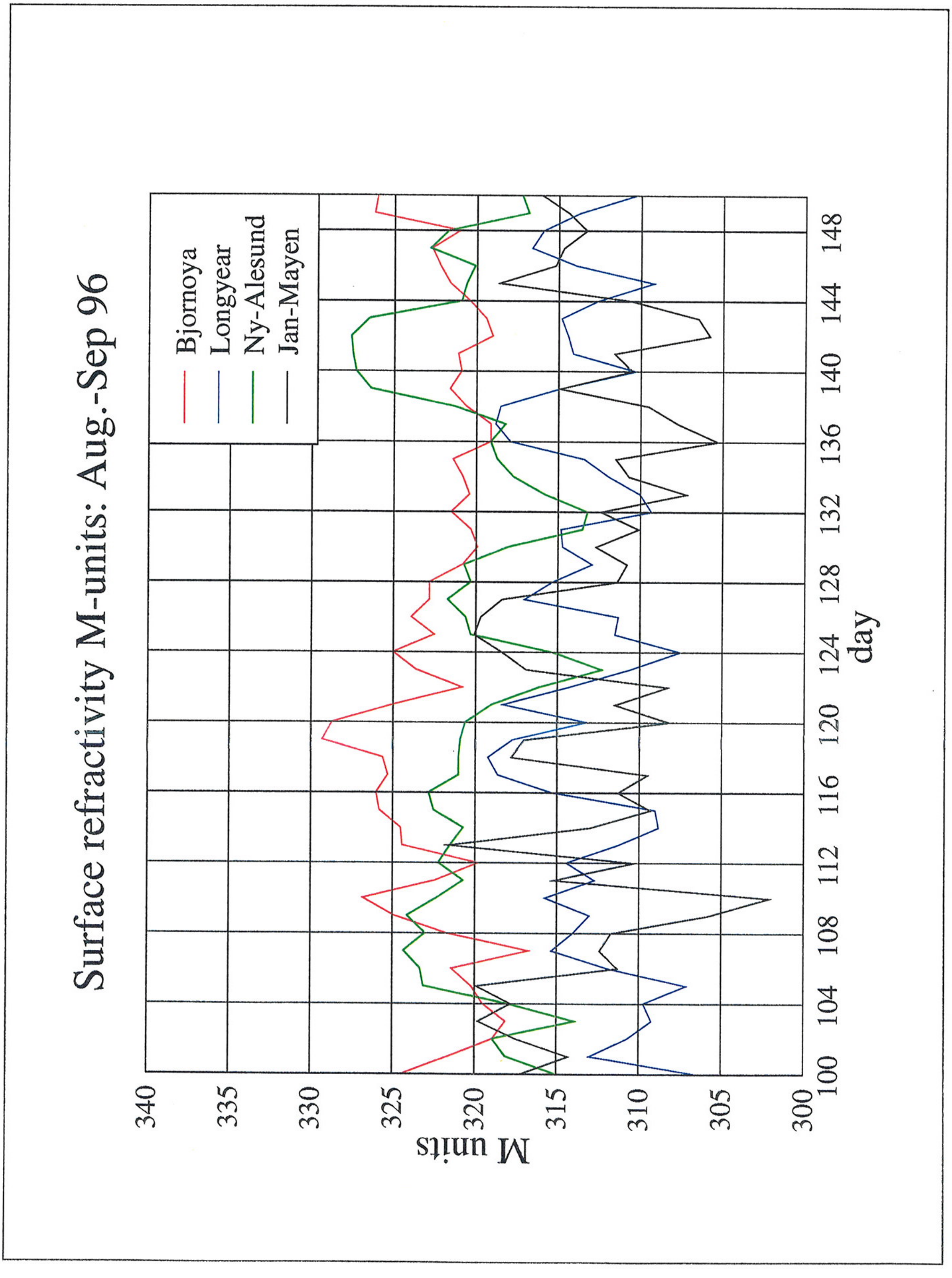


Figure 3.5.2 Surface refractivity 25.8.1996 to 5.9.1998 for Bjørnøya, Longyear, Ny-Ålesund and Jan-Mayen (see text for legend)

