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MANUAL FOR OPERATIONAL CORRECTION OF NORDIC PRECIPITATION DATA

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REPORT NR. 24/96

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ISNN
0805-9918

NORDIC WORKING GROUP ON PRECIPITATION

MANUAL FOR OPERATIONAL CORRECTION OF NORDIC PRECIPITATION DATA

First edition

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Oslo, July 1996

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FOREWORD

This report is worked out by the Nordic Working Group on Precipitation (NWGP). This group is a part of the framework of KOHYNO, the coordinating comittee for hydrology within the Nordic countries. The key members of the working group in the mandatory period 1995-1996 are:

Denmark:	Henning Madsen (DMI)
Finland:	Esko Elomaa (FMI), Jaakko Perälä (Finnish Environmental Agency), Pauli Rissanen (FMI)
Iceland:	Trausti Jónsson (VI)
Norway:	Eirik J. Førland (Chairman) (DNMI), Inger Hanssen-Bauer (DNMI)
Sweden:	Bengt Dahlström (SMHI), Haldo Vedin (SMHI)

In addition Peter Allerup and Flemming Vejen (DMI) have given valuable contributions on the development of statistical models.

The statistical model for correction of solid precipitation is based on data from the comprehensive field investigations in Jokioinen in Finland 1987-1993. The field experiments in Jokioinen were a part of the *WMO Solid Precipitation Measurement Intercomparison*. This international intercomparison was initiated in 1986 by WMO to improve the quality of point precipitation measurements.

Finland was the only Nordic country to put up a complete experimental field according to the WMO recommendations. The NWGP is expressing its gratitude to Dr. **Seppo Huovila** (now retired from FMI) and his staff who succeeded in establishing the well equipped experimental field at Jokioinen. The other Nordic countries were given the opportunity by FMI to include their national gauges in this experimental field. Without this Finnish initiative, it would have been impossible to work out this manual.

Thanks also to Asko Tuominen and his staff at the Jokioinen Observatory for performing excellent measurements twice a day during the intercomparison period. Totally more than 20 precipitation gauges were in operation in the field.

Special thanks to Flosi Hrafn Sigurðsson (VI) for acting as a referee for this report. His useful comments and suggestions were gratefully acknowledged by the members of the working group.

SUMMARY

The amount of precipitation measured in the Nordic countries is giving an underestimate of the "ground true" precipitation. In wind exposed coastal and mountain areas, the measured winter precipitation may be lower than 50% of the true amount, and also the summer precipitation may be substantially underestimated. The main errors for the Nordic precipitation measurements are caused by aerodynamical effects near the rim of the gauges ("aerodynamical error"), but significant errors may also be due to evaporation from the gauge, wetting, blowing/drifting snow, splashing in/out of the gauge, misreadings, leakage from the gauge etc.

In 1986 WMO felt the need of an integrated effort to improve the quality of point precipitation measurements and decided to initiate an international intercomparison of snow measurements through the *WMO Solid Precipitation Measurement Intercomparison.* Finland was the only Nordic country to put up a complete experimental field according to the WMO recommendations. The other Nordic countries were given an opportunity to include their national gauges in this experimental field at the Jokioinen Observatory.

The results from Jokioinen showed that for solid precipitation, the Nordic gauges equipped with a windshield caught about 70% of the "true" precipitation, while the unshielded gauges caught less than 50%. For liquid precipitation, the catch deficiency in the Jokioinen test field was about 5% for shielded gauges and 8% for unshielded. Also special experiments on evaporation and wetting loss for various gauges were performed, and are summarized in this report.

The main emphasis of this report is to present methods for operational correction of precipitation measured at various types of stations, from well equipped automatic or manual weather stations with extensive measurements to the simple precipitation stations with just one element measured once a day. Also a survey is given of previous methods for correcting errors caused by aerodynamic effects, evaporation, wetting etc. in Nordic precipitation gauges.

As model for correcting **liquid** precipitation, the Danish model for unshielded Hellmann was further elaborated. The key basic elements in this correction model are precipitation intensity and windspeed at the level of the gauge orifice. Data from the Jokioinen test field were used to give an independent evaluation of this model.

The model for correcting **solid** precipitation is exlusively based on data from the Jokioinen test field. As reference for the "ground true precipitation", the "Double Fence Intercomparison Reference" (DFIR) is used. The key basic elements in the correction model for solid precipitation are air temperature and wind speed at the level of the gauge orifice.

Detailed descriptions of operational use of the correction models for various station types are presented, as well as some considerations on future improvements.

Finally the Nordic Working Group on Precipitation is presenting recommendations for future improvement of the quality of precipitation measurements in the Nordic countries.

LIST OF SYMBOLS AND ABBREVIATIONS

α = average vertical angle (degrees) of obstacles around the gauge
β = gauge coefficient for solid precipitation (eq. 4.12)
BUSH = Reference gauge (Tretyakov) surrounded by bushes (2-4 m high shrubs)
c = gauge coefficient for liquid precipitation (eq. 4.11)
DFIR = Double Fence Intercomparison Reference gauge
DMI = Danish Meteorological Institute
DNMI = Norwegian Meteorological Institute
e = water vapour pressure (hPa)
FMI = Finnish Meteorological Institute
h = height (m) of the gauge orifice above the ground
H = height (m) of the wind speed sensor above the ground
I = precipitation intensity (mm/h)
k = correction factor due to aerodynamic effects
k_l, k_s, k_m = correction factor for liquid, solid and mixed precipitation
k_v, k_c, k_{va} k_{vr}, k_{vt} = correction factors for Finnish correction model (ch.4.5)
N = number of cases
NWGP = Nordic Working Group on Precipitation
p = atmospheric pressure (hPa) at station level
P_c = corrected ("ground true") precipitation amount (mm)
P_m = measured precipitation amount (mm)
P_r = measured precipitation amount (mm) in a reference gauge
ΔP_E = evaporation loss from a precipitation gauge
ΔP_W = wetting loss from a precipitation gauge
ΔP_{im} = error sources for measured precipitation (se page 22)
ΔP_{ir} = error sources for precipitation measured in a reference gauge (see page 23)
ΔP_g, ΔP_s, ΔP_d, ΔP_h = error sources for precipitation measurements (see page 3)
q = exposure factor (see ch. 4.1)
r_l, r_s, r_m = precipitation amount (mm) as liquid, solid and mixed
SMHI = Swedish Meteorological and Hydrological Institute
T = air temperature (°C) at 2 m level
VI = Icelandic Meteorological Institute (Veðurstofa Islands)
v = wind speed (m/s) measured at 10 m level
v_3 = wind speed (m/s) at 3 m height
v_g = wind speed (m/s) at the level of the gauge orifice
v_H = wind speed (m/s) measured at the height H above the ground
V = volumetric precipitation amount (mm)
W = weighed precipitation amount (mm)
WMO = World Meteorological Organization
ww = WMO present weather code
z_0 = roughness length (m): 0.01 m for winter and 0.03 m for summer

1. INTRODUCTION

The key objective of this report is to supply information on operational techniques to improve the quality of point precipitation measurements. High quality precipitation data sets are of fundamental importance for problems related to water resources, to the energy and environmental sectors and to the climate change issue.

The conventional measurement of point precipitation consists of an extremely simple procedure, where the precipitation collected by a gauge is poured into a graduated glass. The observer then reads the amount of water and writes down the figure. In spite of this simple routine the measurements are impaired by a multitude of error sources. It is also a fact that more advanced devices for measurement of precipitation are affected by a number of error influences.

The fact that these errors generally result in systematic deficits, makes corrections of the errors of great importance. The magnitude of the deficits are particularly large in connection with snow conditions and can frequently amount to more than half of the true quantity. The dominating error source is connected with the deflection of the trajectories of the precipitation particles caused by wind and resulting in systematic deficits when a fraction of the particles are falling outside the gauge orifice. Size, shape and height of gauge above ground are important factors in this connection. In addition errors due to wetting and evaporation are also causing systematic deficits.

The errors inherent with precipitation measurement were identified already during the 18th century and a lot of field investigations have been operated in order to find suitable corrections (e.g. Heberden (1769), Hjeltström (1885), Sevruk (1982), Dahlström et al. (1986), etc.).

In 1986 WMO felt the need of an integrated effort to improve the quality of point precipitation measurements and decided to initiate an international intercomparison of snow measurements. As a reference for the "ground true precipitation", the Organizing Committee of the *WMO Solid Precipitation Measurement Intercomparison* (WMO,1994) designated the ortogoal vertical double-fence shield with a manual Tretyakov gauge (Double Fence Intercomparison Reference, DFIR).

The Nordic countries decided to make a co-ordinated contribution to this initiative and a test-field in Jokioinen, 100 km NW of Helsinki, was established. The Finnish Meteorological Institute has financed and been responsible for a comprehensive field measurement programme. The work has continuously been co-ordinated between the Nordic countries by the Nordic NHP working group on precipitation. The main data collection has took place during 1987 to 1993, but the testfield is still in function with a reduced number of measurements.

The collected stock of data represents a unique bank of information on the characteristics of both manual and automatic precipitation measurement devices. The methods for precipitation correction presented in this report are developed on the basis of the data from Jokioinen. For future research dealing with error correction of precipitation this data collection is expected to be of fundamental importance.

2. PRECIPITATION MEASUREMENTS AND ERROR SOURCES

The following error sources influence the point precipitation measurements:

- **The wind error.** This error source causes large deficits and represents generally the largest problem of precipitation measurement. The deficits in catch are caused by the fact that the gauge and the energy of turbulent wind deflect the trajectories of the precipitation particles. This effect gives the result that the particles that would have reached the catchment area of the gauge will enter outside the orifice of the gauge, causing substantial deficits in catch. The losses in precipitation amount can be particularly large during snowfall and high wind speeds. Most operational precipitation gauges are equipped with a wind shield to reduce the wind error. For reducing this error source a wind-sheltered site of the precipitation gauge should be preferred, but gauges must frequently be located at wind-exposed sites for practical reasons.

- **The evaporation error.** Evaporation of water stored in the gauge is another error source. Generally the gauges have a construction to reduce the evaporation from water that is accumulated within the gauge: frequently an evaporation funnel or similar device is inserted in the gauge for this purpose.

- **The wetting error.** When the observer pours the liquid content of the gauge into a measuring glass, part of the quantity stays in the gauge due to the adhesion of water at the interior of the gauge. This causes a deficit in the measured amount. However, when the gauge is emptied the next day, this deficit may partly be compensated by the excess quantity remaining in the gauge. If, however, the excess quantity has evaporated, partly or entirely, during the time from the previous measurement, the wetting effect results in a deficit ("wetting loss").

  Due to adhesion, some minor quantities of the precipitation will remain in the open catchment part of the gauge. This part of the precipitation does not flow into the lower (container) part of the gauge, and will consequently not be measured when the gauge is emptied. In weather situations with intermittent precipitation, e.g. showers; this adhesion part of the precipitation may evaporate during dry spells between the showers.

  The magnitude of the wetting loss is thus complicated to evaluate as it depends on the wetting and evaporation conditions between consecutive measurements.

- **The splashing error.** If the catchment area of the gauge is too flat, large drops will split and an outsplashing effect may occur causing a deficit of rain water. The opposite effect may occur due to insplashing of water from surrounding nearby surfaces and an excess of water is received in the gauge. Generally this type of error can be avoided by a proper construction of the gauge and with a careful selection of the place where the gauge is located. Wintertime, at wind-exposed locations blowing or drifting snow may cause substantial errors. (For instance, the gauge at the Norwegian arctic station *Hopen* caught 190 mm "precipitation" due to blowing snow during 3 days in January 1995).

- **Unfavourable site.** Objects nearby the gauge may influence the amount of precipitation that is caught by the gauge. If for instance trees are too closely situated with regard to the site of the gauge, a fraction of the falling precipitation will be caught by the trees ("interception") instead of reaching the orifice of the gauge. Generally the gauge shall be situated at least as far from a building or a tree as 1-4 times the height of these objects. However if the distance to nearby objects is too large, the site will generally be too windexposed. Consequently, from the practical point of view a position of the gauge which eliminates the interception error without being too windexposed should be looked for.

- **Instrumental errors.** Depending on the construction of the gauge, a lot of errors may occur. One of the most common instrumental errors are connected with frost damage of the bottom of the gauge causing leakage and systematic underestimation of measured quantities. The gauges that are operated today in most official networks are rugged weather units that are unaffected by frost. Other effects may occur connected with improper use of the precipitation equipment, like for instance location at non-standard height above ground or for instance due to oblique position of the catchment area of the gauge, and errors due to improper graduating of the measurement cylinder.

- **Reading and occasional errors.** A lot of other errors may occur due to improper observations due to the observer such as reading errors, errors due to sabotage, unexpected influence from irrigation and spray of snow from snow-ploughs.

The real amount of precipitation (P_c) can be formally described as follows:

$$P_c = f(P_m, \Delta P_E, \Delta P_W, \Delta P_a, \Delta P_g, \Delta P_s, \Delta P_d, \Delta P_h) \quad (2.1)$$

where P_m denotes observed amount of precipitation and ΔP-factors denote different error sources. Errors originate from evaporation (ΔP_E), wetting (ΔP_W), aerodynamic effects around the gauge (ΔP_a), unfavourable site (incl. interception) (ΔP_g), splashing in/out of the gauge (incl. drifting or blowing snow) (ΔP_s), instrumental errors (ΔP_d) and reading and other occasional errors (ΔP_h).

Errors due to unfavourable site, instruments or observing methods (ΔP_g, ΔP_d, ΔP_h) are minimized by preplanning and quality control of observation material. Errors due to evaporation (ΔP_E) or splashing (ΔP_s) (except for exposed sites with drifting/blowing snow) are mainly quite small in the Nordic countries. However evaporation from the gauges may be significant in the spring when funnel is not used inside the gauge. The most important error sources for precipitation measurements in the Nordic countries are caused by aerodynamic effects (ΔP_a), wetting (ΔP_W) and evaporation (ΔP_E).

For operational purposes, a general model for correction of precipitation errors may therefore be simplified to:

$$(2.2) \quad P_c = k\,(P_m + \Delta P_W + \Delta P_E)$$

where P_c is the corrected or "true" amount of precipitation and k is the correction factor due to aerodynamic effect. For developing such a model for the Nordic gauges, the results from the field experiments in Finland (chapter 3) were essential. The description and practical use of the recommended operational correction models are outlined in chapters 4 and 5 of this report.

3. FIELD EXPERIMENTS IN JOKIOINEN, FINLAND

3.1 Description of the site

An evaluation of possible comparison sites revealed that the most suitable site was in the neighbourhood of the Jokioinen observatory of the Finnish Meteorological Institute in the south-western part of Finland (60° 49'N, 23° 29'E), see Figure 3.1.

3.1.1 Climate of Jokioinen

In the area, the mean length of the thaw-free period is less than 60 days and the number of frost degree days is 620 - 799 (Solantie, 1980). The maximum snow depth is 40-70 cm and a winter without snow on the ground is fairly rare (recurrence interval over 20 years). The mean temperature drops below zero (the thermal winter begins) on the 15th of November and the thermal winter, on the average,lasts 142 days until 5 April (Table 3.1).

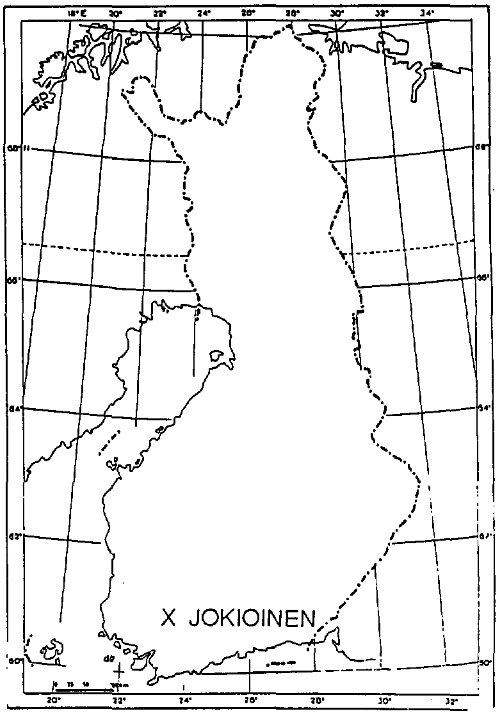


Figure 3.1 Location of the experimental field at Jokioinen, Finland

Table 3.1. Climatological data for Jokioinen, southwestern Finland, 1961-1990.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
Atmospheric pressure at mean sea level (hPa-1000)	12.4	14.6	12.8	12.9	15.5	12.3	11.0	11.7	11.2	12.3	09.3	09.9	12.1
Mean air temperature (degC)	-7.5	-7.4	-3.5	2.4	9.4	14.3	15.8	14.2	9.4	4.7	-0.4	-4.9	3.9
Mean daily maximum temp.	-4.6	-4.1	0.4	6.8	15.0	19.7	20.9	19.1	13.4	7.7	1.7	-2.2	7.4
Mean daily minimum temp.	-11.2	-11.2	-7.7	-1.8	3.2	7.9	10.3	9.4	5.6	1.8	-3.0	-8.1	-0.5
Absolute maximum temp.	7.4	9.4	14.0	21.2	27.7	31.5	29.9	30.4	27.6	18.4	11.3	7.2	31.5
Absolute minimum temp.	-36.7	-39.3	-29.0	-20.9	-7.0	-3.1	0.8	-1.5	-8.8	-13.4	-24.5	-33.4	-39.3
Sunshine hours (%)	23	26	41	38	48	57	50	46	36	27	16	14	40
Global radiation (MJ/m2)	28	89	241	386	565	633	578	435	238	109	33	16	3350
Precipitation (mm)	36	24	25	32	35	46	80	83	65	58	55	42	582
Precipitation days (>1.0 mm)	9	7	8	7	7	8	11	11	12	11	11	10	112
Potential evapotransp. (mm)	-	-	-	-	61	112	108	82	38	20	-	-	-
Precipitation deficit (*)	-	-	-	-	26	66	28	-1	-27	-38	-	-	-
Mean relative humidity (%)	89	88	82	76	67	67	74	80	86	88	91	90	82
Snow depth on the 15th of each month (cm)	23	35	39	16	0	-	-	-	-	-	2	11	-
Mean windspeed 30m (m/s)	3.9	3.8	4.0	4.0	3.9	3.7	3.5	3.4	3.8	4.0	4.1	4.0	3.9

Thermal seasons:
Summer (T>10 degC) : Length 114 days starting 23 May
Autumn (10>T>0 degC) : Length 62 days starting 14 September
Winter (T<0 degC) : Length 142 days starting 15 November
Spring (0<T<10 degC) : Length 47 days starting 6 April
Thermal growing season (T>5 degC) : Length 167 days, starting 28 April, ending 12 October

*) Precipitation deficit = [Potential evapotranspiration - Precipitation] (mm) (Ansalehto et al.,1985)

The lasting snow cover, on the average, settles at a temperature of - 4.2 °C when some 14 mm snow has fallen after the first snow cover. At Jokioinen the lasting snow cover in average settles on the 14th of December and disappears from open fields on the 20th April and in the forests 7 to 11 days later. The total duration of temporary snow cover is on the average 16 days (Solantie, 1977).

