# DANISH METEOROLOGICAL INSTITUTE

# TECHNICAL REPORT

# 03-11

# Evaluation of the AMIS Gridded Observations and Radar derived 24-hour Accumulated Precipitation by Comparison with Climate Grid – Denmark Gridded Observations Phase II

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**Steffensen M.**
**Vejen F.**

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# Preface

This report present results from a project carried out by DMI in 2001 and 2002 as phase II of task number 2 “Forbedrede vejrdata til lokal varsling og beslutningsstøtte for behandlingsbehov mod fugtelskende svampe i korn” in the project “Videreudvikling af beslutningsstøttesystemer” in Pesticide Action Plan II commissioned by the Danish Ministry of Environment and Energy and the Ministry of Food, Agriculture and Fisheries.

The results and recommendations of phase I is described in the Technical Report 01-13: ”Evaluation of the AMIS Gridded Observations and Radar derived 24-hour Accumulated Precipitation by Comparison with Climate – Grid Denmark Gridded Observations”, March 2001.

Phase II follows the recommendations given in phase I.

*DMI, May 2002*

*Michael Steffensen*
*Flemming Vejen*

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# 1. Introduction

## 1.1 General

The two main tasks of phase II are to study how the field of 24-hour accumulated precipitation in AMIS depends on the number of observation used in the gridding process and to investigate the effect of calibrating the radar derived 24-hour accumulated precipitation using different techniques.

A central component of DMI's AgroMeteorological Information System (AMIS) is the interpolation of observed meteorological data to the 10 by 10 kilometre AMIS grid. The AMIS observational data are generally of high quality (Hilden and Hansen, 1998), however the fields of 24-hour accumulated precipitation tend to be too smooth, not reflecting the fine-scale spatial structure of the actual precipitation fields, probably stemming in part from the quite simple, isentropic interpolation scheme used to calculate the data from the raw observed values, but also from the relative small number of observations involved in the interpolation.

During the spring of 2002 a number volunteer people will read the daily precipitation 8 o'clock in the morning Danish time and report the measurement through telephone to the Danish Meteorological Institute as soon as possible. This will increase the number of available precipitation observations in the AMIS system. When the number of observations is increased the fine-scale spatial structure of the actual precipitation fields is expected to be better represented. This will be demonstrated by comparison of the operational AMIS precipitation pattern on specific day and the precipitation pattern obtained with more observation in the interpolation that day. It has also been investigated how the verification measures depend on the number of observation.

In phase I it has been demonstrated in the case studies that field fine-scale structure was better represented in the radar derived 24-hour accumulated precipitation than in the operational AMIS system. The overall statistical verification measure, such as ME, MAE and HR, on the other hand was not as good as those for the operational AMIS. The aim of phase II was to correct the radar data for anaprop errors and to adjust the radar derived 24-hour accumulated precipitation to get overall statistical verification measure comparable to AMIS.

## 1.2 Methods and Data

The data sets used in phase II are basically the same as those used in phase I with one major exception. The AMIS data are supplemented with observation from those locations where the additional precipitation observations made available through telephone are expected. These observation are available for the growing seasons 1998 and 1999 though not on daily basis at that time.

## 1.3 Outline

The report is organised as follows:

Chapter 2 contains brief descriptions of the modifications of the operational AMIS field used in this analysis, and the methods of the calibration of the radar data are outlined. The results of the qualitative case studies using the modified methods are discussed. Chapter 3 presents the statistical verification for dependencies on the number of observations used in the interpolation and for adjusted radar derived fields, respectively. Chapter 4 contains the central conclusions. References are given in Chapter 5.

Detailed results of the statistical verification are compiled in an Appendix B to J.

A list of abbreviations and acronyms used throughout the report is given below.

## 1.4 Abbreviations

| | |
|---|---|
| AMIS | AgroMeteorological Information System, see Chapter 2.2 AMIS. |
| RADAR | Radar derived 24-hour accumulated precipitation, see Chapter 2.3. |
| ME | Mean Error, i.e. the sum of the difference between the analysed values and the observations, divided by the number of observations. |
| MAE | Mean Absolute Error, i.e. the sum of the absolute difference between the analysed values and the observations, divided by the number of observations. |
| RMSE | Root Mean Square Error, i.e. square root of the mean squared error. |
| HR | Hit Rate, The sum over each precipitation category of number of correct estimate (AMIS or Radar ) of this category divided be the total number of occurrence in Climate Grid of this category. |
| HKSI | Hanssen-Kuipers' skill index with climate as reference. HKSI is 1 for a perfect forecasting system and 0 for a "no skill" system. Negative values of HKSI indicates that the forecasting system is inferior to the reference. (Hanssen, A.W., and W.J.A. Kuipers, 1965) |

All Hit Rates are given as fractions.

ME, MAE and RMSE are in mm/24hr in tables showing statistics.

## 1.5 Glossary

| | |
|---|---|
| Anaprop: | In meteorological situations associated with nonstandard refraction, strong downward bending of the radar beam may occur leading to echoes from ground targets even far from the radar. This cause spurious echoes. Nonstandard refraction occur when the vertical |

distributions of temperature and specific humidity are other than normal.

Attenuation: The beam power is attenuated due to atmospheric gasses and hydrometeors, i.e. clouds, rain, snow and hail.

Beam filling: The received power corresponds to the backscattering from a volume of air. If the beam volume is not uniform filled with hydrometeors, e.g. in case of partially filling, representativity problems may arise. The cross section of a radar beam increases with increasing range, thus the problem increases with range.

Beam power profile: The power profile is the energy level in the beam across the beam axis.

Bright band: The bright band is the layer in which melting of snow is going on causing a higher reflectivity than in the layers below and above. A thin coating of water results in a very large increase in the reflectivity of a snow sphere due to a larger backscattering cross section.

Clutter: The reflection of the radar beam from non-meteorological targets.

Overshooting: The radar beam is situated above the precipitation layer.

Reflectivity factor: The volumetric integration of the drop diameter in sixth power in the unit $mm^6mm^{-3}$.

Refraction: The air-mass properties, i.e. temperature, pressure and humidity, are sufficently variable to produce small changes in the speed of propagation. This may lead to refraction of the radar ray and produce marked changes in the direction of propagation.

Sidelobe: The energy is concentrated into a beam along the radar parabolas axis which is known as the major lobe. Smaller secondary lobes, the sidelobes, are usually found with their central axis directed at various angles with the parabolas axis.

# 2. The Field Types

## 2.1 CLIMATE GRID - DENMARK

A description of climate grid – Denmark is found in the phase I report Technical Report 01-13: ”Evaluation of the AMIS Gridded Observations and Radar derived 24-hour Accumulated Precipitation by Comparison with Climate – Grid Denmark Gridded Observations”, March 2001.

## 2.2 AMIS

DMI’s operational AgroMeteorological Information System, AMIS, is described in the phase I report Technical Report 01-13: ”Evaluation of the AMIS Gridded Observations and Radar derived 24-hour Accumulated Precipitation by Comparison with Climate – Grid Denmark Gridded Observations”, March 2001.

### 2.2.1 Modified AMIS

In this study four new precipitation fields have been obtain using the same interpolation method as in the operational AMIS, but with a varying number of observations. The total number of available observations is 126 for the Jutland area. Among these observations a subset of 87 observations was randomly chosen in such a way that the coverage has the same degree of homogeneity. The same procedure was performed with 62 and 25 observations.

For each AMIS square, the value at a given time is obtained by a simple distance interpolation with a predefined cutoff radius and weighting with weights proportional to $d^r$, where d is distance and r is a negative power. The cutoff radius and the power has to be estimated. A small value of cutoff radius will have to few observation in the interpolation and a large value of cutoff radius will include to many observations. An optimum cutoff radius may be found. The power on the other hand is connected to the cutoff radius since a large power will suppress observations at large distances even if the cutoff radius is large.

The cutoff radius and the power is estimated by analysis of the mean absolute error, MAE, of the interpolation of each observation from the others.

For small values of cutoff radius (too few observations) the MAE increases when the power is increased because a large power will reduce the influence of distance observation and thereby further reduce the number of observation in the interpolation.

For a large cutoff radius (to many observations) the behaviour if MAE is opposite. MAE decreases when the power is increased because a large power will reduce the influence of distance observation and thereby reduce the number of observation in the interpolation.

The cutoff radius and the power also depend on the total number of observations available. If the total number of observations is small the cutoff radius has to be large to include sufficient number of observations in the interpolation.

The cutoff radius and the power for each of the four additional fields are listed in table 1.

| No of stations | Cut-off radius (km) | Power |
|---|---|---|
| 25 | 66 | 1.5 |
| 62 | 41 | 1.8 |
| 87 | 36.2 | 2.0 |
| 126 | 32 | 1.9 |

Table 1

## 2.2.2 July 14th, 1998: A Cold Front

The synoptic development over Denmark this day is dominated by a low which enters Jutland near Thyborøn and moves eastwards across northern Jutland and Kattegat towards Sweden. During the morning the wind in Jutland is mainly from south to southwest with light showers in the western and southern parts and in Djursland. Strong to heavy showers are reported from Ringkøbing along the west coast to Thisted airport. Light continuos rain in the most southern part of Jutland. A cold front associated with the low reaches Jutland and is at 12:00 UTC stretching from around Mors in the Limfjord southeast across Funen. The synoptic weather map and the position of the cold front at 12:00 UTC are shown in figure 2.1. The wind behind the front is more westerly and light showers prevail across Jutland with still some strong showers on the west coast. At 15:00 UTC the front has moved further eastwards to Kattegat and Sealand and the weather is beginning to clear up in Jutland, though some light widespread showers are still present in Jutland.

Figure 2.2 show the precipitation contours (red curves) for the operational AMIS field together with the contours (blue) of the verifying Climate Grid - Denmark and a scattergram in the lower left corner. The grid precipitation from Climate Grid - Denmark shows up to 15-20 mm of rain at the most wet places. The operational AMIS results show a fairly good corresponds with the wet places in southern Jutland, but a very poor correspondence with wet places in the central and northern Jutland, where the counter lines in many places are even orthogonal.

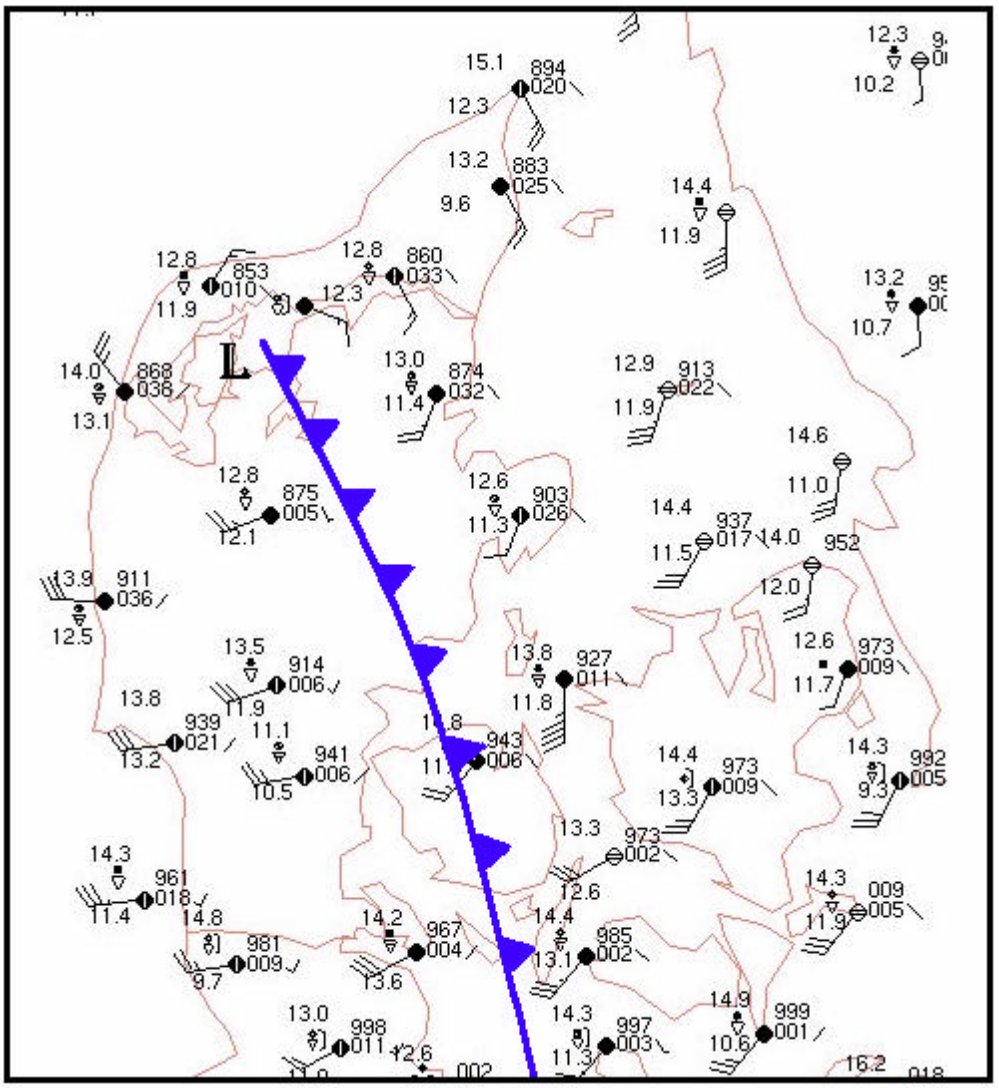



Figure 2.1. Synoptic map for July 14th, 1998, 12 UTC.

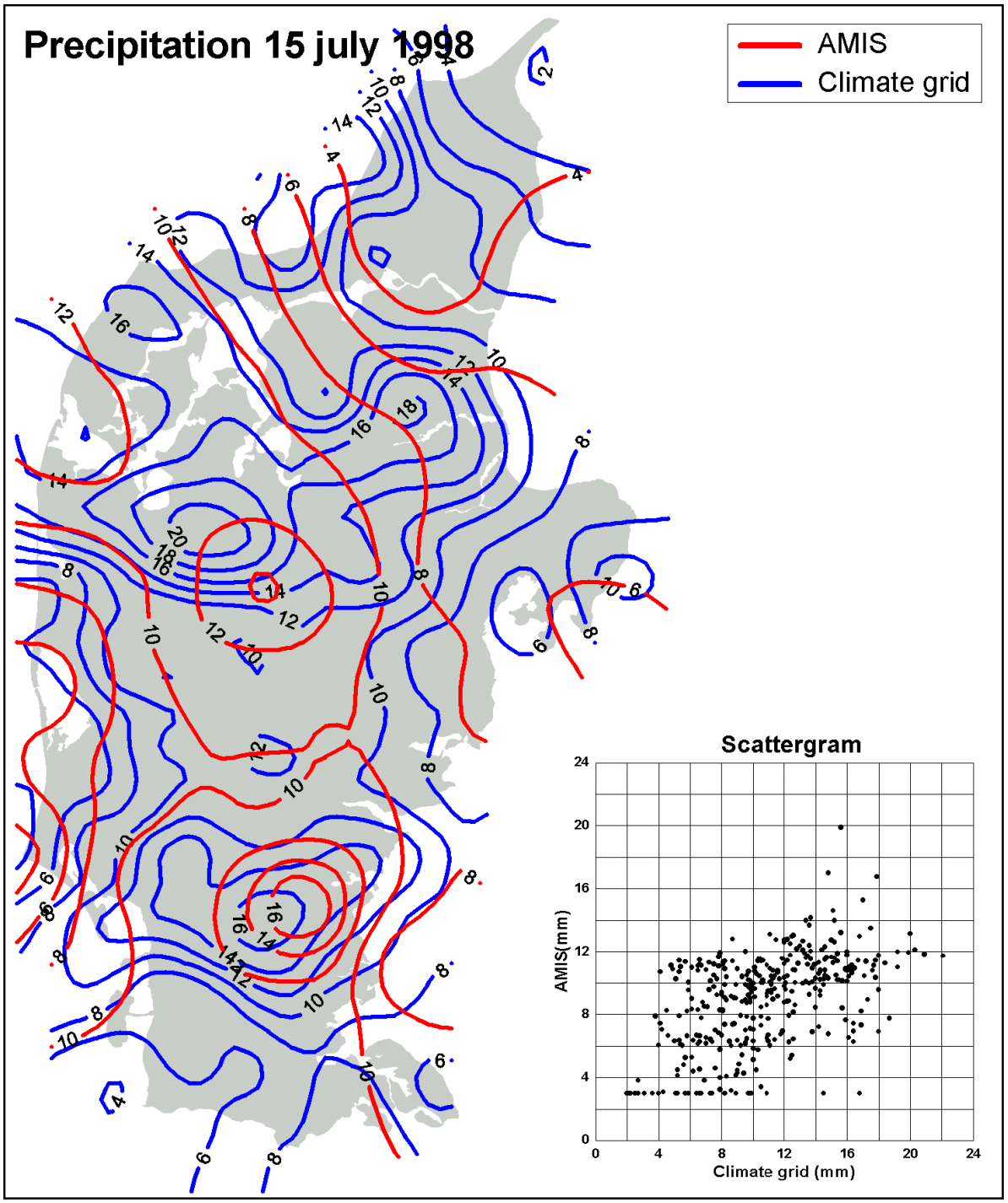



Figure 2.2. Map of precipitation from the operational AMIS for July 15th, 1998, 12 UTC, and a scattergram to show the accuracy. This figure is the same as figure 3.5 in Technical Report 01-13: "Evaluation of the AMIS Gridded Observations and Radar derived 24-hour Accumulated Precipitation by Comparison with Climate – Grid Denmark Gridded Observations"

Figure 2.3 shows four precipitation patterns and scattergrams for fields with an increasing number of observations in the interpolation, starting with 25 observation in the upper left corner, 62 observations in the upper right corner, 87 observations in the lower left corner and finally all 126 available observations in the lower right corner

The scattergrams clearly show how the increasing number of observations is reducing the spread in the scattergrams indicating a better retrieval of the fine-scale structure of the precipitation field. In this case however not much is achieved going from 87 observations to 126. The field based on 87 observations captures most of the fine-scale structure, and is much better than the operational AMIS shown in figure 2.2.

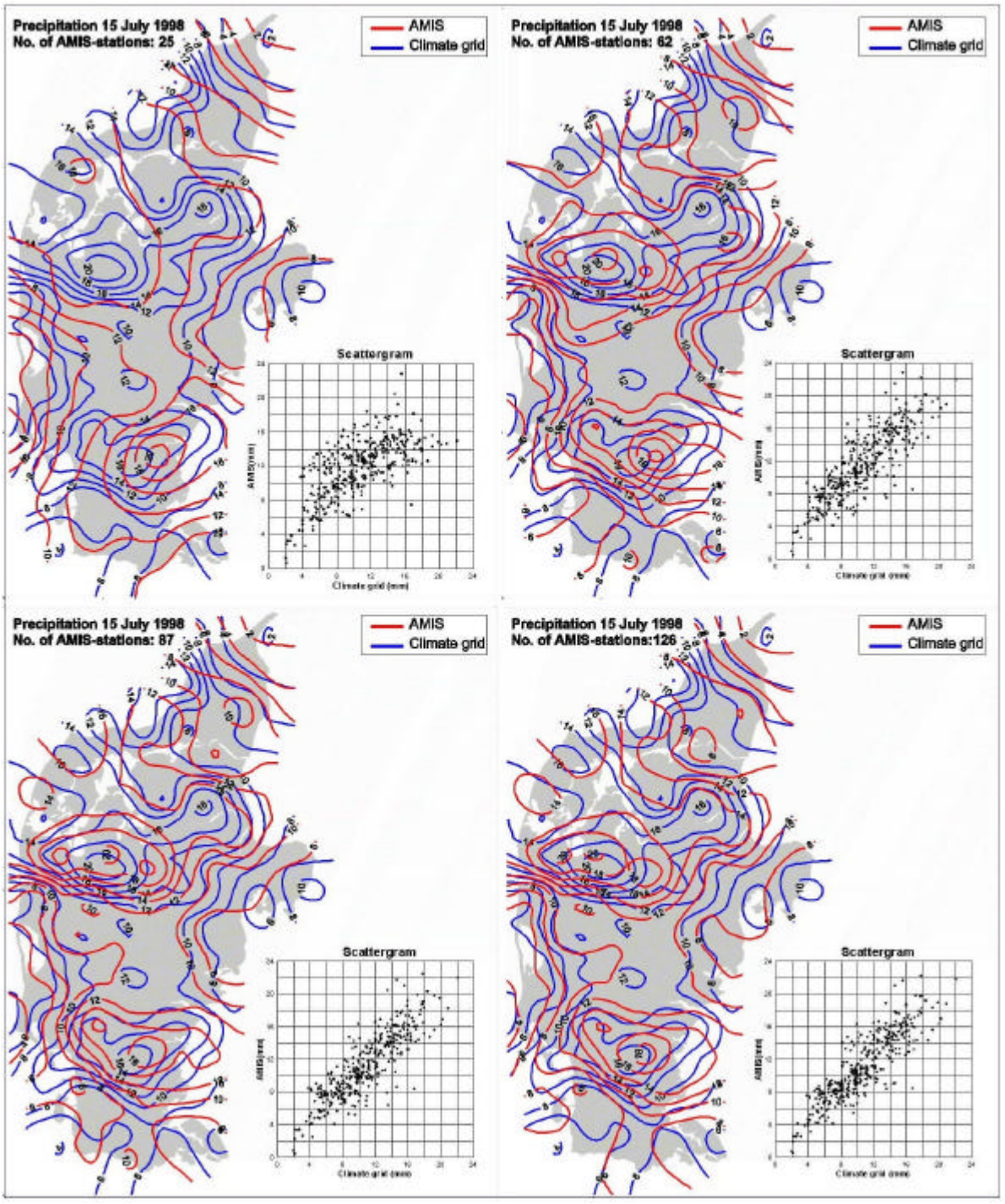



Figure 2.3 Four precipitation patterns and scattergrams for fields with an increasing number of observations in the interpolation, starting with 25 observation in the upper left corner, 62 observations in the upper right corner, 87 observations in the lower left corner and finally all 126 available observations in the lower right corner.

## 2.2.3 June 24th, 1999: Showers

The synoptic situation 12 UTC shown in figure 2.4 is dominated by a high pressure area with more than 1020 hPa and a southeast gradient with wind from northwest. This was the general situation during both 24-25 June 1999. Local showers fell mainly in the two areas seen in figure 2.5 showing the precipitation contours (red curves) for the operational AMIS field together with the contours (blue) of the verifying Climate Grid - Denmark and again a scattergram in the lower left corner.

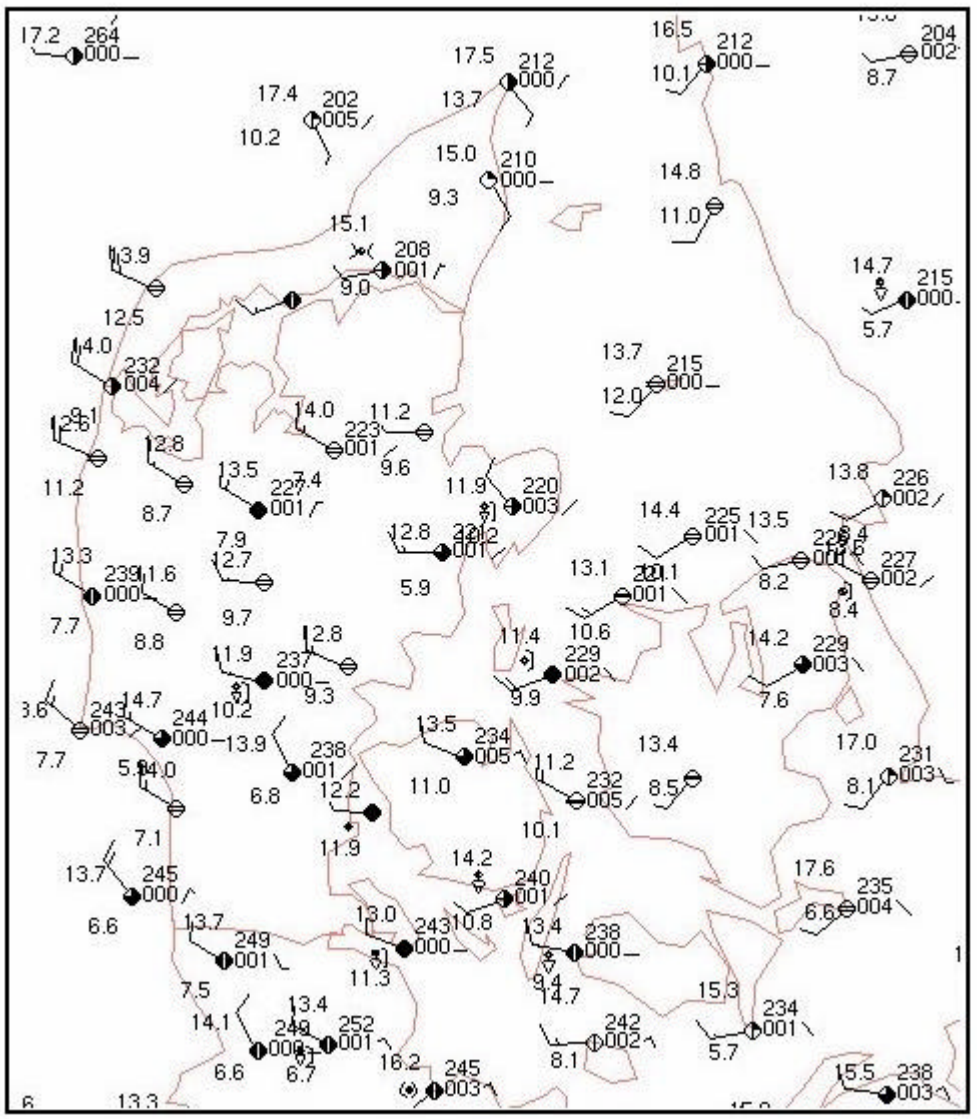


Figure 2.4. Synoptic map for June, 24th 1999, 12 UTC.

The operational AMIS field captures to some extend the small precipitation area to the south but completely misses the rather large amount of precipitation, 16 [mm] south of Aalborg. This may also be seen in the scattergram where the AMIS values tend to lie on a horizontal line around 2 [mm] with the Climate Grid values reaching more than 20 [mm].