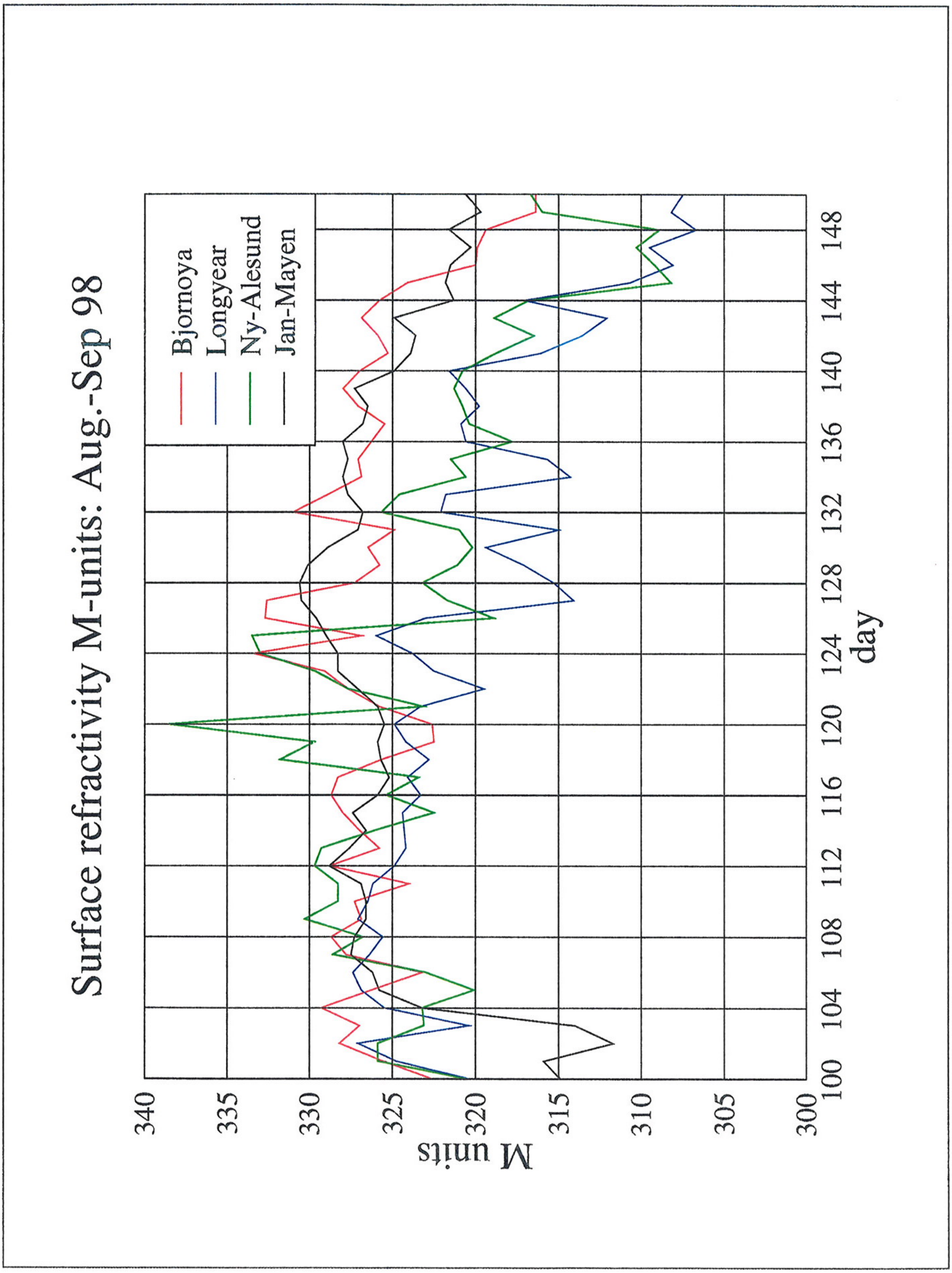
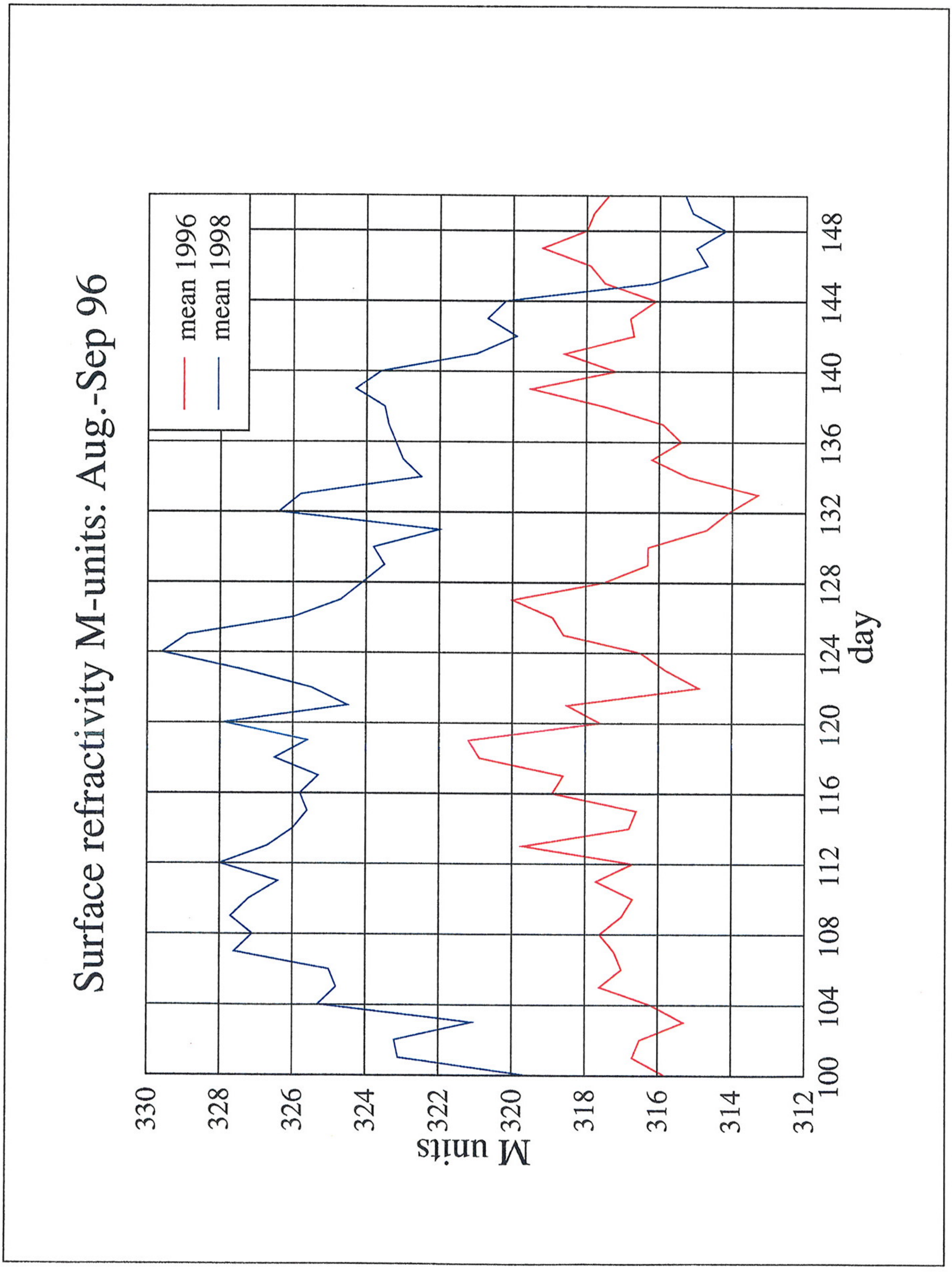


Figure 3.5.3 Surface refractivity 25.8. to 5.9. as pooled mean values for 1996 and 1998. (see text for legend)



4. Comparison of ascents.

In table 4.1 is given dates and hours for the simultaneous radio sonde ascents performed in the area.

year	month	day	hour	LYR1	LYR2	Bjørnøya	Jan-Mayen	Ny-Ålesund
1998	09	01	24	x		x	x	
	09	02	12	x		x	x	x
	09	03	12	x	x	x	x	x
	09	04	12	x		x	x	x

Table 3.2 Simultaneous radio sonde ascents at LYR1, LYR2, Bjørnøya, Jan-Mayen and Ny-Ålesund.