The monthly normal precipitation increases from February until August and then gradually decreases towards February. About 30 % of the total annual precipitation falls as snow. The last snowfall occurs at about the same time as the forests free themselves from their winter snow cover, usually in early May but in extreme cases even in June.

Wind blows most frequently from the sector south to south-west. However, in southwestern Finland snow falls mostly (80 %) when winds are blowing from the eastern half (north-east-south) of the compass and most frequently (50 %) when they are from the sector east to south-east (Figure 3.2).

During the intercomparison most of the winter months were milder than normal (Table 3.2).

Table 3.2 Monthly mean air temperatures and precipitation sums at Jokioinen 1987-1993. Normal values for the period 1961-90 are also included.

a). Air temperature (°C).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1987	18.9	-7.9	-6.8	2.4	7.6	12.1	14.8	11.7	8.4	6.4	-0.7	-5.3	2.0
1988	-3.1	-4.3	-3.5	0.9	11.4	16.5	19.0	14.1	10.8	4.2	-3.9	-7.0	4.6
1989	-0.5	0.0	1.1	5.3	10.4	15.4	16.3	13.7	11.0	4.7	-0.1	-5.9	6.0
1990	-4.0	0.9	1.0	5.6	9.3	14.4	15.2	15.0	8.0	4.9	-1.9	-1.6	5.6
1991	-3.6	-7.5	-1.0	3.4	7.2	12.1	16.6	16.2	9.1	5.4	2.6	-1.6	4.9
1992	-2.1	-2.7	0.4	1.3	11.4	15.6	16.0	14.3	11.2	-0.6	-1.8	0.1	5.3
1993	-2.3	-3.4	-0.9	3.3	13.5	11.4	15.6	12.9	5.7	3.0	-3.6	-3.4	4.3
Normal	-7.5	-7.4	-3.5	2.4	9.4	14.3	15.8	14.2	9.4	4.7	-0.4	-4.9	3.9

b). Precipitation (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1987	18	32	13	4	38	81	68	83	120	42	38	36	572
1988	49	41	45	46	44	25	128	79	85	96	12	55	704
1989	32	61	40	40	41	30	85	92	51	49	69	47	637
1990	73	73	45	35	22	20	85	90	62	48	53	62	668
1991	69	16	31	14	29	69	55	92	80	49	81	34	619
1992	50	31	42	48	7	24	47	107	59	64	63	33	577
1993	56	16	29	29	1	56	107	136	12	51	3	61	558
Normal	36	24	25	32	35	46	80	83	65	58	55	42	582

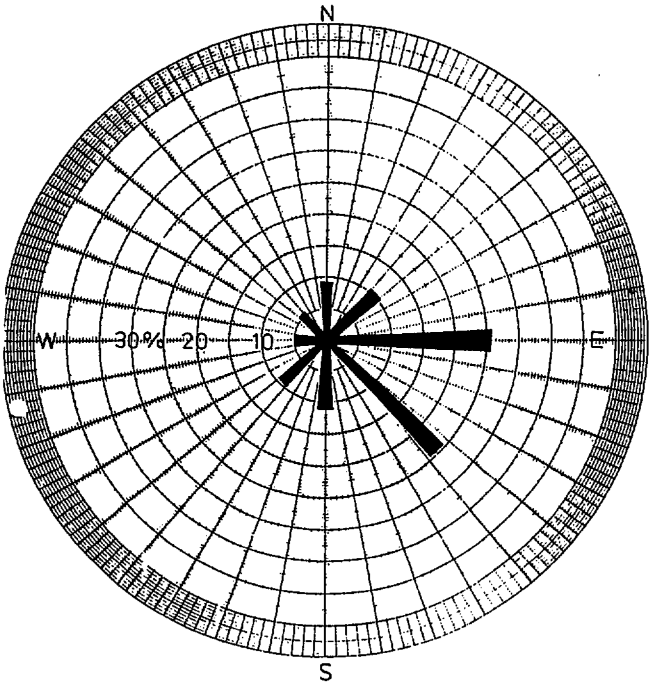


Figure 3.2 Mean annual distribution (1886-1935) of solid precipitation versus different wind directions in Huittinen, 60 km NW of Jokioinen (Korhonen,1942).

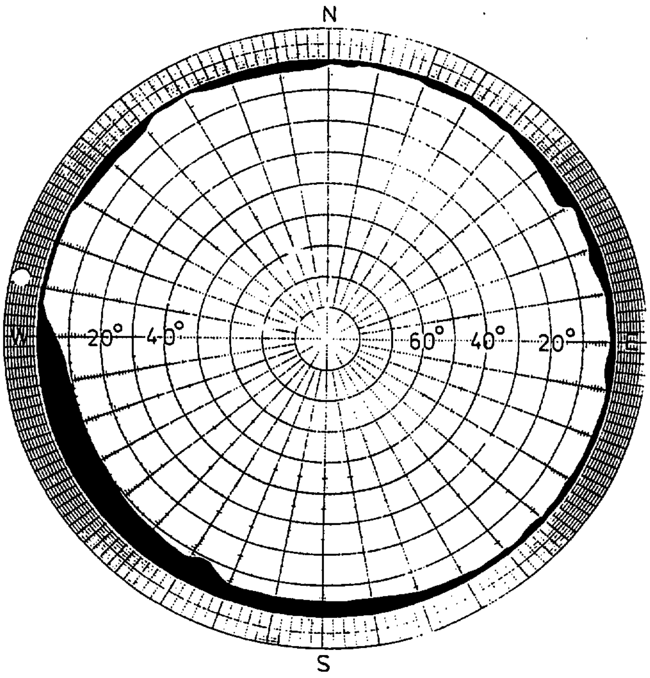


Figure 3.3 Horizon of the intercomparison field measured at a height of 1.5 m in the centre of the field.

3.1.2 Site

The meteorological observatory at Jokioinen lies 104 m above mean sea level on a fairly flat ground surrounded mainly by cultivated fields. There are, however, some shading forests in the sector south-west to west close to the main building of the observatory (Figure 3.3).

For the intercomparison the Valdai double-fences were placed in the western part of the field not to disturb other gauges, because snow falls mainly from the eastern and southeastern sectors. In the easternmost row, most of the gauges were without wind shields, whereas the gauges in the middle row were equipped with wind shield. Measurements have also been made in the summertime and therefore a pit gauge has also been installed in the field. A cabin for manual measurements of amounts of precipitation and for automatic recording by a microcomputer was situated near the northeast corner of the field (Figure 3.4).

3.2 Description of the instruments and methods

3.2.1 Gauges and shields

Measurements were started on the 1st of February 1987. A survey of the gauges used during the experiment is presented in Table 3.3.

Table 3.3 The gauges used at Jokioinen experimental field.

No	Gauge-type	Wind shield	Period	Comments
1	Tretyakov	Tretyakov	01.02.87-30.04.93	Funnel 1.05-30.09
2	Tretyakov	-	01.02.87-30.04.93	Funnel 1.05-30.09
3	Wild (tipping bucket)	-	26.08.87-30.09.92	May-September
4	Friedrichs (tipping bucket)	-	19.01.88-30.04.93	
5	Wilska	-	01.01.89-30.04.93	
6	Hungarian Hellmann	-	01.05.88-30.04.93	
7	Wild	-	01.02.87-30.04.93	
8	Norwegian	Nipher	07.04.87-30.04.93	Summer gauge 1.5-1.10
9	Tretyakov	Tretyakov	01.02.87-30.04.93	Funnel 1.05-30.09
10	Finnish prototype	Tretyakov	01.02.88-28.02.91	Funnel 1.05-30.09
11	Swedish	Nipher	01.02.87-30.04.93	Funnel 1.05-30.09
12	Geonor	Alter	26.08.87-30.04.93	
13	Tretyakov	Tretyakov	01.02.87-30.04.93	Funnel 1.05-30.09
14	Wild	Nipher	01.02.87-30.04.93	
15	Danish Hellmann	-	06.02.87-30.04.93	Snow cross 1.10-30.04
16	Tretyakov (DFIR)	Double fence	01.02.87-30.04.93	Funnel 1.05-30.09
17	Pit gauge (Wild)	-	12.05.87-30.09.92	May-September
18	Geonor	Double fence	26.08.87-30.04.93	
19a	Rainomatic tipping bucket	-	21.02.88-06.03.90	
19b	RIMCO tipping bucket	-	06.03.90-30.04.93	
20	Canadian gauge	Canadian	23.02.89-30.04.93	
21	BT-60, Tretyakov	Tretyakov	08.02.90-30.04.93	Funnel 1.05-30.09
22	Finnish H&H-90	Tretyakov	01.03.91-30.04.93	Funnel 1.05-30.09
23	Vaisala FD12P	-	09.04.92-30.04.93	Present weather sensor

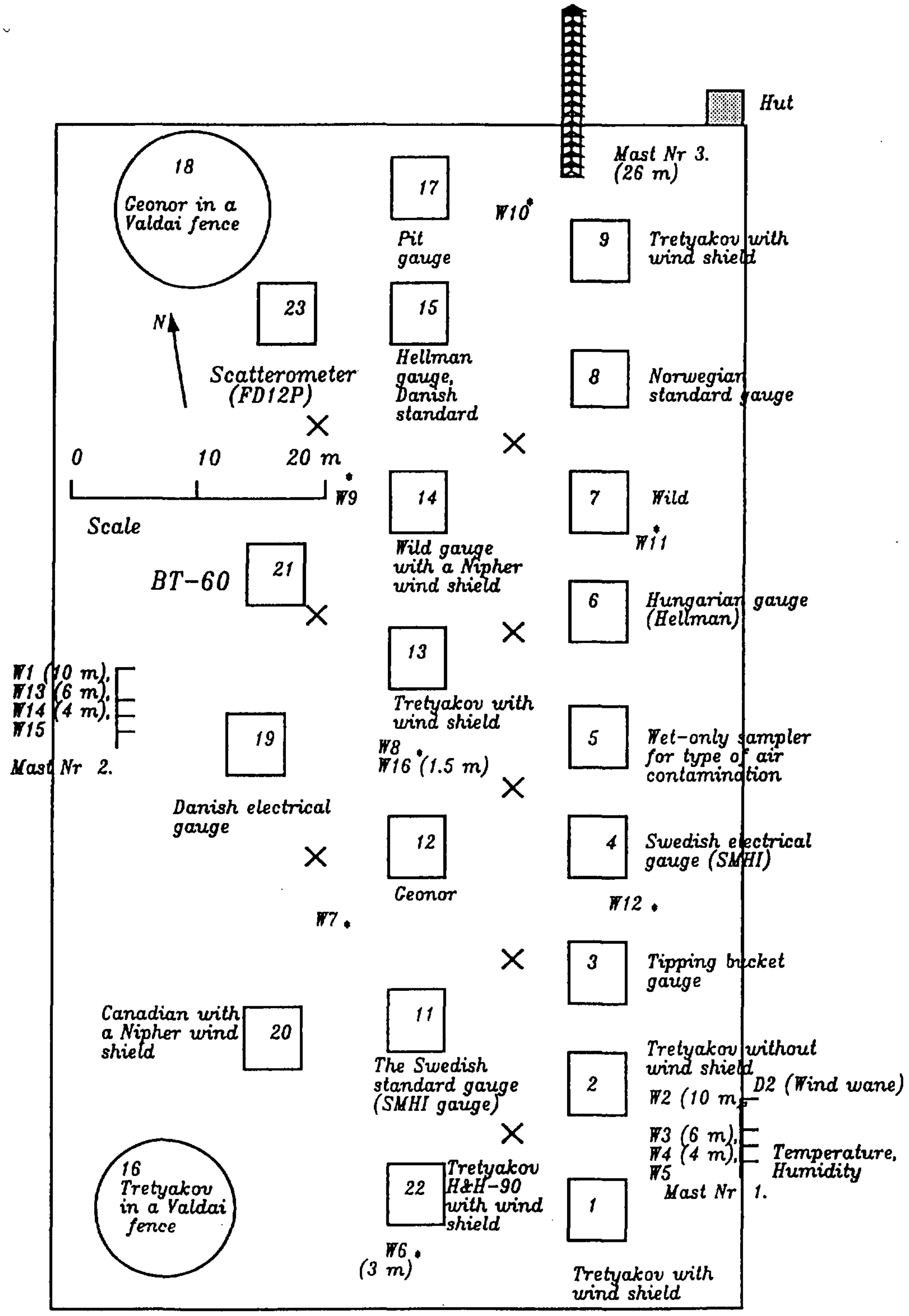


Figure 3.4 Location of the gauges at Jokioinen precipitation intercomparison field as 01.08.1992. Snow gauges are numbered 1,2,...,23. Anemometers (W1,W2,...,W16) are at the height of 2 m if not explicitly shown. Snow stakes are presented by X. (Gauge 4 is a Friedrichs heated tipping bucket gauge)

All the national Nordic gauges (except the Icelandic) were tested at Jokioinen (gauges no. 8,10,11,15,22). As recommended by the WMO Intercomparison Project, Russian Tretyakov gauges (No. 1,9,13), and reference gauges in Valdai double fence (No. 16,18) and ground level (No. 17) were also installed. Automatic gauges were also tested, both tipping bucket (No. 3,4,19a &b) and weighing (12,18). In addition there were also parallell measurements in gauges without windshield (No. 2 and 7) and gauges from outside the Nordic countries (No. 6,20).

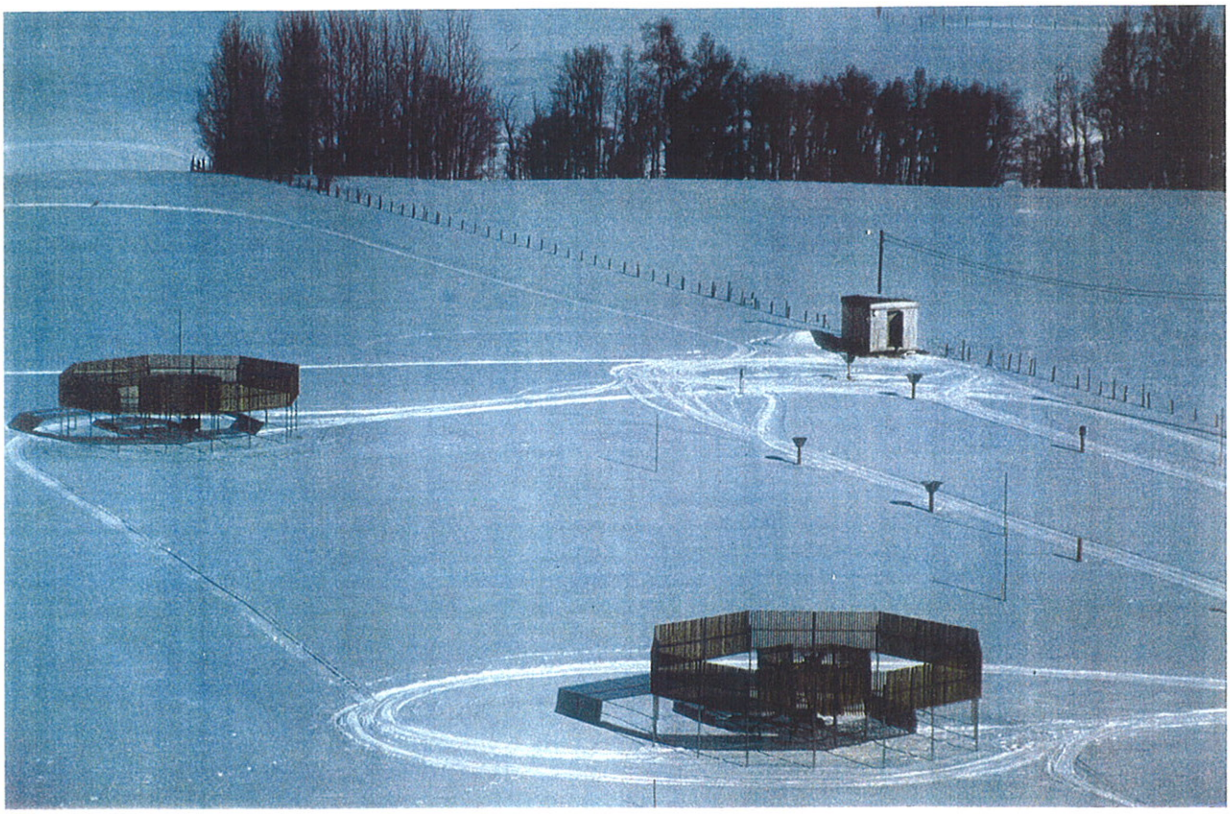
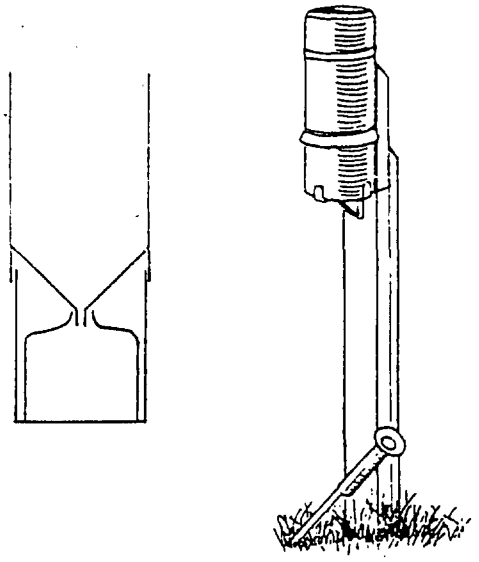
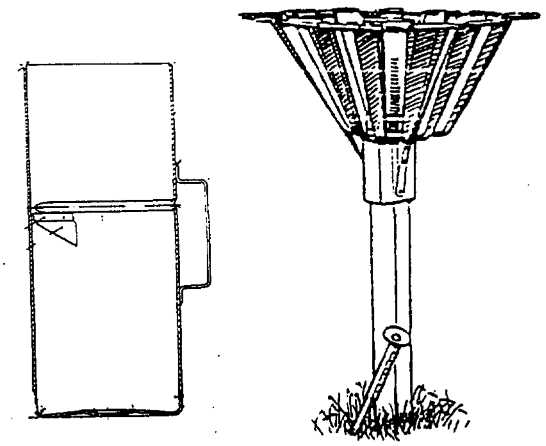