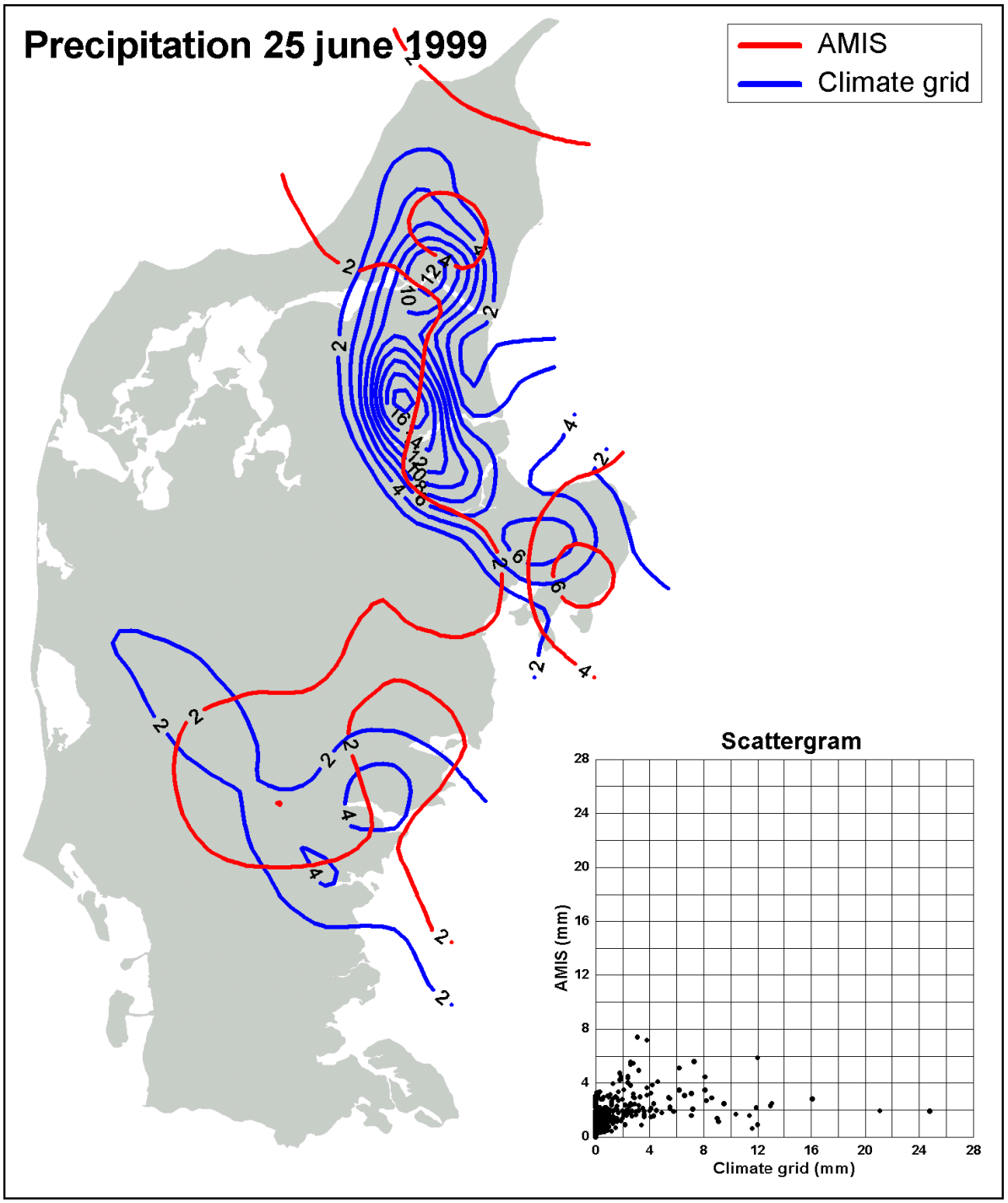



Figure 2.5. Map of precipitation using AMIS for June 25th 1999, 12 UTC, and a scattergram to show the accuracy.

Figure 2.6 shows again the four precipitation patterns and scattergrams for fields with an increasing number of observations in the interpolation. Similar to the case 15 July 1998 the precipitation pattern with 87 observations captures both precipitation areas. The scatter in this case however is not so good, which may be due to the rather step gradients in the field. again not much is gained when the number of observations is increased from 87 to 126.

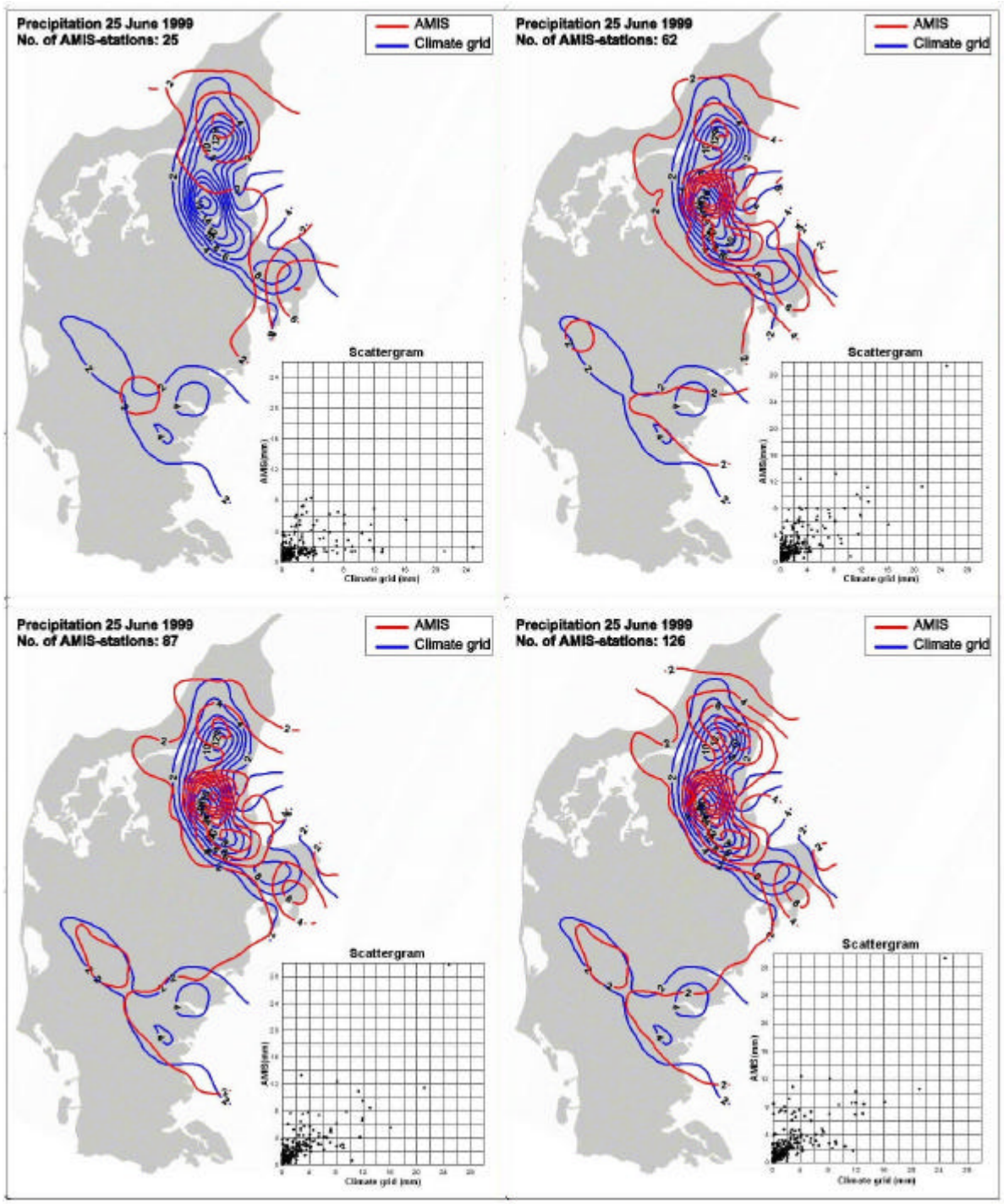



Figure 3.6. Four precipitation patterns and scattergrams for fields with an increasing number of observations in the interpolation, starting with 25 observation in the upper left corner, 62 observations in the upper right corner, 87 observations in the lower left corner and finally all 126 available observations in the lower right corner.

## 2.2.4 August 19th, 1999: Heavy Precipitation

During 18-19 August the synoptic situation 12 UTC shown in figure 2.7 is dominated by a high pressure area with more than 1000 hPa and a northeast gradient with wind from south to southeast. The area got widespread and partly heavy convective precipitation, at places quite huge amounts.

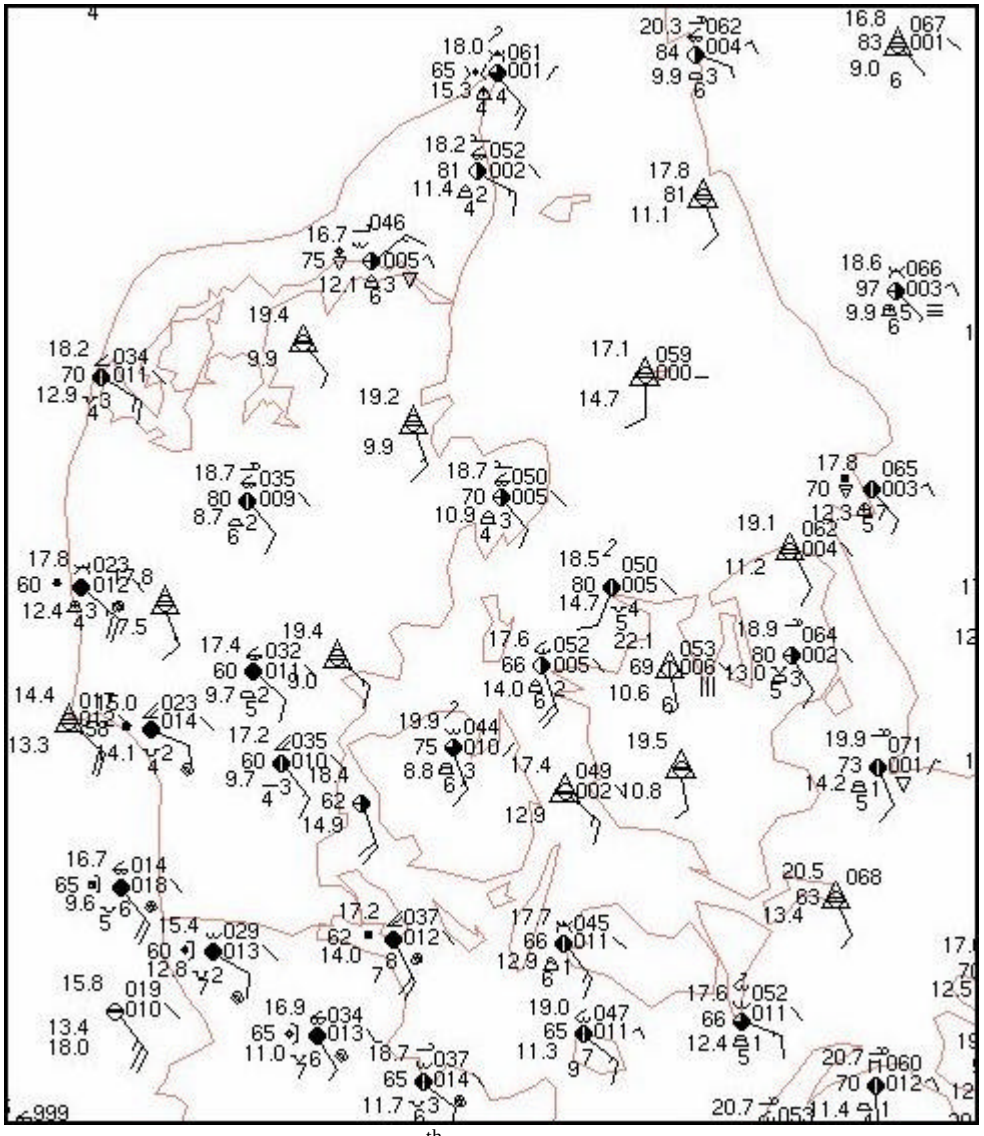


Figure 2.7. Synoptic map for August, 19th 1999, 12 UTC.

According to climate grid precipitation there were several precipitation maxima with up to about 30 mm of rain as seen in figure 2.8 showing the precipitation contours (red curves) for the operational AMIS field together with the contours (blue) of the verifying Climate Grid - Denmark and again a scattergram in the lower left corner. Generelly, AMIS has difficulties in locating the maximum precipitation correctly. Moreover, the precipitation amounts are very wrong and there are large discrepancies between climate grid and AMIS which can also be seen in the scattergram.

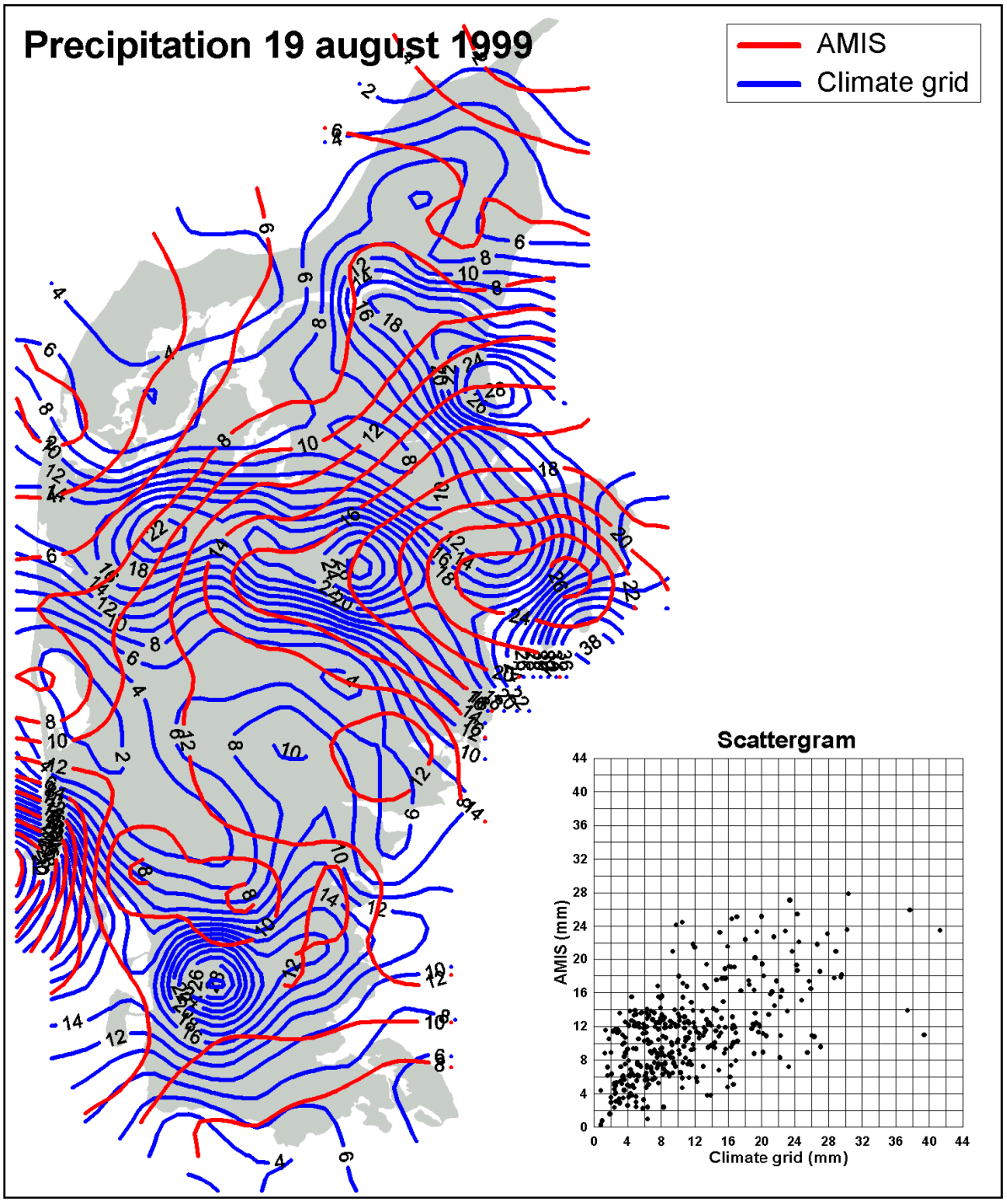



Figure 2.8. Map of precipitation using AMIS for August 19th 1999, 12 UTC, and a scattergram to show the accuracy.

The four precipitation patterns and scattergrams for fields with an increasing number of observations in the interpolation shown in figure 2.9 is again demonstrating the increased ability to capture the fine-scale structure as the number of observation is increase. In this case already 62 observations seems to capture the fine-scale structure well, which can also be seem in the

scattergrams where the spread around the identity line looks like a cone structure pointing towards the intersection between the x- and y-axis.

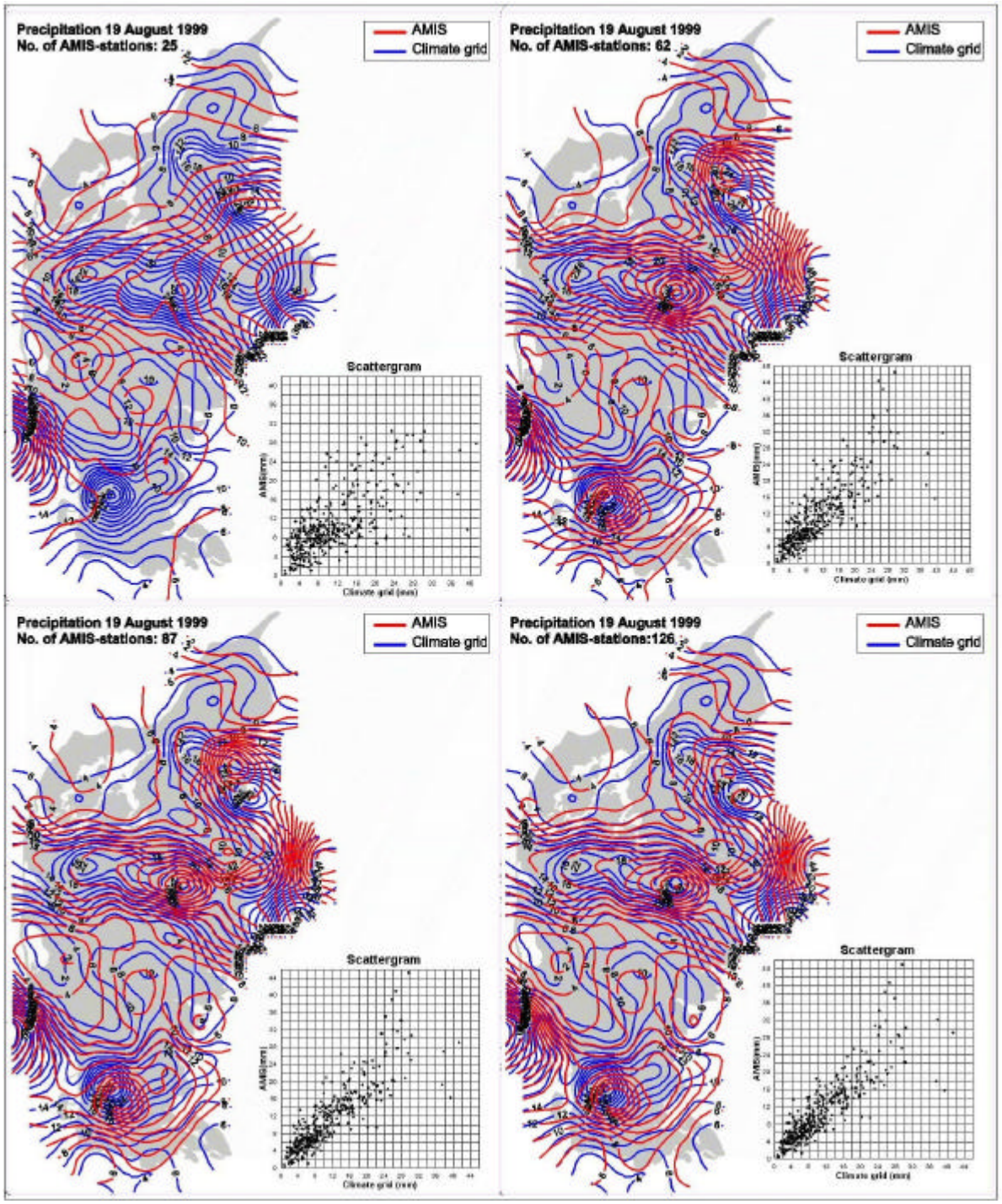



Figure 2.9. Four precipitation patterns and scattergrams for fields with an increasing number of observations in the interpolation, starting with 25 observation in the upper left corner, 62 observations in the upper right corner, 87 observations in the lower left corner and finally all 126 available observations in the lower right corner.

### 2.2.5 Conclusions

The main conclusion drawn from the case studies is, that increasing the number of observations applied in the interpolation from 25 to 90 is enhancing the resolution of the fine scale structure significantly, whereas increasing the number of observations beyond 90 not much additional structure is gained in the fields. Chapter 3 will illustrate this further using the overall verification statistics.

## 2.3 Radar derived 24-hour Accumulated Precipitation

In the phase I report: "Evaluation of the AMIS Gridded Observations and Radar derived 24-hour Accumulated Precipitation by comparison with ClimateGrid – Denmark Gridded observations", it was recommended that improvements of radar derived 24-hour precipitation totals could be attained if anaprop infected radar observations were identified and excluded from the analyses. Daily adjustments should be made of radar derived precipitation amounts by using data from raingauge stations. The survey of possible improvements of the AMIS product from the use of radar data is concentrated on these two items.

### 2.3.1 Data

In a survey on default calibrated radar data against raingauges (Southern Water, 1985), it was shown that the radar performs better than raingauges in frontal situations except at distances up to a few km from the gauges, and in convective events at all ranges except very close to the gauges. To resolve the problem of spatial variations in the adjustment a large number of raingauges are required in the analyses of radar data. Daily precipitation totals from app. 115 raingauge stations have been used out of which 50 stations are full automatic (tipping bucket or weighting type) while the rest are manual stations.

In the analyses are used nearly the same radar data set as in phase I, except that a small number of days has been removed as a result of extended quality control.

### 2.3.2 Pre-processing of radar data

There are various sources of error on radar data, e.g. anaprop, bright-band effect, vertical reflectivity profile variations, attenuation of the radar beam at range and clutter. Corrections for all known systematic errors on radar data should be applied before any raingauge adjustment (Joss and Waldvogel, 1987).

Correction for beam attenuation, which is due to atmospheric gases and hydrometeors, are carried out to account for the loss of power during propagation of the beam through the atmosphere. Bright-band may lead to big errors on rain rate, up to a factor of five, provided the radar has the necessary spatial resolution to resolve the bright-band layer (Joss, 1990). Corrections for resolving this error should be applied but is not needed because bright-band is normally no problem in the

growth season except in April and early May. Corrections for effects related to vertical reflectivity profile variations, such as the effects of range and orographic enhancement, have not been applied but are only a problem at large range. The correction for clutter uses higher elevation beams close to the radar and filters to remove pixels affected by clutter (for more details, see Steffensen et al., 2001). Biggest problem left is anaprop that is too severe and is not been removed by this method, and efforts have been put to develop a simple approach for identification of anaprop days.

### 2.3.3 Identification of anaprop days

Anaprop is a significant source of inaccuracy on radar derived precipitation sums. Apart from true precipitation, anaprop echoes move in an erratic manner or are stationary. Anaprop is associated with regions of no precipitation at all and is due to temperature and moist inversions during stable weather conditions. The aim of the anaprop identification scheme is to identify: (i) severe anaprop days with spurious radar patterns, and (ii) days where anaprop and precipitation occurs in the same period.

Efforts have been put to investigate if a simple method can lead to substantial improvements of the AMIS results, and the goal is to evaluate the gain by just excluding anaprop contaminated 24-hour periods of radar data. Anaprop days are mostly characterised by large discrepancies between raingauge and radar precipitation totals: while the raingauge totals are close to zero, the radar totals can become extremely high. If there is a good agreement between radar and raingauge totals, anaprop has probably not been present in the 24-hour period.

In order to help the anaprop identification, a ratio F is defined:

$$F = \frac{1}{P}\sum_{n=1}^{N}\sum_{p=1}^{P} R_{np(24h)} \Big/ \sum_{n=1}^{N} G_{n(24h)}$$

F is the ratio of the sum of the radar totals to the sum of raingauge totals. R=the 24-hour radar total in one pixel at the same position as the raingauge n, G=the 24-hour raingauge total of raingauge n, N=the total number of raingauge stations, and P=the number of pixels being used for estimation of the average radar total at raingauge site n. For description of the method for estimation of R, see chapter 2.3.4 “Procedures for raingauge adjustment”. If no rain has been reported F is undefined, but this has been the case only on three days in 1999.

Figure 2.10 shows a scatter plot of daily radar and raingauge precipitation amounts averaged over the number of raingauge stations. On the most days, there is a quite good agreement between the radar estimates and raingauge values, the radar over- or underestimating by a factor 3 or less in most cases. A large group of points have averaged radar totals much higher than for the raingauges. Probably, these points represent anaprop days.

The idea is that if F exceeds a certain threshold value z there is an increased risk of anaprop contamination within the 24-hour period, and the probability of anaprop, P, is set to a fixed value

1. Then, radar data do not enter the estimation of the AMIS field. If F<z there is probably no anaprop:

$$P = \begin{Bmatrix} 1 & \text{if} & F \geq z \\ 0 & \text{if} & F < z \end{Bmatrix}$$

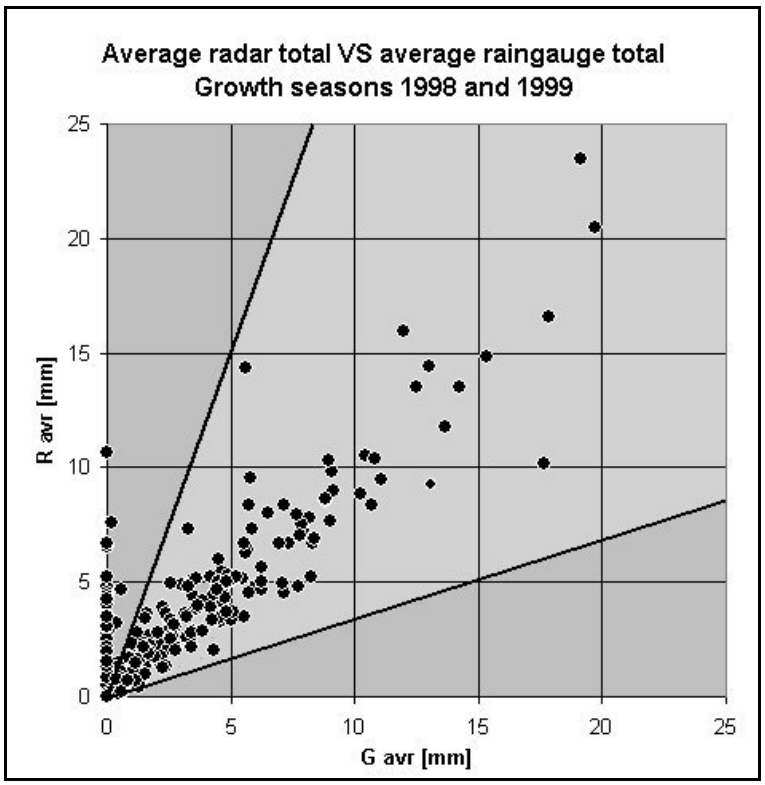



Figure 2.10. Daily precipitation totals for the growth seasons 1998 and 1999 in Jutland averaged over the number of actually reporting raingauge stations, where $R_{avr}$ is based on from radar data and $G_{avr}$ on raingauges. The full lines indicate a factor 3 difference between $R_{avr}$ and $G_{avr}$.

In order to verify F and establish a threshold value z, it is examined whether F is a confident measure for identification of anaprop days. On anaprop days, it normally takes some time for widespread frontal rain to enter the area, thus in the most cases only a few or no raingauge stations would be expected to report rain. If they are reporting rain, the amount is probably low. In some cases, severe anaprop and significant rain may hit an area within the same 24-hour period and affect the radar totals deleteriously, and F should reach high values.

The magnitude and variation of F is compared with the maximum values of daily raingauge observations and the percentage of raingauge stations with >0 mm (Figure 2.11). For F values close to one, about 10-100% of the raingauge stations are reporting rain, and anaprop has probably not been present during the 24-hr period. When F reaches extremely high values most or all raingauge stations are dry, and anaprop is expected. In almost all cases with high F values, the 24-hour maximum amount of precipitation at the raingauge stations has been less than 1 mm, and for the highest F values the amount has been very low, 0.2 mm or less.