First we draw the profiles obtained from the stations on figures 4.1 to 4.4 for the above mentioned days. From the figures we can recognise the following: At the night-observation of the first of September exist duct structures for LYR1 Jan-Mayen and Bjørnøya around 1000 m the lowest level at Bjørnøya (750 m) and the highest level at LYR1 (1250 m). It is reasonable that if the elevated structures are part of a more grand scale system that the local elevation of the terrain should have a direct effect on the elevation of the structures. At Bjørnøya the highest point is the «Misery mountain» with an elevation of 536 m, at Jan-Mayen except for Berenberg (2277 m) is «Rudolf mountain» with an elevation of 769 m. For LYR1 we have the mountains along the Adventsdalen with elevations of more than 1000 m that naturally will lift an approaching air mass. Possible evaporation ducts will be a more local phenomenon resulting from the sea and the surface based evaporation duct at Bjørnøya (visible in the lower left corner of figure 4.1) does not at this time exist at the two other places. As mentioned this is a result of air and sea temperatures and for the LYR-stations a favourable wind is necessary to drive such structures into the valley.

For the noon observation of the 2 of September we recognise more or less the same picture, irregularities and ducts in the refractivity profile around 1000 m. A well developed duct over Jan-Mayen and superrefractive structures over both Ny-Ålesund and Longyear (LYR1).

At noon of the third of September we find the same features, ducts and superrefractive structures in the height interval from 1000m to 1500 m. Jan-Mayen, however has a most regular and linear refractivity profile. At the same hour the 4 of September we recognise the above mentioned duct at Bjørnøya, where as the other stations have more regular profiles although with small irregularities.

Although this set of data count no more than four cases and as such is by no means a basis for secure conclusions an attempt to a conclusion can be that if elevated ducts exist in the area and are experienced at both Jan-Mayen and Bjørnøya it is most probable that such structures also exist over Svalbard and Longyear. To make a similar statement for surface based ducts is more or less impossible from the collected set of data. Here firstly pure local effects will play a role as well as more big scaled factors as wind fields with favourable direction.