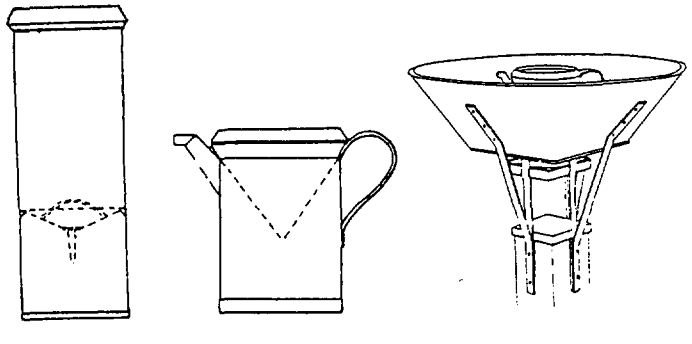
Figure 3.5 Photo of the two double fence intercomparison references in the Jokioinen experimental field



Gauge 15: Hellmann
(Denmark)

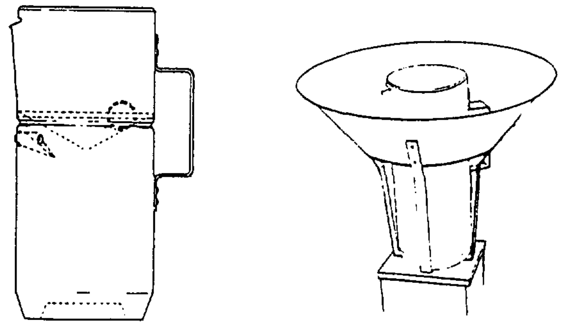


Gauge 22: Finnish H&H-90)
(Finland)



Winter *Summer*

Gauge 8: DNMI
(Norway)



Gauge 11: SMHI
(Sweden & Norway)

Figure 3.6 Nordic gauges used in the Jokioinen experimental field

3.2.2 Gauge orifice area and height above ground

The gauge heights above the ground (measured in April 1990) are presented in Table 3.4.

The area of each gauge orifice was measured using a precision ruler at angular intervals of 45 degrees, i.e. by taking four measurements of the diameter. The areas were then calculated using the diameters and the mean value of the four calculations has been used in the data analysis. The biggest difference of the gauge orifice area compared to the nominal value of the gauge was about 5 % (Table 3.4).

Table 3.4 Height above ground and orifice areas of precipitation gauges in Jokioinen. Two units (A and B) of each manual gauge type were used alternately in the field.

Gauge		Height ab.gr.	Nominal area	Ratio measured/nominal area		
No	Type	cm	(cm^2)	A	B	Mean
01	Tretyakov	152	200	0.9840	0.9940	0.9890
02	Tretyakov	155	200	0.9868	0.9922	0.9895
03	Wild	152	500	0.9472	-	-
04	Friedrich	156	200	0.9976	-	-
05	Wilska	152	300	1.0350	1.0163	1.0256
06	Hungarian Hellmann	155	200	1.0018	0.9912	0.9966
07	Wild	157	500	0.9908	0.9965	0.9936
08	Norwegian (winter)	160	225	1.0043	1.0120	1.0082
09	Tretyakov	153	200	0.9881	0.9834	0.9858
10	Finnish prototype	150	200	1.0018	1.0025	1.0022
11	Swedish	148	200	0.9906	0.9912	0.9909
12	Geonor	155	200	-	-	-
13	Tretyakov	155	200	0.9750	0.9922	0.9836
14	Wild	155	500	0.9916	0.9827	0.9872
15	Danish Hellmann	155	200	0.9916	0.9940	0.9928
16	Tretyakov	311	200	0.9816	0.9860	0.9838
17	Wild	0	500	1.0020	0.9998	1.0009
18	Geonor	305	200	-	-	-
19a	Rainomatic	-	200	-	-	-
19b	RIMCO	155	324	-	-	-
20	Canadian	153	125	1.0110	1.0142	1.0126
21	Tretyakov	-	200	0.9916	0.9872	0.9894
22	Finnish H&H-90	-	200	0.9966	0.9912	0.9939

One should note that the orifice area of gauges no 8A and 8B (the old Norwegian standard gauge for snow measurements) were of square form while all the others were circular. The walls of the orificies of these Norwegian gauges also appeared to be slightly convex, thus leading to measured orifice area larger than the nominal area. In Table 3.4 the area of a small and short spout of the gauges 11 (Swedish) and 10 (Finnish prototype) were not included in the orifice area.

3.3 Sampling procedure

The observation cabin, the two Valdai double-fences and the posts of the gauges were installed before the end of January 1987.

The Valdai double fences were grounded to the depth of 70 cm, but that proved to be too low a depth. During a ground frost melting period in 1988 the fences almost fell down because of strong NW-winds at Jokioinen.

In summertime the measuring site is grass covered. Pathways covered with concrete slabs connect the different gauges to the observation cabin and to other buildings of the observatory.

Routine observations were started on 1 February 1987. Observations were made at 00 and 12 hrs local time in order to suit the daily observation routine of the observatory.

The gauges were replaced by empty ones always in the same order, and taken into the cabin. The gauges were not changed if the observer was convinced that there had been no precipitation or condensation since the preceding observation. A snowmobile was used for carrying the gauges in the wintertime and a wheelbarrow in the summer. All gauges were covered with their lids during the transport. Inside the cabin, snow was allowed to melt with lids on the gauges.

The water equivalent of solid precipitation in the gauges was measured both by measuring cylinders (volumetrically) and by weighing with a digital balance. In order to arrive at comparable results, the measuring cylinders were wetted before starting the measurements. Afterwards the empty gauges were allowed to dry thoroughly before bringing them back to the measuring site.

While using a digital balance for water equivalent measurements, condensation of water on the cold gauges was a problem. Observers consequently had to wait for some minutes before a reading could be taken.

If the amount of snow in a gauge was rather large, say at least one third of the measuring capacity, the observer on duty also sketched on the measuring site the shape of the snow surface in the gauge. This information may be used in evaluating the influence of wind (e.g. blowing out of the gauge) on each type of the gauges. The homogeneity of the measuring site may also be estimated in this way.

3.4 Supporting observations

The following routine observations of the meteorological observatory at Jokioinen supported the measurements on the intercomparison field:

- synoptic weather observations every 3 hours including the height of cloud base
- monitoring weather elements with a time resolution of 5 minutes
- global radiation and net radiation measurements
- soil temperature measurements
- ground frost measurements
- snow board measurements
- wind speed and direction on the top of an instrument tower (about 30 m above the field)
- radiosonde measurements giving air pressure, temperature, relative humidity and upper wind data two or three times a day.

3.5. Special experiments and measurements

Special experiments and measurements were made separately at the Jokioinen testfield, without violating the intercomparison experiments.

3.5.1 Wetting

Wetting amount can be taken as a difference between weighted and volumetrically measured precipitation. It was also measured separately for each type of the gauges. Three different amounts of water 0.5, 5.0 and 10.0 mm were at first poured and later on sprayed into each gauge during the tests.

The wetting amounts were measured at three different periods (1987, 1989 and 1992) according to the following procedure (cf. Huovila et.al., 1988):

1. Each gauge was weighted empty, with a resolution of 0.1 gram, using an accurate digital balance (Reading A).
2. Certain amounts of water were measured for each gauge, using its own measuring glass. In the first series of observations 0.5 mm of water, in the second series 5.0 mm of water and in the third series 10.0 mm of water was used.
3. Each amount of water was poured (1987 and 1989) and sprayed (in 1992) into the respective gauge and left there for a time of about ten minutes. Then the water was poured out of each gauge in the same way as in a routine precipitation measurement.
4. Each gauge was then weighted again with the resolution of 0.1 gram (Reading B).
5. Each gauge was then left to dry without any cover at room temperature (about 20 °C).
6. Gauges with small funnel openings were dried by heating.
7. Each gauge was weighted again dry with a resolution of 0.1 gram (Reading C).
8. The difference D = B - C for each gauge were then calculated.
9. The difference D is the wetting value for each gauge.
10. The above described procedure 1-9 was repeated 20 times for each gauge with 0.5, 5.0 and 10.0 mm of water respectively.
11. Wetting amounts were calculated for each gauge for the three water amounts.
12. The mean values of wetting amounts with their standard deviations were then calculated and converted into millimeters of water.

The results from these experiments showed that the wetting amounts depended only slightly on the amount of water sprayed into the buckets. On the average the wetting amounts varied from 0.1-0.3 mm/case. (Note: The outside walls of the gauges were carefully dried before the weighings).

The wetting amounts were also determined as a difference of weighted and volumetrically measured precipitation (Tables 3.6-3.9). These values were greatest in rainfall cases, and varied for different gauges from 0.05 to 0.15 mm/case. For snowfall the wetting amounts varied from 0.05 to 0.10 mm/case.

3.5.2 Evaporation

Evaporation from various gauges (Table 3.5) was measured in the winter-time from snow and in the summer-time from water in the gauges. The daily procedure used was as follows (cf. Huovila et.al., 1988):

1. Gauges were weighted dry (empty) with resolution of 0.1 gram (Reading A).
2. In the winter 1-2 cm of light snow was put into the gauges. In the summer 2.0 mm on paired days and 3.0 mm on odd days was poured into the gauges.
3. The gauges were weighted with the resolution of 0.1 gram (Reading B).
4. The gauges were kept outdoors on their own stands from 08 until 20 o'clock local time i.e. for 12 hours.
5. The gauges were weighted (in the case no precipitation had occurred) with a resolution of 0.1 gram (Reading C).
6. The differences D=B-C were calculated to indicate the evaporation of snow or water.
7. The results were converted into millimeters of water.

Mean, minimum and maximum evaporation values from these experiments are summed up in Table 3.5. The reason behind the high evaporation loss in April is that the gauges 01, 08, 11 and 22 are operated without funnel until 1. May (cf. Table 3.3).

Table 3.5 Evaporation loss (mm/day) from different gauges. (Jokioinen: 1989-1993).

a). Mean values

	Finnish (22)	Tretyakov (01)	Wild (14)	Danish (15)	Swedish (11)	Norwegian (08)
January	0.18	0.15	0.09	0.41	0.17	0.17
February	0.17	0.19	0.17	0.17	0.14	0.13
March	0.30	0.36	0.21	0.16	0.21	0.18
April	0.81	0.87	0.07	0.20	0.56	0.64
May	0.22	0.58	0.03	0.22	0.33	0.14
June	0.16	0.59	0.04	0.27	0.44	0.18
July	0.18	0.55	0.04	0.26	0.36	0.16
August	0.10	0.35	0.03	0.16	0.30	0.10
September	0.04	0.20	0.02	0.06	0.08	0.02
October	0.20	0.20	0.02	0.04	0.17	0.16
November	0.11	0.09	0.01	0.24	0.08	0.09
December	0.14	0.13	0.09	0.03	0.09	0.10

b). Minimum and maximum values

	Finnish (22)	Tretyakov (01)	Wild (14)	Danish (15)	Swedish (11)	Norwegian (08)
January	0.02/0.73	0.02/0.66	0.00/1.57	0.00/0.54	0.01/0.63	0.00/0.65
February	0.02/0.49	0.01/0.69	0.00/1.08	0.01/0.52	0.02/0.41	0.00/0.41
March	0.04/0.88	0.00/2.11	0.00/1.06	0.02/0.58	0.02/0.48	0.02/0.44
April	0.04/1.65	0.00/2.27	0.00/1.08	0.03/1.37	0.05/1.24	0.00/1.66
May	0.01/0.86	0.10/2.19	0.00/0.08	0.09/0.41	0.13/0.65	0.04/0.32
June	0.02/0.62	0.18/1.21	0.01/0.38	0.15/0.62	0.20/0.91	0.08/0.40
July	0.04/0.59	0.17/1.38	0.01/0.20	0.16/0.40	0.18/0.67	0.07/0.30
August	0.04/0.36	0.10/1.16	0.01/0.10	0.08/0.37	0.17/0.86	0.04/0.30
September	0.00/0.18	0.03/0.47	0.01/0.09	0.02/0.12	0.00/0.17	0.00/0.05
October	0.03/0.64	0.01/0.78	0.00/0.14	0.00/0.11	0.08/0.47	0.00/0.63
November	0.05/0.24	0.00/0.38	0.00/0.06	0.01/0.83	0.05/0.18	0.02/0.23
December	0.00/0.83	0.00/0.66	0.00/0.49	0.00/0.05	0.02/0.31	0.00/0.32

3.5.3 Total sums measured volumetrically and by weighing in Jokioinen 1987-1993

Total precipitation sums during the intercomparison are grouped according to the type of precipitation: snow, rain, drizzle and mixed precipitation (Table 3.6-3.9). Both weighed and volumetrically measured values are presented as well as the difference which give an estimation of wetting. As a reference for the "ground true precipitation", the recommended (WMO, 1994) Double Fence Intercomparison Reference, ***DFIR*** (ortogoal vertical double-fence Valdai shield with a manual Tretyakov gauge) was used. It was however recognised (Golubev,1989, WMO,1994) that the best estimates of "ground true" is measured in gauges sited in bushes kept at gauge height (***BUSH***). Measurements of snowfall in DFIR and bushes at Valdai, Russia was used to establish correction equations for DFIR-values to the "ground true" value of the bush gauge. The DFIR-values from Jokioinen were corrected by using the equations (3.1) (Golubev,1992) and (3.2) (Yang et al.,1992):

(3.1)

$$\frac{BUSH}{DFIR}\ (\%) = 100\ [1+0.005 * v_3^2(\frac{p}{1000}*\frac{273}{273+T}*\frac{p}{p+0.4e})^2]\ ,$$

Where

p = *pressure at station level (hPa)*
T = *temperature (°C)*
e = *water vapour pressure (hPa)*
v_3 = *windspeed (m/s) at 3 m level*

(3.2)

$$\frac{BUSH}{DFIR}\ (\%) = 100+1.888 * v_3+6.5358 * 10^{-4}*v_3^3+6.539*10^{-5}*v_3^5\ ,$$

Where v_3 = wind speed (m/s) at 3 meters height

For snowfall the DFIR-values (gauge 16a) were corrected by equation 3.1 and 3.2, and the results are presented in Table 3.6 as gauge 16b and 16c respectively. Table 3.6 shows that the total amount of snow measured in the gauges without windshield was only 40-50% of the "ground true" (gauge 16b). Similar figures for the gauges with windshield were 57-78%.

For other precipitation types, the catch ratio was higher (Table 3.7-3.9)

According to Table 3.6-3.9, the wetting varied between 0.02-0.10 mm/case for snow, 0.05-0.15 mm/case for rain, 0.04-0.14 mm/case for drizzle, and 0.05-0.18 mm/case for mixed precipitation.