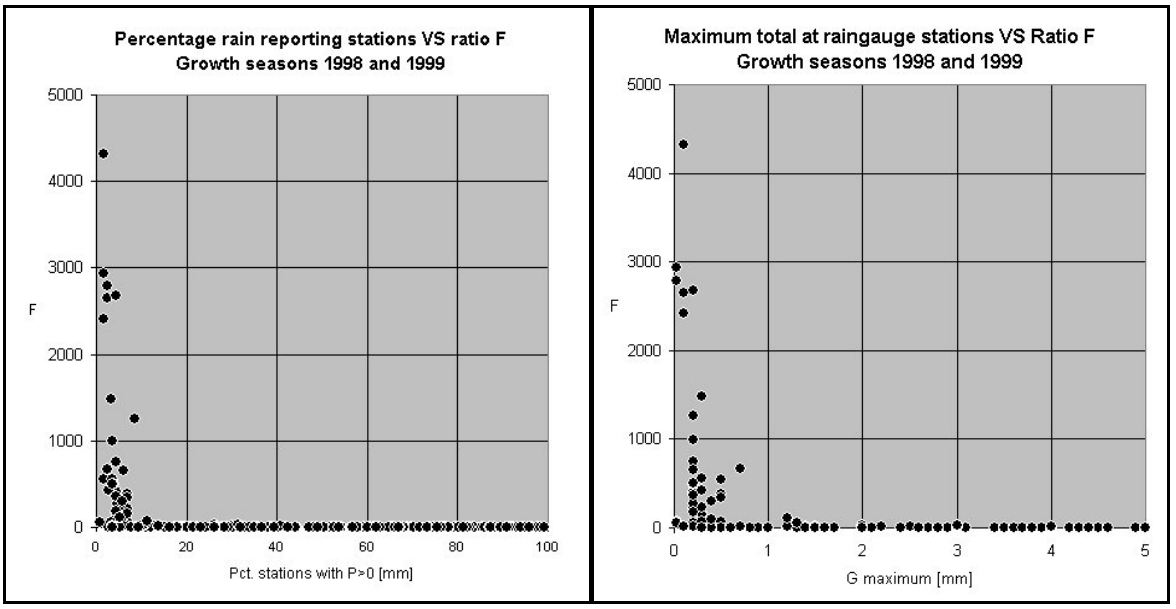



Figure 2.11. Left: scatter plot of F versus pct of stations having more than 0 mm of rain for 1998-1999. Right: scatter plot of F versus mm of rain at the wettest raingauge station for 1998-1999.

Table 2.2 shows the frequency of F in 1998, 1999 and totally together with statistics on gauge totals for various F classes (average and maximum totals, and the percentage of stations reporting rain). Only few or no stations are reporting rain if F has large values. If F=10 it is seen that only 1.5-4.9% of the stations were reporting rain on average, i.e. 2-5 stations. On clear days, trace precipitation (<0.1 mm) or 0.1mm is often reported at manual stations. The reason is nearly always fog or dewdrop accumulation in the gauge leading the observer to report precipitation, and in the whole study period only three days were completely dry at all stations.

| F statistics | | Intervals for F groups | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0<F<3 | 3=F<5 | 5=F<10 | 10=F<50 | 50=F<200 | 200=F<500 | 500=F |
| 1998 | N | 139 | 12 | 3 | 5 | 4 | 3 | 3 |
| 1999 | | 105 | 4 | 7 | 8 | 7 | 9 | 11 |
| Total | | 244 | 16 | 10 | 13 | 11 | 12 | 14 |
| 1998 | N% | 82.25 | 7.10 | 1.78 | 2.96 | 2.37 | 1.78 | 1.78 |
| 1999 | | 69.54 | 2.65 | 4.64 | 5.30 | 4.64 | 5.96 | 7.28 |
| Total | | 76.25 | 5.00 | 3.13 | 4.06 | 3.44 | 3.75 | 4.38 |
| $G_{avr}$ | Avr | 3.2176 | 0.1486 | 0.1206 | 0.0448 | 0.0058 | 0.0066 | 0.0035 |
| | max | 19.68 | 0.42 | 0.57 | 0.21 | 0.01 | 0.01 | 0.01 |
| | Min | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $G_{max}$ | Avr | 15.0 | 3.2 | 4.0 | 1.5 | 0.3 | 0.3 | 0.2 |
| | max | 84.0 | 11.0 | 26.5 | 6.0 | 1.2 | 0.5 | 0.7 |
| | Min | 0.3 | 0.3 | 0.2 | 0.1 | 0.0 | 0.2 | 0.03 |
| %rain | Avr | 67.7 | 25.9 | 14.2 | 1.5 | 4.7 | 4.9 | 3.4 |
| | max | 99.2 | 53.0 | 40.9 | 31.3 | 11.2 | 6.9 | 8.5 |
| | min | 2.6 | 6.9 | 3.4 | 3.4 | 0.9 | 2.6 | 1.7 |

Table 2.2. Statistics of various F classes are shown for 1998, 1999 and totally. N=total number of days, N%=percentage of days in a F group, $G_{avr}$=daily raingauge totals averaged over all stations, $G_{max}$=daily maximum if raingauge totals, and %rain=daily percentage of stations reporting rain.

According to Table 2.2, app. 81% of all days in 1998 and 1999 had reasonable F values (<5), but 10-15% of the period may have been contaminated by anaprop. Moreover, anaprop was much more frequent in 1999 than in 1998. Normally, the weather conditions during anaprop are stable and persistent, and frontal rain systems are often weakened and moving slowly when approaching. In fact, widespread rain did not occur together with severe anaprop within the same 24-hour period in 1998 and 1999.

Only in a few cases, isolated showers or weak fronts occured together with anaprop, but then $G_{max}$=0.5 mm was measured even in case of very high F values. In the most cases, F is well below 10, and F<3 are always associated with rain. This argues F=3 to be chosen as the threshold value **z**.

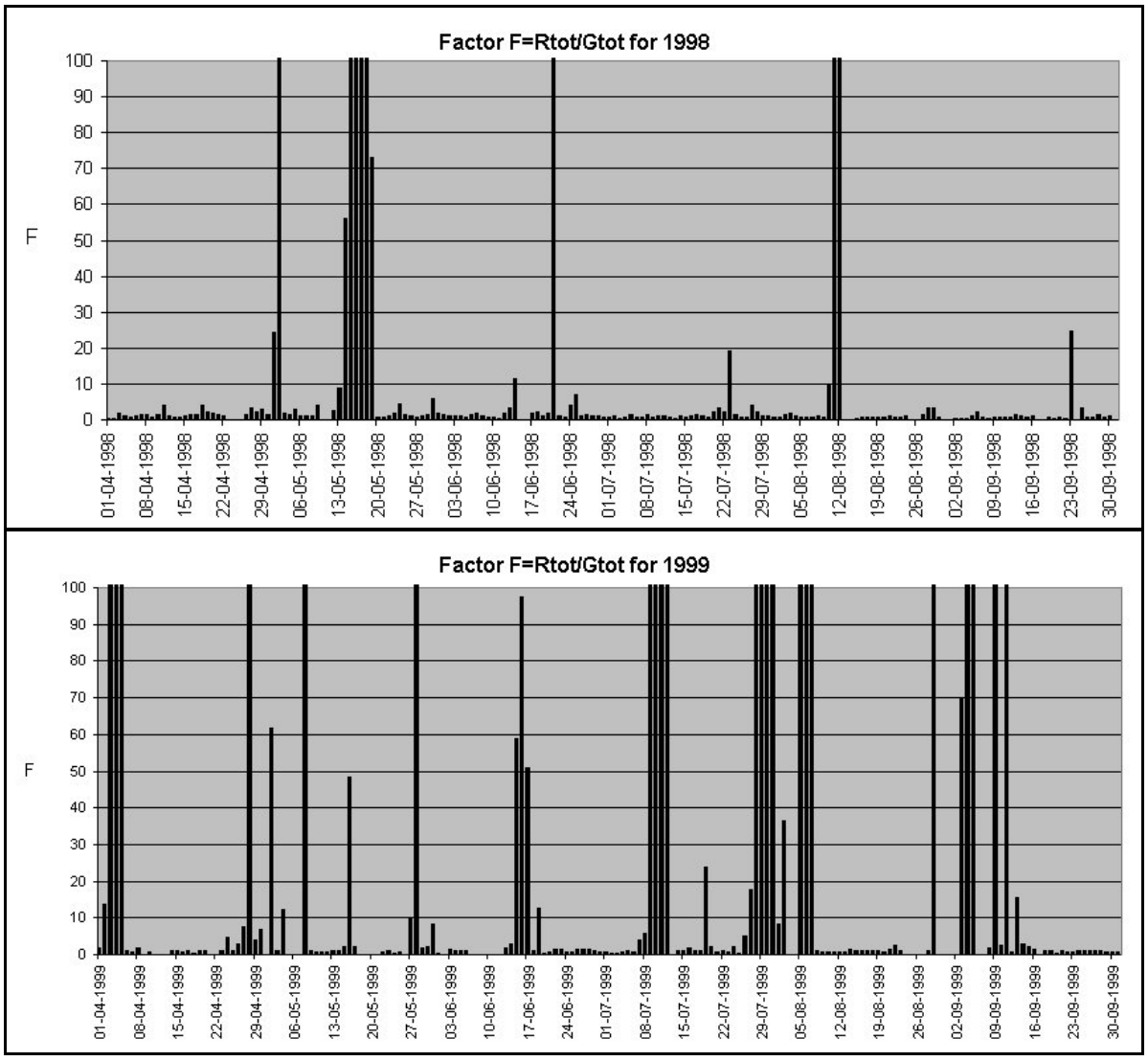



Figure 2.12. The magnitude of the ratio F during the growth seasons 1998 and 1999. On several days, F was much larger than 100, in few cases more than 1000, but the y-axis has been cut off to show small F values.

The day-to-day variations of F can be very large (Figure 2.12) and the absolute value of F is often extremely high. The y-axis is cut off at F=100 to accentuate small values of F. Of no doubt, days with large F values do have serious anaprop and it is not recommended to let the radar rain totals enter the AMIS system. In order to verify the results of the analyses of F=10 by independent information, 24-hour sequences of radar images have been subject to subjective assessment in order to classify them according to the intensity of anaprop. The persistency of anaprop is not considered. The detailed results in Table 2.3 are summarised in Table 2.4.

Table 2.3(a). Statistics for days with F=10 for the growth seasons 1998-1999 sorted by increasing F value. N=number of raingauge stations. N>0: number of raingauge observations with rain or tracer (<0.1mm). $G_{max}$=largest amount of precipitation at the raingauge stations. $R_{max}$=highest amount of precipitation according to the radar. ? G, ?R =rain total at the raingauge stations and radar, respectively. F=ratio between radar and raingauge totals. $A_{rømø}$ and $A_{sindal}$: classification of anaprop contamination for a 24-hour sequence of radar images, where 0=no anaprop, 1=patches of anaprop, 2=quite strong anaprop, but land contour is not seen in radar images, 3=severe and widespread anaprop, land contour is evident in radar images. The date indicates the 24-hour period since the previous day. (Table continues on next page…)

| Date | N | N>0 | $G_{max}$ | $R_{max}$ | ? G | ? R | F | $A_{rømø}$ | $A_{sindal}$ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 15-05-1998 | 117 | 2 | 0.1 | 73.3 | 0.1 | 561.0 | 4315.0 | 3 | 3 | Fog reported |
| 11-09-1999 | 116 | 2 | <0.1 | 44.7 | 0.1 | 176.4 | 2940.5 | 2 | 2 | Fog reported |
| 28-04-1999 | 115 | 3 | <0.1 | 35.7 | 0.1 | 251.1 | 2790.1 | 3 | 3 | Some fog reported, few clouds |
| 30-07-1999 | 116 | 5 | 0.2 | 210.7 | 0.5 | 1233.6 | 2681.8 | 3 | 3 | Fog reported |
| 29-07-1999 | 116 | 3 | 0.1 | 139.0 | 0.2 | 608.4 | 2645.1 | 3 | 3 | Fog reported |
| 08-05-1999 | 116 | 2 | 0.1 | 49.3 | 0.1 | 313.7 | 2412.9 | 0 | 3 | Small shower lines in the beginning |
| 05-08-1999 | 117 | 4 | 0.3 | 133.9 | 0.5 | 784.3 | 1479.9 | 3 | 3 | Fog reported |
| 18-05-1998 | 117 | 10 | 0.2 | 198.8 | 0.6 | 767.2 | 1257.6 | 3 | 3 | Fog reported |
| 03-04-1999 | 116 | 4 | 0.2 | 96.4 | 0.5 | 526.3 | 993.0 | 3 | 1 | Nearly cloudless |
| 02-05-1998 | 117 | 5 | 0.2 | 172.4 | 0.6 | 419.1 | 748.3 | 3 | 3 | In the North rain in the beginning |
| 31-07-1999 | 116 | 3 | 0.7 | 110.5 | 0.8 | 508.5 | 669.0 | 3 | 2 | Fog reported |
| 05-09-1999 | 116 | 7 | 0.2 | 63.0 | 0.6 | 402.1 | 648.5 | 3 | 3 | |
| 11-07-1999 | 116 | 4 | 0.3 | 53.7 | 0.5 | 293.5 | 553.8 | 3 | 3 | Fog reported |
| 10-07-1999 | 116 | 2 | 0.5 | 47.8 | 0.5 | 290.7 | 548.5 | 2 | 2 | Fog reported |
| 04-09-1999 | 115 | 4 | 0.2 | 98.1 | 0.4 | 178.9 | 497.0 | 2 | 2 | Fog reported |
| 12-07-1999 | 52 | 2 | 0.2 | 24.8 | 0.2 | 113.1 | 491.7 | no data | 3 | |
| 28-05-1999 | 114 | 3 | 0.3 | 33.6 | 0.4 | 151.9 | 422.1 | 3 | 1 | Fog reported |
| 04-04-1999 | 116 | 5 | 0.2 | 63.5 | 0.6 | 229.7 | 410.2 | 2 | 1 | |
| 11-08-1998 | 116 | 8 | 0.5 | 105.1 | 1.2 | 466.5 | 382.4 | 2 | 3 | Anaprop and rain in same images |
| 21-06-1998 | 116 | 5 | 0.2 | 76.4 | 0.5 | 186.4 | 380.4 | 3 | 1 | Fog and drizzle reported |
| 28-07-1999 | 116 | 5 | 0.2 | 48.2 | 0.6 | 227.5 | 361.1 | 2 | 2 | |
| 06-08-1999 | 118 | 8 | 0.5 | 124.9 | 1.5 | 500.1 | 335.6 | 2 | 3 | Showers in the beginning |
| 07-08-1999 | 52 | 3 | 0.4 | 48.6 | 0.5 | 158.0 | 298.1 | no data | 2 | |
| 09-07-1999 | 65 | 3 | 0.2 | 16.6 | 0.6 | 163.0 | 271.6 | 3 | no data | |
| 05-04-1999 | 116 | 6 | 0.3 | 22.5 | 0.8 | 179.0 | 235.5 | 1 | 2 | |

Table 2.3(b). (… Table continued). See table text on previous page for explanation.

| Date | N | N>0 | $G_{max}$ | $R_{max}$ | ? G | ? R | F | $A_{rømø}$ | $A_{sindal}$ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 17-05-1998 | 117 | 8 | 0.2 | 31.4 | 0.7 | 151.9 | 211.0 | 2 | 2 | Fog reported |
| 29-08-1999 | 117 | 5 | 0.2 | 14.6 | 0.3 | 58.2 | 181.8 | 1 | 1 | A shower in the beginning |
| 16-05-1998 | 117 | 5 | 0.3 | 45.5 | 0.8 | 127.9 | 168.3 | 2 | 2 | |
| 12-08-1998 | 116 | 8 | 0.3 | 15.7 | 0.6 | 88.2 | 152.0 | 2 | 3 | Anaprop and rain in same images, fog reported |
| 09-09-1999 | 115 | 6 | 1.2 | 65.2 | 1.4 | 153.2 | 107.9 | 1 | 2 | Local rain |
| 16-06-1999 | 117 | 5 | 0.4 | 21.9 | 0.9 | 83.8 | 97.4 | 2 | 0 | Fog reported |
| 19-05-1998 | 117 | 8 | 0.5 | 8.5 | 0.8 | 57.1 | 73.2 | 2 | 2 | Fog and local drizzle reported |
| 03-09-1999 | 116 | 13 | 0.3 | 23.4 | 1.3 | 93.4 | 69.7 | 2 | 1 | Showers in the beginning (rain, drizzle and fog reported) |
| 02-05-1999 | 116 | 1 | <0.1 | 1.0 | <0.1 | 1.9 | 61.7 | 0 | 0 | Local fog reported |
| 15-06-1999 | 117 | 1 | <0.1 | 0.7 | <0.1 | 1.8 | 58.7 | 1 | 0 | Fog reported |
| 14-05-1998 | 117 | 4 | 0.2 | 5.0 | 0.6 | 35.4 | 56.2 | 0 | 1 | Isolated showers, fog reported |
| 17-06-1999 | 117 | 4 | 0.2 | 7.6 | 0.7 | 35.6 | 50.9 | 1 | 0 | |
| 16-05-1999 | 116 | 5 | 1.3 | 29.3 | 1.5 | 72.0 | 48.3 | 1 | 2 | Rain in the beginning, fog reported |
| 02-08-1999 | 118 | 13 | 6.0 | 139.1 | 24.6 | 899.5 | 36.6 | 3 | 3 | Cb's with rain and thunder |
| 23-09-1998 | 115 | 36 | 0.3 | 88.5 | 5.3 | 130.4 | 24.6 | 1 | 3 | Showers in the beginning |
| 01-05-1998 | 115 | 30 | 2.0 | 110.3 | 14.0 | 341.5 | 24.4 | 2 | 1 | Rain in the beginning, otherwise anaprop |
| 19-07-1999 | 116 | 12 | 3.0 | 33.0 | 4.9 | 116.4 | 23.7 | 2 | 0 | Showers in the beginning |
| 23-07-1998 | 116 | 7 | 0.3 | 2.2 | 0.7 | 13.4 | 19.3 | 1 | 1 | Isolated showers |
| 27-07-1999 | 116 | 5 | 0.3 | 2.9 | 0.5 | 8.7 | 17.8 | 1 | 0 | Isolated showers in the South, local fog reported |
| 13-09-1999 | 116 | 4 | 0.1 | 2.3 | 0.3 | 4.0 | 15.4 | 0 | 0 | Local fog reported |
| 02-04-1999 | 116 | 7 | 1.4 | 6.6 | 3.3 | 46.0 | 13.8 | 1 | 1 | Nearly cloudless |
| 19-06-1999 | 117 | 7 | 0.2 | 3.7 | 0.8 | 10.0 | 12.6 | 1 | 0 | |
| 04-05-1999 | 116 | 8 | 1.2 | 22.5 | 3.0 | 36.7 | 12.3 | 0 | 1 | Shower lines |
| 14-06-1998 | 116 | 15 | 1.4 | 12.8 | 5.6 | 63.5 | 11.4 | 1 | 0 | Small showers in the beginning |
| 10-08-1998 | 116 | 12 | 2.2 | 3.9 | 3.1 | 31.2 | 10.0 | 1 | 2 | Anaprop in the North, in the beginning rain in the South |
| 05-05-1999 | 116 | 0 | 0 | - | 0.0 | 24.8 | - | 0 | 2 | Cloud streets, isolated showers |
| 06-05-1999 | 116 | 0 | 0 | - | 0.0 | 5.0 | - | 0 | 1 | |
| 07-05-1999 | 67 | 0 | 0 | - | 0.0 | 1.2 | - | 0 | no data | |

Four anaprop classes are defined: for the classes 2 and 3 anaprop is severe and widespread, and in class 3 land contours and coast lines are clearly seen, but not in class 2. In class 1 only patches of anaprop occurs, and in class 0 no anaprop is present at all.

$R_{max}$ is extremey high compared to $G_{max}$ in most cases, especially for large F values, and is associated with severe anaprop in the Rømø or Sindal radar area, or the both. Sometimes, rain or tracer precipitation (<0.1mm) has been reported, but it is caused either by dewpoint accumulation, or by weak fronts and isolated showers entering the area during the period. For example, on the 4-5th of May 1999, very isolated showers were present according to the radars, but at the same time the raingauge stations did not report any rain at all, and later on quite severe anaprop popped up in the Sindal radar area. On the 2nd of August 1999, a few quite heavy showers were present in the radar images. A few weather stations were reporting Cb clouds with rain and thunder, and one station got 6.0 mm. In the same 24-hour period severe anaprop was present (anaprop class 3). The reported rain totals caused F to be only 36.6, but anyway it indicated that something spurious was going on. The examples show that even though true radar rain areas are present in the images, they should not enter AMIS if anaprop is present.

Now is left to answer the question how many of the anaprop days had true precipitation (Table 2.4). For increasing anaprop classes the average value of F and the number of occurrences in higher F classes increases. The number days with severe anaprop (class 2 and 3) and radar rain echoes during the same period were only 6 out of 22, and only two anaprop days had significant precipitation with one or more stations reporting >0.5 mm. The rain echoes were corresponding to isolated showers in almost all cases.

| Anaprop Class | N(P=0) | N(P>0) | N(P>0.5) | $F_{avr}$ | F categories | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 10-19 | 20-49 | 50-99 | 100-299 | 300-499 | 500-999 | =1000 |
| 0.0 | 2 | 0 | 0 | 38.5 | 1 | | 1 | | | | |
| 0.5 | 3 | 4 | 2 | 31.4 | 4 | | 3 | | | | |
| 1.0 | 2 | 3 | 1 | 67.2 | 2 | 1 | 1 | 1 | | | |
| 1.5 | 3 | 5 | 3 | 414.9 | 1 | 2 | 1 | 2 | 1 | | 1 |
| 2.0 | 11 | 1 | 0 | 576.5 | | 1 | 1 | 3 | 4 | 2 | 1 |
| 2.5 | 1 | 3 | 1 | 384.8 | | | | 1 | 2 | 1 | |
| 3.0 | 10 | 2 | 1 | 1493.3 | | 1 | | 1 | 1 | 3 | 6 |

Table 2..4. Statistics on 24-hour radar image sequenses sorted by anaprop class (for definition, see text). The table shows the number of sequenses in different F classes and precipitation classes N. N(P=0): number of completely dry images sequences. N(P>0): number of sequenses in which rain echoes have been observed. N(P>0.5): number of sequenses in which radar rain echoes have been observed and more than 0.5 mm has been reported from at least one raingauge station. $F_{avr}$=average F value for all sequenses in an anaprop class.

## 2.3.4 Procedures for raingauge adjustment

For adjustment of radar derived 24-hour accumulated precipitation a system is developed. Because there seems to be case-to-case variations in the errors on radar data, particularly at long range, only raingauges within certain ranges should be used (Kitchen and Jackson, 1993). Simple comparisons between gauge and radar at long range may not reflect the true rain rate underestimation by radar because of the detection failures of the radar (Kitchen and Jackson,

1993), thus, according to experience only raingauges up to 100 km's distance enter the adjustment scheme to avoid that vertical reflectivity profile problems at range influence the adjustment.

The energy of the returned radar beam power reflected from hydrometeors in a volume of air depends on the drop diameter D in sixth power and the number of drops N. The reflectivity factor Z is estimated from the returned power, which the radar measures. Z depends on the drop size distribution and thereby the precipitation type, and it is related to rain rate R (mm/hr) by Z-R relationships of the general form $Z=AR^b$, where A and b are empirical constants (e.g. see Battan, 1973). Knowing that the value of Z is proportional to the number of drops in first power but the drop diameter D in sixth power, the reflectivity factor Z reaches, for the same rain rate, large values in convective precipitation and small values in drizzle because the number of large drops is much larger in convective precipitation than in drizzle.

The best way of comparing results is to make sample sizes of radar and raingauges as similar as possible by integrating the linear quantity of interest in time and space. The integration is done in rain rate, not in reflectivity, as recommended by Joss (pers. comm.). The 24-hour amount of rain, R', is estimated firstly by integrating every radar image (pseudo-CAPPI image) in rain rate units over all 10-minute pixels, i, by using a standard Z-R relation valid for widespread rain (Marshall-Palmer, 1948):

$$R' = \frac{1}{P} \sum_{i=1}^{N} \sum_{p=1}^{P} d_i \cdot (Z_{ip} / A)^{1/b}$$

A=220, b=1.60, d=a time correction factor which is estimated from the actual temporal resolution of the radar images, P=the number of pixels in a matrix J×J around the raingauge location, and N=the number of images.

Secondly, the accumulated radar totals are adjusted by using the most appropriate adjusting formula for the day in question, and, finally, $10\times10 km^2$ grid cells are estimated on the basis of the 24-hour adjusted precipitation sum image.

Weather radars are quite accurate in measuring the extent of a rainfall area, but bias may arise if large differences exist between the standard Z-R relationship used and the actual Z-R conditions. The raingauge adjustment scheme focuses on reduction of systematic variations and residual errors in radar rain amount, and the adjustment domain is the whole area of radar coverage. Because it is a procedure designed to work in near real-time, it must respond to daily changes, but a sampling period must not be too short as to introduce sampling errors (Collier, 1987). The radar and raingauge total is integrated over 24 hour because the fact that most manual stations are measuring only once a day.

The adjustment scheme consists of 3 steps:

- *Step 1:* Estimation of the actual Z-R relationship.
- *Step 2:* If step 1 fails, estimation of a calibration factor **m**.

- *Step 3:* If step 2 fails, a standard Z-R relationship is applied.

In step 1, a regression method is used which works in a spatial-temporal domain. The actual Z-R relationship is estimated on the basis of statistical analyses of 24-hour integrates of Z and R. The Z-R relation is evaluated by correlation analysis, tests of significance and estimation of error statistics, and it is assessed whether the constants A,b in $Z=AR^b$ attains realistic values. Numerous Z-R relationships have been derived (Battan, 1973), but almost no effort has been put to the calculation of R-Z relationships, i.e. $R=(Z/A)^{1/b}$. Stout and Mueller (1968) argued that Z should be the independent parameter in the correlation of the logarithms of R and Z. Even if the correlation coefficient is larger than 0.9 the use of Z-R relationships instead of R-Z may cause errors in R of up to 50% (Kreuls, 1991). Therefore, R-Z relationships enter the adjustment scheme.

In certain weather situations the actual Z-R relationship does not lead to significant reduction of the bias between the radar and the raingauge totals, or any significant Z-R relationship may not be found, or A,b do not attain realistic values (rejection reasons, see Table 2.5). In that case, a simple adjustment method is applied to step 2. It is based on simple deterministic principles by which an adjustment factor derived from temporally and spatially integrated values of G and R' is defined as **m**=? $G_n$/? $R'_n$ that is applied to the default calibrated radar image. $G_n$=the raingauge accumulation at station n, and $R'_n$=the default adjusted radar sum at gauge position, where G is assumed to represent the true precipitation. By this mean the effect of adjustment should be to try and minimise the errors in area accumulations, which would tend to be dominated by low rainfall rates if factor **m** just was calculated as an average G/R' ratio.

| Step 1 | Step 2 |
|---|---|
| no raingauge data and/or no radar data available | |
| Ttest failure on 5% level | factor m out of bounds: m<0.3333 or m>3 |
| bad A constant:<br>$A_z$>999 or $A_z$<50 or $A_r$<0 | |
| bad b constant: $b_z$>2.49 or $b_z$<1.10 or $b_r$<0 | too low G or R' totals:<br>gauge total ? G<5 or radar total ?R'<5 |
| skew adjustment Z, unrealistic(Z):<br>$R_{min(Z)}=(Z/A_z)^{1/bz}$ = 0.05, where Z=0.25 is set | |
| Skew adjustment R,unrealistic(R):<br>$R_{min(R)}=(Z/A_r)^{1/br}$ = 0.05, where Z=0.25 is set | too few wet obs: n<20 |
| Rrad adjustment problems | |

Table 2.5. Reasons for rejection of the Z-R relationship in step 1, and for rejection of the adjustment factor in step 2.