Figure 4.1 Refractivity profiles for Lyr1, Jan-Mayen and Bjørnøya

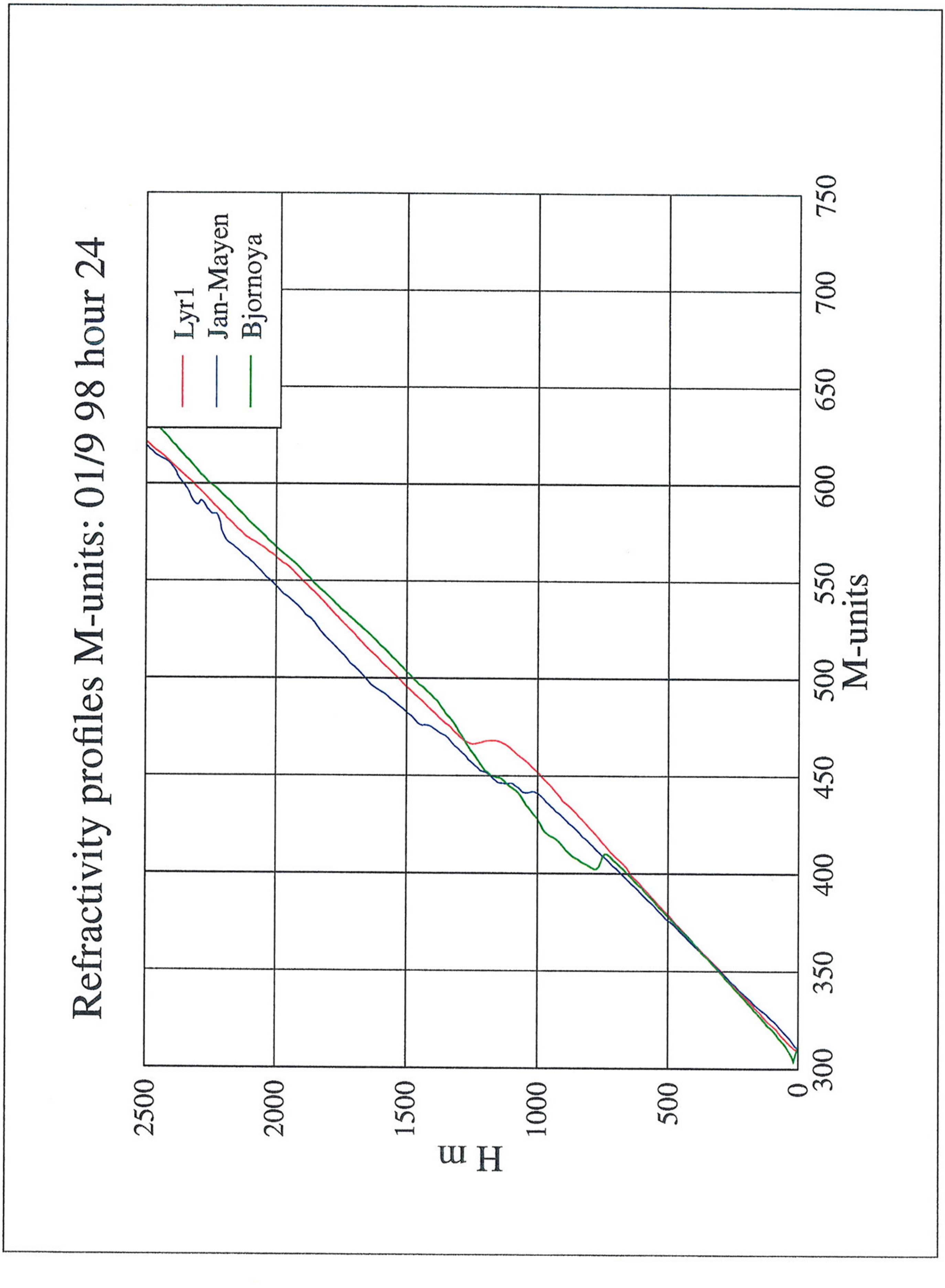


Figure 4.2 Refractivity profiles for Lyr1, Jan-Mayen, Bjørnøya and Ny-Ålesund

