Improved Clear-air refractivity parameters and atmospheric description using high resolution radiosondes

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INTRODUCTION

The capabilities of modern high resolution radiosondes are reviewed, with particular reference to thin layers and multiple ducts in the atmosphere. Statistics based on 2 year's data are given for four Norwegian radiosonde stations.

THE RADIOSONDE STATIONS.

High resolution data (HIRES, 2 seconds data) from four radiosondes are considered. Information about the radiosonde stations is given in table 1.

Station name	Latitude	Longitude	masl [m]	Type	Obs. hour	Observation period
Gardermoen	60.12N	11.06E	204	manual	06	12/5 98-31/10 00
Sola	58.53N	5.38E	37	autosonde	12/00	01/5 98-31/10 00
Ørland	63.42N	9.24E	10	manual	12/00	01/5 98-31/10 00
Ekofisk	56.53N	3.22E	47	manual	12/00	16/9 99-29/10 00

Table 1 General information about the radiosonde stations.

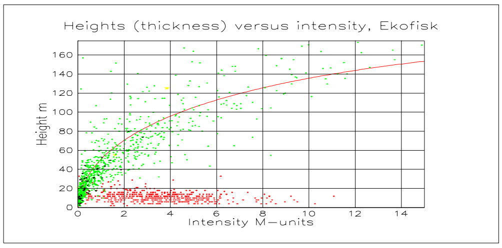
Gardermoen is the main airport at the Norwegian capital Oslo situated about 50 km north of the city. It can be looked upon as an "inland station". Sola is an airport near by the city of Stavanger in the south-western Norway near by the coast, a "coastal station". Ørland, not far from Trondheim, is an airport at the northern part of the west coast and again a coastal station. Ekofisk is an oilrig in the North Sea and can be seen as a real "maritime station".

HIRES RADIOSONDES.

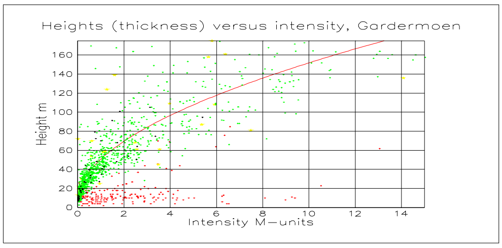
The modern radiosonde has had in the last years rapid improvements in both hardware, the sensors for registration of temperature, humidity, pressure and position, i.e. the wind as well as the software (build in data editing programs). Using the Finish Vaisala sondes, RS80, with the modern DigiCORA system the NMI has the possibility to receive 2 sec data. With an ascent rate of 5m/sec this give a spatial resolution of about 10 m. The included software making the "data editing" consists of four phases: 1. coarse filtering, 2. fine filtering, 3. Completion of the data by interpolation, 4. Data smoothening between turning points. The purpose of data editing is to reject physically inconsistent data values. Editing is a non-linear, non-recursive method of data quality control. It is necessary because of the presence of telemetry noise that tends to distort the determination of the signal frequency. Data editing is carried out in real time. In addition it is done a further smooth by using running 3-point means of the data. The built-in data editing programs are in more detail shown in [1] or [2]. In [2] are the capabilities of HIRES-data shown, also the effect on radiowave propagation of sub-structures in ducts

INTENSITY AND THICKNESS OF DUCTS

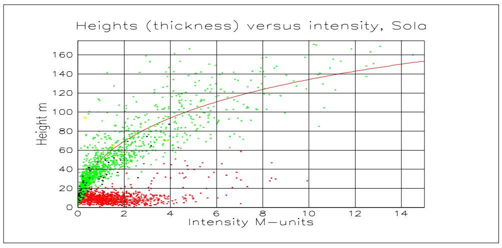
In figures 1a-d are shown the duct height versus the duct intensity for the various duct types. The colour representation is as follows: red dots: surface based ducts, black dots: elevated surface duct, green dots, elevated ducts and yellow stars: included structures. The red line is a regression line concerning only elevated ducts. For the two main types of ducts, the surface based and the elevated we clearly see for each station a red band mainly below 20 meter in duct height or thickness. A green band representing the elevated ducts is going from the lower left corner to the upper right corner representing an increase in thickness as the intensity increases. For the elevated ducts it seems to be some functional dependence between duct height and duct intensity. For the surface based ducts the red band of dots is rather