If step 2 fails, e.g. because the number of Z-R data pairs is too small or the adjustment factor is supposed to be unrealistic large or small (see Table 2.4), a standard Z-R relationship is used instead, which is the Marshall-Palmer equation $Z=220R^{1.60}$ for widespread rain (Marshall and Palmer, 1948).

## 2.3.5 General results

Table 2.6 shows the overall performance of the radar adjustment scheme. On approximately 31% of all days in the growth seasons 1998 and 1999, it was possible to estimate an actual Z-R relation that in fact was able to improve the estimates of radar rain totals. For various reasons, this was not possible in the rest of the growth seasons. The reasons for this are summarised in the table. In many cases, the empirical constants A and b were not realistic because they attained too high or low values. In other cases, the relationship between Z and R was not significant, or R' attained unrealistic values.

| Number of adjustments | | | | |
|---|---|---|---|---|
| | 1998 | 1999 | Total | Total % |
| Actual Z-R relation | 53 | 47 | 100 | 30.9 |
| Adjustment factor m | 73 | 66 | 139 | 42.9 |
| Standard adjustment Z-R | 43 | 42 | 85 | 26.2 |
| Total | 169 | 155 | 324 | 100.0 |
| Rejection reasons for actual Z-R relation | | | | |
| Unrealistic value of b | 16 | 14 | 30 | 13.4 |
| Unrealistic value of A | 48 | 46 | 94 | 42.0 |
| R' adjustment problems | 38 | 35 | 73 | 32.5 |
| Unrealistic value of R' | 9 | 8 | 17 | 7.6 |
| T test failure | 5 | 5 | 10 | 4.5 |
| Total | 116 | 108 | 224 | 100.0 |
| Rejection reasons for adjustment factor m | | | | |
| ? G,? R totals are too low | 21 | 20 | 41 | 48.2 |
| Factor m out of bounds | 20 | 20 | 40 | 47.1 |
| too few observations of rain | 2 | 2 | 4 | 4.7 |
| Total | 43 | 42 | 85 | 100.0 |

Table 2.6. The table shows the overall performance of the adjustment scheme by statistics on the number of adjustments being done by actual Z-R relations, adjustment factor m and standard adjustments Z-R. It also shows statistics on the number of various reasons of rejection of the two adjustment methods

Nevertheless, it is a quite good result that it was possible to calculate a Z-R relation in about one-third of all days during 1998 and 1999. In case of Z-R failure, the more simple adjustment factor method is applied for estimation of radar totals. This method accounts for about 43% of all adjustments. The most common reasons for failure of this method are that the adjustment factor **m** is out of bounds, or that the amounts of rain is very small so that problems would probably arise if the adjustment factor were applied. When **m** is out of bounds, the reason is probably presence of anaprop during the period, i.e. the ratio F attains very high values. If ? G is very small, anaprop may also be present, and if both ? G and ? R' is very small the adjustment factor is probably not representative of the rain area.

Finally, if the above methods fail a standard Z-R relation is applied. This happened in 26% of all occurrences.

The scatter plots in Figure 2.13, 2.14 and 2.15 shows the overall performance of the actual Z-R relationships, the adjustment factors **m** and the standard Z-R relation, respectively.

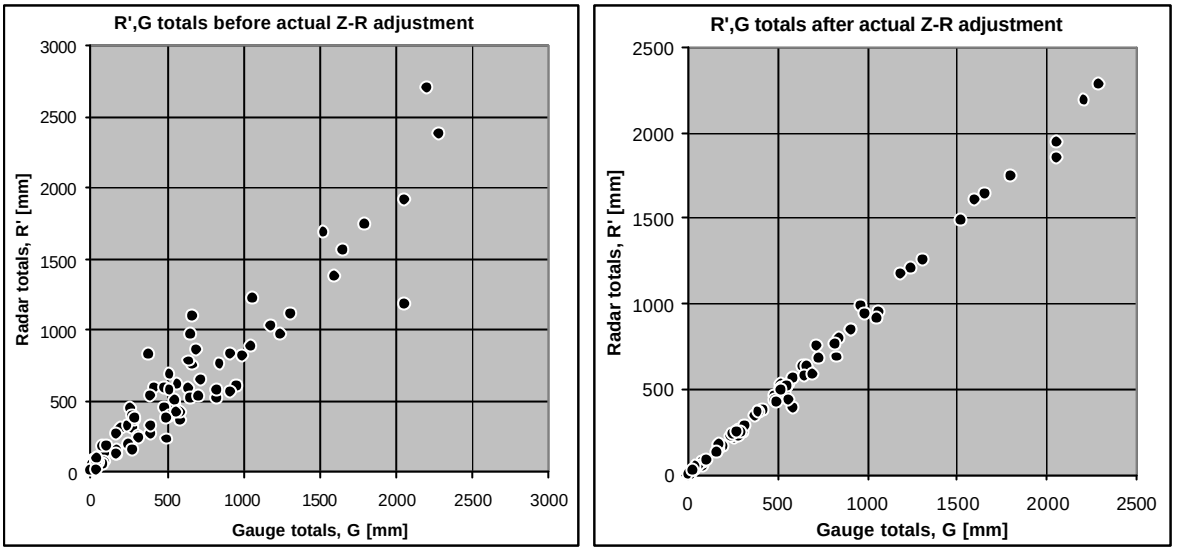



Figure 2.13. The overall results of the actual Z-R adjustment for 1998 and 1999. The gauge and radar totals are estimated by summing up all R' and G comparisons. The average amount of rain for the whole radar area is estimated by the radar or gauge total divided by the number of raingauges. Left: rain totals before the Z-R adjustment is applied. Right: rain totals after the Z-R adjustment is applied.

Figure 2.13 shows the overall results before and after the actual Z-R relations have been applied to the radar totals. Each point represents the gauge and radar totals, ? R' and ? G, on each day, but the plot do not say anything about the daily values of the individual scatter on G and R'. It is seen, that the Z-R adjustment improves the radar estimates by reducing the under- and overestimation of the radar rainfall which is clearly seen before the adjustment is carried out, i.e. the overall bias is reduced. The average amount of rain at each raingauge can be estimated by dividing the radar or gauge total by the number of raingauges.

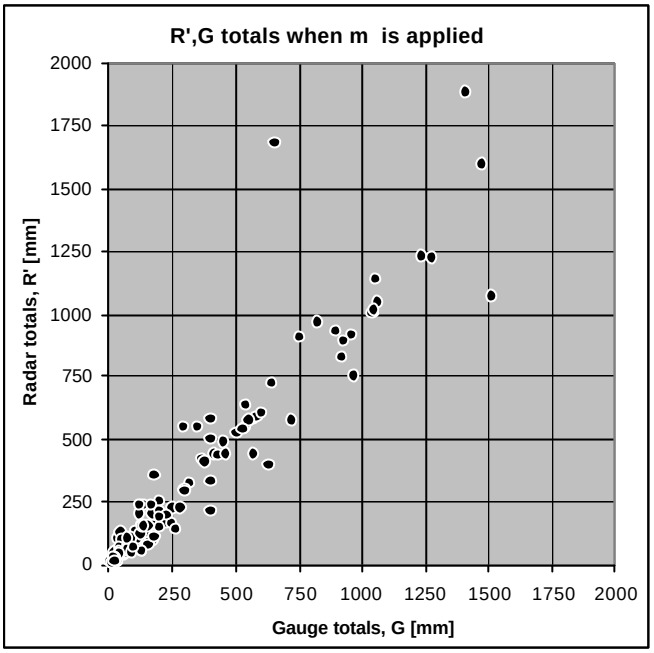



Figure 2.14. The overall results of the adjustment factor m for 1998 and 1999. The gauge and radar totals are estimated by summing up all R' and G comparisons. The average amount of rain for the whole radar area is estimated by the radar or gauge total divided by the number of raingauges.

Figure 2.14 shows the overall performance of the adjustment factor **m**. When **m** is applied, the scatter disappears but is has no meaning to show this because the method is designed at revealing adjustments for problems with the radar sensitivity as argued in the description of the method in the chapter about this.

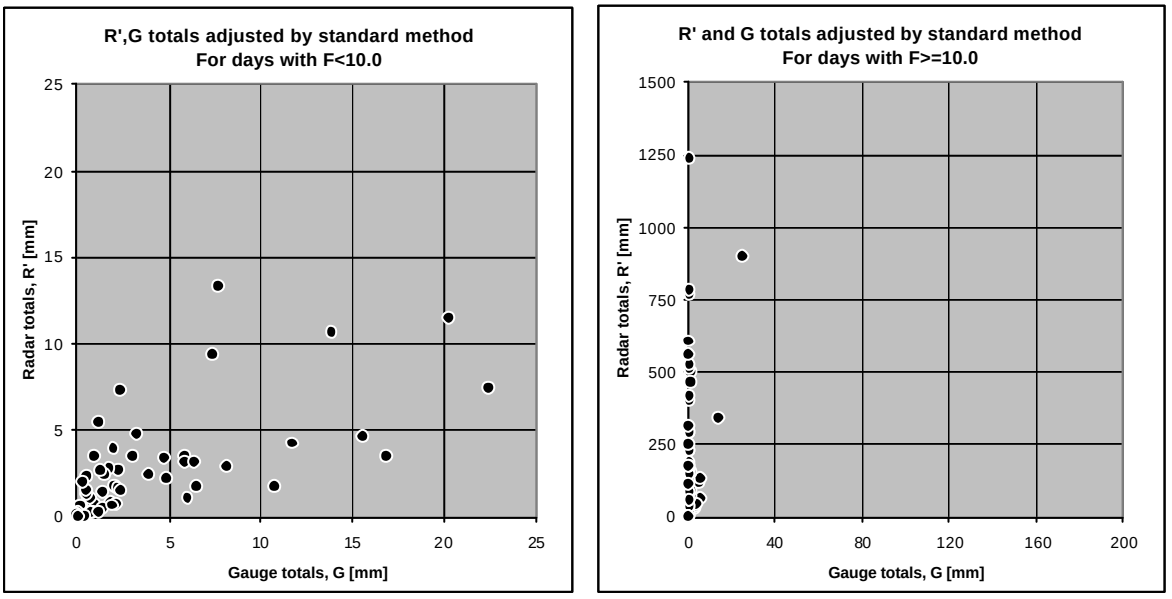



Figure 2.15. The overall results of the standard Z-R adjustment for 1998 and 1999. Left: adjustment results if F<10. Right: adjustment results if F=10. The gauge and radar totals are estimated by summing up all R' and G comparisons. The average amount of rain for the whole radar area is estimated by the radar or gauge total divided by the number of raingauges.

It is very interesting to see, what happens when the adjustment factor fails and a standard Z-R adjustment is applied (Figure 2.15). When F<10, there has probably not been anaprop, especially when F is close to 3 or below, and on many days the radar over- or underestimates the amount of rain. If F=10, it follows from the discussions in the chapter about anaprop identification that there may be very big problems with anaprop contamination in the radar images.

### 2.3.6 July 14th, 1998: A Cold Front

At larger ranges, the radar obviously underestimates the precipitation amount, but within 100 km range, the radar shows the precipitation pattern quite well. In the radar images from 14 Juli 1999 at 12UTC, it is seen that the precipitation echoes are becoming weaker at the larges ranges. In the overlap areas, the two radars are seeing almost the same distribution of precipitation but the rain rate is different (figure 2.16).

Up to a distance of at least 100 km, radar data can be used quantitatively, but at large ranges it can most often only be used qualitatively unless data is corrected for range related sources of error which can improve results to a certain extent. In the scatter plots in figure 2.17 is shown the R' and G samples for both radar areas, estimated for raingauge locations up to a 100 km's distance from the radar.

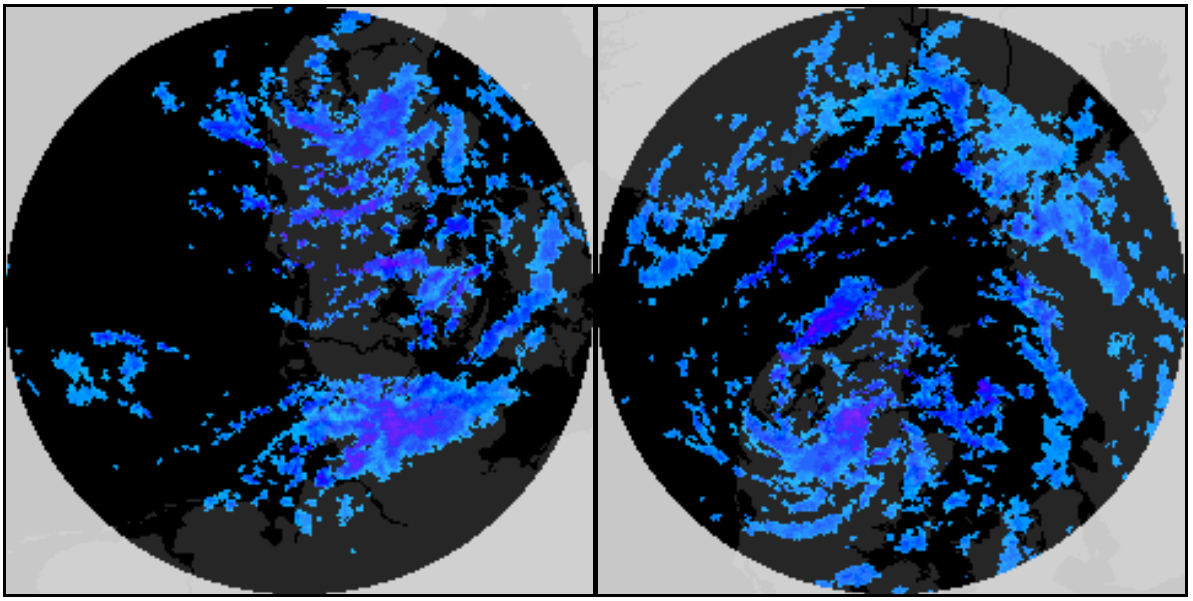


Figure 2.16. Rømø (left) and Sindal (right) images on 14 July 1998 at 12UTC. Reddish blue indicates the heaviest rain, and light blue is the weakest.

The scatter plot shows, that there is a quite large spread in the samples, but that the scatter has a structure looking like an ice cake, which is well in accordance with the multiplicative structure of the Z-R model. The representativeness problem might explain much of the large and often extreme scatter between radar measures and raingauge data (Joss, 1990), and is due to small-scale variability and gradients of precipitation, differences in the characteristics of samples from radar and raingauges.

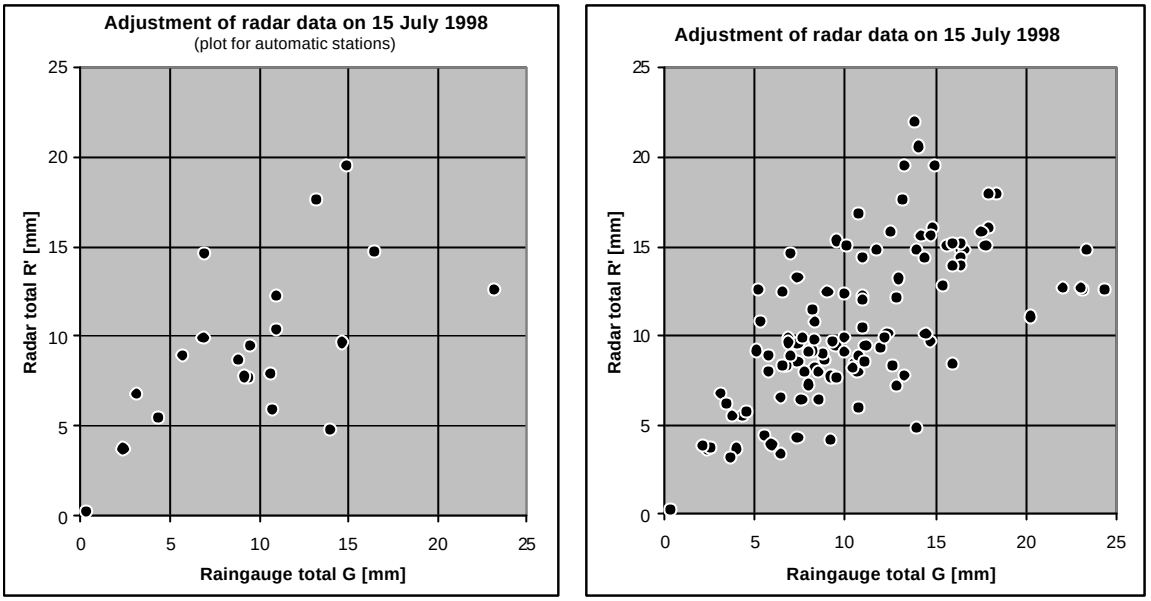



Figure 2.17. Scatter plots of individual R' and G samples on 15 July 1998. Left: R' and G samples for automatic synoptic stations is plotted. Right: R' and G samples are plotted for all comparisons. Prad=unadjusted radar samples, ZRadj=adjusted radar samples.

The radar measures the meteorological targets within a volume of air at a certain altitude above the ground surface, but the raingauge measures only a very small proportion of these particles, i.e. a pixel representing 2×2 $km^2$ is compared with a point measure. The drop size distribution may have changed until the rain hits the raingauge, and evaporation or precipitation growth may have taken place (e.g. Austin, 1987). The effect of updraufts and downdrafts can influence the accuracy of the radar and raingauge comparison (Battan, 1976), and partially and non-uniform beam filling combined with reduced visibility may lead to considerable errors at longer ranges (Joss et al., 1995).

The plot shows, that the Z-R adjustment generally results in a slight increase in the radar totals, and it has as effect that the radar do not underestimate the amount of rain. The correlation analyses resulted in $r^2$=0.79 (r=0.89) for the Z-R relation in the log domain, and the calculated Z-R relation is $Z=198R^{1.48}$. The standard error of the residuals (1×standard deviation) is 3.86.

### 2.3.7 June 24th, 1999: Showers

Figure 2.18 shows two illustrative examples of what the problem is about when adjusting radar images in case of showers. The precipitation pattern is scattered, but the showers were quite heavy. Some raingauge stations got more than 10 mm of rain, and one station got about 23 mm during the 24-hour period (Figure 2.19).

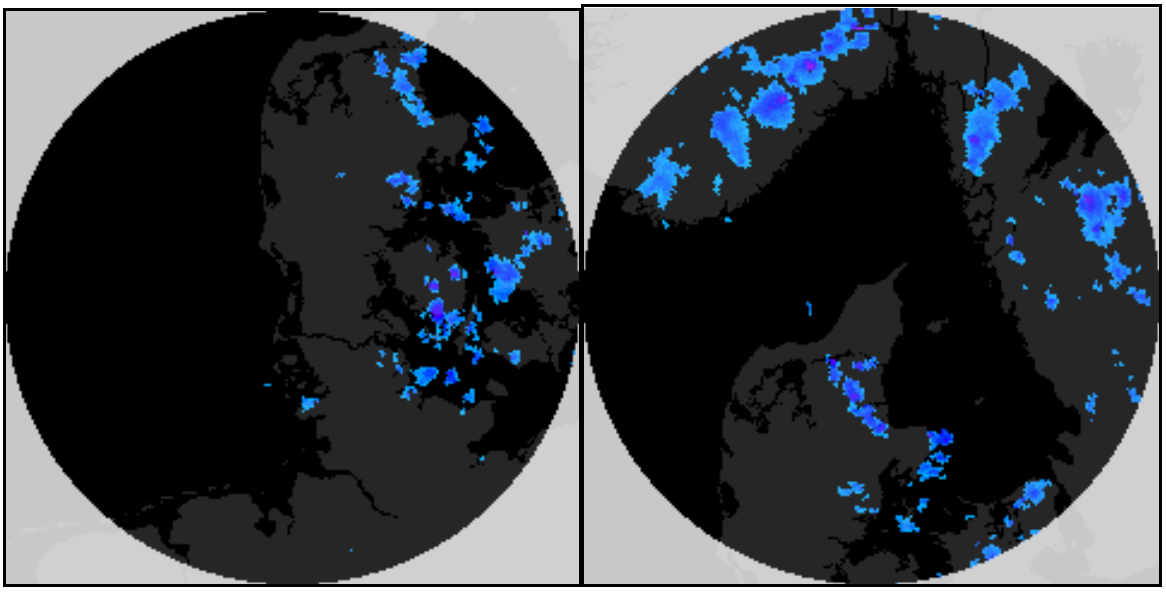


Figure2.18. Rømø (left) and Sindal (right) radar images on June 24th 1999 at 15 UTC. Reddish blue indicates the heaviest rain, and light blue is the weakest.

In figure 2.19 is seen, that there is a large scatter in the G and R' comparison, as expected, because it is a situation with showers where the radar sample may not represent the situation at the raingauge station, or the opposite. The correlation analyses resulted in $r^2$=0.89 (r=0.94) for the Z-R relation in the log domain, and the calculated Z-R relation is $Z=222R^{1.48}$. The standard error of the residuals (1×standard deviation) is 3.13.

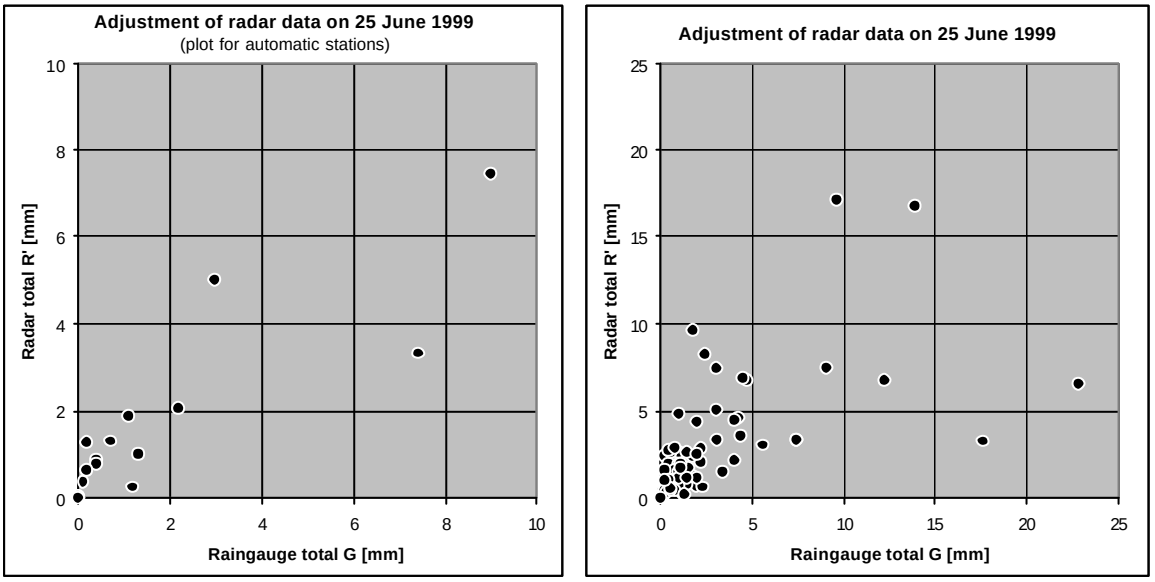



Figure 2.19. Scatter plots of individual R' and G samples on 25 June 1999. Left: R' and G samples for automatic synoptic stations is plotted. Right: R' and G samples are plotted for all comparisons. Prad=unadjusted radar samples, ZRadj=adjusted radar samples.

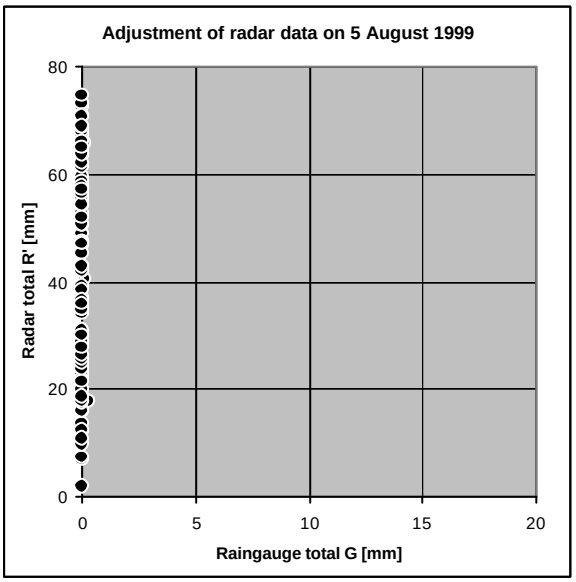
During showers, there are often large horizontal variations in the rain rate, and there is an increased risk that the radar over- and underestimates the total amount of rain. There seems to be a marked difference between the GR comparison for automatic synop stations, and all stations including

manual raingauge stations. The result for synop stations only is better than when all stations are included. The reason may be that the raingauge at manual stations is not emptied at exactly the same time. There is also the risk that some of the manual stations represent accumulation over more than one day, and that the value on a specific day is an estimated one.

### 2.3.8 August 5th , 1999: Anaprop

During anaprop, the refraction of the radar beam causes it to be bended downwards more than the curvature of Earth, and it hits targets on the ground randomly at nearly all ranges. The result is artificial radar precipitation amounts unless correction for this effect is applied. Methods exist for dampening or removal of anaprop, but this requires careful filtering of the images, especially because anaprop and precipitation may appear in the same image.

Figure 2.20 shows severe anaprop in a Sindal image on August 5th 1999 at 6 UTC. The effect of the terrain shows up as distinct echoes due to the coastal areas of Southern Norway, Sweden, Zealand and Jutland. The scatter plot shows that something spurious is really going on. The value of F was 1479.9, which indicates heavy anaprop according to the definition of F.



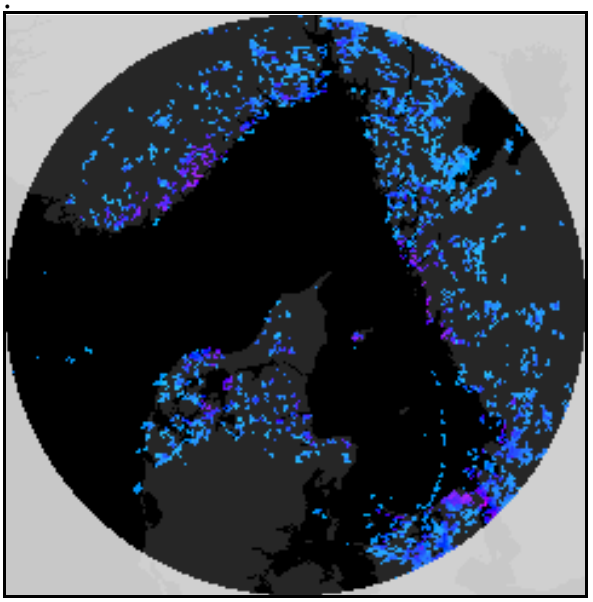



Figure 2.20. Left: scatter plots of individual R' and G samples on 5 August 1999. The R' and G samples are plotted for all comparisons. Right: an anaprop contaminated radar image (Sindal radar image) on 5 August 1999 at 6 UTC. Reddish blue indicates the heaviest rain, and light blue is the weakest.