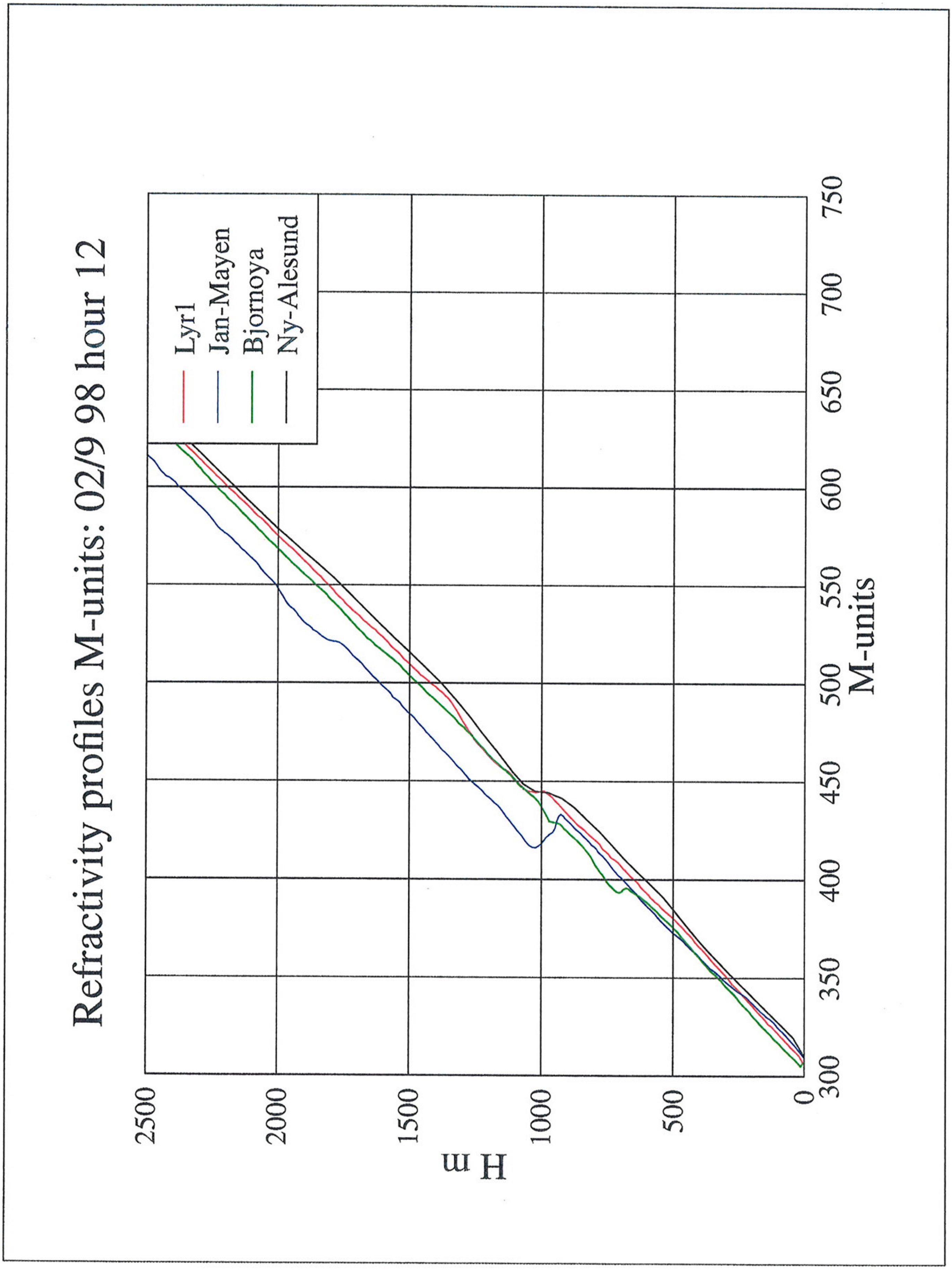


Figure 4.3 Refractivity profiles for Lyr1, Jan-Mayen, Bjørnøya and Ny-Ålesund

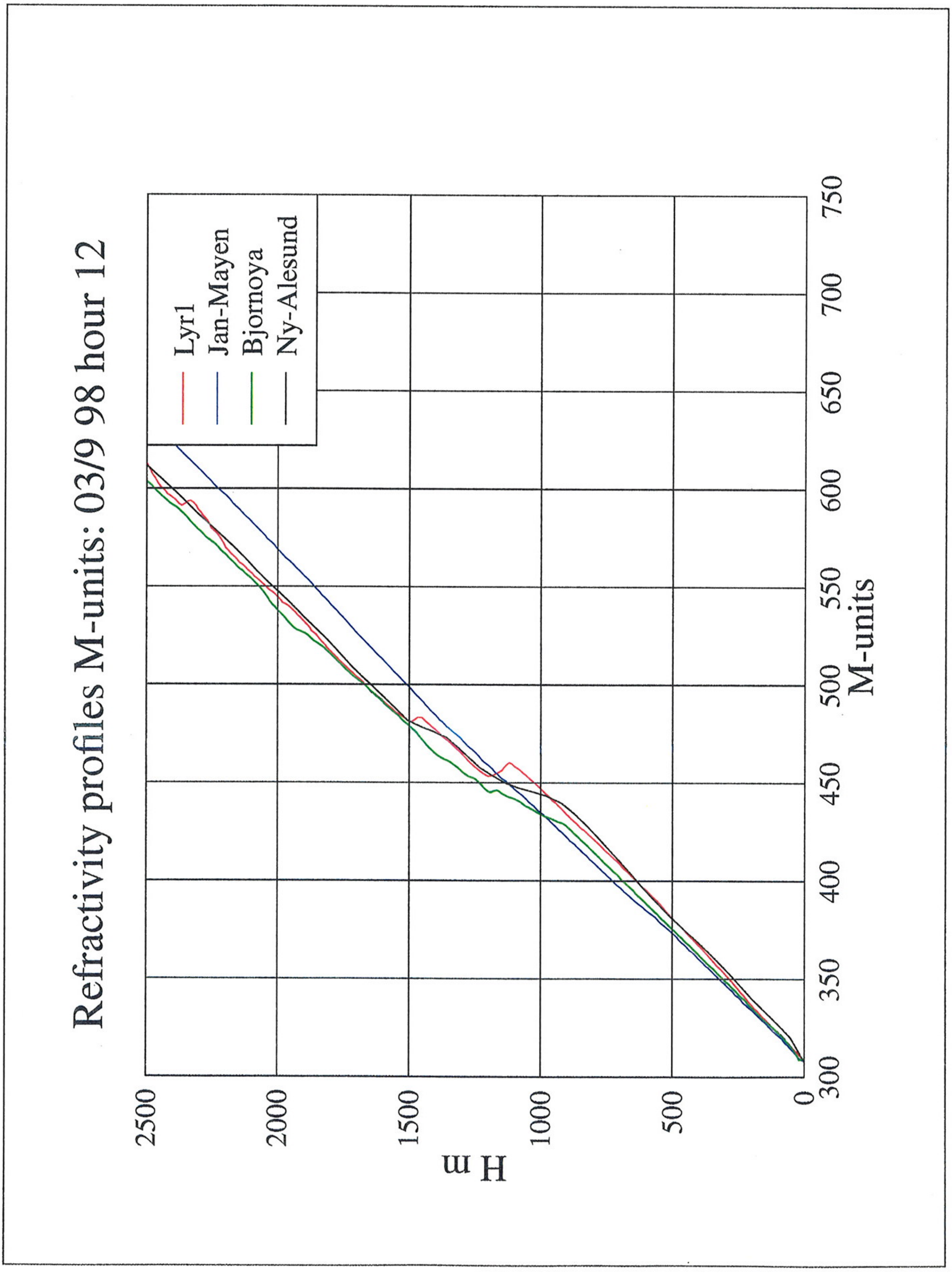
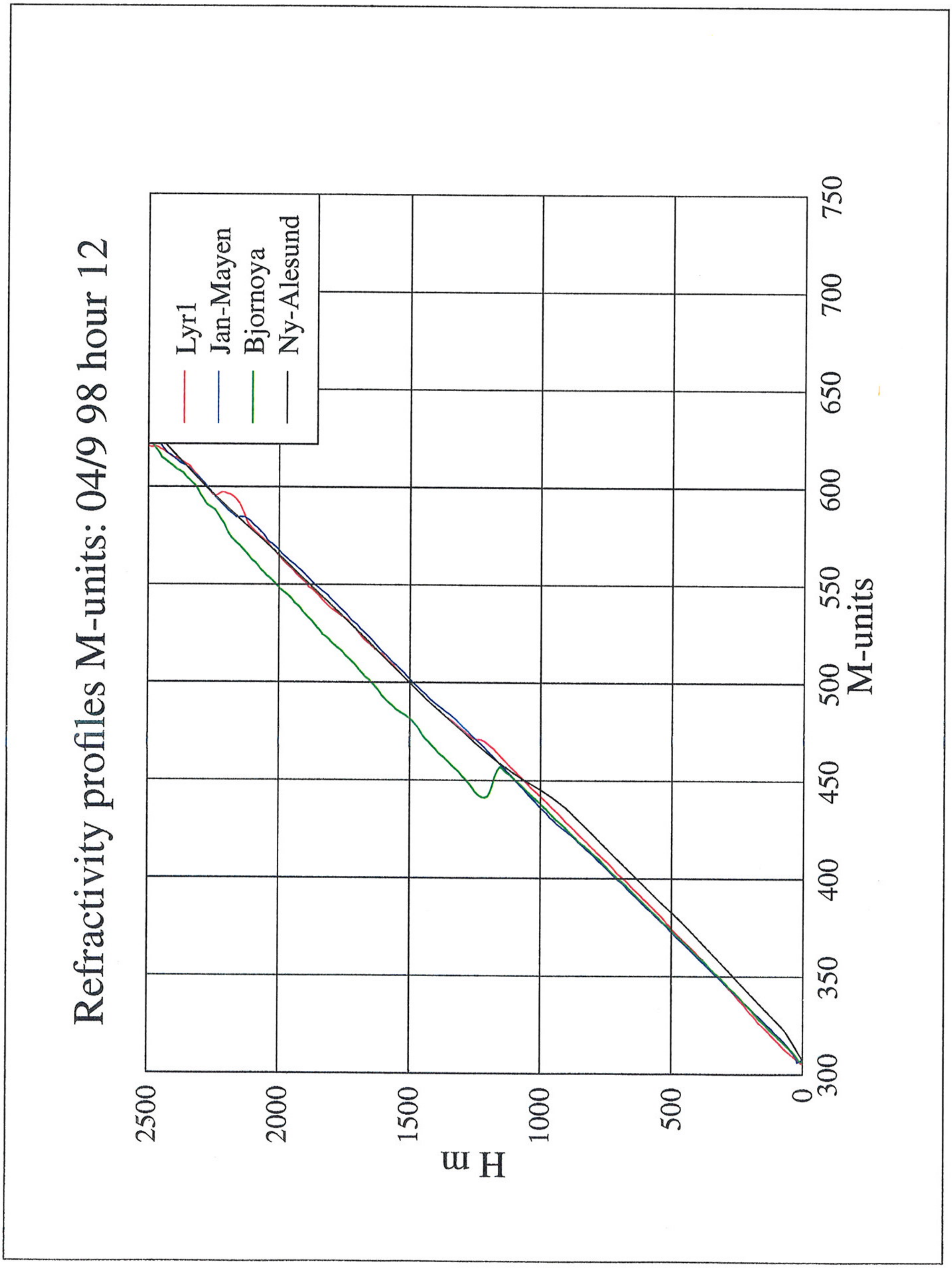