Table 3.6 **SNOW.** Precipitation sum, mm and % of the "ground true" reference (gauge 16b) Weighted values (W) and volumetrically measured values (V), wetting loss: (W-V)/W•100 (%) and (W-V)/N (mm/case). N is number of cases. All measurements are corrected to nominal area

Gauge No	Type	Wind-shield	N	Weight (mm)	(%)	Volumetric mm	(%)	Wetting (%)	(mm/N)
2	Tretyakov	No	448	424	48.5	394	45.0	7.2	0.07
7	Wild	No	448	351	40.1	336	38.4	4.5	0.04
15	Danish Hellmann	No	448	422	48.2	379	43.3	10.1	0.10
1	Tretyakov	Yes	448	652	74.5	611	69.8	6.3	0.09
8	Norwegian (*)	Yes	448	573	65.4	550	62.9	4.0	0.05
9	Tretyakov	Yes	448	635	72.5	601	68.7	5.3	0.08
11	Swedish	Yes	448	601	68.6	591	67.5	1.6	0.02
13	Tretyakov	Yes	448	644	73.5	601	68.7	6.6	0.10
14	Wild	Yes	448	498	56.9	490	56.0	1.5	0.02
10	Finnish prototype	Yes	267	389	78.4	382	76.6	1.8	0.03
22	Finnish H&H-90	Yes	117	219	74.0	213	72.7	2.8	0.05
16a	DFIR (a)	Yes	448	829	94.7	802	91.7	3.2	0.06
16b	DFIR (b)	Yes	448	875	100.0	875	100.0	0.1	0.00
16c	DFIR (c)	Yes	448	872	100.0	872	100.0	0.1	0.00

(a) Tretyakov gauge with a wind shield in a Valdai double fence

(b) As (a), but corrected for wetting loss, and to "ground true" with Yang's equation (eq. 3.2)

(c) As (a), but corrected for wetting loss, and to "ground true" with Golubev's equation (eq. 3.1)

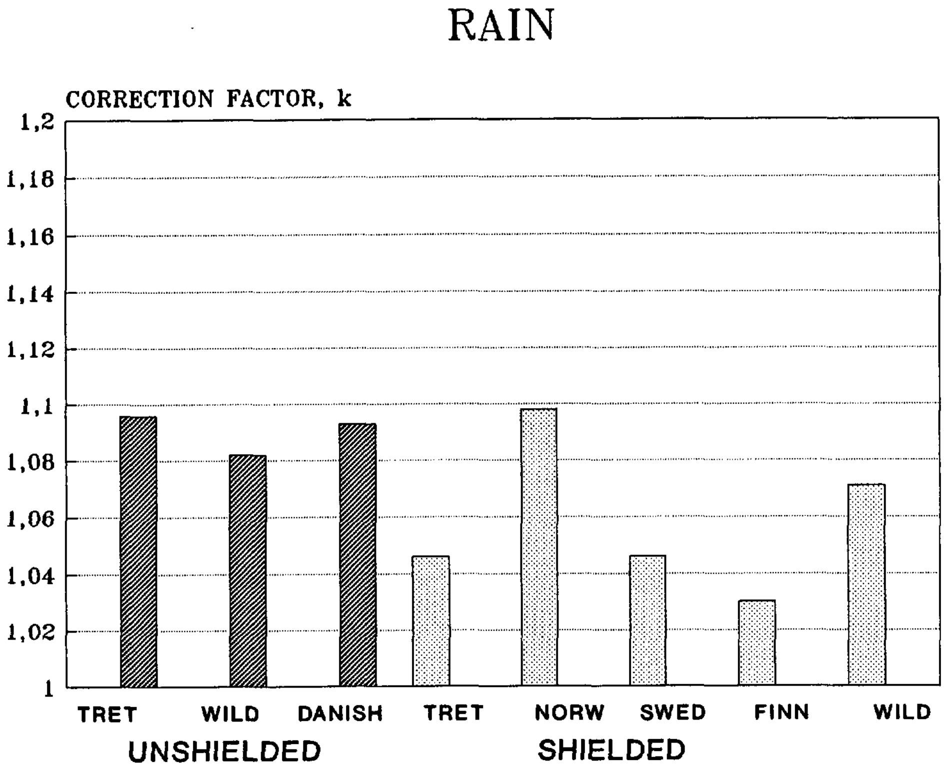
Table 3.7. **RAIN.** Precipitation sum, mm and % of the "ground true" reference (gauge 16b). Weighted values (W) and volumetrically values (V), wetting loss: (W-V)/W•100 (%) and (W-V)/N (mm/case). N is number of cases. All measurements are corrected to nominal area.

Gauge No	Type	Wind-shield	N	Weight (mm)	(%)	Volumetric mm	(%)	Wetting (%)	(mm/N)
2	Tretyakov	No	277	623	91.2	584	85.4	6.4	0.14
7	Wild	No	277	631	92.4	610	89.2	3.4	0.08
15	Danish Hellmann	No	277	625	91.5	587	85.8	6.2	0.14
1	Tretyakov	Yes	277	659	96.4	617	90.3	6.4	0.15
8	Norwegian (*)	Yes	277	622	91.1	581	85.0	9.7	0.15
9	Tretyakov	Yes	277	644	94.2	610	89.3	5.2	0.12
11	Swedish	Yes	277	653	95.6	633	92.7	3.0	0.07
13	Tretyakov	Yes	277	656	96.1	618	90.4	5.8	0.14
14	Wild	Yes	277	638	93.4	625	91.4	2.0	0.05
10	Finnish prototype	Yes	127	352	97.2	343	93.8	2.7	0.08
22	Finnish H&H-90	Yes	125	253	97.1	237	91.6	6.4	0.13
16a	DFIR (a)	Yes	277	683	100.0	648	94.9	5.1	0.13
16b	DFIR (b)	Yes	277	683	100.0	683	100.0	-0.0	0.00

(a) Tretyakov gauge with a wind shield in a Valdai double fence

(b) As (a) but corrected for wetting loss

(*) In Norway, since 1982 the Norwegian (DNMI) gauge is gradually being exchanged by the Swedish (SMHI) gauge (not at old homogeneous stations). Before this change was decided, 12 series of parallell measurements in DNMI and SMHI gauges were compared (see Appendix 2). The mean ratio between SMHI and DNMI gauges was 0.998 and 0.994 for winter and summer precipitation. In table 3.6 and 3.7 the ratios are 1.05. The low values for the DNMI gauge in Table 3.6 and 3.7 (in Table 3.7 even lower than for the unshielded gauges 2, 7 and 15) may not be representative, as they partly could be due to differences in exposures in the Jokioinen field



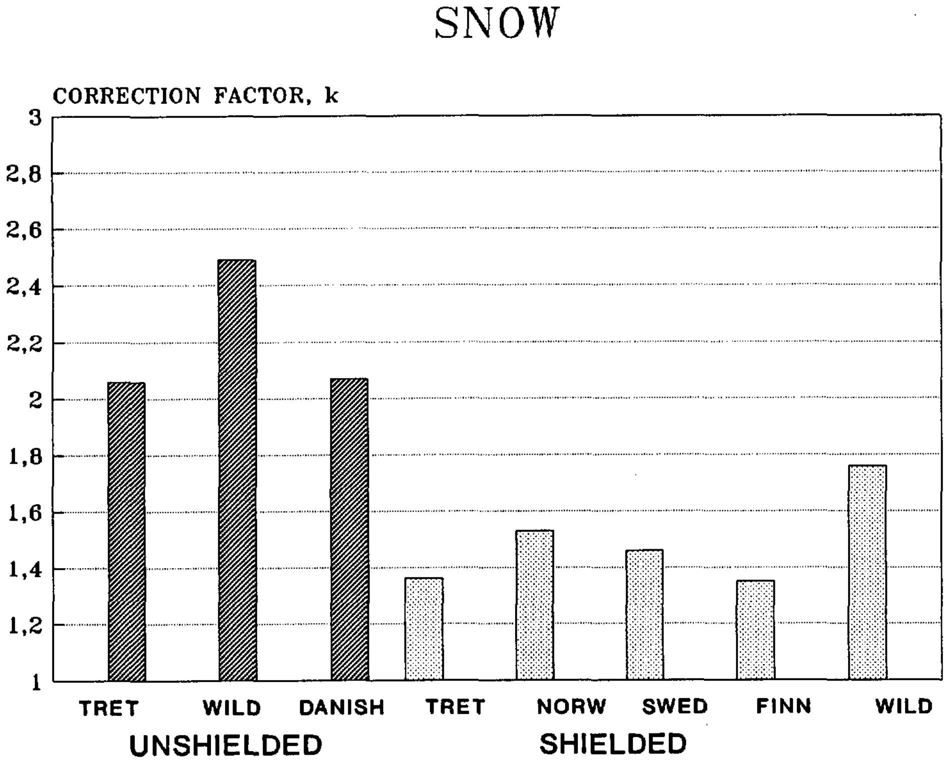


Figure 3.7 Correction factors for various gauges.
Values are based on weight measurements in Jokioinen 1987-93 (Table 3.6 and 3.7)

Table 3.8. **DRIZZLE.** Precipitation sum, mm and % of the "ground true" reference (gauge 16b). Weighted values (W) and volumetrically measured values (V), wetting loss: (W-V)/W•100 (%) and (W-V)/N (mm/case). N is number of cases. All measurements are corrected to nominal area.

No	Gauge Type	Wind-shield	N	Weight		Volumetric		Wetting	
				(mm)	(%)	(mm)	(%)	(%)	(mm/case)
2	Tretyakov	No	56	38	68,6	32	58,4	14,9	0,10
7	Wild	No	56	36	64,1	32	57,9	9,6	0,06
15	Danish Hellmann	No	56	38	69,1	31	55,6	19,5	0,13
1	Tretyakov	Yes	56	49	89,2	42	75,5	15,3	0,14
8	Norwegian	Yes	54	43	77,7	35	64,4	17,2	0,14
9	Tretyakov	Yes	56	47	85,5	41	73,3	14,3	0,12
11	Swedish	Yes	56	46	84,0	43	78,4	6,7	0,06
13	Tretyakov	Yes	56	49	88,4	42	75,6	14,6	0,13
14	Wild	Yes	56	41	73,3	38	69,0	5,8	0,04
10	Finnish prototype	Yes	36	34	92,7	30	84,4	9,6	0,09
22	Finnish H&H	Yes	7	10	91,7	10	87,0	6,1	0,09
16a	DFIR (a)	Yes	56	55	100,0	49	89,2	10,8	0,11
16b	DFIR (b)	Yes	56	55	100,0	55	100,0	-0,0	0,00

(a) Tretyakov with a wind shield in a Valdai double fence

(b) As (a), but corrected for wetting loss.

Table 3.9. **MIXED PRECIPITATION** (Sleet or mixture of rain & snow). Precipitation sum, mm and % of the "ground true" reference (gauge 16b). Weighted values (W) and volumetrically measured values (V), wetting loss: (W-V)/W•100 (%) and (W-V)/N (mm/case). N is number of cases. All measurements are corrected to nominal area.

No	Gauge Type	Wind-shield	N	Weight		Volumetric		Wetting	
				(mm)	(%)	(mm)	(%)	(%)	(mm/case)
2	Tretyakov	No	253	546	76,1	511	71,2	6.4	0,14
7	Wild	No	253	520	72,4	500	69,7	3,9	0,08
15	Danish Hellmann	No	252	540	75,3	495	69,0	8,3	0,18
1	Tretyakov	Yes	253	649	90,4	610	85,0	6,0	0,15
8	Norwegian	Yes	245	568	81,8	537	77,3	5,6	0,13
9	Tretyakov	Yes	253	628	87,5	595	82,9	5,3	0,13
11	Swedish	Yes	253	626	87,3	610	85,0	2,5	0,06
13	Tretyakov	Yes	253	646	90,1	610	85,0	5,6	0,14
14	Wild	Yes	253	559	77,9	547	76,2	2,1	0,05
10	Finnish prototype	Yes	132	374	92,5	364	89,4	2,8	0,08
22	Finnish H&H-90	Yes	91	227	92,5	216	89,3	4,6	0,11
16a	DFIR (a)	Yes	253	718	100,0	691	96,2	3,8	0,11
16b	DFIR (b)	Yes	253	718	100,0	718	100,0	0,0	0,00

(a) Tretyakov with a wind shield in a Valdai double fence

(b) As (a), but corrected for wetting loss.

3.6 Quality control of data

The measurements and experiments in the Jokioinen experimental field were performed by a professional staff, and accordingly are of very high quality. All data from the experimental field have been subjected to control and correction of syntax errors before statistical analysis. This control did detect some missing records and has corrected records of wrong cronological order.

After this first-hand control, a quality control of data from automatic registrations as well as from manual measurements has been undertaken. Erroneous data are mainly deleted, but in a few cases they are corrected; this concerns measurements from the manual precipitation gauges only.

By comparing the wind speeds from the field, sensor no. W8 (cf. Figure 3.4) was found to be the most representative, and only data from this wind sensor have been used in the analysis. However it can be noticed, that an analysis of mean wind speed during precipitation showed the presence of a small wind gradient (Elomaa et al, 1993).

Among the recording precipitation gauges, data from the Geonor (No 18) in the Valdai double fence are most reliable. The control of data from the manual precipitation gauges, which concerns all precipitation in the period November 1987 - April 1993, resulted in relatively few deleted and corrected values. For this period about 325 twelve-hour values of snow and about 175 values of mixed precipitation have been available for the statistical analysis. When comparing number of measurements in Tables 3.6 and 3.9 these figures seem to be low, but it should be noticed, that the analysis only includes data observed after October 1987. Further, the number of cases for the two finnish gauges No. 10 and 22 are relatively low.

4. SURVEY OF CORRECTION METHODS USED IN THE NORDIC COUNTRIES

4.1 Previous Nordic methods for correction of errors caused by aerodynamic effects

In the course of years many attempts to estimate the errors in precipitation measurements have been undertaken. A lot of methods to make error corrections have been developed, but in this paper only the latest and most relevant studies will be outlined.

In order to correct point precipitation measurements due to systematic errors we have to focus on following three main types of precipitation:

1. Liquid (rain and drizzle)
2. Solid (snow)
3. Mixed (sleet or combination of rain and snow)

The general model for correction of systematic errors in precipitation measurements (cf. eq. 2.2) is:

$$(4.1) \quad P_c = k\,(P_m + \sum \Delta P_{im})$$

where P_m is the measured amount of precipitation, P_c is the corrected or "true" amount, $\sum \Delta P_{im}$ is the sum of various error sources (cf. chapter 2), and k is the correction factor due to aerodynamic effect. For liquid precipitation k is a function of wind speed at gauge rim level and rain intensity, and for solid precipitation k is a function of wind speed and temperature. Mixed precipitation is treated as a proportion of liquid and solid precipitation.

In practice P_c is estimated as $P_c \sim P_r + \sum \Delta P_{ir}$ where P_r is measured precipitation amount in a reference gauge (pit gauge, double fence gauge, snow pillow, bush gauge, etc.), and $\sum \Delta P_{ir}$ are the (known) errors for the reference gauge.

In the Nordic countries, different models for estimating the correction factor *k* have been used.

In **Denmark** Allerup and Madsen (1980) have set up a model for liquid precipitation measured in unshielded Hellmann gauge:

$$(4.2) \quad k = \exp[-0.00101 \cdot \ln(I/10) - 0.0082 \cdot v \cdot \ln(I/10) + 0.0420 \cdot v + 0.0100]$$

depending on wind speed v (m/s) measured at 10 m level and rain intensity I (mm/h).

In Denmark the operational corrections are based on measurements from unsheltered sites. Accordingly the gauge site exposure is taken into account when correcting the measured precipitation from the different stations. Three classes of shelter have been used:

A) Well-sheltered (q = 0.50)
B) Moderately sheltered (q = 0.75)
C) Unsheltered (q = 1.00)

where q is the constant to multiply (k-1) (cfr. eq. 4.2) to adjust for different site exposures. This model is further evaluated in this report, by incorporating the shelter effect directly in the reduction of wind speed from 10 m level to gauge level (see eq. 4.10).

For the **Finnish** gauge, (Solantie (1985a) proposed the following correction formula for liquid (eq. 4.3), and for solid and mixed precipitation (eq. 4.4):

(4.3) $k = 1/(1-0.0149v)$

and

(4.4) $k = 1/(1-0.0657v)$,

where wind speed v (m/s) is measured at 10 m level.

Field experiments in **Norway** (Førland,1981, Førland & Aune,1985, Dahlström et al.,1986) showed that the catch deficiency in the Norwegian gauge was quite similar to that of the US Belfort gauge, and could be described by a correction model suggested by Hamon (1973):

(4.5) $k = \exp[a(T) \cdot v]$

where v is windspeed (m/s) at the gauge orifice, and $a(T)=0.0134$ for rain ($T>1.7$°C), $a(T)=0.0271$ for mixed precipitation ($0<T\leq 1.7$°C), $a(T)=0.0486$ for snow and $-5<T\leq 0$ °C and $a(T)=0.0820$ for snow and temperature $-10<T\leq -5$ °C.

For the **Swedish** gauge, Dahlström (1973) has developed models for liquid (4.6) and solid precipitation (4.7):

(4.6) $k = 1+0.002v^2$

and

(4.7) $k = 1+0.004v^2$,

where the wind speed v is measured at 10 m level.

Some of the above-mentioned models are based on wind speed measured at gauge rim level, which, contrary to measurements at standard level 10 m, offers the advantage, that the influence of the roughness parameter can be ignored. Most of the Nordic models are based on measurements at rather low wind speeds. It is therefore uncertain whether these models are valid for higher windspeeds.

Concerning solid precipitation it must be pointed out, that blowing/drifting snow can influence the measurements seriously, especially in open fields and mountainous areas, when high wind speeds occur (cf. Sevruk (1982)). However, in most parts of the Nordic countries, this effect can be neglected.

4.2 Previous estimates of wetting and evaporation loss in Nordic precipitation gauges

Earlier investigations of wetting and evaporation errors for the gauges used in the Nordic countries were summed up by Dahlström et al. (1986).

4.2.1 Denmark.

For the Hellmann gauge, the wetting loss per precipitation day was estimated to 0.10 mm/day in winter increasing to 0.25 mm/day in the summer months. On an annual basis wetting loss was estimated to be 4.1 percent of the annual precipitation.

The evaporation error was stipulated to be only 0.24 per cent of the annual precipitation, i.e. about 2 mm per year.

4.2.2 Finland.

For wetting loss of the Tretyakov gauge the following corrections developed in USSR were confirmed by Finnish field studies: Solid precipitation 0.1 mm/precip.day, mixed or liquid precipitation 0.1-0.2 mm/precip.day.

From Russian investigations, the evaporation error for the Tretyakov gauge was stipulated to: May 1.3 mm, June 2.0 mm, July 2.8 mm, August 1.4 mm, September 1.4 mm, October 1.4 mm, with an annual total of 10.3 mm. Thus the monthly evaporation losses were of the same magnitude as the monthly sums of wetting losses.

4.2.3 Norway.

Wetting losses from the Norwegian gauges were estimated to 30-40 mm/year. It was pointed out that the Norwegian snow gauges can get a rough and cracked painted inner surface with large (>1 mm) waterholding capacity.

Field experiments showed that the average evaporation loss from the raingauge was less than 0.1 mm/day. The evaporation loss from the snow gauges was negligible during winter. During autumn and spring the mean evaporation from the snow gauges with funnel was about 0.3 mm/day. Without the loose funnel it was 0.9 mm/day, with maximum values exceeding 3 mm/day.