### 2.3.9 August 19th, 1999: Heavy Precipitation

The area got widespread and heavy convective precipitation at places. As shown by the radar images in figure 2.21, the precipitation was at the same time widespread at some places and isolated at others in form of smaller heavy showers.

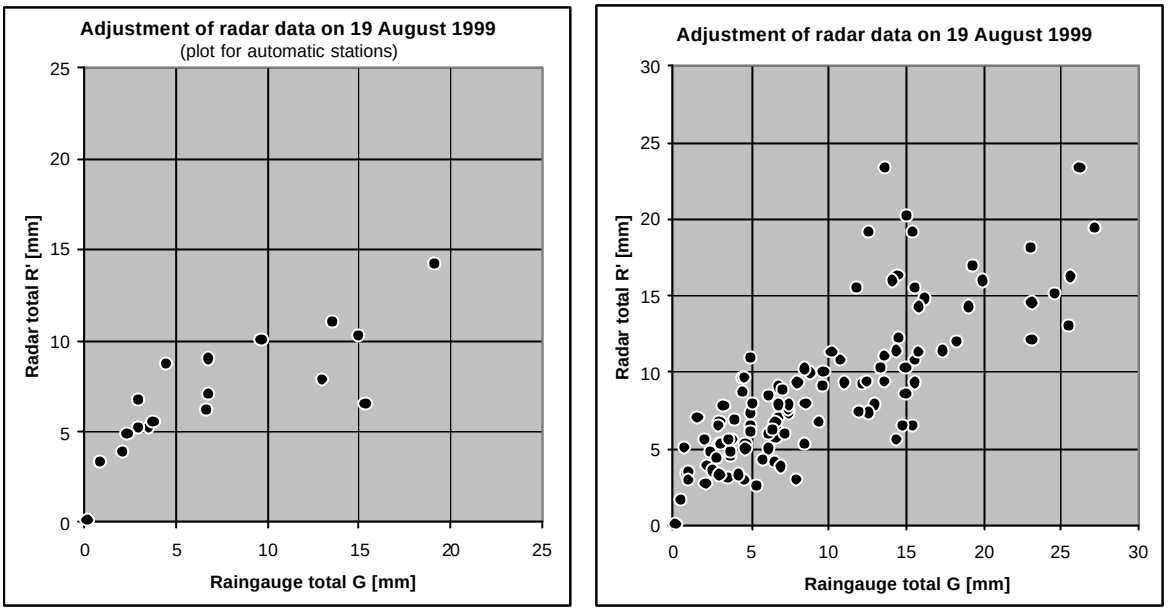



Figure 2.21. Scatter plots of individual R' and G samples on 19 August 1999. Left: R' and G samples for automatic synoptic stations is plotted. Right: R' and G samples are plotted for all comparisons.

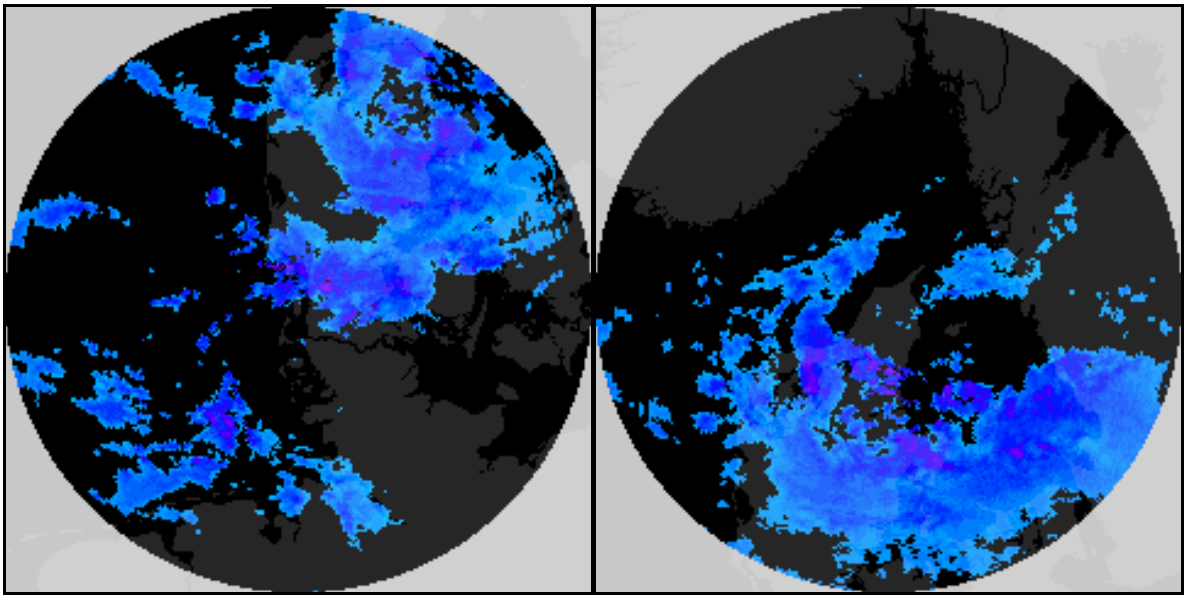


Figure 2.22. Radar images from Rømø (left) and Sindal (right) on August 19th 1999 at 6 UTC. Dark blue indicates the heaviest rain, yellow and grey is the weakest. Reddish blue indicates the heaviest rain, and light blue is the weakest.

The scatter plot in figure 2.21 shows the expected scatter between radar and raingauges, and the spread around the identity line looks like a cone structure pointing towards the intersection between the x- and y-axis. The correlation analyses resulted in $r^2$=0.80 (r=0.985) for the Z-R relation in the log domain, and the calculated Z-R relation is $Z=475R^{1.31}$. The standard error of the residuals (1×standard deviation) is 6.00.

Due to the spatial differences in the precipitation pattern, there are probably rather large

differences in the drop size distribution in the rain area. The performance of raingauge adjustment depends on the precipitation type (e.g. Koistinen and Puhakka, 1984, Jacquet, Andrieu and Denoeux, 1987, Austin, 1987), and the drop size distribution governing the reflectivity factor may show considerable spatial and temporal variations, even within the same rain area (Stout and Mueller, 1968). The scatter plot suggest the possibility of this, because it seems that the radar is overestimating for small amounts of rain, but underestimating for large totals at the raingauge stations.

Moreover, C-band radars are generally sufficient for monitoring moderate precipitation events, but for monitoring of heavy storms there would probably be no energy left in the radar beam for detection of hydrometeors from the far side of the storm. This effect may also have been affecting the result of the radar and gauge comparison. For example, in the Sindal image in figure 2.22 the southern edge of the rain area appears rather ambiguous, but the same edge found in the Rømø image is very distinct and with much higher echo intensities.

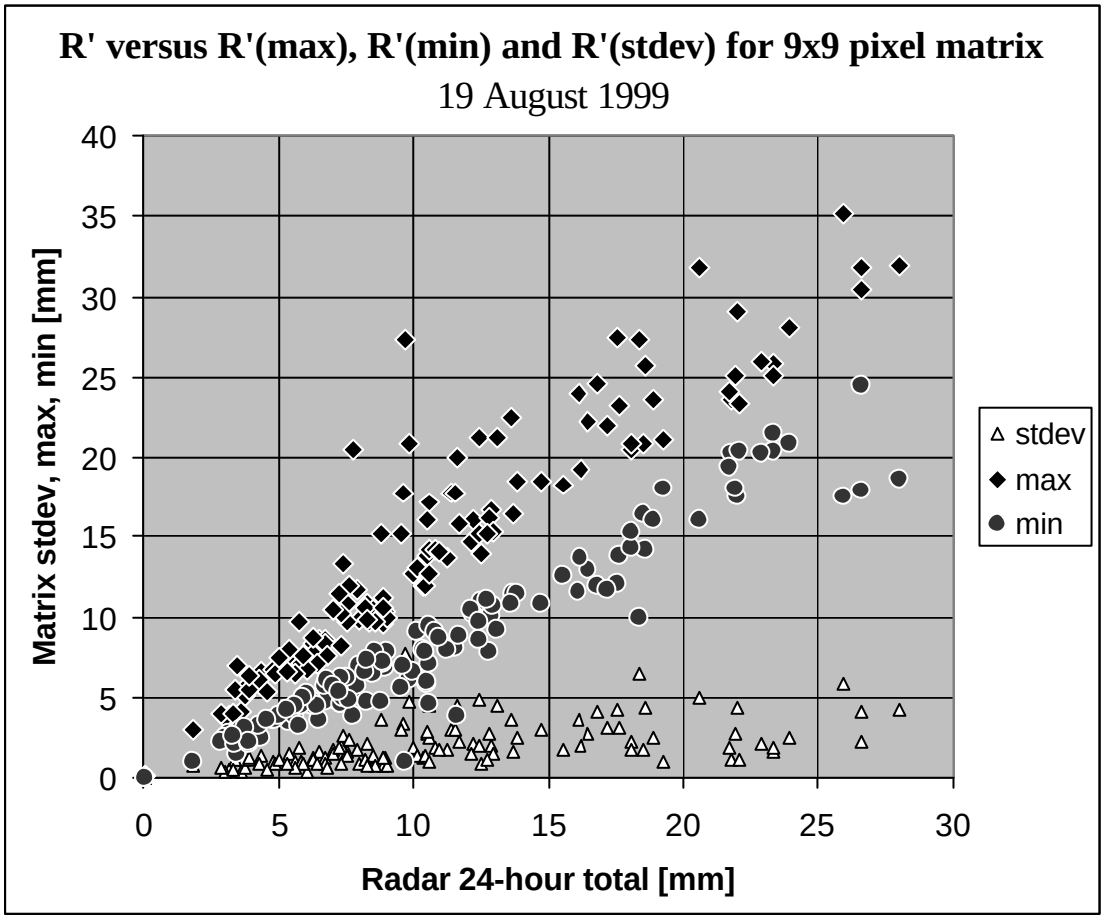



Figure 2.23.Illustration of the small-scale spatial variation in radar precipitation amount within a 9×9 pixel matrix, for which is shown the standard deviation (stdev), maximum value of R' (max) and minimum value of R' (min).

To illustrate the problem of small-scale spatial variations in the radar amount of precipitation, Figure 2.23 shows a scatter plot of the standard deviation, maximum and minimum value of the radar total for a 9×9 pixel matrix situation around the raingauge location. The spatial dimension of a

pixel is 2×2 $km^2$. The spatial variations can be quite extensive, especially for large values of the radar total in this specific weather situation. For example, the pixel with the largest value of R'=28.0 mm, had variations of R' between 18.7 and 32.0 mm in the neighbour pixels. Therefore, the raingauge adjustment could be improved if corrections for this effect is incorporated, e.g. by resampling of the images.

These effects may argue for implementation of improvements of the adjustment scheme in order to take the spatial variability of precipitation systems into account.

### 2.3.10 Conclusions and outlook

The analyses of anaprop lead to the conclusion, that estimation of F and using a threshold value z=3 is a good method for identification of 24-hour image sequences probably contaminated by anaprop. In few cases with a high value of F isolated showers may be present, but the amount of precipitation should be limited in most cases. It is better to exclude anaprop days from the calculation of AMIS fields than using spurious looking radar totals, even though small rain areas may have been present.

When anaprop and precipitation is present in the same image or during the accumulation period of the raingauges, other anaprop identification methods than the one supposed should be developed. For example, satellite information could help the identification of no-rain areas, or analyses of the reflectivity distribution in radar images and analyses of the Polar data volume of the radar could enter a correction method for reduction of the anaprop problem.

C-band radars are generally sufficient in monitoring moderate precipitation events, but in heavy rain storms there would probably be no energy left in the radar beam for detection of hydrometeors from the far side of the storm. On average, reflectivity will decrease with range due to the increasing height of the radar beam. According to Kitchen and Jackson (1993) the underestimation of rainfall accumulations at longer ranges (>100 km) is mainly caused by a steep decline in probability of detection and not so much by underestimation of the precipitation rate in each image. The subsequent rainfall accumulation might be subject to significant underestimation, and range adjustments should be applied to improve the radar performance at long range.

Following Kitchen (1995), the poor understanding of the uncertainty in gauge adjustment does not support a complex method. A wide range of Z-R relationships have been derived which generally is ascribed to the natural variability of drop-size distributions. This variability introduces one of many errors and not the most severe at that.

The adjustment approach in this study focuses on correction of systematic errors on radar data in the whole image. It does not assign real-time, or near real-time raingauge adjustments which may vary over the radar image as demonstrated by Lord and Young (1994). Local adjustments based on a small number if Z-R comparisons may cause the adjustment surface to vary in an unrealistic manner because of a too low number of degrees of freedom, and the effect of not representative

samples would have a too big effect on the adjustment. The adjustment system could be improvements by taking into account the variability of a precipitation system in a better way. On the other hand, the adjustment system may have difficulties in deriving reliable model parameters in some events. In homogeneous rain areas, the adjustment is quite stable, but in case of showers, or different precipitation types in the same radar image, it may be difficult to derive confident parameter values. Isolated showers may pass the raingauge network and not monitored, and the image retains standard calibration. If the precipitation types in the radar image are recognized and appropriate Z-R adjustments are applied, the adjustment results could be better.

The effect of not representative samples can be reduced by using many Z-R values in the same rainfall system (Austin, 1987), and the scatter between the two measures can be reduced by increasing the integration period. On the other hand, many samples do not remove the scatter in the individual measurements (Zawadski, 1984).

The bright-band effect can have a substantial effect on the precipitation estimates in the beginning of the growth season, and a method for correction of this effect could gain improvements of the radar rain estimates.

Finally, the radar integration should take into account the velocity of a precipitation area. If the integration of radar data is not treated correctly, the so-called "fishbone" effect might appear in the integrated radar image (Bellon, Fabry and Austin, 1991). From a hypotetical experiment, they found that errors caused by an inproper accumulation procedure could be larger than those caused by inaccurate Z-R relations.

To sum up possibilities for improvements of the grid estimates:

- Apply improved methods for anaprop removal.
- Implement improved estimation of radar totals.
- Implement a bright-band correction method.
- Implement correction for vertical reflectivity profile variations.
- Take into account the velocity of precipitation systems.

# 3. Verification

## 3.1 Data

The objective verification has been done for the two growing seasons separately, i. e. for April 1 to September 30 1998 and for April 1 to September 30 1999. For the radar derived 24 hour accumulated precipitation and all the observation based 24 hour accumulated precipitation fields, the field data has been further stratified according to month. Result are calculated for each month for both years.

The raw radar data are subject to the same restrictions as in phase I. Statistics for the amount radar data is given in the report "Evaluation of the AMIS Gridded Observations and Radar derived 24-hour Accumulated Precipitation by Comparison with Climate – Grid Denmark Gridded Observations" phase I.

## 3.2 Verification Methods

All data fields are verified against the Climate Grid - Denmark. For each matched grid point the mean error (ME), the mean absolute error (MAE) and the root mean square error (RMSE) is calculated on monthly basis.

Contingency tables with categories 0-0.05, 0.05-2, 2-6, 6-10 and 10-100 mm precipitation/24hr for all fields has been constructed. The contingency tables for the growing seasons are presented below. The contingency tables for each month are placed in appendices C to J. Based on the contingency tables the hit rate (HR) and Hansson Kuipers skill index (HKSI) are calculated for each grid point for every month in the growing seasons.

The maximum, the mean and the minimum value of the ME, MAE and HR values of all the grid points covering Jutland are presented in a graphical form for each month in the growing seasons. Tables of all the verification parameters are placed in appendix B.

## 3.3 Results: Increasing Number of Stations in the Interpolation

### 3.3.1 1998

Table 3.1 shows for the whole growing seasons 1998 the contingency tables for the four precipitation fields with the 25 observations in the interpolation at the top and then increasing the number of observations downwards. The corresponding monthly contingency tables are placed in the appendices.

| 25 KLIMA | | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 18331 | 1764 | 53 | 12 | 5 | |
| 0.05 | 2 | 8991 | 15253 | 2552 | 122 | 16 | |
| 2 | 6 | 116 | 2403 | 8000 | 1143 | 208 | |
| 6 | 10 | 14 | 150 | 1420 | 2303 | 777 | |
| 10 | 100 | 0 | 23 | 181 | 762 | 3067 | |

**mm nedbør**

| 62 KLIMA | | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 21483 | 1711 | 23 | 1 | 0 | |
| 0.05 | 2 | 5950 | 15763 | 1842 | 61 | 9 | |
| 2 | 6 | 30 | 2050 | 9084 | 1026 | 107 | |
| 6 | 10 | 0 | 65 | 1157 | 2605 | 654 | |
| 10 | 100 | 0 | 5 | 99 | 650 | 3303 | |

**mm nedbør**

| 87 KLIMA | | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 22437 | 1761 | 17 | 0 | 0 | |
| 0.05 | 2 | 5006 | 16031 | 1725 | 45 | 8 | |
| 2 | 6 | 23 | 1760 | 9375 | 964 | 96 | |
| 6 | 10 | 0 | 44 | 1010 | 2729 | 586 | |
| 10 | 100 | 0 | 1 | 80 | 605 | 3383 | |

**mm nedbør**

| 126 KLIMA | | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 22800 | 1686 | 11 | 0 | 0 | |
| 0.05 | 2 | 4652 | 16229 | 1698 | 37 | 7 | |
| 2 | 6 | 15 | 1648 | 9472 | 956 | 80 | |
| 6 | 10 | 0 | 33 | 955 | 2766 | 565 | |
| 10 | 100 | 0 | 2 | 68 | 583 | 3421 | |

**mm nedbør**

Table 3.1 Contingency table for April 1st 1998 to September 30th 1998.

The values in the off-diagonal elements representing either over- or underestimation of the precipitation amount compared to Climate-Grid are quit large, when only 25 observations are used in the interpolation. However already with 62 observations used, these values has dropped significantly. Increasing the number of observations further to 87 and 126 continues to reduce the value of the off-diagonal elements but at a much slower rate. The values in the diagonal elements representing the correct categories of cause increase correspondingly especially for small amounts

of precipitation. 87 observations seems to be close to an optimum amount of observations judged from contingency tables.

Figure 3.1 show curves for the ME (a), MAE (b) and HR (c) verification measures for each month in the growing season 1998. The blue curves is calculated with 25 observations, the red curve with 62 observations, the yellow curve with 87 observations and the green curve with 126 observations in the interpolation. Finally the operational AMIS is represented by a black curve. For each verification measure three sets of diagrams are shown one for the minimum value, one for the mean value and one for the maximum value all taken over all grid points in the month.

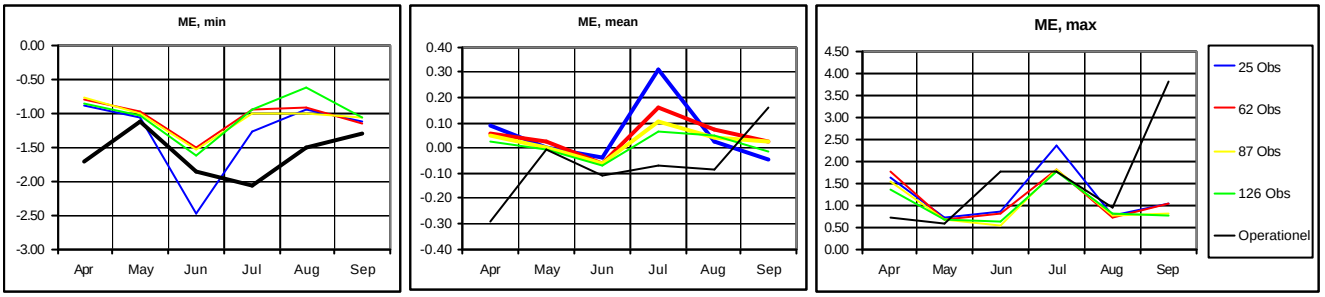



Figure 3.1a. ME. Minimum, mean and maximum.

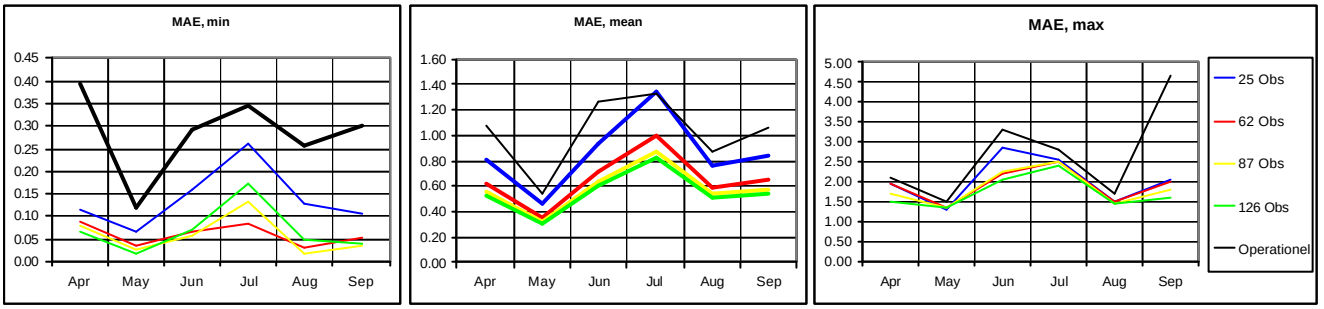



Figure 3.1b. MAE. Minimum, mean and maximum.

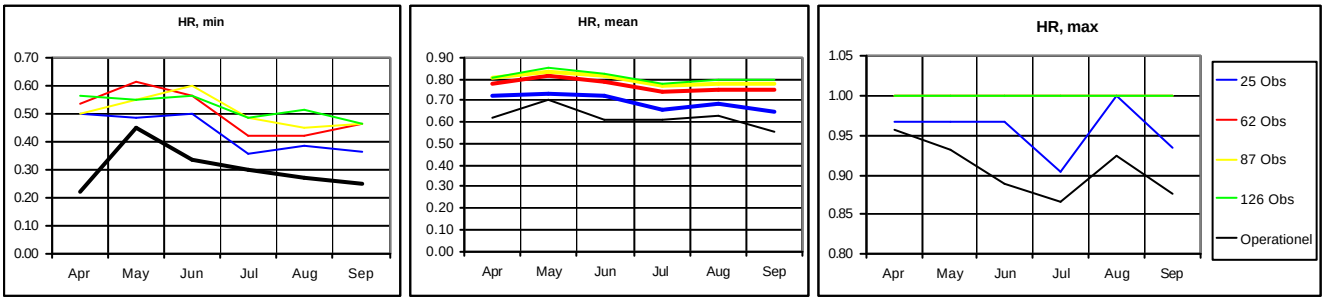



Figure 3.1c. HR. Minimum, mean and maximum.

The minimum ME decreases as the number of observations in the interpolation increases and with 87 and 126 observations the minimum ME is closer to zero than the operational AMIS at that time. The mean ME has become positive for some of the months in the growing season especially July. The mean ME has been improved significantly though with only small improvements going to 87 and 126 observations in the interpolation. The large maximum ME in September in the operational AMIS is reduced from more than 3.5 to around 1. The large maximum ME in the

operational AMIS was due to a reported precipitation amount of 14 mm/12hr September 9th at 18:00 UTC at station Bågø (06111), see phase I report. This station was not used in the 25 station sample explaining why the maximum ME even in this case is small. However the Bågø station is included in the samples with more observations and the wrong observation is thus suppressed by the larger amount of the other more correct observations.

The MAE is decreasing for both minimum, mean and maximum values as the number of observations in the interpolation is increasing, with the minimum value having the largest decrease and maximum value the smallest decrease, except again in September, where Bågø observation gives a large maximum MAE in the operational AMIS. All together a significant improvement again with no significant difference between 87 and 126 observations in the interpolation.

The HR is increasing for both minimum, mean and maximum values as the number of observations in the interpolation is increasing, with the minimum value having the largest increase and maximum value the smallest increase but with maximum hit rate around 100%

Figure 3.2 show the mean of the MAE for all months as function of the number of observations in the interpolation. The curve illustrates the already mentioned small different between 87 and 126 observations in the interpolation indicating that 87 observations is close to an optimal number of observations. Adding further observations will not improve the results significantly.

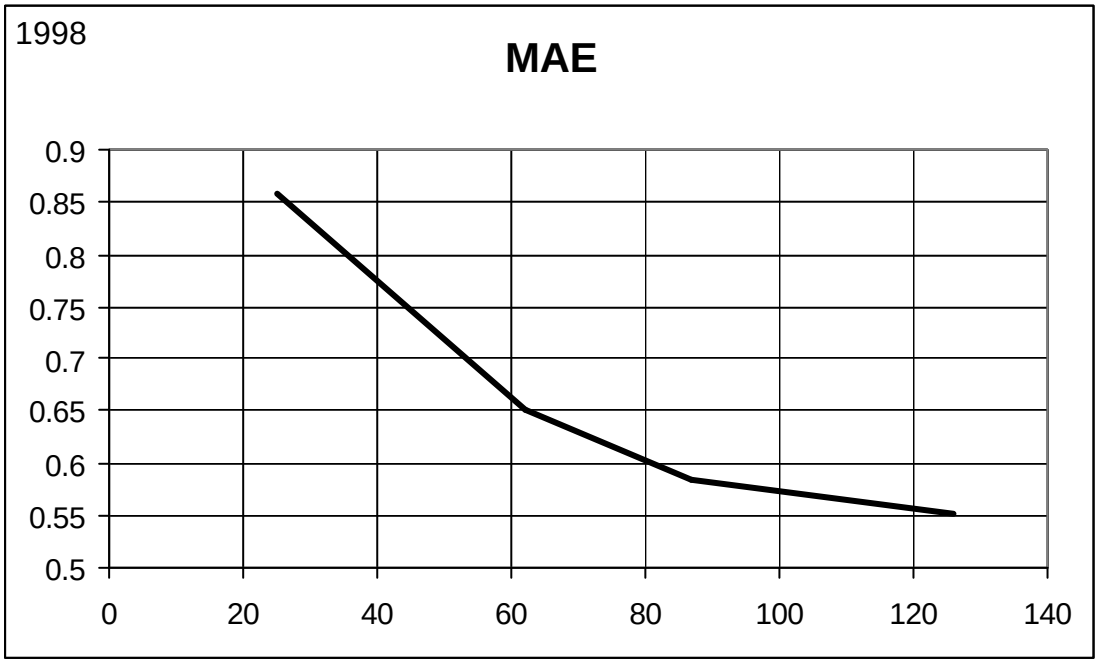



Figure 3.2 MAE absolute error as function of the number of observations used in the interpolation.