Figure 4.4 Refractivity profiles for Lyr1, Jan-Mayen, Bjørnøya and Ny-Ålesund



4.1 Some strategies for mathematical or statistical comparison of ascents.

To compare the results of two radio sonde ascents (as observed or computed variables) is the same as comparing two "shapes" or two different "curves". If the shapes or curves are known as analytical functions this can in some way be done either by within the mathematical theory known as topology or by other mathematical means as use of the concept of measure or the L-norm, say for instance the L^2 norm. If the two shapes are given by the functions, say f(x) and g(x), the idea is to look at value the integral

4.1 $d=\int f(x)g(x)\, dx$

In this case one of the functions should be some kind of a stable long-term set of values. For the refractivity profiles exist only one such set of data, that is the values given in [4] a ten year mean of values of refractivity profiles both in N- and M-units from both Jan-Mayen and Bjørnøya (but not Ny-Ålesund neither Longyear) with standard deviation and observed maximum and minimum values. The profile under consideration could then be viewed with the extreme values as reference but they should not be part of the same ascent and a not be part of the same ascent and as such no good reference for a profile. The set of mean values is, however, made from the ordinary TEMP and PILOT telegrams (see [5] or [6]) and as such interpolated linearly to each one hundred metre up to 2100 m. The profile as such is extremely smoothened but have still no definite analytical expression. One strategy could then be to express both profiles, both the long-term and the actual, by for instance some kinds of spline functions and then integrate

4.2 $d=\int \langle \Sigma sf(z)\Sigma sg(z)\rangle\, dz$

and look at the magnitude of d for given sg(z) if sf(z) is the spline representation of the long-term profile.

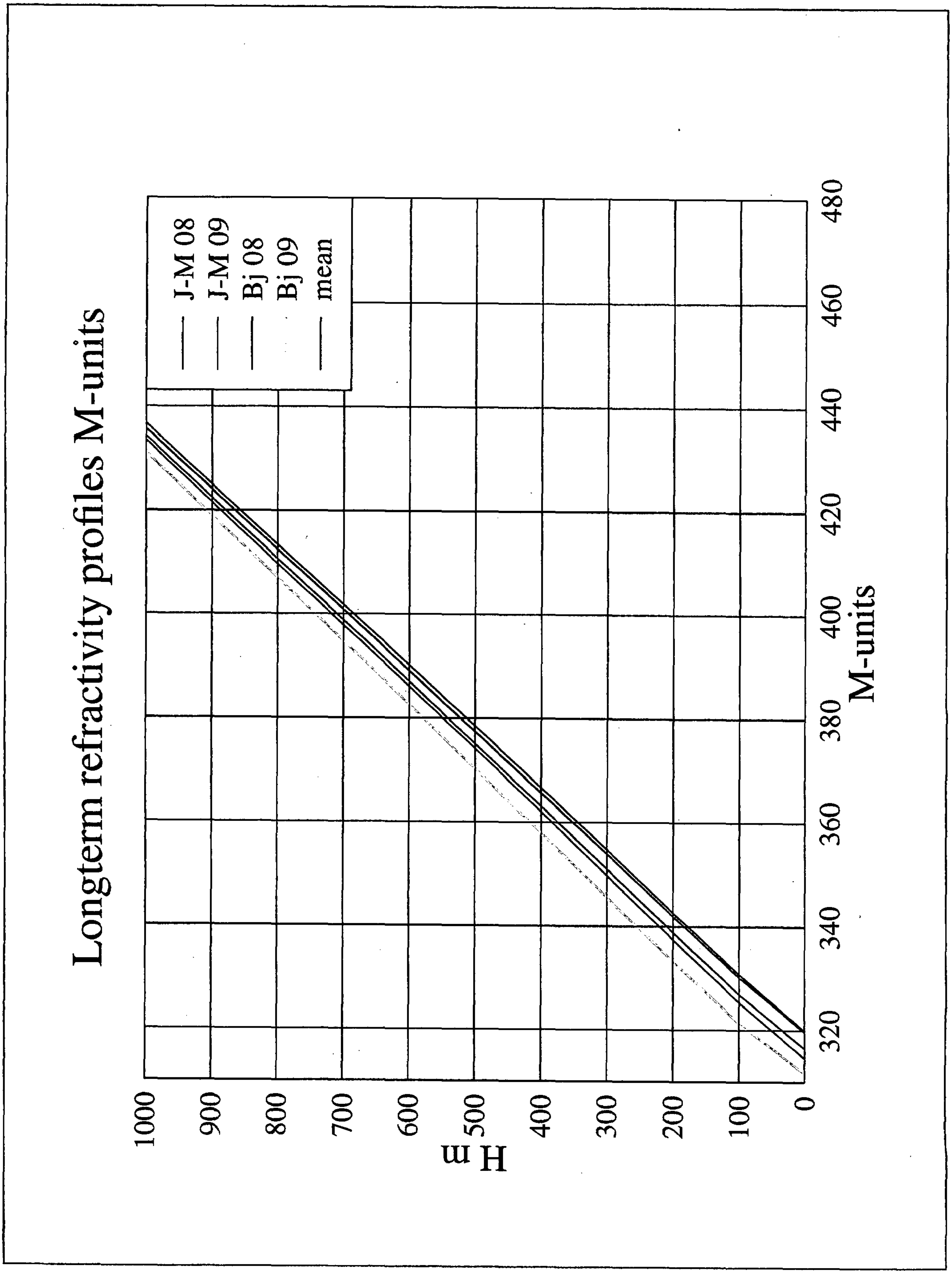
Another strategy is to use pure statistics for the values of two ascents , and this has to be done by some sort of "non -parametric statistics" since no shape or curve can directly be associated to a defined mathematical distribution of values. The comparison must then be done between an "actual shape" with the "standard shape" or as the deviation between this values. The distribution of the deviation or the real values of the set of an actual ascent can then by some sort of non-parametric statistics give the distribution within the set of actual shapes that has the least deviation from a defined standard distribution. A standard and secure method to compere distributions in non-parametric statistics is the Kolmogorov- Smirnov statistics which we will apply. The procedure will then be: let for example the "standard values" of an ascent be represented by the long-term values for the ascents from Jan-Mayen or Bjørnøya in the above mentioned period of ten year be denoted by MM. Let all other ascents, that are from Jan-Mayen in 1996 or 1998 or Bjørnøya 1996 or 1998 as well as the ascents from Lyr1 or Lyr2 in 1998 be designated A_i. We then compare the deviations D_i in the distributions where:

$D_i = MM - A_i$

Obvious the least difference D_i is when A_i=MM, that is everywhere zero, it is then possible to get the "next similar shape" to MM by varying A_i and then the next and so on by applying the Kolmogorov-Smirnov technique. This is then the technique that will be applied. The "number of observations" for the series need not be the same, the originally one hundred metres values can be as they were computed and the "modern" 10 meters "raw data" can be as observed, only the maximum distance between the cumulative distributions is the evidence if a distribution (of a curve or shape) in some degree differs from another.

Since the monthly mean profiles differ from another (figure 4.1.1, Jan-Mayen and Bjørnøya) we compute a "grand mean" of both stations for both months, say August and September. In figure 4.1.1 is shown the five profiles (Jan-Mayen and Bjørnøya for the months August and September together with the mean value as above denoted as MM. Jan-Mayen in August and September is shown as black and blue, Bjørnøya in the respective months as green and yellow and the grand mean as red. Note the latitude dependence as mentioned in section 3.5 and also the seasonal dependence shown as slightly higher M-values for August in comparison with September.

Figure 4.1.1. Long-term means of refractivity profiles for August and September for Bjørnøya and Jan-Mayen together with a «grand mean».



4.2 Kolmogorov - Smirnov statistics as the tool for comparison.

We use here the computed area mean profile as the normal distribution of refractivity values within the profile up to 2000 m. The actual profiles obtained through the ascents will the serve as the other distribution. The normal profile is more or less linear or at least picewise linear and should therefore give a rather «flat» distribution of values. The normal profile also consists of a mean of both noon and night observations.

If in the actual profiles ducts or other irregularities should appear, the distribution will be clustered at some values of the refractivity. Comparison of the cumulative distributions can then easily be performed by the Kolmogorov-Smirnov test to check the deviations. In tables 4.2.1 to 4.2.4 is given the probabilities that the single refractivity profile is drawn from the same universe as the normal profile. The value of the maximum deviation between the two cumulative distributions for the Kolmogorov-Smirnov test, D, is also given. We may from the magnitude of the probability detect the most adverse profiles, and as such days with problems for the electromagnetic communications.

To use the normal profile as comparison for Jan-Mayen and Bjørnøya causes no additional problems, since the two stations regularly have both day and night observations. For Ny-Ålesund we have a bias towards day observations and for the LYR-stations the ascents originate for all parts of the day with a bias towards morning observations. If we assume that the normal profile covers the extremes in at least the profile gradient it should also be applicable for more or less the whole day but keeping in mind the possible bias for Ny-Ålesund and LYR.

If possible we also include in the statistics the two relevant profiles from 1996, that is for the 28 of August hour 24 and the 29 of August hour 12.

year	month	day	hour	D	prob
1998	8	31	12	0.08498287	0.29278934
1998	8	31	24	0.08851889	0.16613722
1998	9	01	12	0.06449515	0.59916645
1998	9	01	24	0.11523432	0.05272244
1998	9	02	12	0.08164057	0.31183293
1998	9	02	24	0.13657713	0.00962855
1998	9	03	12	0.05384320	0.78678554
1998	9	03	24	0.16051978	0.00095029
1998	9	04	12	0.04796499	0.89413488
1998	9	04	24	0.08438951	0.25399899
1996	8	28	24	0.13858700	0.00782587
1996	8	29	12	0.11836064	0.03679176

Table 4.2.1 Probabilities and the K-S maximum deviation D for profiles from Jan-Mayen.

The most adverse profiles from the statistics in the period of 1998 we find at night of the 3 September as well as the night of 2 September both with probability values less than 0.01. This is also the case of the night profile of the 28 of August in 1996. The most «regular» profile we obtain at the 4 of September at hour 12 with a probability of about 0.89. This is quite in accordance with the discussion of the profiles in section 3.4. Inspection of the table shows also that the day profiles generally have greater probability than the night profiles. No real explanation to this can be put forward.

It is also worth noting the low probability values for the result of both ascents in 1996.

year	month	day	hour	D	prob
1998	8	31	12	0.06431350	0.59693533
1998	8	31	24	0.08018868	0.32174969
1998	9	01	12	0.05013782	0.87190217
1998	9	01	24	0.04509652	0.92405754
1998	9	02	12	0.04910714	0.87076497
1998	9	02	24	0.04557854	0.92922467
1998	9	03	12	0.09158355	0.20252044
1998	9	03	24	0.07125777	0.50336158
1998	9	04	12	0.07223648	0.45218560
1998	9	04	24	0.06826095	0.52363712
1996	8	28	24	0.07553069	0.40741810
1996	8	29	12	0.09399736	0.13220595

Table 4.2.2 Probabilities and the K-S maximum deviation D for profiles from Bjørnøya.

Probability values for the profiles encountered at Bjørnøya are higher than those of Jan-Mayen. The lowest values for the probability are 0.20 and 0.32 for the 3 of September hour 12 and 31 of August hour 24 respectively. The highest value 0.93 we get at 2 of September hour 24. Again this is more or less in accordance with the discussion in section 3.3. We note also from the table that the bias towards higher probability for the day profiles does not exist here.

Again we recognise the low probability values for the 1996 profiles with the morning ascent for the 29 of August as the absolute extreme value.

For Ny-Ålesund in table 4.2.3 we also note quite high probability values in the period of 1998 as should be the case for a well mixed atmosphere as discussed in section 3.2. Since also the set of data consists of values at each 50 m (and not at each 5 m as for the other stations) the profile will be much more smoothened, and as a result probably give a better fit to the «normal profile» and hence the rather constant high probability values.