4.2.4 Sweden.

For the Swedish gauge the wetting loss was estimated to be about 0.1 mm per precipitation day. The evaporation error was stipulated to be between 0.5 and 1.0 mm on a monthly basis.

4.3 Recommended model 1 : "DYNAMIC CORRECTION MODEL".

As stated in chapter 2, the most important ΔP_{im} terms in the Nordic countries, are evaporation (ΔP_E) and wetting loss (ΔP_W), i.e. eq. (4.1) may be simplified to

$$(4.8) \quad P_c \sim k\,(P_m + \Delta P_E + \Delta P_W)$$

The first step in this model is to correct measured precipitation P_m for evaporation and wetting by using the values proposed in Table 5.2 and 5.3 respectively.

The errors caused by aerodynamic effects around the gauge are mainly dependent on the gauge type (structure of collector, windshield etc.), wind speed at the rim of the gauge, droplet size of raindrops and crystal structure of snowflakes.

The main assumptions in the "Dynamic Model" are that the droplet size for liquid precipitation can be described by rain intensity, and that the crystal structure for solid precipitation is a function of air temperature in the 2 m level. For mixed precipitation, the structure of the hydrometeors is dependent on both precipitation intensity and temperature.

The aerodynamic correction factor for precipitation accordingly can be expressed as the weighted sum of the corrections of liquid (l), solid (s) and mixed (m) precipitation:

$$(4.9) \quad k=(k_l \bullet r_l + k_s \bullet r_s + k_m \bullet r_m) \,/\, (r_l + r_s + r_m)$$

where k is the correction factor and r is the precipitation amount.

The wind speed (v_g) should preferably be measured at the level of the gauge orifice. If wind speed is measured at another level, WMO (1994) states: The reduction of wind speed to the level of the gauge orifice should be made according to the following formula:

$$(4.10) \quad v_g = (\log h z_0^{-1}) \bullet (\log H z_0^{-1})^{-1} \bullet (1-0.024\alpha) \bullet v_H$$

where

v_g = wind speed (m/s) at the level of the gauge orifice
h = height (m) of the gauge orifice above the ground
z_0 = roughness length (m): 0.01 m for winter and 0.03 m for summer
H = height (m) of the wind speed measuring instrument above the ground
v_H = wind speed (m/s) measured at the height H above the ground
α = average vertical angle (degrees) of obstacles around the gauge

The vertical angle (α) depends on the exposure of the gauge site, and can be based either on the average value of direct measurements, in eight directions of the wind rose of the vertical angle of obstacles around the gauge, or on the classification of the exposure using station informations stored in the archives of Meteorological Services. The different exposure classes are as presented in Table 4.1.

Table 4.1 Recommended values of α (eq.4.10) for different exposures.

Class	Angle(α)	Description
Exposed site	0 - 5	Only a few small obstacles such as bushes, group of trees, a house
Mainly exposed site	6 - 12	Small groups of trees or bushes, or one or two houses
Mainly protected site	13 - 19	Parks, forest edges, village centres group of houses, yards
Protected site	20 - 26	Young forest, small forest clearing, park with big trees, city centres, closed deep valleys, strongly rugged terrain, leeward of big hills

4.3.1 Correction model for liquid precipitation

It must be noticed that "liquid precipitation" means that no observations of snow or sleet have occurred during the observation period, i.e. $r_s = r_m = 0$ in eq.4.9.

For correcting liquid precipitation for systematic errors caused by aerodynamic effects around the gauge, a modified version of the model (eq. 4.2) of Allerup and Madsen (1980) has been selected. This model has the advantage of being based on a relatively large data set. Further the model is a function of wind speed during precipitation and rain intensity.

The model was originally (eq. 4.2) just valid for an unshielded Hellmann gauge. To apply this correction model for other gauges, different gauge coefficients should be included in eq. 4.2. Data from e.g. the measurements of liquid precipitation in the Jokioinen experimental field may be used to elaborate gauge coefficients for the gauges there. However, the main purpose of the WMO Intercomparison Project was to study solid precipitation, and accordingly the Nordic Working Group has been concentrating its efforts on correction methods for snow. It therefore still remains to implement exact gauge coefficients in eq.4.11.

From the investigations in Jokioinen (cf. Table 3.7) and other empirical results (Førland, 1994), a first approximation is that shielded gauges catch about 5% more liquid precipitation than unshielded gauges (cf. Table 4.5). Therefore a rough gauge coefficient c is introduced in eq. 4.2 to distinguish between correction for gauges with and without windshield.

Eq. 4.2 is based on wind speed measured at the 10 m level, and in Denmark corrections for more sheltered locations are performed as stated in chapter 4.1. Instead of modifying the correction factors by shelter classes, it is more appropriate to use wind speed at gauge level in the correction model. If wind speed is measured at other levels or at a representative neighbouring site, it should be reduced to gauge level by eq. 4.10.

The modified model for aerodynamic correction of liquid precipitation is then:

(4.11) $k_l = \exp[-0.00101\bullet\ln I - 0.012177\bullet v_g\bullet\ln I + 0.034331\bullet v_g + 0.007697 + c]$

depending on gauge coefficient c (unshielded gauge c=0.0, shielded gauge c=-0.05), windspeed v_g (m/s) measured at gauge level and rain intensity I (mm/h).

This model is tested on liquid precipitation measured during the winter season at the Jokioinen experimental field. The results for the Hellmann gauge are shown in Figure 4.1.

If intensity (I) in eq.(4.11) is not recorded or cannot be deduced from a neighbouring station, or from rain amount and duration, the present weather code (ww) can be used to get a rough measure of I. In a regression analysis based on Swedish data (Häggmark, 1995), precipitation amount RR was calculated as a function of the WMO present weather code ww. The predictand was 12-hour acccumulated precipitation, and predictors were 4 observation terms of ww. Through this analysis 10 classes of 3 hour precipitation rates were established. The results are reproduced in Table 4.2.

Table 4.2 Estimated precipitation intensity class from observed WMO present weather code

ww	0	1	2	3	4	5	6	7	8	9
00	00	00	00	00	00	00	00	00	00	00
10	00	00	00	02	00	01	02	03	01	00
20	01	03	01	03	01	03	01	02	00	05
30	00	00	00	00	00	00	01	00	03	00
40	00	00	00	00	00	00	01	01	00	00
50	01	02	02	03	03	05	01	02	03	04
60	03	04	04	07	08	10	02	01	03	07
70	01	02	02	04	02	07	01	01	01	01
80	03	06	07	03	04	01	02	02	05	05
90	05	04	10	09	09	07	04	09	00	08

Table 4.3 Precipitation intensity (mm/3h) for intensity classes in Table 4.2

Class	0	1	2	3	4	5	6	7	8	9	10
mm/3h	0.00	0.16	0.45	0.85	1.70	2.38	2.93	3.78	5.53	7.22	7.98
=>mm/h	0.00	0.05	0.15	0.28	0.57	0.79	0.98	1.26	1.84	2.40	2.66

Thus, if a station reports ww=62, Table 4.2 indicates that the intensity-class is 04 and according to Table 4.3 the intensity I=0.57 mm/h.

Table 4.2 and 4.3 were based on totally 136 000 precipitation observations from Sweden. In areas in the Nordic countries with enhanced orographic precipitation, these intensities probably will underestimate the precipitation intensity. Until further informations are available, we recommend to use one of the following procedures for estimation of intensity a). Adjustment of values in Table 4.3 for ww=21-24 and 60-79 for differences in normal precipitation. It is anticipated that the intensities in Table 4.2 are representative for stations with a normal precipitation of 1000 mm/year. For a station with normal annual precipitation of PN, the intensities in table 4.3 should be multiplied by a factor F1= PN/1000. Thus for a station with PN=400 mm/year, ww=62 indicates I=0.23 mm/h, while for a station with PN=3000 mm/yr, ww=62 indicates I=1.7 mm/h.

b). Application of measured precipitation amount, P_m. If duration (t) of precipitation can be estimated, the intensity can be roughly estimated as: $I=P_m/t$. Accordingly for a precipitation amount of 12 mm, and a duration of 7h, the mean intensity is I=12/7=1.7 mm/h.

4.3.2 Correction model for solid precipitation

Data from the experimental field at Jokioinen have been submitted to statistical analysis with the purpose of setting up models for correcting solid and mixed precipitation. The data include twelve-hour precipitation values from the period November 1987 - March 1993 measured at a reference gauge placed in a Valdai double fence (DFIR) and at the national gauges from the Nordic countries of Denmark, Finland, Norway and Sweden. The values resulting from weighing, thus wetting errors are partly excluded. For the same period 10 minutes values of registration of wind and temperature are providing averages of wind speed measured at gauge rim and temperature during precipitation. Furthermore synoptic weather observations from the Jokioinen Observatory gave detailed information about precipitation types (rain, sleet, snow etc.)

"Solid precipitation" means that no observations of rain have occcurred during the observation period, i.e. $r_l = r_m = 0$ in eq.(4.9). The model for correcting aerodynamic effect for solid precipitation are based on about 325 twelve-hour observations of snowfall larger than 0.1 mm (Madsen,1995, Allerup et al.,1996):

$$k_s = \exp[\beta_0 + \beta_1 \cdot v_g + \beta_2 \cdot T + \beta_3 \cdot v_g \cdot T] \qquad (4.12)$$

where v_g is wind speed (m/s) at gauge level and T temperature (°C). The constants β_0, β_1, β_2 and β_3 have been estimated for the four Nordic gauges, taking into account the correction of the DFIR according to eq. (3.1) of Golubev (see Table 5.6).

Figure 4.2 shows scatter plot of predicted and observed correction factors in the Jokioinen experimental field for the Hellmann gauge.

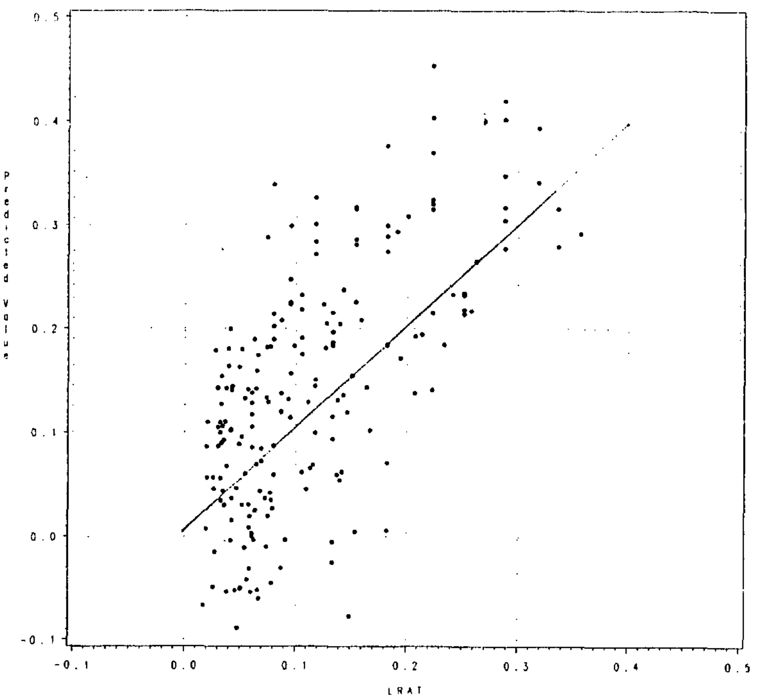


Figure 4.1 Predicted logarithmic correction factors k_l for **liquid precipitation** in the Hellmann gauge using model 4.11 (ordinate) and observed ratio DFIR/Hellmann (abscissa). Overall fit: $R^2=0.41$. Site: Jokioinen, Finland.

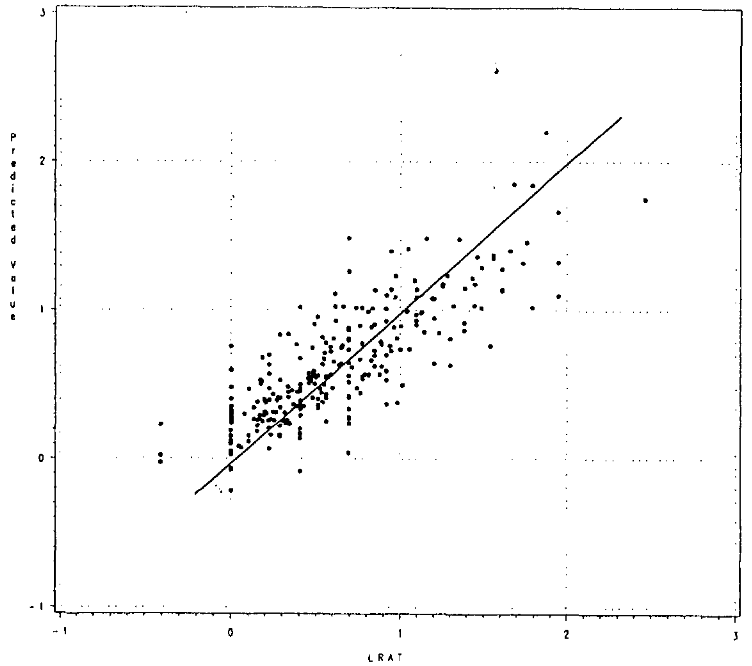


Figure 4.2 Predicted logarithmic correction factor k_s for **solid precipitation** in the Hellmann gauge using model 4.12 (ordinate) and observed ratio DFIR/Hellmann (abscissa). Overall fit: $R^2=0.61$. Site: Jokioinen, Finland

4.3.3 Correction model for mixed precipitation

In this report "Mixed precipitation" means that the precipitation type is reported as sleet or as a mixture of rain and snow.

It was attempted to develop a specific correction model for mixed precipitation, based on a dataset from Jokioinen of 219 cases of mixed precipitation. Unfortunately too much noise in data made it impossible to establish any significant correction model.

Mixed precipitation is compounded by solid, liquid and/or melting precipitation particles. Accordingly it is reasonable to expect that the mixed model should combine the models for liquid (chapter 4.3.1) and solid (chapter 4.3.2) precipitation. Thus the correction factor (k_m) for mixed precipitation could be written as:

$$(4.13) \quad k_m = (r_l \cdot k_l + r_s \cdot k_s) / (r_l + r_s)$$

where k_l and k_s are correction factors for liquid (eq. 4.11) and solid (eq. 4.12) precipitation, and r_l and r_s are proportions of precipitation falling in liquid and solid form. When $r_l >> r_s$ the correction factor k_m will be close to the liquid model, while it will be close to the solid correction factor if $r_s >> r_l$.

The models (4.11) and (4.12) for liquid and solid precipitation is thus used for calculating the correction factor k_m. The air temperature T should be averaged during the solid part of the precipitation and the rain intensity I should represent the liquid part only.

A serious problem with this procedure, is that normally the proportions of liquid and solid precipitation are not known. Also it is difficult to estimate T, I and v_g during liquid respectively solid precipitation. If the precipitation type has not been observed it can be derived from air temperature (see section 5.4.3).

If it is not possible to estimate the relative proportions r_l and r_s, the approximation $r_s = r_l = 0.5$ should be used. In this case eq.(4.13) becomes:

$$(4.14) \quad k_m = 0.5 \cdot k_l + 0.5 \cdot k_s$$

This is only correct if the aerodynamic error of mixed precipitation is the average of the error of the solid and liquid part. On average this is assumed to be correct.

4.3.4 Evaluation of the dynamic correction model

The models (eq. 4.11 and 4.12) provide point estimates of the correction values for liquid and solid precipitation respectively. Since the models have been fitted to the data using regression analysis techniques with log-values of eq. 4.11 and 4.12, confidence limits for expected values of the correction factor k can readily be obtained. In fact if S is standard deviation, the general formula for a 95% confidence interval of the expected value E(log*k*) is the following:

$\mathrm{Conf}_{95\%}(E(\log k)) = \text{point estimate } \pm t_{97.5\%} \bullet S$

where the "point estimate" for liquid precipitation is represented by the correction factor k for a given wind speed v_g and rain intensity I (cf. eq.4.11). Similarly the "point estimate" for solid precipitation is represented by the correction factor k for wind speed v_g and temperature T (cf. eq.4.12).

It can be estimated as an average that the standard deviation S ~ 0.06 for liquid and S ~ 0.08 for solid precipitation. Consequently, a ±1 standard deviation means approximately 0.94 to 1.06 as <u>error</u> factor to be multiplied to the correction factor in case of liquid precipitation, and approximately 0.92 to 1.08 to be multiplied as <u>error</u> factors to the correction factor in case of solid precipitation.

Additional uncertainties are caused by systematic local wind gradients in the test field. E.g. there are differences even in total amounts for the three identical Tretyakov gauges (no. 1, 9 and 13) in the Jokioinen experimental field (cfr. Table 3.6-3.9). For individual events the differences may be even larger. Some of these differences are systematic, caused by wind gradients within the test field. Such wind gradients are documented by the network of wind sensors within the test field, and will influence on the constants β in eq.4.12.

Also it should be recognised that rather few cases with high wind speeds and/or low temperatures were experienced in the Joikionen test field during the rather mild winters (cf. Table 3.2) in the intercomparison period. The model for solid precipitation is thus just valid for wind speeds below 7 m/s and temperatures higher than -12°C.

The models outlined in this section should be evaluated on independent data from other sites. Some scattered parallel measurements (cf. eg. Appendix 2), indicate that the correction models may be different for sites in different climatic regions. One possible reason may be that temperature is not a perfect descriptor of the structure of snow crystals (see also chapter 5.1). The structure of snow crystals clearly is not solely dependent on ground temperature, but also on temperature, humidity, windspeed etc. in the clouds and along the trajectory from the cloudbase to the ground. In addition to obvious differences between individual snow events, it is not unreasonable to expect systematic differences in snow crystals for a given temperature at coastal resp. continental sites.