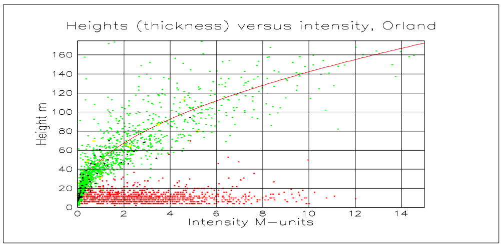
a. Ekofisk.



b. Gardermoen.



c. Sola



d. Ørland.

Fig. 1a-d Height (thickness) versus intensity for the different duct types.

concentrated for Ekofisk and Ørland indicating a mean height irrespective of intensity, but for Gardermoen and Sola there is some spread in the distribution of the points. The plots indicate some increase of the height with increasing intensity, but the distribution of points seems to be too erratic to draw any safe conclusions. For the other types of ducts the numbers are to small compared with the above-discussed types to make any sensible statistics. From figures **1a-d** it seems reasonably to make a regression between the two parameters, at least for the elevated ducts where the data points seem to have some regular course. The course indicates that the height has some sort of square root dependence of the intensity. Using the height as dependent variable and a linear term in intensity together with a square root term we find reasonably good correlation about 90 percent, best fit for the inland station. For the one-parameter approach, using the square root of the intensity alone, we get values almost as good. Using the intensity alone we find acceptable correlation for Gardermoen and Ørland, but with this independent variable the correlation at Ekofisk and Sola have a substantial reduction.

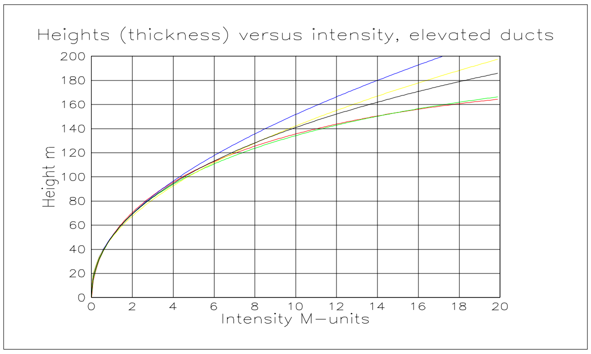


Fig 2 Regression curves for thickness versus intensity for the four stations.
Red: Ekofisk, Blue: Gardermoen, Yellow: Sola, Green: Ørland, Black: Grand mean

MULTIPLE DUCTING STRUCTURES.

From the HIRES data we have a possibility to record a far more detailed structure of the atmosphere than we do with the LORES based on the meteorological TEMP- and PILOT-codes. Small, narrow structures are detected with multiple structures of ducts. In the data under consideration is found up to 18 layers with ducting ability. In figure 3 is given the percentage of simultaneous ducts, that is number of ducts observed in one ascent of the radiosonde where ducts are recognised. For Gardermoen we have 48.25 % with one duct, 28.52 % with two ducts and so on. Percentages are chosen because the period for Ekofisk is shorter than the periods for the three other stations and percentages are readily comparable. The distributions for the coastal stations are quite similar throughout the spectrum of ducts, whereas the