It is again most interesting to note the low probability value in the 1996 period, that of the morning observation of the 29 of August.

year	month	day	hour	D	prob
1998	8	30	12	0.08875537	0.90011376
1998	8	31	12	0.11198747	0.68899405
1998	9	01	12	0.09658146	0.79883838
1998	9	02	12	0.09002495	0.91731441
1998	9	03	12	0.09511933	0.86480474
1998	9	03	24	0.07427084	0.97149658
1998	9	04	12	0.04361191	0.99999887
1998	9	04	24	0.07950711	0.92712396
1996	8	28	12	0.07698143	0.96060580
1996	8	29	12	0.13376135	0.41248149

Table 4.2.3 Probabilities and the K-S maximum deviation D for profiles from Ny-Ålesund.

year	month	day	hour	D	prob
1998	8	31	18	0.10689534	0.13264108
1998	9	01	18	0.07022107	0.49481294
1998*	9	01	18	0.09131873	0.20217037
1998	9	01	24	0.11501619	0.04596505
1998	9	02	04	0.05765143	0.74950832
1998	9	02	08	0.07277831	0.39274654
1998	9	02	12	0.10613060	0.09533558
1998	9	02	18	0.06431359	0.63559157
1998	9	03	04	0.08376336	0.29016125
1998	9	03	08	0.10843536	0.07994802
1998	9	03	12	0.09804973	0.15147430
1998*	9	03	12	0.07800448	0.39204639
1998	9	04	12	0.05365854	0.81943655

Table 4.2.4 Probabilities and the K-S maximum deviation D for profiles from LYR1 and LYR2. The LYR2 ascents marked with an asterisk.

For the LYR-stations we find the highest probability for the profile at noon the 4 of September, this is also by the discussion in section 3.1 found to be the most regular of all profiles obtained. The least values we find for the profiles from the 1 of September at night and from the 3 of September at hour 8, both days with well developed duct structures . We may from the above results conclude that low probability values and sub- or super-refractive structures and even ducts have a rather close connection. Since the Kolmogorov-Smirnov test only look at the differences in the cumulative distributions and not consider point to point connection between the two profiles, there will naturally be some degree of uncertainty in such an approach. But the comparison of the above Kolmogorov-Smirnov probabilities by direct inspection of the profiles (sections 3.1 to 3.4) show a rather satisfactory resemblance, well mixed atmospheres give high probabilities and days with irregular layering gives low probabilities.

It can also be interesting to try to compare the probabilities of the simultaneous obtained profiles in the period.

year	month	day	hour	LYR1	LYR2	Bjørnøya	Jan-Mayen	Ny-Ålesund
1998	09	01	24	0.0460		0.9241	0.0527	
	09	02	12	0.0953		0.8708	0.3118	0.9173
	09	03	12	0.1515	0.3920	0.2025	0.7868	0.8648
	09	04	12	0.8194		0.4522	0.8941	0.9999

Table 4.2.2 Rounded off probability values for the simultaneous refractivity profiles at LYR1, LYR2, Bjørnøya, Jan-Mayen and Ny-Ålesund.

The area represented by the stations is rather big, the range in longitude is about 27. degrees (8° 40' W for Jan-Mayen to 19° 01' E for Bjørnøya) and in latitude we have approximately 8 degrees (70° 56' for Jan-Mayen to 78° 55' for Ny-Ålesund). To experience the more or less the same weather conditions in such a vast area is rare. A high pressure situation could provide this, but if we face a situation with wandering lows with its fronts surely the results would and should be different. From table 4.2.2 we find the 4 of September with rather high probability values for all stations, the least value at Bjørnøya, the eastern most station. realising that the macro weather very often has a easterly movement this is in accordance with the theory. For the other days we necessarily will have differences since fronts existed somewhere in the area. We could also wonder why the simultaneous profiles from LYR1 and LYR2 deviates, but a part of the explanation here lies in the topography of Adventsdalen and the rather big mountains surrounding it. Moving air in such an environment will inevitably be influenced by rather local conditions.

If we then again look at the conditions in 1996 collected in table 4.2.3 we may put forward the following: Low probability values for most of the stations. The night before the accident the eastern most station has the highest value as the weather moved from west towards east. The western most station Jan-Mayen has at that time a very low value. The standard observation at noon the day of the accident both Jan-Mayen and Bjørnøya have low values, at Jan-Mayen the value has improved a little but at Bjørnøya the value is substantial reduced. At Ny-Ålesund the value appears to be rather high, but bearing in mind the smoothening effect of the vertical resolution for this radio sonde this is not surprising and inspection of table 4.2.3 shows that this represents the absolute lowest value in the set of data from Ny-Ålesund.

year	month	day	hour	Bjørnøya	Jan-Mayen	Ny-Ålesund
1996	08	28	24	0.4074	0.0078	
	08	29	12	0.1322	0.0368	0.4125

Table 4.2.2 Rounded off probability values for the simultaneous refractivity profiles at Bjørnøya, Jan-Mayen and Ny-Ålesund of 1996.

5. Conclusions.

During a 5 days radio sonde campaign near by Longyear at Svalbard was launched 13 sondes to examine the radio climatic conditions in the landing route through Adventsdalen to Longeyear airport.

Although super refractive conditions and duct situations were observed none of these had the necessary intensity or height (depth) to catch the frequencies from the ILS-system at the airport.

Another major difference between the radio climatic conditions in August/September of 1996 and that of the same period in 1998 was the lack of strong ground based or evaporation ducts.

A Kolmogorov-Smirnov technique applied to the data obtained at the Longyear stations and the other meteorological stations in the area and long-term mean values for the area shows a clear connection of low probability values of being a normal profile and conditions for anomalous propagation conditions.

In spite of rather few ascents it is some evidence that there is a necessary similarity between the stations, at least in showing up simultaneous high probability, but when adverse weather with low pressure and fronts the propagation conditions are determined on a more local scale.

Using the same technique on the data from the period of the accident very low values of the probability are obtained indicating anomalous propagation conditions.

Examination of the surface refractivity gives for the period of 1996 the curious result that the southern most station Jan-Mayen has against theory the lowest refractivity values, this can also lead to the conclusion of anomalous propagation conditions at this time.

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