### 3.3.2 1999

Table 3.2 shows for the whole growing seasons 1999 the contingency tables for the four precipitation fields with the 25 observations in the interpolation at the top and then increasing the number of observations downwards. The corresponding monthly contingency tables are placed in the appendices.

| 25 KLIMA | | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 25251 | 1111 | 29 | 9 | 3 | |
| 0.05 | 2 | 8266 | 10521 | 1658 | 100 | 47 | |
| 2 | 6 | 75 | 2046 | 6144 | 1409 | 297 | |
| 6 | 10 | 1 | 126 | 1490 | 2489 | 1075 | |
| 10 | 100 | 0 | 58 | 361 | 1173 | 3901 | |

**mm nedbør**

| 62 KLIMA | | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 28967 | 1115 | 35 | 9 | 4 | |
| 0.05 | 2 | 4623 | 11126 | 1381 | 79 | 30 | |
| 2 | 6 | 33 | 1557 | 6726 | 1119 | 165 | |
| 6 | 10 | 0 | 56 | 1329 | 2933 | 802 | |
| 10 | 100 | 0 | 22 | 209 | 1039 | 4322 | |

**mm nedbør**

| 87 KLIMA | | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 29794 | 1207 | 26 | 2 | 0 | |
| 0.05 | 2 | 3801 | 11229 | 1295 | 73 | 28 | |
| 2 | 6 | 21 | 1370 | 6993 | 1053 | 149 | |
| 6 | 10 | 1 | 50 | 1219 | 3110 | 794 | |
| 10 | 100 | 0 | 16 | 144 | 939 | 4352 | |

**mm nedbør**

| 126 KLIMA | | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 30259 | 1181 | 24 | 3 | 0 | |
| 0.05 | 2 | 3331 | 11335 | 1329 | 77 | 33 | |
| 2 | 6 | 31 | 1313 | 7050 | 1041 | 121 | |
| 6 | 10 | 1 | 57 | 1147 | 3153 | 793 | |
| 10 | 100 | 0 | 10 | 128 | 906 | 4376 | |

**mm nedbør**

Table 3.2 Contingency table for April 1st 1999 to September 30th 1999.

Also this year the values of the off-diagonal elements decrease as the number of observations in the interpolation is increased. The tendency is however not so pronounced as in the growing season 1998.

Figure 3.3 is similar to figure 3.1 showing curves for the ME, MAE and HR but here for each month in the growing season 1999. Colours and line types are similar to figure 3.1.

Also these verification measures show the same pattern as those of 1998.

The peak in the operational AMIS September 8$^{th}$ is due to a reported precipitation amount of 34 mm/24hr at 06:00 UTC at station Borris II (05410). This peak is being suppressed as the number of more correct observations is added in the interpolation.

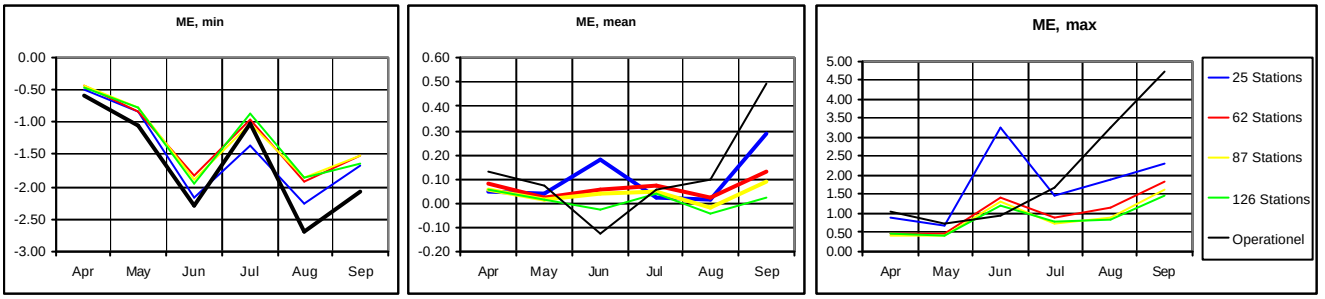



Figure 3.3a. ME. Minimum, mean and maximum.

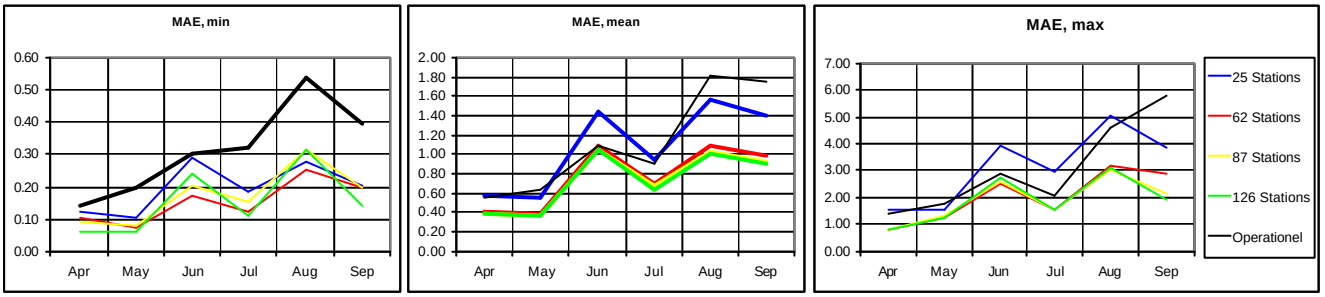



Figure 3.3b. MAE. Minimum, mean and maximum.

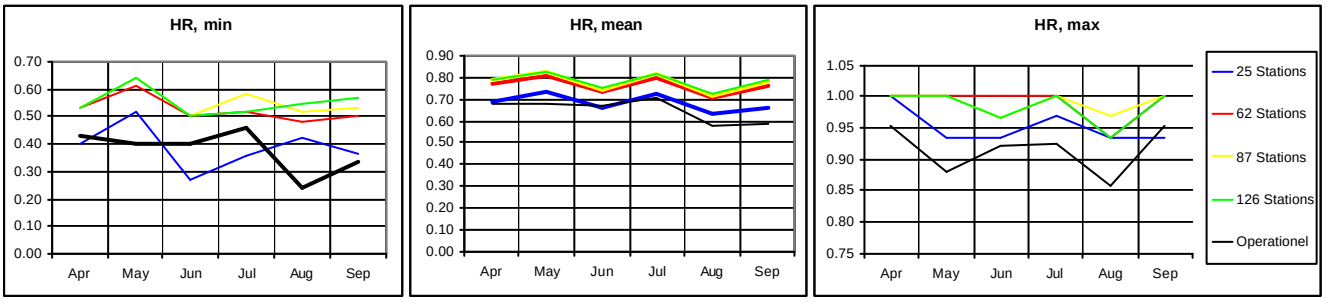



Figure 3.3c. HR. Minimum, mean and maximum.

Figure 3.4 show the mean of the MAE for all months as function of the number of observations in the interpolation for 1999 and is similar to figure 3.2 for 1998. This year 62 observations seems to be close to an optimal number of observations.

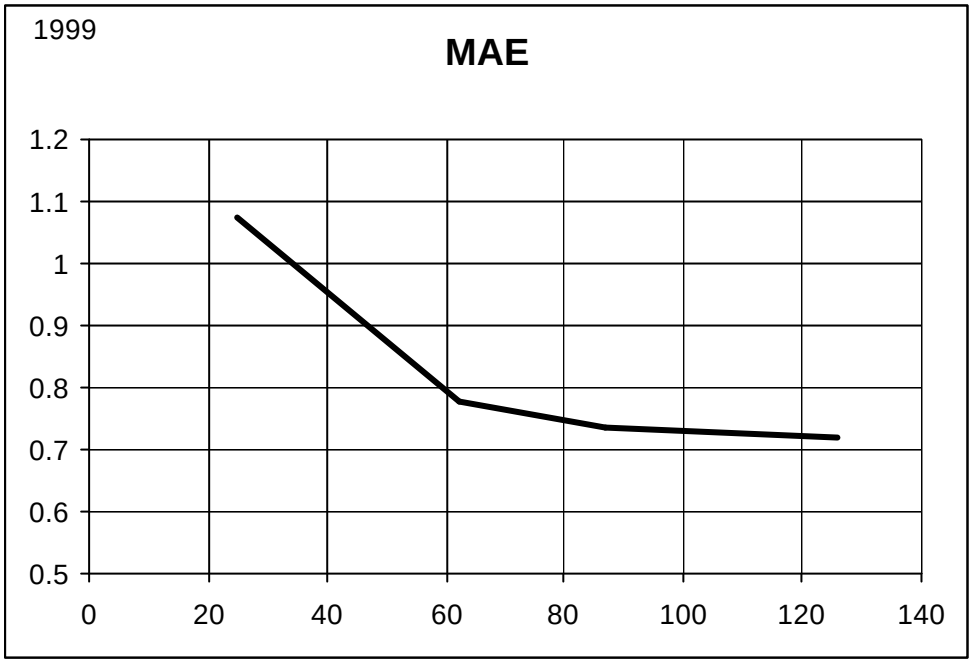



Figure 3.4 MAE absolute error as function of the number of observations used in the interpolation.

## 3.4 Results: Radar

In phase I it has been demonstrated, that the overall statistical verification measure for the radar derived 24-hour accumulated precipitation are not as good as those for the operational AMIS. The reason for this was partly due to anaprop and the use of raw uncalibrated radar data. The aim of phase II is to correct the radar data for anaprop errors and to adjust the radar derived 24-hour accumulated precipitation to get overall statistical verification measures comparable to AMIS. The results of this part of the phase II study are presented for the growing season 1999 first, because this year had 26 days with anaprop whereas 1998 had only 2, see chapter 2.3.3. The adjustment has been performed using SYNOP (automatic) observations only since the observations reported daily on phone had a relative poor correspondence with the radar derived precipitation.

### 3.4.1 1999

Figure 3.5 show curves for the ME (a), MAE (b) and HR (c) verification measures for each month in the growing season 1999. The blue curve is the result from phase I. The red curve shows the verifications measures after anaprop days has been put equal to 0. In 1999 as mention the number of days with anaprop is 26, see chapter 2.3.3. The green curve shows the verifications measures when the anaprop days has been put equal to 0 and the radar derived precipitation has been calibrated using the method described in chapter 2.3.4. The yellow curve shows the verifications

measures after adjustment of the radar derived precipitation and elimination of days with a large difference in the precipitation sum. This is done by removing day with F > 10 the ratio of radar derived precipitation sum to observed precipitation sum(see chapter 2.3.3), The result is that some days will be eliminated even if it is not a day with anaprop but just a bad day. The method will however also remove days with anaprop so a separate anaprop procedure is unnecessary.

Finally the operational AMIS is represented by a black curve. For each verification measure three sets of diagrams are shown one for the minimum value, one for the mean value and one for the maximum value all taken over all grid points in the month.

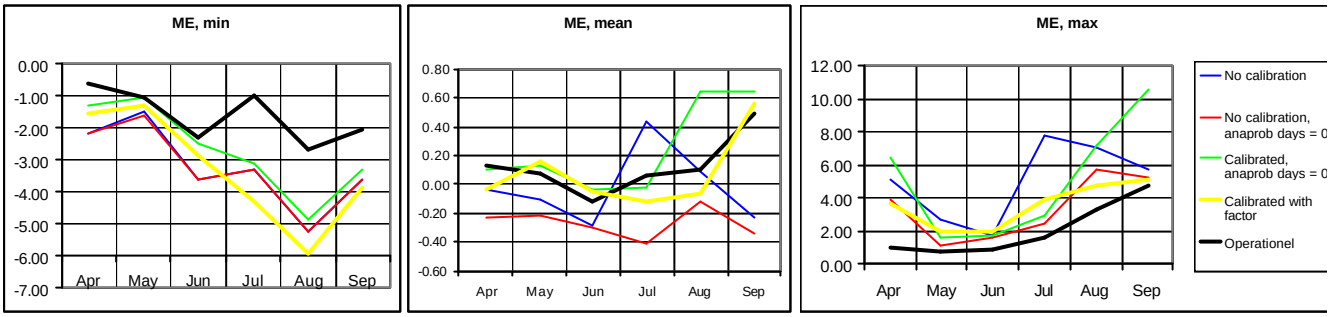


Figure 3.5a. ME. Minimum, mean and maximum.

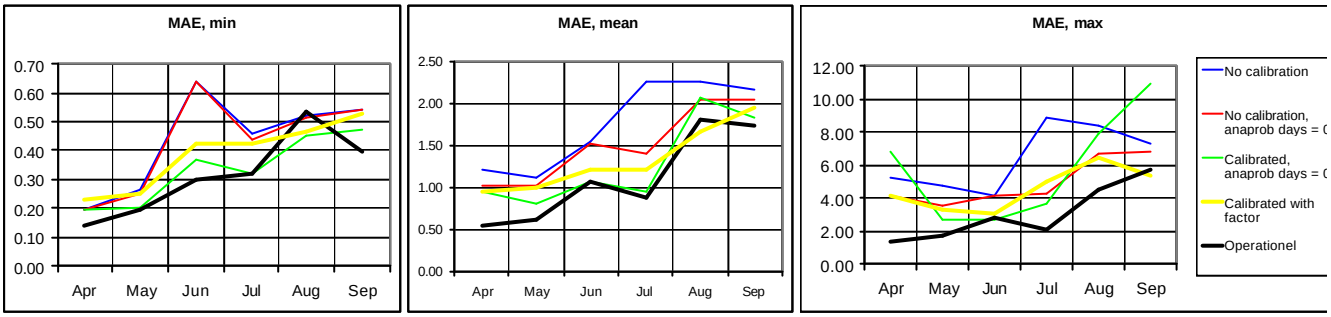


Figure 3.5b. MAE. Minimum, mean and maximum.

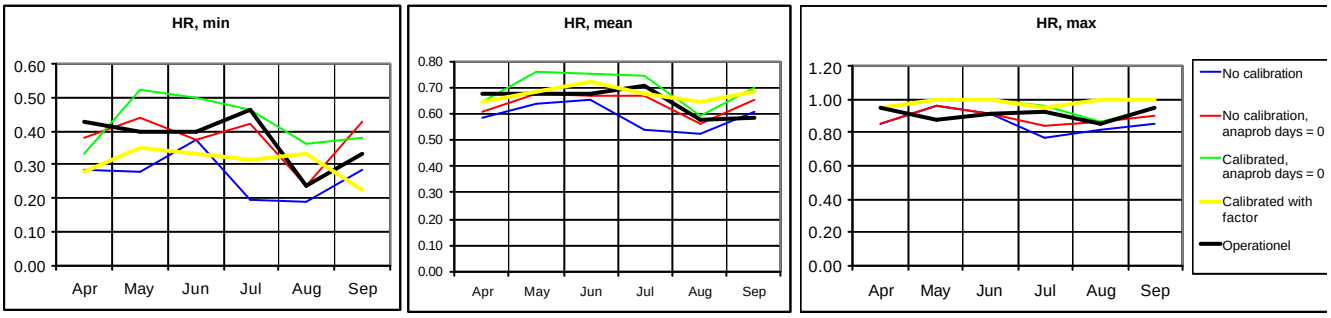


Figure 3.5c. HR. Minimum, mean and maximum.

The minimum ME values are not changing much for any of the four radar derived precipitation fields. This is more or less expected since anaprop correction and calibration will have the largest impact on the largest differences from the true (Climate-Grid Denmark)

The mean ME is somewhat better with anaprop correction than without and even more when adjustment is performed. The method with adjusted radar derived precipitation and elimination of bad days has improved the mean ME so that it is comparable with the operational AMIS This is also the situation for the maximum ME, where the method with adjusted radar derived precipitation and elimination of bad days reduces the maximum ME of 10 reached for the anaprop correction and adjustment (green curve) to about 4, which is just above the operational AMIS.

The minimum MAE for the anaprop corrected field is no better than without the correction. Adjusted and anaprop corrected field (green curve) and the field from the method with adjusted radar derived precipitation and elimination of bad days are both closer to the operational AMIS than the unadjusted fields especially in June, with the adjusted and anaprop corrected field being the best. However the method with adjusted radar derived precipitation and elimination of bad days though is still comparable to the operational AMIS.

The anaprop corrected field reduces the mean MAE compared to the original field, but again here the adjusted and anaprop corrected field and the field from the method with adjusted radar derived precipitation and elimination of bad days are both comparable to the operational AMIS, with the adjusted and anaprop corrected field being the best.

The same pattern is seen for maximum MAE except here the field from the method with adjusted radar derived precipitation and elimination of bad days is much better than the adjusted and anaprop corrected field in April and September. this is the reason why the method with adjusted radar derived precipitation and elimination of bad days was introduced. This method eliminates some days in April and September, which has precipitation sum very different from the SYNOP observations and these days therefore, as seen, verify very bad.

For the minimum HR the anaprop corrected field is very close the operational field. The adjusted and anaprop corrected field and the field from the method with adjusted radar derived precipitation and elimination of bad days are not that close to the operational AMIS, but still somewhat better than the original field.

For the mean and maximum HR the adjusted and anaprop corrected field and the field from the method with adjusted radar derived precipitation and elimination of bad days both has a higher HR than the operational AMIS, except in April and July for the mean where the field from the method with adjusted radar derived precipitation and elimination of bad days is slightly smaller than the operational AMIS.

### 3.4.2 1998

Figure 3.6 is similar to figure 3.5 curves for the ME (a), MAE (b) and HR (c) verification measures for each month, but for the growing season 1998. As mentioned before only 2 days had anaprop detected, thus it has no meaning showing the red curves representing an anaprop corrected field only (red curves in figure 3.5).

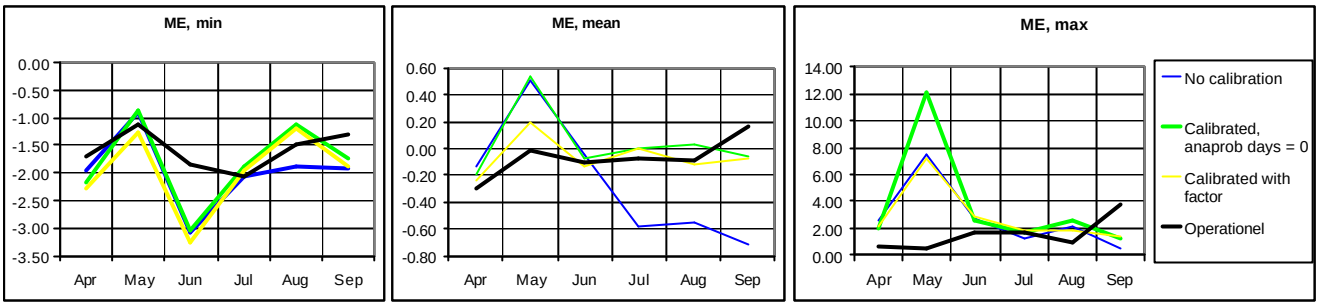



Figure 3.5a. ME. Minimum, mean and maximum.

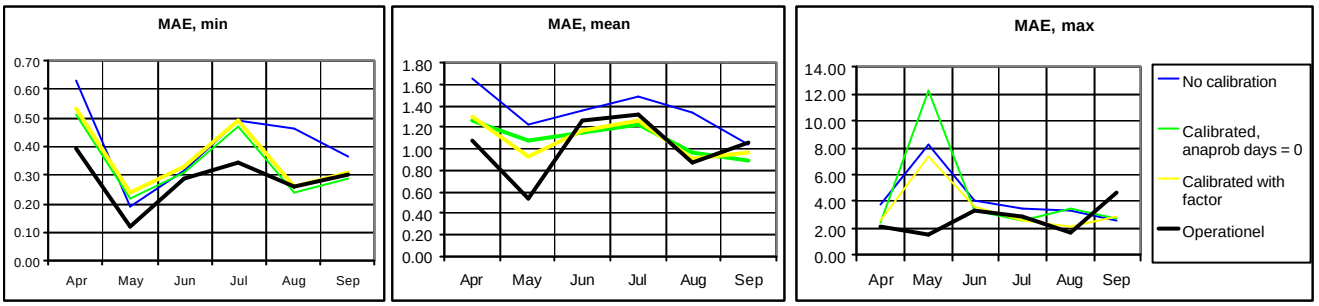



Figure 3.5b. MAE. Minimum, mean and maximum.

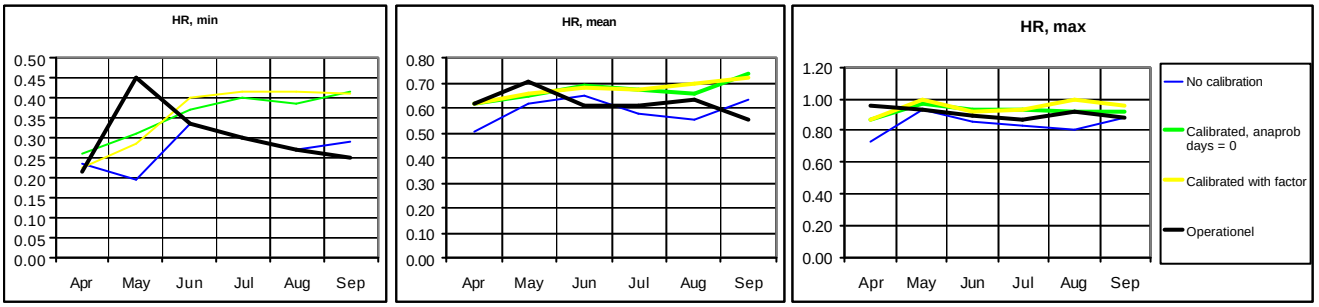



Figure 3.5c. HR. Minimum, mean and maximum.

Generally the improvements for the growing season 1998 are not as significant as they were in the growing season 1999. this partly due to the small number of anaprop days in 1998, but also a yearly variance in the performance. On the other hand are the performance in 1998 comparable or sometimes better than in 1999, which then is difficult to improve further.
However 1998 show a relative bad verification in May.

The minimum ME has not changed much from the original field. The mean and maximum ME are comparable with the operational AMIS except in May. This is due to some days with very large radar derived precipitation at a few grid points which is not found in the climate-grid Denmark. They result in a large ME value at these grid points which gives a large maximum ME and some influence on the average ME. If these grid points are removed the maximum and mean ME in May would smaller. However it should be remembered, that Climate-Grid Denmark is not the exact true precipitation.

The minimum MAE is improved especially in August and September. The mean MAE is rather constant and better than 1999 and comparable with the operational AMIS except again in May. The same is the situation for the maximum MAE.
All hit rates are better than the operational AMIS again except in May for the minimum and mean HR, though not very much for the mean HR.

# 4. Conclusions

Increasing the number of observations in the interpolation will improve the resolution of fine structure of the precipitation pattern. this was clearly demonstrated during the case studies. These also indicated that only small improvements results from increasing the number observations in the interpolation beyond 90. This conclusion was further supported from the overall statistical verification measures. The reduction of MAE is large going from 25 observations to 87 observations used in the interpolation, whereas only minor improvements results from further up to 126 observations , chapter 3.3. Thus 90-100 observations for Jutland seems to be a kind optimal number of observation. this corresponds to mean distance between observing stations of about 20 km.

The second aim of this project was to enhance the performance of radar derived precipitation so the overall statistical verification measures would be comparable to the operational AMIS values. It has been shown in chapter 3.4 that this could best be done by first using the adjustment procedure outlined in chapter 2.3.4 and then exclude days with large ratios of radar derived precipitation sums to observational precipitation sums for the whole area. Then both days with anaprop and days when the radar performs badly are excluded. The separate anaprop analysis outlined in chapter 2.3.3 is then not necessary.
Using these techniques the overall statistical measures becomes comparable to the operational AMIS. It should however be mentioned that one has to rely on other data sources the days the derived precipitation fields are excluded.

Some further possibilities for improving the radar derived precipitation are outlined in chapter 2.3.10

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# Appendix A

**A brief explanation of errors on weather radar data**
In the following, important sources of error on radar data will be briefly explained and discussed.

*Clutter and anomalous beam propagation (anaprop):*
Clutter which is reflection of the radar beam from ground targets close to the radar is always more or less present in a radar image. In stable weather conditions temperature and vapour inversions may be present causing the radar beam to be refracted more than the curvature of Earth. Therefore, the beam hits ground targets at random radar ranges and artificial precipitation patterns are seen in the image (anaprop).

*The bright-band effect:*
If melting snow is present at level the reflection of the beam can be enhanced by up to a factor of 5 due to the fact, that the backscatter cross section of the hydrometeor becomes larger because of a coverage of a thin water film on the melting show. The rain rate is unchanged but the radar echo increases. As noted by Smith (1990) it is not so complicated to recognise a bright-band in stratiform precipitation as it is in convective. For correction of the bright-band effect, the radar must have the necessary spatial resolution to resolve the bright-band layer. This is possible for the Sindal and Rømø radars and the newly installed radar at Stevns.

*Beam attenuation due to hydrometeors and atmosphere:*
If melting snow, hail or ground clutter is present, incorrect values for attenuation correction will be applied to the bins causing errors in the output (Collier, 1989). For example, the correction for attenuation due to hail is so unreliable that the derived rain rates cannot be used with any confidence, because for a C band radar, dry hail causes large reflectivities but smaller attenuation than rain. However, if hail less than some specific diameter is coated with a thin film of water the attenuation increases (Battan, 1973).

*Beam power losses at range and beam filling conditions*
At increasing range the volume of the polar bin increases. The spatial distance between the Polar bins increases with range and the resampling becomes more inaccurate at longer range. At range beam filling conditions may not be fulfilled and, together with small scale variability of precipitation, the radar echo may not be representative of the precipitation conditions within the distant Polar bins. The radar measures the meteorological targets within a volume at a certain altitude above the ground surface. The problem increases with range, and for example, beam filling combined with reduced visibility can play an important role at longer ranges (Joss et al., 1995).

A rule of thumb is that closer to the radar than 100-150 km data can be used quantitatively, but at large ranges it can most often only be used qualitatively unless data are corrected for range related sources of error which can improve results to a certain extent.

*Vertical reflectivity profile variations and beam overshooting*

At increasing range from the radar, the vertical distance between the sampling volume and the ground surface usually increases, and serious errors may arise from the variations in the vertical reflectivity profile. For example, below the radar beam the rain rate may change due to low level evaporation in a dry atmosphere, low growth in a moist atmosphere or orographic growth due to local terrain effects.

At long range, overshooting of the radar beam can cause no detection of precipitation areas, but also, missing radar samples at low altitudes may lead to a strongly underestimated rain rate. The overshooting problem is especially important in winter where the vertical extent of snowfall echoes are often less than 2 km above the ground.

When the radar beam is passing near the top of the precipitation layer the reflectivity fluctuations are not well correlated with the changes in the rain rate near the ground. In fact, Kitchen and Jackson (1993) discussed that the underestimation of rainfall accumulations at longer ranges (>100 km) is mainly caused by a steep decline in probability of detection, i.e. detection failure, and not so much by underestimation of the precipitation rate.

*Rain gauge adjustment*

Following Joss and Waldvogel (1987) that corrections for all known systematic errors on radar data should be applied before any rain gauge adjustment. And really, something can be done to nearly all, and at least to the most important errors. On the other hand, raingauge adjustment must be done carefully because of the different nature of radar and raingauge measurements; radar data are an instant volume measure and rain gauging is a point measure of accumulated precipitation. The representativity problem can affect the comparison and has to be considered. Statistical methods for comparison can to some extent eliminate, or at least reduce, the effect of this problem.

In order to use radar for measuring rainfall intensity R, most investigators have employed an empirical expression of the general form $Z=AR^b$ where A and b are constants. The relationship between Z and R is affected by various physical processes. Spatial and temporal variations of rain rate will affect the radar and rain gauge samples differently, and, unless treated, it will affect the raingauge adjustment. By experience it is known that the effect of not representative samples can be reduced by using many Z-R values in the same rainfall system (Austin, 1987), but on the other hand many samples do not remove the scatter of the individual samples (Zawadski, 1984).

*Variations in the drop size distribution*

The rain gauge measurements are affected by the aerodynamic error and shelter effect and, if the wind speed is high, it must be dealt with before rain gauge adjustment. The magnitude of the error on the adjustment when fixed constants in the Z-R equation is used depends on how much the drop size distribution of the actual rainfall deviates from the drop size distribution assumed in the equation. In this pilot study it is the Marshall and Palmers equation, thus spatial and temporal variations in rain rate can affect the results. This argues for an adjustment based on parallel rain gauge and radar measures.