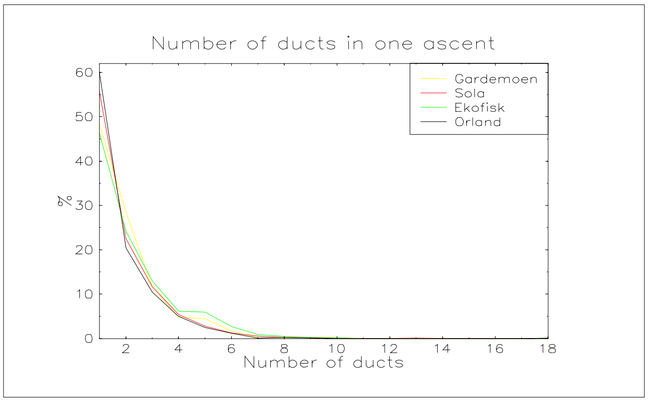


Fig. 3 Percentage of simultaneous ducts for the stations

inland station and the maritime stations differ from those from 4 ducts of until 8 ducts. We find in the mean a little more than 50 % of the «duct ascents» with one duct. The coastal stations have more than 50 %, presumably by an evaporative low layer forming a steady surface based duct, existing nearly whatever the weather conditions may be. This should also be the case for the maritime station at Ekofisk, but remembering the start level at 47 meters above sea level and the fact that evaporative ducts in the North Sea area have a characteristic height below 20 m, such ducts would never be recognised by the sonde. We also recognise that all stations contribute with cases of nine ducts in one ascent. Cases with more ducts are more rare, Gardermoen, Ekofisk and Ørland have one each, Sola contribute with two. For ascents with more than ten ducts, we find one case at Sola with 13 ducting layers and one at Ørland with 18 ducts.

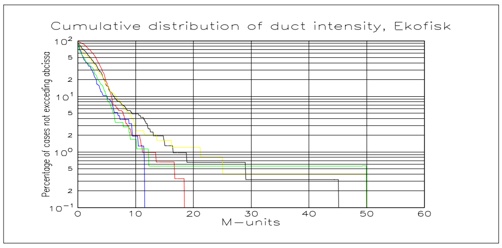
No	Gardermoen				Ekofisk				Sola				Ørland			
of	% of type of duct				% of type of duct				% of type of duct				% of type of duct			
D.	sur	esur	elev	incl	sur	esur	elev	incl	sur	esur	elev	incl	sur	esur	elev	incl
1	39.3	1.6	59.1	0.0	83.3	0.0	16.7	0.0	86.9	0.0	13.1	0.0	79.0	0.0	21.0	0.0
2	12.0	2.4	85.6	0.0	38.6	0.6	60.2	0.0	35.0	0.2	64.9	0.0	33.5	1.5	65.0	0.0
3	6.5	2.2	87.9	3.5	25.3	0.4	73.2	1.1	22.7	0.0	75.4	1.9	20.8	1.3	75.4	2.5
4	3.9	0.0	85.9	10.2	15.2	0.0	78.7	6.1	19.1	0.3	76.4	4.2	14.3	1.0	78.0	6.7
5	2.8	2.8	83.4	11.0	13.5	0.0	79.5	7.0	14.1	1.6	78.4	5.9	11.4	0.0	78.4	10.3
6	3.0	4.5	84.8	7.6	14.8	0.9	75.9	8.3	10.4	0.0	82.3	7.3	10.8	2.9	81.4	4.9
7	14.3	0.0	85.7	0.0	14.3	0.0	76.2	9.5	10.2	0.0	79.6	10.2	14.3	0.0	78.6	7.1
8	0.0	0.0	62.5	37.5	4.2	0.0	87.5	8.3	12.5	0.0	79.2	8.3	9.4	3.1	78.1	9.4
9	0.0	0.0	88.9	11.1	11.1	0.0	72.2	16.7	5.6	0.0	77.8	16.7	0.0	0.0	100.	0.0
10	0.0	0.0	90.0	10.0	0.0	0.0	90.0	10.0	10.0	0.0	80.0	10.0	0.0	0.0	0.0	0.0

Table **2** Numbers of ducting layers within one ascent (No of D.) with the percentage of the type of ducts (sur : surface, esur : elevated surface, elev : elevated and incl : included duct) associated with that number of layers.