The structure of the correction model for liquid precipitation (eq. 4.11) has been subject to test of fit on several independent data sets (Allerup et al., 1996), including data from Jokioinen (Figure 4.1). The actual values for the coefficients in eq.4.11 should however be evaluated also for shielded gauges, and not by the rather crude "windshield" coefficient c.

For solid precipitation, no data were available at this stage to perform detailed verification of the models on independent datasets. Hopefully the data compiled within the WMO Solid Precipitation Measurement Intercomparison will provide material for testing of models on data from different climate regimes.

However, some key data from the WMO intercomparison sites are presented by Yang et al. (1995). For the shielded Tretyakov gauge, a simplified equation of the (daily) gauge catch ratio (R) of snow versus (daily) wind speed was developed from the compiled Intercomparison set:

$$(4.15) \quad R = \exp(4.605-0.06 \cdot v_g^{1.4}) \qquad (n=392, \quad r^2=0.65)$$

where v_g is wind speed (m/s) at gauge level. The correction factor k from eq. 4.15 and from earlier studies by Goodison (1977) and Golubev (1985) are summarised in Table 4.4 together with results from equation 4.12 in this study.

Table 4.4 Correction factor k for shielded Tretaykov gauge for different wind speeds. Results are based on models developed by Goodison (1977), Golubev (1985), Yang et al. (1995) and eq. 4.12 in this study

Model	Wind speed at gauge level (m/s)								
	0	1	2	3	4	5	6	7	8
Goodison	1.00	1.10	1.24	1.43	1.64	1.89	2.22	2.70	3.23
Golubev	1.00	1.01	1.14	1.30	1.54	1.82	2.13	2.63	3.13
Yang et al.	1.01	1.06	1.18	1.33	1.52	1.79	2.08	2.50	3.03
This study *									
a). T=0	1.00	1.09	1.25	1.42	1.63	1.86	2.13	2.43	2.78
b). T=-5	1.00	1.07	1.25	1.47	1.72	2.02	2.37	2.78	3.26
c). T=-10	1.00	1.05	1.26	1.52	1.83	2.20	2.65	3.18	3.83

* Equation 4.12 with coefficients for shielded Tretyakov gauge (Table 5.6, see ch.5.3.1b). Please notice that for low wind speeds (<2 m/s) the model leads to some minor discrepancies.

The results in Table 4.4 are visualised in Figure 4.3. For temperatures in the interval -5 to 0 °C, there is an excellent agreement between the earlier studies and the results from eq.4.12 in this study. The correction factors for low temperatures (T=-10°C) seem to be underestimated by the models not including temperature.

Figure 4.3 and Table 4.4 states that even for wind speeds as low as 5 m/s, all models indicate that the true solid precipitation is about twice as high as the measured.

Based on informations presented by Yang et al.(1995), Table 4.5 gives a survey of intercomparison results for the Tretyakov gauge from 11 WMO experimental fields. The correction factor k1 in Table 4.5 is calculated by just inserting the mean values of temperature (average of maximum and minimum temperatures) and mean wind speed in eq. 4.12. Although using mean values in exponential models like eq.4.12 gives rather crude estimates, Figure 4.4 indicates that this model provides quite representative correction factor for all experimental fields. In fact the largest discrepancy is for the Jokioinen field.

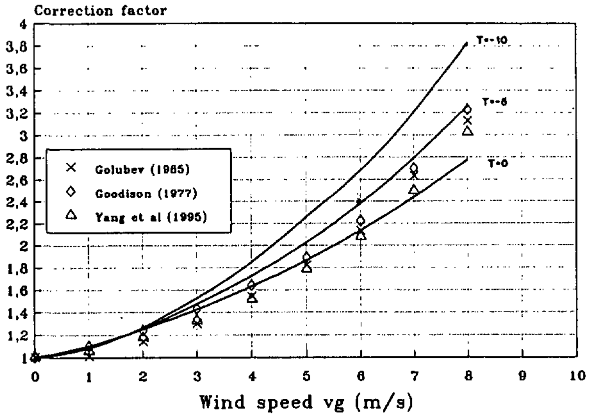


Figure 4.3 Correction factors for solid precipitation in shielded Tretyakov gauge.

Full drawn lines are based on eq. 4.12. Correction factors for three earlier studies (see Table 4.4) are also included

Table 4.5 Key data from 11 WMO Intercomparison sites (from Yang et al., 1995).

k1 is correction factor from eq.4.12 and k2 is correction factor estimated by Yang et al.

Site	Country	Alt masl	N	Tmax degC	Tmin degC	Tmean degC	V3 m/s	V1.5 m/s	DFIR mm	TRET mm	DF/TR	k1	k2
Valdai (VA)	RUS	194	304	-2.8	-4.2	-3.5	4.1	3.6	1182	746	1.58	1.59	1.58
Reynolds (RN)	USA	1193	50	3.0	-6.3	-1.7	2.5	2.2	106	89	1.19	1.28	1.11
Vermont (VE)	USA	552	157	-2.2	-11.7	-7.0	1.5	1.3	1036	950	1.09	1.12	1.09
Jokioinen (JK)	FIN	104	334	-2.3	-5.8	-4.1	2.6	2.3	741	498	1.49	1.31	1.37
Harzgerode (HA)	GER	404	42	-1.1	-6.3	-3.7	3.0	2.6	113	81	1.39	1.37	1.36
Bismarck (BI)	USA	502	32	-5.4	-12.3	-8.9	3.3	2.9	95	62	1.53	1.48	1.33
Joseni (JS)	ROM	750	94	-1.0	-8.9	-5.0	1.1	1.0	194	167	1.16	1.07	1.11
Parg (PA)	CRO	863	65	-1.4	-8.6	-5.0	1.0	0.9	487	443	1.10	1.05	1.08
Peterborough (PE)	CAN	230	76	-1.5	-12.2	-6.9	2.0	1.8	262	213	1.23	1.21	1.17
Regina (RG)	CAN	577	86	-5.0	-14.9	-10.0	3.1	2.7	160	99	1.62	1.44	1.38
Kortright (KO)	CAN	208	107	-0.8	-10.6	-5.7	2.5	2.2	275	228	1.21	1.30	1.28
Overall			1347	-1.9	-9.3	-5.6	2.4	2.1	4650	3575	1.30	1.27	1.27

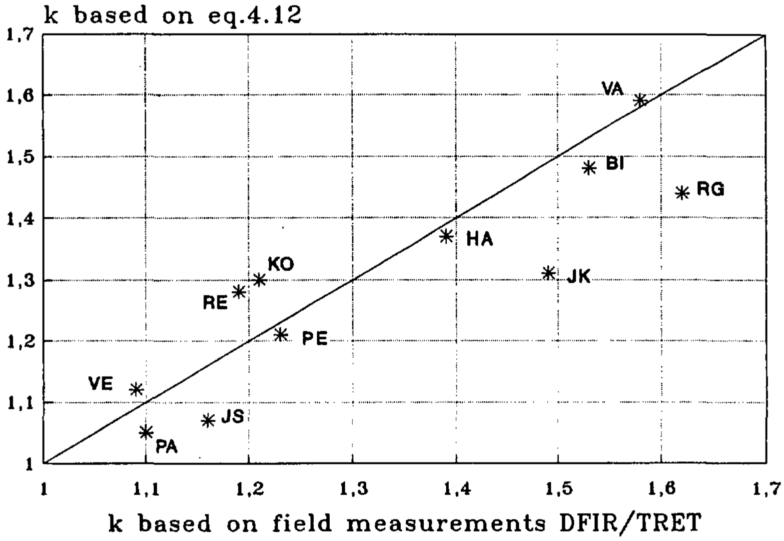


Figure 4.4 Correction factors for shielded Tretyakov gauge at 11 WMO Intercomparison sites. Abscissa is ratio DFIR/Tretyakov and ordinate is mean values of T and v inserted in eq.4.12

4.4 Recommended model 2 : "SIMPLE CORRECTION MODEL" (Monthly values)

For rough correction of monthly values for shielded Nordic gauges, Dahlström et al. (1986) recommended standard correction factors for solid and liquid precipitation (Table 4.4). For mixed precipitation the correction factors for liquid and solid precipitation are weighted according to the relative amounts of rain and snow.

Table 4.4 Standard correction factors for monthly precipitation

Class	Exposure	Correction factor k		
		Liquid	Solid	Solid (Wild)
1	Extremely sheltered small glade in forest	1.02	1.05	1.04
2	Intermediate position between forest and plain	1.05	1.10	1.20
3	Relatively unsheltered location on a plain	1.08	1.20	1.40
4	Relatively unsheltered location in coastal or mountain region	1.11	1.40	1.80
5	Extremely unsheltered location in coastal or mountain region	1.14	1.80	2.50

These correction factors are recommended for gauges with windshield. For **unshielded gauges** the correction factor is higher than the values above. For snow, Table 4.5 shows precipitation amounts 21 to 75 percent higher in shielded than unshielded gauges. For mixed precipitation the difference is 4 to 26 percent and for rain below 10 percent.

Table 4.5. Ratio between precipitation measured in shielded and unshielded gauges at various experimental fields.

				Ratio shielded / unshielded		
Country	Site	(Reference)	Gauge type	Rain	Mixed	Snow
Finland	Jokioinen	(a)	Tretyakov	1.05	1.17	1.50
		(a)	Wild	1.01	1.08	1.42
USA	Idaho	(b)	US Standard	1.09	1.26	1.45-1.75
Norway	3 stations 0-300 ma.s.l.	(c)	Norwegian	1.00	1.04	-
	7 stations 300-800 m a.s.l.	(c)	Norwegian	1.01	1.09	1.21
	6 stations 800-1000 m a.s.l.	(c)	Norwegian	1.03	1.17	1.23
	3 stations 1000-1300 m a.s.l.	(c)	Norwegian	1.09	1.20	1.39
	Fillefjell 950 m a.s.l.	(d)	Norwegian	1.00	1.11	1.59
	Groset 950 m a.s.l.	(e)	Norwegian	1.04	1.21	1.33
	Groset 950 m a.s.l.	(e)	Belfort	1.04	1.18	1.36

References: a) Elomaa et. al. 1993, b) Hamon (1973) c) Hesselberg (1945) d) Furmyr (1975) e) Førland & Joranger (1980)

4.5 Finnish correction model

In Finland an "exposure model" is used to correct point precipitation measurements. This correction method is developed by Solantie (1985a,b) and it is based on the theory of Korhonen (1942). Sarkanen (1989) has developed computer methods to calculate corrections.

The exposure method is adequate for a station, where no wind sensor exists at precipitation gauge level.

In this model the correction factor k in eq. (2.2) is:

$$k = 1 + k_v \bullet k_c = 1 + (k_{va} \bullet k_{vr} \bullet k_{vt}) \bullet k_c \tag{4.15}$$

The factor k_c depends on the form of precipitation and on the type of the gauge (cf. Table 4.6). The wind factor $k_v = k_{va} \bullet k_{vr} \bullet k_{vt}$ consists of an exposure factor k_{va}, an areal wind coefficient k_{vr} and an actual wind coefficient k_{vt}.

This method is based on mean wind conditions in Finland, and is only valid for gauges used in Finland (Wild, Tretyakov, Finnish H&H gauge). At the moment it is therefore not possible to use this method in the other Nordic countries. However it should be mentioned that a verification of the method by using data from Jokioinen experimental field gave very promising results for the Tretyakov and H&H gauges (see Appendix 1).

The exposure method provides tools to correct precipitation values from a climate or a precipitation station by using weather data from the nearest synoptic station as help. Still the coast area and stations located far away from the nearest synoptic station cause problems. One solution might be that wind field could be calculated from weather prognosis.

Table 4.6 "Precipitation type" correction factor k_c in the exposure model for Wild and Tretyakov gauge.

Precipitation type	Temperature (T) interval (°C)	Correction factor k_c	
		Wild	Tretyakov
Drizzle	-	0.34	0.05
Rain	-	0.01	0.01
Sleet, Mix Rain/Snow	≥ 0	0.13	0.05
Snow	$-8 < T < 0$	0.28	0.18
Snow	$T \leq -8$	0.40	0.18
Shower	$T \leq 1$	0.28	0.18
Shower	$T > 1$	0.01	0.01

5. GUIDELINES FOR OPERATIONAL PRECIPITATION CORRECTION FOR DIFFERENT TYPES OF STATIONS

5.1 Introductory comments

The general precipitation correction models developed for the Nordic countries are described in chapter 4. The essential meteorological information needed for correction of aerodynamic errors are wind speed at the rim of the gauge, size of raindrops and crystal structure of snowflakes. The size and structure of hydrometeors are difficult to assess at regular measuring sites. Therefore in the models in chapter 4, rain intensity is used as a measure of droplet size and air temperature at the ground is used to indicate the crystal structure of snowflakes.

Actually the droplet size is not uniform but exhibits a wide spectrum, and in addition this spectrum usually varies during the sampling interval. Thus there is no perfect relationship between rain intensity and droplet size. Likewise, the structure of snowflakes is not just a function of the ground temperature, but of temperature, humidity, windspeed etc. in the clouds and along the trajectory from cloudbase to ground. Thus the use of intensity and temperature to describe size and structure of hydrometeors implies rather coarse approximations, and unfortunately also other coarse approximations have to be done in operational corrections.

The aerodynamic error is different for different types of gauges and windshields. Also the wetting and evaporation errors are depending on the gauge type. Accordingly the operational corrections for wind, wetting and evaporation must be specified for each gauge type. Table 5.1 gives a survey of the most common precipitation gauges in the Nordic countries, and which gauges were tested in the experimental field in Jokoionen.

Table 5.1 Precipitation gauges in the Nordic countries

Gauge type	Country	Shield-type	Jokioinen No. (see ch. 3.2.1)
Manual			
Hellmann	Denmark	-	15
Swedish	Sweden, Norway	Nipher	11
Finnish H&H	Finland (from 1992)	Tretyakov	22
Norwegian	Norway	Nipher	8
Tretyakov	Finland (1982-1991)	Tretyakov	1,9,13
Vedurstofa	Iceland	Nipher	-
Wild	Finland (until 1982)	Nipher	14
Automatic			
Tipping b.			
Friedrichs	Sweden	-	4
Rimco	Denmark	-	19
Lambrect	Norway	Alter	-
Plumatic	Norway, Sweden	-	-
Wild	Finland	-	3
Weightpluv.			
Belfort	Norway	Alter	-
Geonor	DK, FI, IC, NO, SW	Alter	12

5.2 Operational correction of wetting and evaporation loss

Wetting and evaporation for different gauges were studied in the experimental field at Jokioinen (cf. chapter 3). Earlier studies of wetting and evaporation from the Nordic gauges are presented by Dahlström et al. (1986), and are summed up in chapter 4.2.

The rather high evaporation values during springtime is mainly due to the practice of using gauges without funnel during the cold season. For the Finnish and Tretyakov gauges the mean evaporation in April is higher than 0.8 mm/day due to this practice (cf. Table 3.5a). During summer the evaporation is reduced by loose funnels inserted into the collectors. The Norwegian gauge consists of a winter gauge with loose funnel, while the summer gauge has a fixed funnel with good protection against evaporation. Note that the old Wild gauge has very low evaporation during the whole year, while the Tretyakov gauge has the highest values for three of the seasons. To reduce evaporation, it is of crucial importance that the loose funnel in the gauges is inserted during warm periods spring and autumn.

The mean evaporation values from the field experiments in Jokioinen (Table 3.5a) are representing an overestimate of the real evaporation loss from precipitation gauges. This is due to the fact that evaporation was just measured at dry days without precipitation, and that the water in the gauges was exposed to evaporation during the whole day. Typical evaporation values are therefore estimated by comparing minimum values (Table 3.5b) to values equal to 25% of the mean values (Table 3.5a). The smoothed monthly values recommended for operational use are presented in Table 5.2.

The wetting error may differ substantially between identical gauges with different wear and tear. Recommended wetting amounts for different precipitation types based on the field experiments in Jokionen (Table 3.6-3.9) are presented in Table 5.3.

There are large day to day variations in the magnitude of the evaporation and wetting errors, depending on radiation, precipitation amount, duration of precipitation, storage time of precipitation in the gauges, air humidity, wind speed, etc.

However, on monthly, seasonal and annual basis, the results from Table 5.2 and 5.3 probably give a realistic magnitude of evaporation and wetting for the **manual** gauges in the Nordic countries.

Even recordings from **automatic** gauges are influenced by evaporation and wetting errors. For the tipping bucket gauges, remaining precipitation in the "buckets" after a rain event may evaporate before the next event. In the weight pluviographs, evaporation from the storage container is reduced by an oil film at the top of the collected water, but this oil film will not totally prevent evaporation. By proper software handling of the signals from the weight pluviograph, it is however possible to detect and correct for evaporation during periods without precipitation. In addition there are wetting losses from the walls and funnels in the automatic gauges.

Table 5.2 Recommended values of mean daily evaporation loss (mm/day) for Nordic manual gauges

	FinnishH&H90 (22)	Tretyakov (01)	Wild (14)	Danish (15)	Swedish (11)	Norwegian (08)
January	0.03	0.03	0.01	0.01	0.02	0.02
February	0.04	0.04	0.02	0.02	0.03	0.02
March	0.06	0.05	0.03	0.03	0.04	0.03
April	0.20	0.22	0.01	0.04	0.12	0.16
May	0.04	0.13	0.01	0.09	0.10	0.04
June	0.05	0.15	0.01	0.15	0.15	0.06
July	0.05	0.15	0.01	0.16	0.15	0.06
August	0.05	0.10	0.01	0.08	0.10	0.05
September	0.04	0.05	0.01	0.02	0.05	0.03
October	0.03	0.03	0.01	0.01	0.03	0.02
November	0.03	0.03	0.00	0.01	0.03	0.02
December	0.03	0.03	0.00	0.01	0.02	0.02

Weighing gauges:	Evaporation is zero (if correct evaporation preventing oil is applied)
Tipping bucket gauges:	Evaporation should be estimated as 25% of bucket capacity.