# Appendix B Tables with the overall statistics for 1998 and 1999

The verifications parameters are calculated for each of the grid point covering Jutland on monthly basis. Minimum, maximum values of all the grid points are presented below together with the average values over all grid points covering Jutland. Minimum, maximum and average values for the whole growing season is also presented.

| 1998 | 25 Obs | ME | MAE | RMSE | HR | HKSI |
|---|---|---|---|---|---|---|
| MIN | Apr | -0.90 | 0.11 | 0.22 | 0.50 | 0.30 |
| | May | -1.05 | 0.07 | 0.14 | 0.48 | 0.22 |
| | Jun | -2.46 | 0.16 | 0.31 | 0.50 | 0.33 |
| | Jul | -1.26 | 0.26 | 0.47 | 0.35 | 0.17 |
| | Aug | -0.96 | 0.13 | 0.27 | 0.39 | 0.17 |
| | Sep | -1.12 | 0.11 | 0.20 | 0.37 | 0.13 |
| | All | -0.61 | 0.14 | 0.37 | 0.52 | 0.35 |
| MAX | Apr | 1.64 | 2.00 | 4.30 | 0.97 | 0.96 |
| | May | 0.70 | 1.33 | 4.05 | 0.97 | 0.97 |
| | Jun | 0.83 | 2.85 | 7.15 | 0.97 | 0.95 |
| | Jul | 2.33 | 2.57 | 7.26 | 0.90 | 0.87 |
| | Aug | 0.75 | 1.54 | 3.43 | 1.00 | 1.00 |
| | Sep | 1.02 | 2.08 | 4.68 | 0.93 | 0.91 |
| | All | 0.75 | 1.54 | 3.43 | 0.92 | 0.90 |
| MEAN | Apr | 0.09 | 0.81 | 1.45 | 0.72 | 0.62 |
| | May | 0.00 | 0.46 | 1.11 | 0.74 | 0.62 |
| | Jun | -0.04 | 0.93 | 1.96 | 0.72 | 0.63 |
| | Jul | 0.31 | 1.34 | 2.64 | 0.66 | 0.55 |
| | Aug | 0.03 | 0.75 | 1.44 | 0.68 | 0.56 |
| | Sep | -0.05 | 0.85 | 1.65 | 0.65 | 0.54 |
| | All | 0.06 | 0.86 | 1.89 | 0.69 | 0.59 |

| 1998 | 62 Obs | ME | MAE | RMSE | HR | HKSI |
|---|---|---|---|---|---|---|
| MIN | Apr | -0.79 | 0.09 | 0.21 | 0.53 | 0.39 |
| | May | -0.99 | 0.04 | 0.08 | 0.61 | 0.35 |
| | Jun | -1.49 | 0.07 | 0.19 | 0.57 | 0.37 |
| | Jul | -0.96 | 0.08 | 0.15 | 0.42 | 0.23 |
| | Aug | -0.93 | 0.03 | 0.06 | 0.42 | 0.28 |
| | Sep | -1.14 | 0.05 | 0.09 | 0.47 | 0.27 |
| | All | -0.61 | 0.07 | 0.16 | 0.60 | 0.45 |
| MAX | Apr | 1.76 | 1.96 | 3.88 | 1.00 | 1.00 |
| | May | 0.65 | 1.35 | 3.91 | 1.00 | 1.00 |
| | Jun | 0.82 | 2.21 | 5.00 | 1.00 | 1.00 |
| | Jul | 1.82 | 2.53 | 7.25 | 1.00 | 1.00 |
| | Aug | 0.72 | 1.51 | 3.43 | 1.00 | 1.00 |
| | Sep | 1.04 | 2.00 | 5.40 | 1.00 | 1.00 |
| | All | 0.54 | 1.31 | 3.15 | 0.96 | 0.93 |
| MEAN | Apr | 0.06 | 0.63 | 1.17 | 0.78 | 0.70 |
| | May | 0.02 | 0.35 | 0.87 | 0.82 | 0.73 |
| | Jun | -0.06 | 0.71 | 1.52 | 0.79 | 0.71 |
| | Jul | 0.16 | 0.99 | 1.89 | 0.74 | 0.66 |
| | Aug | 0.07 | 0.59 | 1.14 | 0.75 | 0.66 |
| | Sep | 0.03 | 0.65 | 1.29 | 0.75 | 0.67 |
| | All | 0.05 | 0.65 | 1.44 | 0.77 | 0.69 |

25 and 62 observations in the interpolation 1998

| 1998 | 87 Obs | ME | MAE | RMSE | HR | HKSI |
|---|---|---|---|---|---|---|
| MIN | Apr | -0.77 | 0.08 | 0.15 | 0.50 | 0.35 |
| | May | -1.00 | 0.03 | 0.07 | 0.55 | 0.30 |
| | Jun | -1.52 | 0.06 | 0.13 | 0.60 | 0.44 |
| | Jul | -1.00 | 0.13 | 0.31 | 0.48 | 0.28 |
| | Aug | -0.99 | 0.02 | 0.05 | 0.45 | 0.28 |
| | Sep | -1.05 | 0.04 | 0.08 | 0.47 | 0.27 |
| | All | -0.61 | 0.08 | 0.21 | 0.62 | 0.50 |
| MAX | Apr | 1.53 | 1.70 | 3.74 | 1.00 | 1.00 |
| | May | 0.66 | 1.36 | 4.04 | 1.00 | 1.00 |
| | Jun | 0.54 | 2.29 | 4.81 | 1.00 | 1.00 |
| | Jul | 1.81 | 2.51 | 7.22 | 1.00 | 1.00 |
| | Aug | 0.75 | 1.46 | 3.44 | 1.00 | 1.00 |
| | Sep | 0.80 | 1.83 | 4.91 | 1.00 | 1.00 |
| | All | 0.46 | 1.22 | 3.14 | 0.97 | 0.94 |
| MEAN | Apr | 0.05 | 0.56 | 1.04 | 0.80 | 0.73 |
| | May | 0.00 | 0.32 | 0.81 | 0.84 | 0.75 |
| | Jun | -0.06 | 0.64 | 1.39 | 0.82 | 0.75 |
| | Jul | 0.10 | 0.87 | 1.65 | 0.77 | 0.70 |
| | Aug | 0.04 | 0.54 | 1.08 | 0.78 | 0.69 |
| | Sep | 0.03 | 0.58 | 1.16 | 0.78 | 0.71 |
| | All | 0.03 | 0.58 | 1.30 | 0.80 | 0.72 |

| 1998 | 126 Obs | ME | MAE | RMSE | HR | HKSI |
|---|---|---|---|---|---|---|
| MIN | Apr | -0.85 | 0.07 | 0.17 | 0.57 | 0.42 |
| | May | -1.04 | 0.02 | 0.04 | 0.55 | 0.28 |
| | Jun | -1.61 | 0.07 | 0.13 | 0.57 | 0.37 |
| | Jul | -0.94 | 0.17 | 0.35 | 0.48 | 0.28 |
| | Aug | -0.64 | 0.05 | 0.10 | 0.52 | 0.36 |
| | Sep | -1.06 | 0.04 | 0.07 | 0.47 | 0.28 |
| | All | -0.39 | 0.08 | 0.24 | 0.63 | 0.50 |
| MAX | Apr | 1.36 | 1.54 | 3.08 | 1.00 | 1.00 |
| | May | 0.64 | 1.39 | 3.99 | 1.00 | 1.00 |
| | Jun | 0.60 | 2.08 | 4.80 | 1.00 | 1.00 |
| | Jul | 1.77 | 2.44 | 7.02 | 1.00 | 1.00 |
| | Aug | 0.79 | 1.47 | 3.23 | 1.00 | 1.00 |
| | Sep | 0.78 | 1.61 | 4.63 | 1.00 | 1.00 |
| | All | 0.40 | 1.11 | 3.05 | 0.96 | 0.94 |
| MEAN | Apr | 0.03 | 0.53 | 0.98 | 0.81 | 0.74 |
| | May | -0.01 | 0.30 | 0.79 | 0.85 | 0.76 |
| | Jun | -0.07 | 0.61 | 1.33 | 0.82 | 0.76 |
| | Jul | 0.07 | 0.83 | 1.57 | 0.78 | 0.71 |
| | Aug | 0.05 | 0.51 | 1.01 | 0.79 | 0.72 |
| | Sep | -0.01 | 0.53 | 1.08 | 0.79 | 0.72 |
| | All | 0.01 | 0.55 | 1.24 | 0.81 | 0.74 |

87 and 126 observations in the interpolation 1998

| 1999 | 25 Obs | ME | MAE | RMSE | HR | HKSI | 1999 | 62 Obs | ME | MAE | RMSE | HR | HKSI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIN | Apr | -0.51 | 0.12 | 0.24 | 0.40 | 0.14 | MIN | Apr | -0.428 | 0.10 | 0.18 | 0.53 | 0.36 |
| | May | -0.83 | 0.10 | 0.23 | 0.52 | 0.28 | | May | -0.84 | 0.08 | 0.15 | 0.61 | 0.48 |
| | Jun | -2.18 | 0.29 | 0.46 | 0.27 | 0.07 | | Jun | -1.82 | 0.17 | 0.25 | 0.50 | 0.37 |
| | Jul | -1.35 | 0.19 | 0.45 | 0.35 | 0.08 | | Jul | -0.95 | 0.12 | 0.24 | 0.52 | 0.32 |
| | Aug | -2.26 | 0.28 | 0.59 | 0.42 | 0.22 | | Aug | -1.92 | 0.25 | 0.50 | 0.48 | 0.31 |
| | Sep | -1.67 | 0.20 | 0.43 | 0.37 | 0.16 | | Sep | -1.53 | 0.20 | 0.31 | 0.50 | 0.33 |
| | All | -0.82 | 0.23 | 0.58 | 0.45 | 0.27 | | All | -0.55 | 0.17 | 0.35 | 0.63 | 0.52 |
| MAX | Apr | 0.87 | 1.56 | 3.02 | 1.00 | 1.00 | MAX | Apr | 0.45 | 0.77 | 1.73 | 1.00 | 1.00 |
| | May | 0.69 | 1.55 | 5.36 | 0.94 | 0.92 | | May | 0.46 | 1.26 | 5.43 | 1.00 | 1.00 |
| | Jun | 3.27 | 3.93 | 8.72 | 0.93 | 0.93 | | Jun | 1.43 | 2.49 | 7.12 | 1.00 | 1.00 |
| | Jul | 1.46 | 2.92 | 6.97 | 0.97 | 0.95 | | Jul | 0.89 | 1.55 | 5.10 | 1.00 | 1.00 |
| | Aug | 1.90 | 5.04 | 12.45 | 0.93 | 0.91 | | Aug | 1.13 | 3.20 | 12.01 | 0.94 | 0.92 |
| | Sep | 2.33 | 3.87 | 7.77 | 0.93 | 0.93 | | Sep | 1.86 | 2.89 | 6.28 | 1.00 | 1.00 |
| | All | 1.28 | 2.97 | 6.48 | 0.92 | 0.89 | | All | 0.50 | 1.36 | 5.34 | 0.94 | 0.92 |
| MEAN | Apr | 0.05 | 0.56 | 1.13 | 0.69 | 0.59 | MEAN | Apr | 0.08 | 0.40 | 0.80 | 0.77 | 0.70 |
| | May | 0.04 | 0.55 | 1.26 | 0.73 | 0.65 | | May | 0.02 | 0.39 | 0.92 | 0.81 | 0.75 |
| | Jun | 0.18 | 1.44 | 2.54 | 0.66 | 0.58 | | Jun | 0.05 | 1.08 | 1.91 | 0.74 | 0.68 |
| | Jul | 0.03 | 0.95 | 2.10 | 0.73 | 0.62 | | Jul | 0.07 | 0.70 | 1.59 | 0.80 | 0.72 |
| | Aug | 0.02 | 1.56 | 3.28 | 0.63 | 0.52 | | Aug | 0.03 | 1.09 | 2.31 | 0.71 | 0.63 |
| | Sep | 0.29 | 1.40 | 2.75 | 0.66 | 0.57 | | Sep | 0.13 | 0.99 | 2.01 | 0.76 | 0.70 |
| | All | 0.10 | 1.08 | 2.43 | 0.68 | 0.59 | | All | 0.06 | 0.78 | 1.78 | 0.77 | 0.70 |

25 and 62 observations in the interpolation 1999

| 1999 | 87 Obs | ME | MAE | RMSE | HR | HKSI | 1999 | 126 Obs | ME | MAE | RMSE | HR | HKSI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIN | Apr | -0.44 | 0.09 | 0.17 | 0.53 | 0.40 | MIN | Apr | -0.48 | 0.06 | 0.12 | 0.53 | 0.36 |
| | May | -0.79 | 0.08 | 0.14 | 0.65 | 0.51 | | May | -0.78 | 0.06 | 0.10 | 0.65 | 0.50 |
| | Jun | -1.89 | 0.20 | 0.31 | 0.50 | 0.42 | | Jun | -1.96 | 0.24 | 0.36 | 0.50 | 0.40 |
| | Jul | -1.02 | 0.16 | 0.34 | 0.58 | 0.43 | | Jul | -0.86 | 0.11 | 0.23 | 0.52 | 0.30 |
| | Aug | -1.85 | 0.32 | 0.58 | 0.52 | 0.36 | | Aug | -1.87 | 0.32 | 0.52 | 0.55 | 0.36 |
| | Sep | -1.51 | 0.19 | 0.36 | 0.53 | 0.38 | | Sep | -1.64 | 0.14 | 0.30 | 0.57 | 0.41 |
| | All | -0.56 | 0.20 | 0.39 | 0.67 | 0.55 | | All | -0.63 | 0.17 | 0.43 | 0.68 | 0.57 |
| MAX | Apr | 0.45 | 0.77 | 1.76 | 1.00 | 1.00 | MAX | Apr | 0.47 | 0.76 | 1.85 | 1.00 | 1.00 |
| | May | 0.41 | 1.32 | 5.49 | 1.00 | 1.00 | | May | 0.42 | 1.26 | 5.36 | 1.00 | 1.00 |
| | Jun | 1.33 | 2.61 | 7.44 | 0.97 | 0.97 | | Jun | 1.20 | 2.73 | 7.69 | 0.97 | 0.96 |
| | Jul | 0.75 | 1.56 | 5.01 | 1.00 | 1.00 | | Jul | 0.80 | 1.57 | 4.67 | 1.00 | 1.00 |
| | Aug | 0.87 | 3.04 | 12.03 | 0.97 | 0.95 | | Aug | 0.85 | 3.07 | 12.25 | 0.94 | 0.92 |
| | Sep | 1.60 | 2.12 | 4.94 | 1.00 | 1.00 | | Sep | 1.45 | 1.92 | 4.32 | 1.00 | 1.00 |
| | All | 0.51 | 1.31 | 5.34 | 0.93 | 0.90 | | All | 0.46 | 1.37 | 5.41 | 0.91 | 0.89 |
| MEAN | Apr | 0.06 | 0.38 | 0.77 | 0.79 | 0.72 | MEAN | Apr | 0.06 | 0.38 | 0.77 | 0.79 | 0.72 |
| | May | 0.01 | 0.37 | 0.87 | 0.83 | 0.77 | | May | 0.02 | 0.37 | 0.87 | 0.83 | 0.78 |
| | Jun | 0.04 | 1.04 | 1.84 | 0.75 | 0.69 | | Jun | -0.03 | 1.04 | 1.86 | 0.75 | 0.70 |
| | Jul | 0.05 | 0.67 | 1.52 | 0.81 | 0.74 | | Jul | 0.04 | 0.64 | 1.46 | 0.82 | 0.75 |
| | Aug | -0.02 | 1.02 | 2.13 | 0.72 | 0.64 | | Aug | -0.04 | 1.00 | 2.11 | 0.72 | 0.65 |
| | Sep | 0.09 | 0.93 | 1.89 | 0.78 | 0.72 | | Sep | 0.03 | 0.90 | 1.82 | 0.79 | 0.73 |
| | All | 0.04 | 0.73 | 1.68 | 0.78 | 0.72 | | All | 0.01 | 0.72 | 1.66 | 0.78 | 0.72 |

87 and 126 observations in the interpolation 1999

| | No calibration | | | | | | | No calibration, anaprob days = 0 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1998 | | ME | MAE | RMSE | HR | HKSI | 1998 | | ME | MAE | RMSE | HR | HKSI |
| MIN | Apr | -1.94 | 0.63 | 0.97 | 0.23 | -0.05 | MIN | Apr | -1.94 | 0.63 | 0.97 | 0.23 | -0.05 |
| | May | -0.92 | 0.19 | 0.38 | 0.19 | -0.14 | | May | -0.92 | 0.19 | 0.38 | 0.26 | -0.08 |
| | Jun | -3.08 | 0.32 | 0.58 | 0.33 | 0.08 | | Jun | -3.08 | 0.32 | 0.58 | 0.33 | 0.08 |
| | Jul | -2.05 | 0.49 | 0.78 | 0.30 | 0.09 | | Jul | -2.05 | 0.49 | 0.78 | 0.30 | 0.09 |
| | Aug | -1.87 | 0.47 | 0.81 | 0.27 | 0.02 | | Aug | -1.87 | 0.47 | 0.81 | 0.27 | 0.02 |
| | Sep | -1.92 | 0.36 | 0.60 | 0.29 | 0.00 | | Sep | -1.92 | 0.36 | 0.60 | 0.29 | 0.00 |
| | All | -1.33 | 0.88 | 1.62 | 0.45 | 0.15 | | All | -1.33 | 0.88 | 1.62 | 0.45 | 0.16 |
| MAX | Apr | 2.56 | 3.78 | 8.57 | 0.73 | 0.64 | MAX | Apr | 2.56 | 3.78 | 8.57 | 0.73 | 0.64 |
| | May | 7.53 | 8.26 | 22.31 | 0.94 | 0.82 | | May | 7.31 | 8.04 | 22.28 | 0.94 | 0.82 |
| | Jun | 2.72 | 4.09 | 14.25 | 0.85 | 0.80 | | Jun | 2.72 | 4.09 | 14.25 | 0.85 | 0.80 |
| | Jul | 1.26 | 3.43 | 6.24 | 0.83 | 0.77 | | Jul | 1.26 | 3.43 | 6.24 | 0.83 | 0.77 |
| | Aug | 2.10 | 3.37 | 9.71 | 0.81 | 0.69 | | Aug | 2.10 | 3.37 | 9.71 | 0.81 | 0.69 |
| | Sep | 0.47 | 2.64 | 5.93 | 0.88 | 0.76 | | Sep | 0.47 | 2.64 | 5.93 | 0.88 | 0.76 |
| | All | 1.55 | 3.06 | 10.37 | 0.71 | 0.55 | | All | 1.42 | 2.93 | 10.36 | 0.71 | 0.56 |
| MEAN | Apr | -0.14 | 1.66 | 3.08 | 0.51 | 0.34 | MEAN | Apr | -0.14 | 1.66 | 3.08 | 0.51 | 0.34 |
| | May | 0.50 | 1.23 | 3.00 | 0.62 | 0.35 | | May | 0.34 | 1.07 | 2.59 | 0.65 | 0.37 |
| | Jun | -0.05 | 1.36 | 2.98 | 0.65 | 0.50 | | Jun | -0.05 | 1.36 | 2.98 | 0.65 | 0.50 |
| | Jul | -0.57 | 1.48 | 2.73 | 0.58 | 0.44 | | Jul | -0.57 | 1.48 | 2.73 | 0.58 | 0.44 |
| | Aug | -0.55 | 1.35 | 2.69 | 0.56 | 0.35 | | Aug | -0.55 | 1.35 | 2.69 | 0.56 | 0.35 |
| | Sep | -0.72 | 1.05 | 2.09 | 0.64 | 0.43 | | Sep | -0.72 | 1.05 | 2.09 | 0.64 | 0.43 |
| | All | -0.23 | 1.36 | 3.07 | 0.59 | 0.40 | | All | -0.26 | 1.34 | 2.97 | 0.60 | 0.40 |

Radar derived precipitation 1998, original phase I, original phase I with anaprop correction

| | Calibrated, anaprob days = 0 | | | | | | | Calibrated with factor | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1998 | | ME | MAE | RMSE | HR | HKSI | 1998 | | ME | MAE | RMSE | HR | HKSI |
| MIN | Apr | -2.18 | 0.51 | 0.75 | 0.26 | -0.07 | MIN | Apr | -2.28 | 0.53 | 0.77 | 0.23 | -0.13 |
| | May | -0.88 | 0.22 | 0.39 | 0.31 | 0.13 | | May | -1.25 | 0.24 | 0.41 | 0.29 | 0.09 |
| | Jun | -3.04 | 0.31 | 0.49 | 0.37 | 0.22 | | Jun | -3.28 | 0.33 | 0.50 | 0.40 | 0.24 |
| | Jul | -1.88 | 0.47 | 0.66 | 0.40 | 0.16 | | Jul | -1.95 | 0.49 | 0.67 | 0.41 | 0.17 |
| | Aug | -1.10 | 0.24 | 0.55 | 0.38 | 0.18 | | Aug | -1.20 | 0.26 | 0.54 | 0.42 | 0.20 |
| | Sep | -1.73 | 0.29 | 0.57 | 0.42 | 0.17 | | Sep | -1.89 | 0.31 | 0.59 | 0.41 | 0.18 |
| | All | -1.27 | 0.69 | 1.25 | 0.42 | 0.26 | | All | -1.41 | 0.72 | 1.30 | 0.44 | 0.27 |
| MAX | Apr | 2.03 | 2.47 | 6.24 | 0.87 | 0.84 | MAX | Apr | 2.13 | 2.59 | 6.38 | 0.86 | 0.83 |
| | May | 12.12 | 12.19 | 31.82 | 0.97 | 0.95 | | May | 7.18 | 7.27 | 22.76 | 1.00 | 1.00 |
| | Jun | 2.63 | 3.38 | 13.06 | 0.93 | 0.91 | | Jun | 2.84 | 3.65 | 13.57 | 0.92 | 0.93 |
| | Jul | 1.74 | 2.59 | 5.67 | 0.93 | 0.90 | | Jul | 1.80 | 2.66 | 5.77 | 0.93 | 0.90 |
| | Aug | 2.61 | 3.51 | 10.25 | 0.92 | 0.91 | | Aug | 1.82 | 2.21 | 3.78 | 1.00 | 1.00 |
| | Sep | 1.32 | 2.69 | 7.64 | 0.92 | 0.91 | | Sep | 1.44 | 2.93 | 7.98 | 0.95 | 0.95 |
| | All | 2.73 | 3.48 | 14.16 | 0.79 | 0.70 | | All | 1.33 | 2.15 | 9.04 | 0.80 | 0.72 |
| MEAN | Apr | -0.20 | 1.27 | 2.35 | 0.62 | 0.48 | MEAN | Apr | -0.23 | 1.30 | 2.38 | 0.62 | 0.48 |
| | May | 0.53 | 1.07 | 2.65 | 0.65 | 0.54 | | May | 0.19 | 0.93 | 2.16 | 0.66 | 0.54 |
| | Jun | -0.07 | 1.15 | 2.47 | 0.69 | 0.58 | | Jun | -0.14 | 1.18 | 2.42 | 0.69 | 0.58 |
| | Jul | 0.00 | 1.23 | 2.40 | 0.68 | 0.56 | | Jul | 0.00 | 1.27 | 2.44 | 0.67 | 0.56 |
| | Aug | 0.02 | 0.97 | 2.00 | 0.66 | 0.53 | | Aug | -0.12 | 0.90 | 1.77 | 0.70 | 0.58 |
| | Sep | -0.06 | 0.89 | 1.89 | 0.74 | 0.63 | | Sep | -0.07 | 0.97 | 1.97 | 0.73 | 0.62 |
| | All | 0.05 | 1.10 | 2.60 | 0.67 | 0.55 | | All | -0.06 | 1.10 | 2.44 | 0.68 | 0.56 |

Radar derived precipitation 1998, adjusted radar and anaprop correction, factor calibration

| | | No calibration | | | | | | | No calibration, anaprob days = 0 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1999 | | ME | MAE | RMSE | HR | HKSI | 1999 | | ME | MAE | RMSE | HR | HKSI |
| MIN | Apr | -2.16 | 0.20 | 0.36 | 0.29 | -0.06 | MIN | Apr | -2.16 | 0.20 | 0.36 | 0.38 | 0.00 |
| | May | -1.51 | 0.26 | 0.48 | 0.28 | -0.01 | | May | -1.59 | 0.25 | 0.40 | 0.44 | 0.08 |
| | Jun | -3.60 | 0.64 | 1.03 | 0.38 | 0.14 | | Jun | -3.60 | 0.64 | 1.03 | 0.38 | 0.14 |
| | Jul | -3.29 | 0.46 | 0.91 | 0.19 | -0.01 | | Jul | -3.32 | 0.44 | 0.91 | 0.42 | 0.07 |
| | Aug | -5.25 | 0.52 | 0.84 | 0.19 | -0.08 | | Aug | -5.25 | 0.51 | 0.84 | 0.24 | -0.03 |
| | Sep | -3.61 | 0.54 | 1.04 | 0.29 | 0.12 | | Sep | -3.62 | 0.54 | 1.04 | 0.43 | 0.16 |
| | All | -2.77 | 0.61 | 1.24 | 0.37 | 0.09 | | All | -2.78 | 0.60 | 1.24 | 0.48 | 0.17 |
| MAX | Apr | 5.15 | 5.32 | 18.05 | 0.86 | 0.73 | MAX | Apr | 3.98 | 4.15 | 14.04 | 0.86 | 0.77 |
| | May | 2.70 | 4.72 | 10.30 | 0.96 | 0.91 | | May | 1.10 | 3.59 | 9.82 | 0.96 | 0.91 |
| | Jun | 1.75 | 4.11 | 9.60 | 0.92 | 0.88 | | Jun | 1.58 | 4.11 | 9.60 | 0.92 | 0.88 |
| | Jul | 7.73 | 8.88 | 22.54 | 0.77 | 0.65 | | Jul | 2.52 | 4.32 | 10.52 | 0.85 | 0.74 |
| | Aug | 7.07 | 8.41 | 20.69 | 0.82 | 0.74 | | Aug | 5.75 | 6.75 | 20.62 | 0.86 | 0.79 |
| | Sep | 5.77 | 7.31 | 13.45 | 0.86 | 0.83 | | Sep | 5.29 | 6.79 | 13.36 | 0.90 | 0.89 |
| | All | 3.68 | 5.13 | 12.87 | 0.78 | 0.64 | | All | 2.17 | 3.46 | 10.27 | 0.81 | 0.67 |
| MEAN | Apr | -0.03 | 1.22 | 2.71 | 0.58 | 0.34 | MEAN | Apr | -0.23 | 1.02 | 2.15 | 0.61 | 0.37 |
| | May | -0.11 | 1.13 | 2.53 | 0.64 | 0.42 | | May | -0.22 | 1.02 | 2.34 | 0.68 | 0.46 |
| | Jun | -0.28 | 1.55 | 2.90 | 0.65 | 0.53 | | Jun | -0.30 | 1.53 | 2.89 | 0.67 | 0.54 |
| | Jul | 0.43 | 2.25 | 4.87 | 0.54 | 0.35 | | Jul | -0.41 | 1.41 | 3.29 | 0.67 | 0.48 |
| | Aug | 0.09 | 2.26 | 4.36 | 0.53 | 0.37 | | Aug | -0.12 | 2.05 | 4.09 | 0.56 | 0.41 |
| | Sep | -0.23 | 2.16 | 3.95 | 0.61 | 0.47 | | Sep | -0.34 | 2.06 | 3.85 | 0.65 | 0.52 |
| | All | -0.01 | 1.76 | 3.95 | 0.59 | 0.41 | | All | -0.27 | 1.50 | 3.40 | 0.64 | 0.46 |