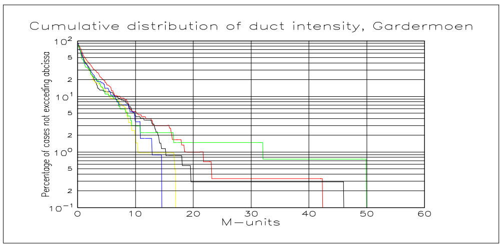
From data is clearly seen the difference between inland and coastal/maritime stations. For the inland station we have ca. 40% surface based ducts and 60% elevated ducts in the case of one duct. For the same case the coastal and maritime stations have ca. 80% surface based ducts caused by the stationary evaporation duct and 20% of elevated ducts. This is also reflected in the cases with more ducts in one ascent. It is also recognised the more ″active″ land surface producing elevated surface layers of a far greater percentage than coastal and maritime weather climates. This gives rise to higher percentages for the included layers, presumably caused by local strong convective processes in an inland climate. In maritime and coastal climates such structures are created on a far greater scale in space when the subsidence caused by a high pressure fights the weather caused by the low pressure in the westerlies. Recognising the different duct combinations that are most common we find for N layers up to and included 6 layers the two most common types are either N elevated or 1 surface together with (N-1) elevated ducts. For more than 6 ducts there are by nature no preferred combination. However, it looks like the more ducting layers the more elevated ducts with included structures are the most common. This is evident for the inland station. There are differences between the stations, also among the coastal stations that should have mainly the same climate. But again we find the presence of ducts caused by evaporation at the coastal stations as a main feature. Combinations of ten ducts and above are few; only one at Gardermoen with nine elevated ducts in combination with one included. For Ekofisk we have exact the same situation. At Sola we have one combination with ten ducts (one surface based, eight elevated and one included) and one situation with thirteen ducts, still the surface duct combined with ten elevated ducts and two included ducts. Ørland has one very rare situation with eighteen ducts, again the coastal surface duct in combination with sixteen elevated ducts and one included structure. Looking at the monthly distribution of the multiple ducting layers we should expect that the continental station should have the most complex atmosphere, i.e. the greatest number of ducts in the summer or late summer, the coastal stations in the late summer or in the autumn and the real maritime stations in the autumn or the early winter, which is confirmed by data. The maritime station has the greatest percentage of 2 simultaneous ducts in October with about 18% of total 162 occurrences of 2 ducts. This is the same case for 3 simultaneous ducts, about 17% in October. For 4 simultaneous ducts the greatest percentage has moved on to the month of November. The cause is presumably that the greatest difference in the temperature between the surface and the air above is in the autumn or the early winter. The percentages for the maritime Ekofisk should be equally distributed through the year as also data show. For 4 simultaneous ducts the maximum value moves on to November, which is according to the theory. For the occurrence of more simultaneous ducts, which are scarcer, the yearly distribution is more stochastic. For the coastal and inland stations we find a clear yearly trend. The highest percentages for cases up and included 5 simultaneous ducts are all in the warm season or in the months from May to September, also included October for the inland station. In this season the terrestrial surface is most active and makes by convective processes layering of the atmosphere. In combination with processes on a greater scale as fronts or high pressures this can give a rather complex atmosphere.

To get an idea of the magnitudes of duct thickness and the duct intensity is shown figures 4 a-d with the cumulative distributions of height (thickness) and intensity of ducts at two stations. The legend for the colours are as follows: red: one single duct, black: 2 simultaneous ducts blue: 3 simultaneous ducts, yellow: 4 simultaneous ducts, green: 5 simultaneous ducts. Cases with six or more simultaneous ducts for each station are so few so that the making of a distribution is rather not worthwhile. To have a reasonable resolution in the figures, is defined a maximum value for intensity of 50 M-units and for height (thickness) of 350 meters. Values greater than this are put in the last bin.

Fig 4 a-b Cumulative distribution of intensity for various of numbers of simultaneous ducts:

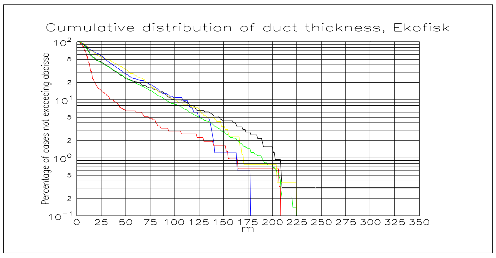


a Ekofisk.

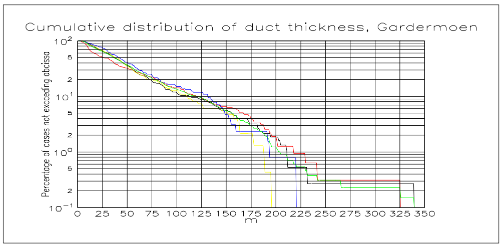


b Gardermoen.

Fig 4 c-d Cumulative distribution of thickness for various of numbers of simultaneous ducts:



c Ekofisk.



d Gardermoen.

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