Table 5.3 Recommended values of wetting amounts in Nordic manual gauges

	WETTING (mm/case)			
GAUGE TYPE	Rain	Drizzle	Snow	Mixed
DANISH HELLM.	0.14	0.13	0.10	0.18
SWEDISH	0.07	0.06	0.02	0.06
FINNISH(H&H90)	0.13	0.09	0.05	0.11
NORWEGIAN	0.15	0.14	0.05	0.13
TRETYAKOV	0.14	0.12	0.09	0.14
WILD	0.07	0.05	0.03	0.07
Weighing gauge	0.15	0.15	0.10	0.15
Tipping bucket	0.15	0.15	0.10	0.15

5.3 Operational correction models for aerodynamic effects

The errors caused by aerodynamic effects around a gauge may be estimated by the models outlined in chapter 4. If a correction model exists for the actual gauge, and all necessary input parameters (wind speed, temperature, rain intensity etc.) are measured at the station, the equations in chapter 4 can be used directly. However, in practice this is rarely the case. Equipment, number of elements observed, and sampling intervals differ substantially for different types of stations. The most common station types for precipitation measurements are listed in Table 5.4.

Table 5.4 Meteorological stations with precipitation measurements

1. Automatic weather station
2. Automatic precipitation station
3. Weather station (synoptic station)
4. Climate station
5. Precipitation station
6. Other types (Monthly precipitation, etc.)

The observation programme at some well-equipped automatic or manual weather stations contains all information needed for operational use of the models in chapter 4. On the other hand, some precipitation stations just measure the amount of precipitation and nothing else. It is therefore important to group the aerodynamic correction models according to input parameters. For simplicity two basic correction models will be recommended for the Nordic countries: a) "Dynamic Correction Model" (chapter 4.3) and b)."Simple Correction Model" (chapter 4.4). For operational correction in Finland, the "Exposure Model" (chapter 4.5) may also be used.

Table 5.5 Definition of variables in correction models for precipitation

I = precipitation intensity (mm/hour)
V_g = wind speed (m/s) at gauge level
P = precipitation amount (mm)
T = temperature (°C)
ww = weather type (synop code)
k = correction factor due to aerodynamic effects (eq.2.2)
β,c = gauge coefficients (se chapter 4.3)

5.3.1. DYNAMIC CORRECTION MODEL

This model (described in chapter 4.3) can be applied for all the Nordic gauges. The **corrected precipitation (P_c)** is estimated as:

$$(5.1) \qquad P_c = k \bullet (P_m + \sum \Delta P_{im}) \sim k \bullet (P_m + \Delta P_W + \Delta P_E)$$

where P_m = measured precipitation

$\sum \Delta P_{im}$ = sum of errors caused by wetting loss, evaporation, etc (cf. ch. 4.1)

ΔP_W = wetting loss (see Table 5.2)

ΔP_E = evaporation loss (see Table 5.3)

k = correction factor

a). Liquid precipitation

$$(5.2) \qquad k_l = \exp[-0.00101 \bullet \ln I - 0.012177 \bullet v_g \bullet \ln I + 0.034331 \bullet v_g + 0.007697 + c]$$

where: c = gauge coefficient (see Table 5.6)

v_g = windspeed (m/s) at gauge height

I = rain intensity (mm/h)

b). Solid precipitation

$$(5.3) \qquad k_s = \exp[\beta_0 + \beta_1 \bullet v_g + \beta_2 \bullet T + \beta_3 \bullet v_g \bullet T]$$

$$\boxed{\begin{array}{c} 1.0 < v_g \leq 7.0 \text{ m/s} \\ T \geq -12^\circ C \end{array}}$$

$$k_s = 1.0 \text{ if } v_g \leq 1.0 \text{ m/s}$$

where: β_i = gauge coefficients (see Table 5.6)

v_g = windspeed (m/s) at gauge height

T = temperature (°C)

c). Mixed precipitation

$$(5.4) \qquad k_m = (r_l \bullet k_l + r_s \bullet k_s) / (r_l + r_s)$$

where k_l and k_s are correction factors for liquid (eq. 4.11) and solid (eq. 4.12) precipitation, and r_l and r_s are amounts of precipitation falling in liquid and solid form. When $r_l >> r_s$ the correction factor k_m will be close to the liquid model, while it will be close to the solid correction factor if $r_s >> r_l$. If it is not possible to estimate the relative proportions r_l and r_s, the approximation $r_s = r_l = 0.5$ should be used. In this case eq.(5.4) becomes:

$$(5.5) \qquad k_m = 0.5 \bullet k_l + 0.5 \bullet k_s$$

Table 5.6 Recommended gauge coefficients for Nordic precipitation gauges

GAUGE	SHIELD	LIQUID	SOLID PRECIPITATION			
		c	B0	β1	β2	β3
Hellmann	-	0.00	0.04587	0.23677	0.017979	-0.015407
Swedish	Nipher	-0.05	-0.08871	0.16146	0.011276	-0.008770
Norwegian*	Nipher	-0.05	-0.12159	0.18546	0.006918	-0.005254
Finnish	Tretyakov	-0.05	-0.07556	0.10999	0.012214	-0.007071
Tretyakov	Tretyakov	-0.05	-0.04816	0.13383	0.009064	-0.005147
Belfort	Alter		Same as Norwegian gauge			
Geonor	Alter		Same as Norwegian gauge			
Friedrichs	-		Same as Hellmann (**)			
RIMCO	-		Same as Hellmann (**)			
Lambrechts	-		Same as Hellmann (**)			

(*) See footnote on page 18

(**) Tipping bucket gauges (even with heating) are not reliable at temperatures below zero degrees Celcius

If k, ΔP_E and ΔP_W are known for a specific gauge, the strictly correct way of correcting precipitation is to add ΔP_E and ΔP_W to the measured precipitation P_m, and then multiply this sum by the correction factor k. Evaporation loss ΔP_E is usually estimated as a 24h value. To avoid to split the daily evaporation into hourly values, the following simplification is recommended for operational correction for stations with more than one daily precipitation measurement (or registration):

Use the factor k for each (*i*) precipitation value: $P_{c,i} = k_i \bullet P_{m,i}$

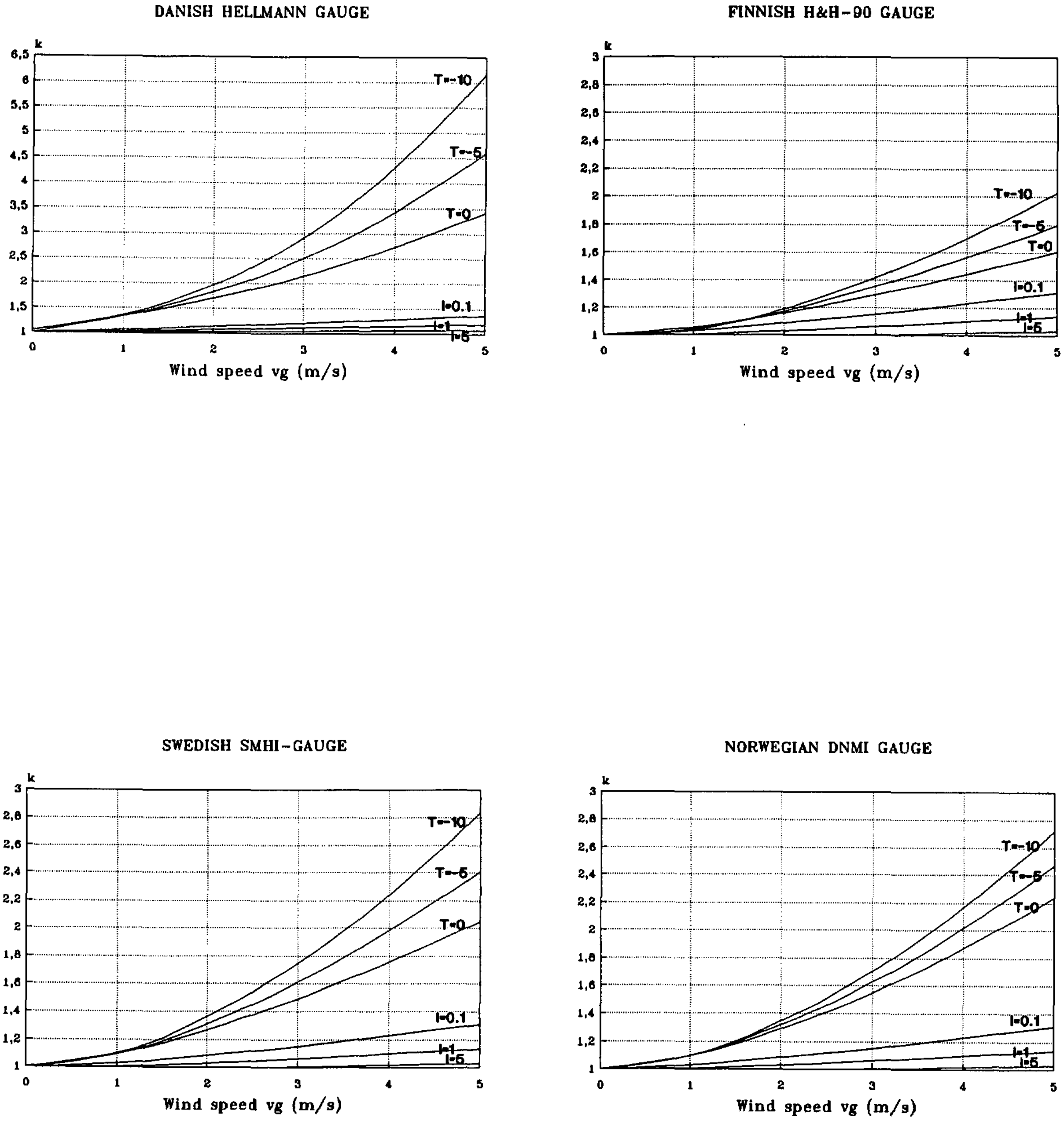
Summarize the measured $(\sum P_{m,i})$ and corrected $(\sum P_{c,i})$ daily sums of precipitation

Calculate the daily correction factor $k=(\sum P_{c,i}) / (\sum P_{m,i})$

Use the daily k-factor to estimate the corrected daily evaporation $(k \bullet \Delta P_E)$ and wetting loss $(k \bullet \Delta P_W)$

The corrected daily precipitation amount is then: $P_c = \sum P_{c,i} + k \bullet \Delta P_E + k \bullet \Delta P_W$

Practical examples of this procedure is presented in chapter 5.4



DANISH HELLMANN GAUGE

FINNISH H&H-90 GAUGE

SWEDISH SMHI-GAUGE

NORWEGIAN DNMI GAUGE

Figure 5.1 Correction factors for Nordic precipitation gauges

Liquid precipitation, eq.4.11 for intensities I=0.1, 1.0 and 5.0 mm/h

Solid precipitation, eq.4.12 for temperatures T=0, -5 and -10 °C

5.3.2 SIMPLE CORRECTION MODEL

By this model (described in chapter 4.4) the corrected precipitation (P_c) is :

$$(5.4) \quad P_c = k \bullet (P_m + \sum \Delta P_{im}) \sim k \bullet (P_m + \Delta P_W + \Delta P_E)$$

where P_m = measured precipitation
$\sum \Delta P_{im}$ = sum of errors caused by wetting loss, evaporation, etc (cf. ch. 4.1)
ΔP_W = wetting loss (see Table 5.3)
ΔP_E = evaporation loss (see Table 5.2)
k = correction factor

In this model (cf. ch. 4.4), the correction factor k is:

Class	Exposure	Correction factor k Liquid	 Solid	 Solid*
1	Extremely sheltered small glade in a forest (inland or coast)	1.02	1.05	1.04
2	Intermediate position between forest and plain, ≥ 10 km from coast	1.05	1.10	1.20
3	Relatively unsheltered location on a plain, ≥10 km inland from the coast	1.08	1.20	1.40
4	Relatively unsheltered location at the coast or in the mountains	1.11	1.40	1.80
5	Extremely unsheltered location at the coast or in the mountains	1.14	1.80	2.50

(*) For liquid precipitation, the correction factor for the Finnish Wild gauge is the same as for the other shielded Nordic gauges

These correction factors are valid for gauges with windshield. For **unshielded gauges** the correction factors are higher than the values above (about 5% higher for liquid precipitation and about 50% for solid precipitation (cf. Table 4.3)).

5.4 Operational correction for AUTOMATIC WEATHER STATIONS

Available input-data.

Sampling interval: $\leq$ 1 h

Weather elements (cf. Table 5.5): P_m, T, v, etc.

Wind speed : Observed (If v is not measured at gauge level: reduce from height H to gauge level height h by using eq.4.10)

Temperature : Observed

Precipitation intensity: Observed

Precipitation type : Not observed. Extrapolated from neighbouring station, or simulated by temperature (T):

$T > 2°C$ ==> Liquid precipitation
$0 < T \leq 2°C$ ==> Mixed precipitation
$T \leq 0°C$ ==> Solid precipitation

Recommended correction procedures :

Aerodynamic error : Dynamic Correction Model (ch. 5.3.1) for solid, liquid and mixed precipitation

Evaporation loss : a). Tipping bucket gauge: 0.25•(bucket capacity) per day with precip.
b). Weighing gauge: Zero, or estimated from algoritm based on decreasing accumulated weight during periods without precipitation

Wetting loss : Liquid precipitation: 0.15 mm/precipitation day
Solid precipitation : 0.10 mm/precipitation day
Mixed precipitation : 0.15 mm/precipitation day

(Wetting loss values are valid for both tipping bucket and weighing gauges)

5.4.1 Example of correction of solid precipitation at automatic weather station

Gauge: Geonor weighing gauge with Alter wind shield.
Data : Hourly registrations of precipitation, hourly mean values of wind speed and temperature. (Wind speed (v_g) is measured at gauge level).

Correction factor (Solid prec. {T < 0°C}, see eq.(4.12) and Table 5.6 for Norwegian gauge)

$$k_s = \exp[-0.12159 + 0.18546 \cdot v_g + 0.0069182 \cdot T - 0.005254 \cdot v_g \cdot T]$$

Time	Temp (°C)	Windspeed (v_g, m/s)	Meas. prec. P_m (mm)	Corr.factor k_s	Corr.prec. $k_s \cdot P_m$ (mm)
01	-9.3	0.7	0.0	-	0.00
.			-	-	-
.			-	-	-
10	-7.2	5.4	0.2	2.81	0.56
11	-6.4	6.0	0.6	3.14	1.88
12	-5.1	6.7	0.3	3.55	1.07
13	-4.0	6.0	1.4	2.97	4.16
14	-4.0	3.1	1.0	1.63	1.63
15	-2.1	4.0	1.5	1.92	2.88
16	-1.5	2.3	1.3	1.37	1.78
17	-0.5	4.0	1.8	1.87	3.37
18	-0.5	2.1	1.0	1.31	1.31
19	-2.0	1.2	0.4	1.11	0.44
.			-	-	-
.			-	-	-
00	-5.2	0.3	0.0	-	0.00
Sum	-	-	9.5	-	19.08

Daily correction factor $k = (\sum P_{c,i}) / (\sum P_{m,i}) = 19.08 / 9.5 = 2.00$ (see page 41)

Evaporation loss $\Delta P_E \sim 0$ mm (see page 38)

Wetting loss $\Delta P_W \sim 0.10$ mm (see page 38)

Corrected precipitation (mm):

$$P_c = \sum P_{c,i} + k \cdot \Delta P_E + k \cdot \Delta P_W = 19.1 + 2.00 \cdot 0.0 + 2.00 \cdot 0.10 = 19.3$$

5.4.2 Example of correction of liquid precipitation at automatic weather station

Gauge: RIMCO tipping bucket gauge without wind shield (Bucket capacity 0.2 mm)
Data : Hourly registrations of precipitation ($P_m = I$) and hourly mean values of windspeed (v_g)

Correction factor (Liquid precip. {T > 2°C}, see eq.(4.11))

$$k_l = \exp[-0.00101 \cdot \ln I - 0.012177 \cdot v_g \cdot \ln I + 0.034331 \cdot v_g + 0.007697 + c]$$

Time	Temperature (°C)	Wind (v_g) (m/s)	Measured prec. (Pm) (mm/h)	Corr. factor k_l	Corrected prec. (mm) $k_l \cdot P_m$
01	9.7	1.7	0	.	0
.	.	.	.	.	.
.	.	.	.	.	.
07	10.4	5.5	0.4	1.29	0.52
08	12.0	6.4	2.0	1.19	2.37
09	12.2	6.6	2.2	1.18	2.61
10	13.8	4.3	3.8	1.09	4.13
11	13.4	4.7	3.4	1.10	3.75
12	13.2	5.8	3.2	1.13	3.62
13	13.6	7.0	3.6	1.15	4.13
14	12.0	5.8	2.0	1.17	2.34
15	12.2	4.6	2.2	1.13	2.48
16	12.6	5.4	2.6	1.14	2.96
17	11.4	6.7	1.4	1.23	1.72
18	11.0	4.0	1.0	1.15	1.15
19	10.6	5.2	0.6	1.24	0.75
20	10.2	6.2	0.2	1.41	0.28
21	10.2	1.5	0.2	1.09	0.22
22	.	.	0	.	.
23	.	.	0	.	.
00					
Sum	-	-	28.8	-	33.02

Daily correction factor $k = (\sum P_{c,i}) / (\sum P_{m,i}) = 33.02 / 28.8 = 1.15$ (see page 41)

Evaporation loss $\Delta P_E \sim 0.25 \cdot 0.2 = 0.05$ mm (see page 38)

Wetting loss $\Delta P_W \sim 0.15$ mm (see page 38)

Corrected precipitation (mm):

$$P_c = \sum P_{c,i} + k \cdot \Delta P_E + k \cdot \Delta P_W = 33.02 + 1.15 \cdot 0.05 + 1.15 \cdot 0.15 = 33.3$$