Radar derived precipitation 1999, original phase I, original phase I with anaprop correction

| | | Calibrated, anaprob days = 0 | | | | | | | Calibrated with factor | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1999 | | ME | MAE | RMSE | HR | HKSI | 1999 | | ME | MAE | RMSE | HR | HKSI |
| MIN | Apr | -1.30 | 0.20 | 0.38 | 0.33 | 0.06 | MIN | Apr | -1.52 | 0.23 | 0.41 | 0.28 | 0.04 |
| | May | -1.08 | 0.20 | 0.44 | 0.52 | 0.24 | | May | -1.29 | 0.25 | 0.50 | 0.35 | 0.04 |
| | Jun | -2.51 | 0.37 | 0.61 | 0.50 | 0.24 | | Jun | -2.87 | 0.42 | 0.65 | 0.33 | 0.19 |
| | Jul | -3.12 | 0.32 | 0.56 | 0.46 | 0.21 | | Jul | -4.28 | 0.43 | 0.66 | 0.32 | 0.14 |
| | Aug | -4.84 | 0.45 | 0.74 | 0.36 | 0.15 | | Aug | -5.94 | 0.47 | 0.77 | 0.33 | 0.15 |
| | Sep | -3.29 | 0.47 | 0.83 | 0.38 | 0.24 | | Sep | -3.83 | 0.53 | 0.86 | 0.22 | 0.12 |
| | All | -2.43 | 0.45 | 0.95 | 0.51 | 0.32 | | All | -2.97 | 0.53 | 1.05 | 0.40 | 0.27 |
| MAX | Apr | 6.45 | 6.87 | 15.43 | 0.95 | 0.92 | MAX | Apr | 3.66 | 4.15 | 9.13 | 0.94 | 0.93 |
| | May | 1.63 | 2.68 | 7.40 | 1.00 | 1.00 | | May | 2.04 | 3.34 | 8.28 | 1.00 | 1.00 |
| | Jun | 1.75 | 2.68 | 6.83 | 1.00 | 1.00 | | Jun | 2.00 | 3.06 | 7.30 | 1.00 | 1.00 |
| | Jul | 2.90 | 3.69 | 13.16 | 0.96 | 0.95 | | Jul | 3.97 | 5.05 | 15.40 | 0.95 | 0.94 |
| | Aug | 7.18 | 7.89 | 24.73 | 0.86 | 0.83 | | Aug | 4.70 | 6.51 | 16.78 | 1.00 | 1.00 |
| | Sep | 10.55 | 10.94 | 38.93 | 0.95 | 0.96 | | Sep | 5.16 | 5.38 | 10.08 | 1.00 | 1.00 |
| | All | 2.93 | 3.74 | 16.30 | 0.84 | 0.78 | | All | 1.98 | 3.27 | 7.30 | 0.82 | 0.76 |
| MEAN | Apr | 0.10 | 0.95 | 2.00 | 0.65 | 0.51 | MEAN | Apr | -0.04 | 0.95 | 1.89 | 0.65 | 0.52 |
| | May | 0.13 | 0.81 | 1.81 | 0.76 | 0.67 | | May | 0.15 | 1.01 | 2.01 | 0.69 | 0.58 |
| | Jun | -0.04 | 1.07 | 2.07 | 0.76 | 0.68 | | Jun | -0.04 | 1.22 | 2.21 | 0.72 | 0.64 |
| | Jul | -0.03 | 0.96 | 2.16 | 0.74 | 0.64 | | Jul | -0.12 | 1.22 | 2.32 | 0.68 | 0.57 |
| | Aug | 0.64 | 2.07 | 4.32 | 0.60 | 0.49 | | Aug | -0.07 | 1.67 | 3.07 | 0.65 | 0.55 |
| | Sep | 0.65 | 1.83 | 3.52 | 0.70 | 0.63 | | Sep | 0.56 | 1.95 | 3.41 | 0.69 | 0.61 |
| | All | 0.22 | 1.26 | 3.01 | 0.71 | 0.60 | | All | 0.07 | 1.33 | 2.74 | 0.68 | 0.58 |

Radar derived precipitation 1998, adjusted radar and anaprop correction, factor calibration

# Appendix C Contingency tables for 25 observations in the interpolation 1998

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 1916 | 342 | 4 | 0 | 0 | |
| 0.05 | 2 | 1165 | 2857 | 343 | 4 | 1 | |
| 2 | 6 | 14 | 513 | 2306 | 258 | 16 | |
| 6 | 10 | 0 | 35 | 238 | 458 | 79 | |
| 10 | 100 | 0 | 0 | 31 | 80 | 428 | |

mm nedbør

**Kontingenstabel for 1/4-98 - 30/4-98**

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 5550 | 303 | 17 | 7 | 5 | |
| 0.05 | 2 | 1732 | 1707 | 293 | 21 | 0 | |
| 2 | 6 | 18 | 241 | 813 | 123 | 34 | |
| 6 | 10 | 10 | 17 | 122 | 268 | 71 | |
| 10 | 100 | 0 | 0 | 10 | 24 | 70 | |

mm nedbør

**Kontingenstabel for 1/5-98 - 31/5-98**

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 3649 | 210 | 3 | 0 | 0 | |
| 0.05 | 2 | 1223 | 2412 | 370 | 16 | 1 | |
| 2 | 6 | 25 | 389 | 1001 | 226 | 41 | |
| 6 | 10 | 0 | 23 | 263 | 375 | 151 | |
| 10 | 100 | 0 | 1 | 23 | 116 | 582 | |

mm nedbør

**Kontingenstabel for 1/6-98 - 30/6-98**

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 1625 | 298 | 7 | 0 | 0 | |
| 0.05 | 2 | 1261 | 2856 | 504 | 20 | 2 | |
| 2 | 6 | 29 | 522 | 1575 | 230 | 51 | |
| 6 | 10 | 1 | 41 | 402 | 606 | 191 | |
| 10 | 100 | 0 | 21 | 86 | 255 | 887 | |

mm nedbør

**Kontingenstabel for 1/7-98 - 31/7-98**

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 2529 | 274 | 4 | 0 | 0 | |
| 0.05 | 2 | 1795 | 3258 | 574 | 29 | 9 | |
| 2 | 6 | 21 | 359 | 1118 | 126 | 9 | |
| 6 | 10 | 2 | 12 | 180 | 286 | 108 | |
| 10 | 100 | 0 | 1 | 20 | 137 | 615 | |

mm nedbør

**Kontingenstabel for 1/8-98 - 31/8-98**

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 3062 | 337 | 18 | 5 | 0 | |
| 0.05 | 2 | 1815 | 2163 | 468 | 32 | 3 | |
| 2 | 6 | 9 | 379 | 1187 | 180 | 57 | |
| 6 | 10 | 1 | 22 | 215 | 310 | 177 | |
| 10 | 100 | 0 | 0 | 11 | 150 | 485 | |

mm nedbør

**Kontingenstabel for 1/9-98 - 30/9-98**

# Appendix D Contingency tables for 62 observations in the interpolation 1998

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 2307 | 358 | 5 | 1 | 0 | |
| 0.05 | 2 | 790 | 3030 | 339 | 3 | 0 | |
| 2 | 6 | 1 | 345 | 2335 | 200 | 8 | |
| 6 | 10 | 0 | 13 | 228 | 539 | 73 | |
| 10 | 100 | 0 | 0 | 15 | 58 | 443 | |

mm nedbør

**Kontingenstabel for 1/4-98 - 30/4-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 6262 | 260 | 2 | 0 | 0 | |
| 0.05 | 2 | 1050 | 1780 | 199 | 13 | 5 | |
| 2 | 6 | 2 | 226 | 944 | 108 | 15 | |
| 6 | 10 | 0 | 4 | 105 | 283 | 54 | |
| 10 | 100 | 0 | 0 | 5 | 39 | 106 | |

mm nedbør

**Kontingenstabel for 1/5-98 - 31/5-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4082 | 243 | 8 | 0 | 0 | |
| 0.05 | 2 | 811 | 2479 | 302 | 15 | 1 | |
| 2 | 6 | 4 | 305 | 1162 | 192 | 15 | |
| 6 | 10 | 0 | 7 | 176 | 424 | 146 | |
| 10 | 100 | 0 | 1 | 12 | 102 | 613 | |

mm nedbør

**Kontingenstabel for 1/6-98 - 30/6-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 2002 | 252 | 2 | 0 | 0 | |
| 0.05 | 2 | 905 | 3040 | 337 | 7 | 2 | |
| 2 | 6 | 9 | 420 | 1874 | 240 | 39 | |
| 6 | 10 | 0 | 22 | 315 | 650 | 150 | |
| 10 | 100 | 0 | 4 | 45 | 214 | 940 | |

mm nedbør

**Kontingenstabel for 1/7-98 - 31/7-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 3052 | 302 | 5 | 0 | 0 | |
| 0.05 | 2 | 1289 | 3207 | 330 | 11 | 0 | |
| 2 | 6 | 6 | 392 | 1379 | 125 | 12 | |
| 6 | 10 | 0 | 3 | 170 | 345 | 102 | |
| 10 | 100 | 0 | 0 | 14 | 97 | 627 | |

mm nedbør

**Kontingenstabel for 1/8-98 - 31/8-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 3778 | 296 | 1 | 0 | 0 | |
| 0.05 | 2 | 1105 | 2227 | 335 | 12 | 1 | |
| 2 | 6 | 8 | 362 | 1390 | 161 | 18 | |
| 6 | 10 | 0 | 16 | 163 | 364 | 129 | |
| 10 | 100 | 0 | 0 | 8 | 140 | 574 | |

mm nedbør

**Kontingenstabel for 1/9-98 - 30/9-98**

# Appendix E Contingency tables for 87 observations in the interpolation 1998

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 2413 | 344 | 3 | 0 | 0 | |
| 0.05 | 2 | 685 | 3064 | 283 | 2 | 0 | |
| 2 | 6 | 1 | 337 | 2409 | 174 | 7 | |
| 6 | 10 | 0 | 4 | 219 | 583 | 71 | |
| 10 | 100 | 0 | 0 | 8 | 42 | 446 | |

mm nedbør

**Kontingenstabel for 1/4-98 - 30/4-98**

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 6408 | 259 | 3 | 0 | 0 | |
| 0.05 | 2 | 907 | 1818 | 200 | 10 | 5 | |
| 2 | 6 | 1 | 188 | 957 | 109 | 18 | |
| 6 | 10 | 0 | 4 | 90 | 289 | 38 | |
| 10 | 100 | 0 | 0 | 5 | 35 | 119 | |

mm nedbør

**Kontingenstabel for 1/5-98 - 31/5-98**

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 4223 | 235 | 5 | 0 | 0 | |
| 0.05 | 2 | 672 | 2553 | 291 | 16 | 1 | |
| 2 | 6 | 2 | 244 | 1218 | 197 | 11 | |
| 6 | 10 | 0 | 3 | 134 | 414 | 119 | |
| 10 | 100 | 0 | 0 | 11 | 106 | 644 | |

mm nedbør

**Kontingenstabel for 1/6-98 - 30/6-98**

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 2162 | 266 | 3 | 0 | 0 | |
| 0.05 | 2 | 748 | 3096 | 338 | 4 | 2 | |
| 2 | 6 | 6 | 358 | 1920 | 206 | 33 | |
| 6 | 10 | 0 | 17 | 279 | 693 | 138 | |
| 10 | 100 | 0 | 1 | 33 | 208 | 958 | |

mm nedbør

**Kontingenstabel for 1/7-98 - 31/7-98**

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 3289 | 343 | 3 | 0 | 0 | |
| 0.05 | 2 | 1052 | 3226 | 319 | 6 | 0 | |
| 2 | 6 | 6 | 333 | 1423 | 138 | 11 | |
| 6 | 10 | 0 | 3 | 141 | 343 | 109 | |
| 10 | 100 | 0 | 0 | 12 | 91 | 621 | |

mm nedbør

**Kontingenstabel for 1/8-98 - 31/8-98**

| | KLIMA | 0 | 0.05 | 2 | 6 | 10 | mm |
|---|---|---|---|---|---|---|---|
| AMIS | | 0.05 | 2 | 6 | 10 | 100 | nedbør |
| 0 | 0.05 | 3942 | 314 | 0 | 0 | 0 | |
| 0.05 | 2 | 942 | 2274 | 294 | 7 | 0 | |
| 2 | 6 | 7 | 300 | 1448 | 140 | 16 | |
| 6 | 10 | 0 | 13 | 147 | 407 | 111 | |
| 10 | 100 | 0 | 0 | 11 | 123 | 595 | |

mm nedbør

**Kontingenstabel for 1/9-98 - 30/9-98**

# Appendix F Contingency tables for 126 observations in the interpolation 1998

| AMIS | | KLIMA 0 0.05 | 0.05 2 | 2 6 | 6 10 | 10 100 | mm nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 2390 | 337 | 3 | 0 | 0 | |
| 0.05 | 2 | 708 | 3114 | 295 | 3 | 0 | |
| 2 | 6 | 1 | 294 | 2414 | 167 | 9 | |
| 6 | 10 | 0 | 2 | 205 | 578 | 59 | |
| 10 | 100 | 0 | 0 | 5 | 52 | 456 | |

mm nedbør

**Kontingenstabel for 1/4-98 - 30/4-98**

| AMIS | | KLIMA 0 0.05 | 0.05 2 | 2 6 | 6 10 | 10 100 | mm nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 6525 | 254 | 3 | 0 | 0 | |
| 0.05 | 2 | 790 | 1818 | 171 | 6 | 5 | |
| 2 | 6 | 0 | 196 | 988 | 108 | 21 | |
| 6 | 10 | 0 | 3 | 90 | 298 | 33 | |
| 10 | 100 | 0 | 0 | 3 | 31 | 121 | |

mm nedbør

**Kontingenstabel for 1/5-98 - 31/5-98**

| AMIS | | KLIMA 0 0.05 | 0.05 2 | 2 6 | 6 10 | 10 100 | mm nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4267 | 229 | 2 | 0 | 0 | |
| 0.05 | 2 | 630 | 2588 | 310 | 12 | 0 | |
| 2 | 6 | 0 | 216 | 1214 | 199 | 16 | |
| 6 | 10 | 0 | 2 | 123 | 420 | 106 | |
| 10 | 100 | 0 | 0 | 10 | 102 | 653 | |

mm nedbør

**Kontingenstabel for 1/6-98 - 30/6-98**

| AMIS | | KLIMA 0 0.05 | 0.05 2 | 2 6 | 6 10 | 10 100 | mm nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 2230 | 278 | 2 | 0 | 0 | |
| 0.05 | 2 | 682 | 3108 | 326 | 4 | 1 | |
| 2 | 6 | 4 | 333 | 1939 | 209 | 18 | |
| 6 | 10 | 0 | 18 | 277 | 702 | 143 | |
| 10 | 100 | 0 | 1 | 30 | 196 | 969 | |

mm nedbør

**Kontingenstabel for 1/7-98 - 31/7-98**

| AMIS | | KLIMA 0 0.05 | 0.05 2 | 2 6 | 6 10 | 10 100 | mm nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 3392 | 296 | 1 | 0 | 0 | |
| 0.05 | 2 | 947 | 3290 | 316 | 8 | 0 | |
| 2 | 6 | 8 | 314 | 1441 | 134 | 5 | |
| 6 | 10 | 0 | 4 | 126 | 351 | 102 | |
| 10 | 100 | 0 | 1 | 14 | 85 | 634 | |

mm nedbør

**Kontingenstabel for 1/8-98 - 31/8-98**

| AMIS | | KLIMA 0 0.05 | 0.05 2 | 2 6 | 6 10 | 10 100 | mm nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 3996 | 292 | 0 | 0 | 0 | |
| 0.05 | 2 | 895 | 2311 | 280 | 4 | 1 | |
| 2 | 6 | 2 | 295 | 1476 | 139 | 11 | |
| 6 | 10 | 0 | 4 | 134 | 417 | 122 | |
| 10 | 100 | 0 | 0 | 6 | 117 | 588 | |

mm nedbør

**Kontingenstabel for 1/9-98 - 30/9-98**

# Appendix G Contingency tables for 25 observations in the interpolation 1999

| AMIS | | KLIMA 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 3851 | 189 | 1 | 0 | 0 | |
| 0.05 | 2 | 1836 | 2482 | 135 | 3 | 0 | |
| 2 | 6 | 6 | 307 | 1130 | 213 | 14 | |
| 6 | 10 | 0 | 11 | 158 | 373 | 136 | |
| 10 | 100 | 0 | 2 | 7 | 67 | 177 | |

mm nedbør

**Kontingenstabel for 1/4-98 - 30/4-98**

| AMIS | | KLIMA 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 5154 | 88 | 4 | 3 | 0 | |
| 0.05 | 2 | 1628 | 1981 | 181 | 7 | 0 | |
| 2 | 6 | 4 | 361 | 1072 | 147 | 22 | |
| 6 | 10 | 0 | 1 | 92 | 249 | 91 | |
| 10 | 100 | 0 | 0 | 2 | 66 | 308 | |

mm nedbør

**Kontingenstabel for 1/5-98 - 31/5-98**

| AMIS | | KLIMA 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 2865 | 177 | 8 | 3 | 0 | |
| 0.05 | 2 | 1076 | 1380 | 274 | 18 | 9 | |
| 2 | 6 | 7 | 334 | 1205 | 348 | 63 | |
| 6 | 10 | 0 | 18 | 454 | 820 | 246 | |
| 10 | 100 | 0 | 1 | 27 | 324 | 1441 | |

mm nedbør

**Kontingenstabel for 1/6-98 - 30/6-98**

| AMIS | | KLIMA 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4962 | 232 | 1 | 0 | 0 | |
| 0.05 | 2 | 1043 | 1954 | 419 | 22 | 12 | |
| 2 | 6 | 2 | 332 | 1014 | 191 | 39 | |
| 6 | 10 | 0 | 39 | 274 | 221 | 135 | |
| 10 | 100 | 0 | 9 | 69 | 141 | 357 | |

mm nedbør

**Kontingenstabel for 1/7-98 - 31/7-98**

| AMIS | | KLIMA 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4404 | 265 | 12 | 3 | 3 | |
| 0.05 | 2 | 1238 | 1322 | 427 | 39 | 18 | |
| 2 | 6 | 49 | 414 | 934 | 311 | 127 | |
| 6 | 10 | 1 | 42 | 194 | 425 | 271 | |
| 10 | 100 | 0 | 44 | 131 | 197 | 554 | |

mm nedbør

**Kontingenstabel for 1/8-98 - 31/8-98**

| AMIS | | KLIMA 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4015 | 160 | 3 | 0 | 0 | |
| 0.05 | 2 | 1445 | 1402 | 222 | 11 | 8 | |
| 2 | 6 | 7 | 298 | 789 | 199 | 32 | |
| 6 | 10 | 0 | 15 | 318 | 401 | 196 | |
| 10 | 100 | 0 | 2 | 125 | 378 | 1064 | |

mm nedbør

**Kontingenstabel for 1/9-98 - 30/9-98**

# Appendix H Contingency tables for 62 observations in the interpolation 1999

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4617 | 220 | 1 | 0 | 0 | |
| 0.05 | 2 | 1075 | 2581 | 150 | 3 | 0 | |
| 2 | 6 | 2 | 182 | 1120 | 147 | 6 | |
| 6 | 10 | 0 | 6 | 154 | 418 | 73 | |
| 10 | 100 | 0 | 2 | 6 | 88 | 248 | |

mm nedbør

**Kontingenstabel for 1/4-98 - 30/4-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 5926 | 113 | 4 | 2 | 0 | |
| 0.05 | 2 | 867 | 2088 | 171 | 1 | 0 | |
| 2 | 6 | 2 | 229 | 1078 | 116 | 2 | |
| 6 | 10 | 0 | 1 | 93 | 270 | 51 | |
| 10 | 100 | 0 | 0 | 4 | 82 | 368 | |

mm nedbør

**Kontingenstabel for 1/5-98 - 31/5-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 3310 | 163 | 7 | 3 | 0 | |
| 0.05 | 2 | 632 | 1432 | 220 | 13 | 6 | |
| 2 | 6 | 8 | 307 | 1391 | 271 | 43 | |
| 6 | 10 | 0 | 7 | 334 | 974 | 237 | |
| 10 | 100 | 0 | 1 | 15 | 252 | 1473 | |

mm nedbør

**Kontingenstabel for 1/6-98 - 30/6-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 5418 | 199 | 3 | 2 | 1 | |
| 0.05 | 2 | 587 | 2033 | 303 | 14 | 9 | |
| 2 | 6 | 3 | 321 | 1203 | 160 | 23 | |
| 6 | 10 | 0 | 8 | 226 | 263 | 102 | |
| 10 | 100 | 0 | 5 | 42 | 136 | 408 | |

mm nedbør

**Kontingenstabel for 1/7-98 - 31/7-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4946 | 265 | 16 | 2 | 3 | |
| 0.05 | 2 | 737 | 1455 | 363 | 40 | 10 | |
| 2 | 6 | 17 | 341 | 1013 | 225 | 58 | |
| 6 | 10 | 0 | 27 | 221 | 496 | 198 | |
| 10 | 100 | 0 | 13 | 85 | 212 | 704 | |

mm nedbør

**Kontingenstabel for 1/8-98 - 31/8-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4750 | 155 | 4 | 0 | 0 | |
| 0.05 | 2 | 725 | 1537 | 174 | 8 | 5 | |
| 2 | 6 | 1 | 177 | 921 | 200 | 33 | |
| 6 | 10 | 0 | 7 | 301 | 512 | 141 | |
| 10 | 100 | 0 | 1 | 57 | 269 | 1121 | |

mm nedbør

**Kontingenstabel for 1/9-98 - 30/9-98**

# Appendix I Contingency tables for 87 observations in the interpolation 1999

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4806 | 242 | 1 | 0 | 0 | |
| 0.05 | 2 | 886 | 2572 | 148 | 4 | 0 | |
| 2 | 6 | 1 | 165 | 1124 | 132 | 6 | |
| 6 | 10 | 0 | 6 | 152 | 431 | 69 | |
| 10 | 100 | 0 | 2 | 6 | 89 | 252 | |

mm nedbør

**Kontingenstabel for 1/4-98 - 30/4-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 6080 | 130 | 1 | 0 | 0 | |
| 0.05 | 2 | 712 | 2118 | 179 | 3 | 0 | |
| 2 | 6 | 1 | 183 | 1072 | 100 | 3 | |
| 6 | 10 | 0 | 0 | 91 | 294 | 56 | |
| 10 | 100 | 0 | 0 | 5 | 72 | 362 | |

mm nedbør

**Kontingenstabel for 1/5-98 - 31/5-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 3421 | 182 | 2 | 1 | 0 | |
| 0.05 | 2 | 526 | 1450 | 174 | 8 | 3 | |
| 2 | 6 | 2 | 271 | 1478 | 251 | 34 | |
| 6 | 10 | 0 | 7 | 298 | 999 | 223 | |
| 10 | 100 | 0 | 0 | 14 | 254 | 1499 | |

mm nedbør

**Kontingenstabel for 1/6-98 - 30/6-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 5522 | 198 | 0 | 0 | 0 | |
| 0.05 | 2 | 481 | 2057 | 283 | 13 | 9 | |
| 2 | 6 | 4 | 300 | 1265 | 159 | 24 | |
| 6 | 10 | 0 | 7 | 203 | 294 | 95 | |
| 10 | 100 | 0 | 4 | 26 | 109 | 415 | |

mm nedbør

**Kontingenstabel for 1/7-98 - 31/7-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 5034 | 286 | 18 | 1 | 0 | |
| 0.05 | 2 | 652 | 1500 | 338 | 37 | 12 | |
| 2 | 6 | 12 | 282 | 1064 | 212 | 56 | |
| 6 | 10 | 1 | 25 | 218 | 532 | 198 | |
| 10 | 100 | 0 | 8 | 60 | 193 | 707 | |

mm nedbør

**Kontingenstabel for 1/8-98 - 31/8-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4931 | 169 | 4 | 0 | 0 | |
| 0.05 | 2 | 544 | 1532 | 173 | 8 | 4 | |
| 2 | 6 | 1 | 169 | 990 | 199 | 26 | |
| 6 | 10 | 0 | 5 | 257 | 560 | 153 | |
| 10 | 100 | 0 | 2 | 33 | 222 | 1117 | |

mm nedbør

**Kontingenstabel for 1/9-98 - 30/9-98**

# Appendix J Contingency tables for 126 observations in the interpolation 1999

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4861 | 236 | 1 | 0 | 0 | |
| 0.05 | 2 | 826 | 2580 | 146 | 4 | 0 | |
| 2 | 6 | 7 | 167 | 1137 | 120 | 2 | |
| 6 | 10 | 0 | 7 | 140 | 454 | 72 | |
| 10 | 100 | 0 | 0 | 7 | 78 | 253 | |

mm nedbør

**Kontingenstabel for 1/4-98 - 30/4-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 6160 | 128 | 0 | 0 | 0 | |
| 0.05 | 2 | 632 | 2112 | 208 | 3 | 0 | |
| 2 | 6 | 3 | 189 | 1046 | 96 | 4 | |
| 6 | 10 | 0 | 2 | 94 | 297 | 54 | |
| 10 | 100 | 0 | 0 | 3 | 76 | 363 | |

mm nedbør

**Kontingenstabel for 1/5-98 - 31/5-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 3532 | 172 | 2 | 2 | 0 | |
| 0.05 | 2 | 414 | 1476 | 177 | 10 | 4 | |
| 2 | 6 | 4 | 247 | 1508 | 288 | 35 | |
| 6 | 10 | 0 | 15 | 262 | 962 | 209 | |
| 10 | 100 | 0 | 0 | 17 | 251 | 1511 | |

mm nedbør

**Kontingenstabel for 1/6-98 - 30/6-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 5579 | 186 | 0 | 0 | 0 | |
| 0.05 | 2 | 427 | 2087 | 292 | 12 | 9 | |
| 2 | 6 | 3 | 283 | 1276 | 145 | 13 | |
| 6 | 10 | 0 | 9 | 186 | 302 | 93 | |
| 10 | 100 | 0 | 1 | 23 | 116 | 428 | |

mm nedbør

**Kontingenstabel for 1/7-98 - 31/7-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 5147 | 287 | 17 | 1 | 0 | |
| 0.05 | 2 | 541 | 1540 | 341 | 40 | 15 | |
| 2 | 6 | 13 | 270 | 1070 | 194 | 46 | |
| 6 | 10 | 1 | 17 | 220 | 553 | 191 | |
| 10 | 100 | 0 | 8 | 48 | 187 | 721 | |

mm nedbør

**Kontingenstabel for 1/8-98 - 31/8-98**

| AMIS | KLIMA | 0<br>0.05 | 0.05<br>2 | 2<br>6 | 6<br>10 | 10<br>100 | mm<br>nedbør |
|---|---|---|---|---|---|---|---|
| 0 | 0.05 | 4980 | 172 | 4 | 0 | 0 | |
| 0.05 | 2 | 491 | 1540 | 165 | 8 | 5 | |
| 2 | 6 | 1 | 157 | 1013 | 198 | 21 | |
| 6 | 10 | 0 | 7 | 245 | 585 | 174 | |
| 10 | 100 | 0 | 1 | 30 | 198 | 1100 | |

mm nedbør

**Kontingenstabel for 1/9-98 - 30/9-98**