5.4.3 Example of correction of mixed precipitation at automatic weather station

Gauge: Geonor weighing gauge with Alter wind shield
Data: Hourly registrations of precipitation (Pm=I), hourly mean values of wind speed (v_g) and temperature (T)

Correction factor:		
	solid prec. $\{T \leq 0°C\}$	see eq. (4.12)
	mixed prec. $\{0°C < T \leq 2°C\}$	see eq. (4.14)
	liquid prec. $\{2°C < T\}$	see eq. (4.11)

Time	Temperature (°C)	Windspeed (vg) (m/s)	Measured precip (I) (mm/h)	Correction factor k (solid/liquid)	Corrected precip. (mm) k•Pm
01	-6.0	4.3	0.0	-/-	0.00
.	-	-	-	-/-	-
.	-	-	-	-/-	-
08	-5.3	5.8	0.5	2.94/-	1.47
09	-5.0	6.0	1.7	3.05/-	6.66
10	-4.3	6.3	1.5	3.17/-	4.76
11	-3.8	6.7	2.0	3.42/-	6.84
12	-2.0	6.5	1.8	3.12/-	5.62
13	-0.5	6.6	2.1	3.05/-	6.41
14	0.5	4.0	1.4	1.85/1.14	2.09
15	0.7	3.8	1.0	1.78/1.15	1.47
16	1.2	3.5	1.6	1.67/1.11	2.22
17	1.5	2.7	1.0	1.45/1.11	1.28
18	2.2	3.0	0.6	-/1.14	0.68
19	2.3	2.2	0.4	-/1.11	0.44
20	2.5	1.8	0.5	-/1.09	0.55
21	2.8	1.4	0.3	-/1.08	0.32
.	-	-	-	-/-	-
.	-	-	-	-/-	-
00	3.0	1.0	0.0	-/-	0.00
Sum	-	-	16.4	-/-	40.81

Example of correcting mixed precipitation at 14h:

$$k_m \cdot Pm = (1/2) \cdot (1.85 + 1.14) \cdot 1.4 = 2.09$$

Daily correction factor $k = (\sum P_{c,i}) / (\sum P_{m,i}) = 40.81 / 16.4 = 2.49$ (see page 41)

Evaporation loss $\Delta P_E \sim 0.00$ mm (see page 38)

Wetting loss $\Delta P_W \sim 0.15$ mm (see page 38)

Corrected precipitation (mm):

$$P_c = \sum P_{c,i} + k \cdot \Delta P_E + k \cdot \Delta P_W = 40.81 + 2.49 \cdot 0.00 + 2.49 \cdot 0.15 = 41.2$$

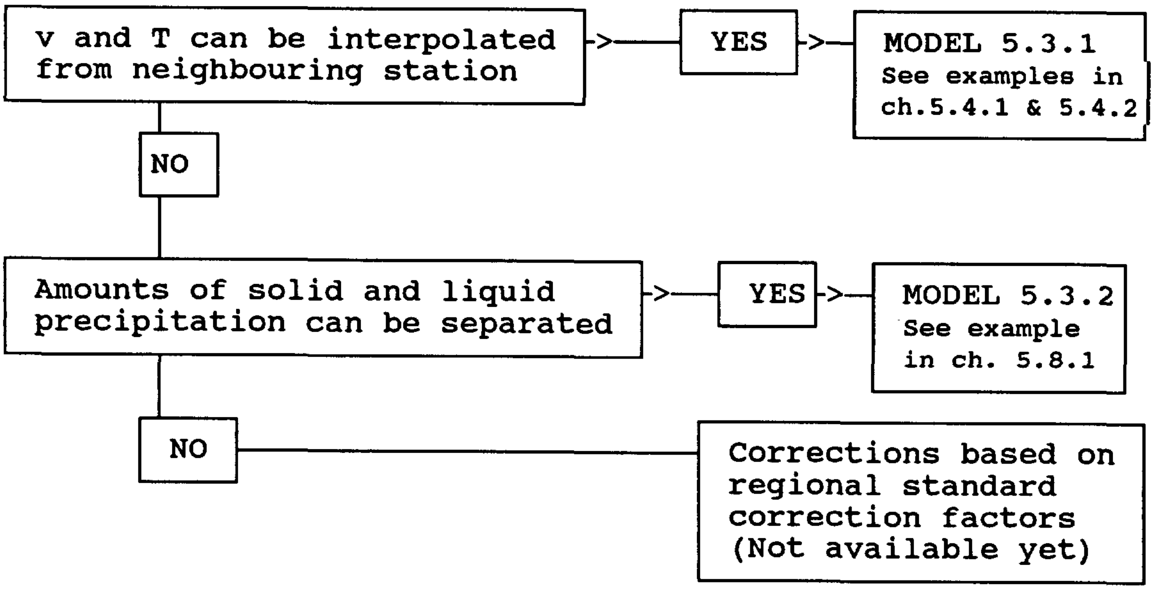
5.5 Operational correction for AUTOMATIC PRECIPITATION STATIONS

Available input-data.

Sampling interval: $\leq$ 1 h
Weather elements : P_m
Wind speed : Not observed
Temperature : Not observed
Precipitation intensity: Observed
Precipitation type : Not observed

Recommended correction procedures

Aerodynamic error:



Evaporation loss : a). Tipping bucket gauge: 0.25•(bucket capacity) per day with precip.
b). Weighing gauge: Zero, or estimated from algoritm based on decreasing accumulated weight during periods without precipitation

Wetting loss : Liquid precipitation: 0.15 mm/precipitation day
Solid precipitation : 0.10 mm/precipitation day
Mixed precipitation : 0.15 mm/precipitation day

(Wetting loss values are valid for both tipping bucket and weighing gauges)

5.6 Operational correction for MANUAL WEATHER STATIONS

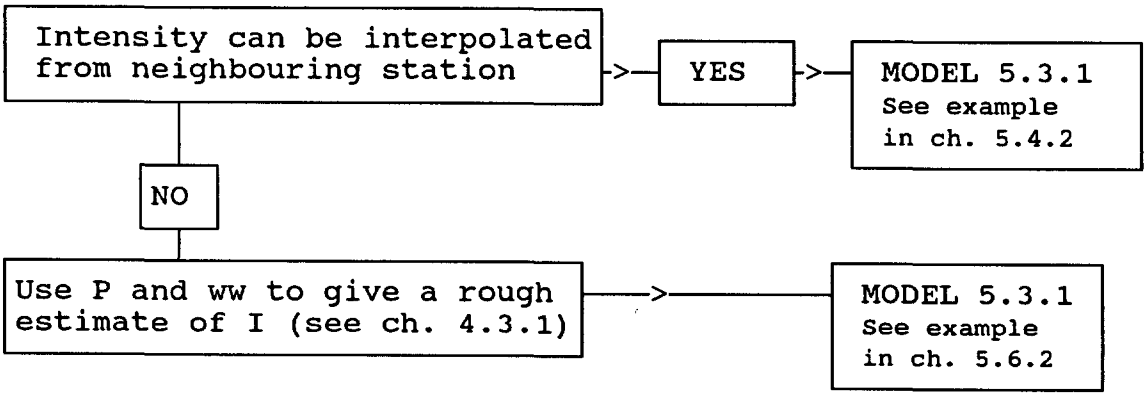
Available input-data.

Sampling interval: 3-12 h
Weather elements : P_m, v, T, ww, etc.
Wind speed : Observed, but usually v is measured ca. 10 m above the ground. Use eq.4.10 to reduce to gauge level
Temperature : Observed
Precipitation intensity: Not observed on an hourly basis
Precipitation type: Observed

Recommended correction procedures:

Aerodynamic error :

a). Liquid precipitation



b). Solid or mixed precipitation
Model 5.3.1 (See example in chapter 5.4.1)

Alternative correction model for Finnish gauge: See chapter 4.5 and Appendix 1.

Wetting loss: Use values in Table 5.3, but note that the actual wetting loss is equal to these wetting values only if the gauge is completely dried out when it is out of position. This may be the case if the gauge is changed at the observation hour and brought indoors for melting of snow. If this is done 2-4 times a day, the wetting may be 2-4 times as high as the values in Table 5.2. On the other hand, during continuous precipitation and no exchange of gauge, there will be no wetting error from the gauge.

Evaporation loss: Use values in Table 5.2.

5.6.1 Example of correction of solid precipitation at a manual weather station

Gauge: Swedish gauge with Nipher wind shield
Data : 3-hourly measurements of windspeed (10 m level), temperature, precipitation type, 12-hourly measurements of precipitation

Correction factor (Solid precipitation, see eq.4.12 and Table 5.6)

$$k_s = \exp[-0.08871 + 0.16146 \cdot v_g + 0.011276 \cdot T - 0.008770 \cdot v_g \cdot T]$$

Month: February

	Observations				Mean values				
Time	Temp. (degC)	Wind (v10) (m/s)	Precip. type	Precip. amount Pm (mm)	Temp. (degC) *	Wind (v10) (m/s) *	Wind (vg) (m/s) **	Correction factor ks	Corrected precip. (mm) ks · Pm
06	-8.2	0.4	No	-	-	-	-	-	-
09	-7.4	1.2	No	-	-	-	-	-	-
12	-6.9	2.5	Snow	x	-	-	-	-	-
15	-6.5	4.2	Snow	x	-	-	-	-	-
18	-5.7	4.9	Snow	4.8	-6.6	3.2	2.0	1.32	6.34
21	-3.4	5.2	Snow	x	-	-	-	-	-
00	-2.8	5.9	Snow	x	-	-	-	-	-
03	-4.2	4.7	No	x	-	-	-	-	-
06	-5.7	2.1	No	3.3	-4.0	5.2	3.3	1.67	5.51
Sum				8.1					11.85

* When hourly values are lacking, the mean values of temperature and windspeed are calculated as arithmetic mean for observations with precipitation. For episodes without continuous precipitation during the whole 12-hour period, the last and first observation without precipitation should also be included when averages are calculated. Accordingly, mean windspeed for the precipitation amount measured at 18h, is (1.2+2.5+4.2+4.9)/4 = 3.2 m/s, and at 06h it is (4.9+5.2+5.9+4.7)/4 = 5.2 m/s.

** Windspeed measured at the 10 m level is reduced to 1.5 m level by eq. 4.10. If α=5 degrees, z0=0.01m (winter value), H=10.0m and h=1.5m, then $vg = 0.638 \cdot v10$

Daily correction factor $k = (\sum P_{c,i}) / (\sum P_{m,i}) = 11.85 / 8.1 = 1.46$ (see page 41)

Evaporation loss: $\Delta P_E \sim 0.03$ mm (Swedish-gauge, February, see Table 5.2)

Wetting loss: $\Delta P_W \sim 2 \cdot 0.02$ mm (2 obs/day, Swedish-gauge, Snow, see Table 5.3)

Corrected precipitation:

$$P_c = \sum P_{c,i} + k \cdot \Delta P_E + k \cdot \Delta P_W = 11.85 + 1.46 \cdot 0.03 + 1.46 \cdot 0.04 = 11.9 \text{ mm}$$

5.6.2 Example of correction of liquid precipitation at a manual weather station

Gauge: Swedish gauge with Nipher wind shield
Data : 3-hourly observations of windspeed (10 m level), temperature, precipitation type, 12-hourly measurements of precipitation

Correction factor (Liquid precipitation, see eq.4.11 and Table 5.6)

$$k_l = \exp[-0.00101\cdot\ln I - 0.012177\cdot v_g\cdot\ln I + 0.034331\cdot v_g + 0.007697 - 0.05]$$

						Mean values				
Time	Temperature (degC)	Wind (vg) (m/s)	Weather code (ww)	Intensity (Tab. 4.3) (mm/h)	Measured precip (mm)	Wind v10 (m/s) *	Wind vg m/s) **	Intensity (mm/h) ***	Correction factor kl	Corrected prec. (mm) kl • Pm
06	10.0	3.5	02	-	-	-	-	-	-	-
09	9.8	4.0	03	-	-	-	-	-	-	-
12	11.5	4.5	60	0.28	-	-	-	-	-	-
15	11.9	2.0	61	0.57	-	-	-	-	-	-
18	11.3	2.5	61	0.57	6.9	3.3	1.7	0.86	1.04	7.18
21	9.6	3.5	63	1.26	-	-	-	-	-	-
00	8.5	3.0	63	1.26	-	-	-	-	-	-
03	8.7	2.0	61	0.57	-	-	-	-	-	-
06	9.3	1.0	01	-	8.9	2.4	1.2	0.89	1.02	9.08
Sum	-	-		-	15.8	-	-	-	-	16.26

* When hourly values are lacking, the mean values of windspeed are calculated as arithmetic mean for observations with precipitation. For episodes without continous precipitation during the whole 12-hour period, the last and first observation without precipitation should also be included when averages are calculated. Accordingly, mean windspeed for the precipitation amount measured at 18h, is (4.0+4.5+2.0+2.5)/4 = 3.3 m/s, and at 06h it is (2.5+3.5+3.0+2.0+1.0)/5 = 2.4 m/s.

** Windspeed measured at the 10 m level is reduced to 1.5 m level by eq. 4.10. If $\alpha=10$ degrees, $z0=0.03$m (summer value), $H=10.0$m and $h=1.5$m, then $vg = 0.512\cdot v10$

*** Mean intensity can be calculated from the ww-code, or as a combination of rain amount and duration. If at 18h the duration has been 8 hours, the mean intensity (I) is 6.9 mm/8 h, i.e. 0.86 mm/h.

Daily correction factor $k = (\sum P_{c,i}) / (\sum P_{m,i}) = 16.26 / 15.8 = 1.03$ (see page 41)

Evaporation loss $\Delta P_E \sim 0.15$ mm (Swedish gauge, July, see Table 5.2)

Wetting loss $\Delta P_W \sim 2\cdot0.07$ mm (Swedish gauge, Rain, two measurements/day, Table 5.3)

Corrected precipitation:

$$P_c = \sum P_{c,i} + k\cdot\Delta P_E + k\cdot\Delta P_W = 16.26 + 1.03\cdot0.15 + 1.03\cdot0.14 = 16.6 \text{ mm}$$

5.7 Operational correction for MANUAL CLIMATE STATIONS

Available input-data.

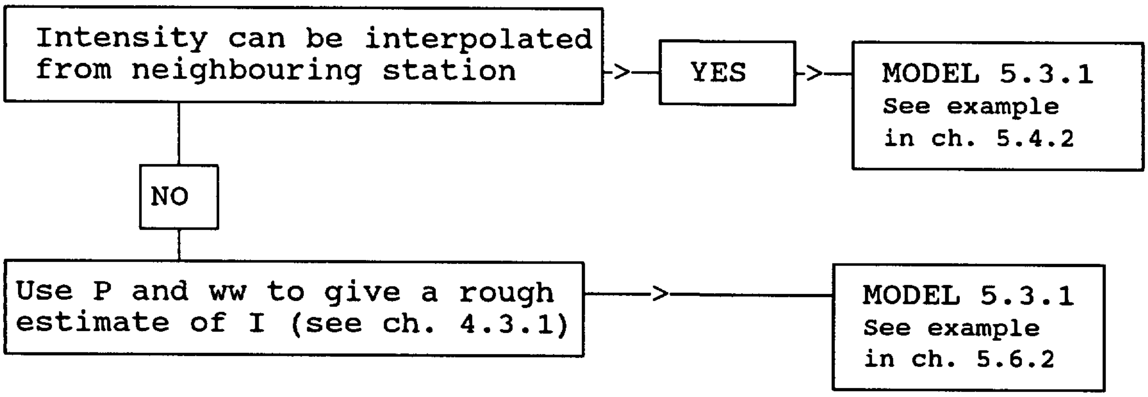
Sampling interval: 1 - 3 observations/day
Weather elements : P_m, v, T, ww, etc.
Wind speed : Usually not observed.
Temperature : Observed
Precipitation intensity: Not observed on an hourly basis
Precipitation type: Observed

Recommended correction procedures:

Aerodynamic error :

A). If windspeed is observed, or can be estimated: use same procedure as in ch.5.6

a). Liquid precipitation



b). Solid precipitation ==> Model 5.3.1 (See example in chapter 5.6.1)

Alternative correction model for Finnish gauge: See chapter 4.5 and Appendix 1.

B). If windspeed is not available (neither measured nor estimated):
===> Model 5.3.2 (See example in chapter 5.8.1)

Evaporation loss: Use values in Table 5.2.

Wetting loss: Use values in Table 5.3. (See comments in chapter 5.6)

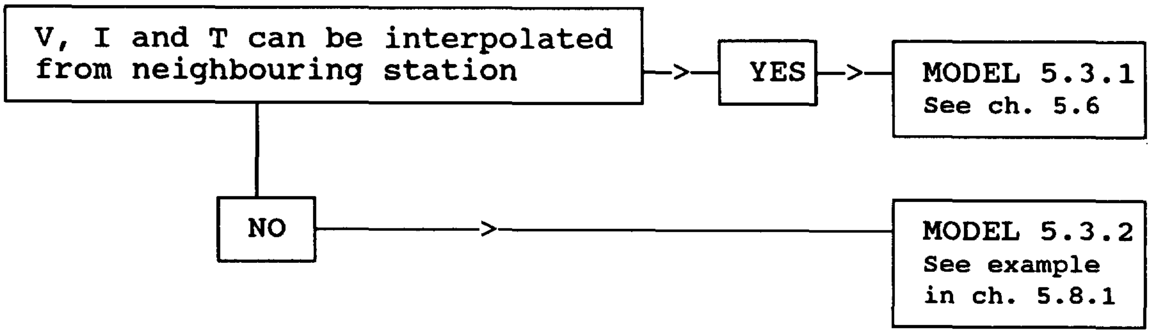
5.8 Operational correction for MANUAL PRECIPITATION STATIONS

Available input-data.

Sampling interval: 24 h
Weather elements : P_m , precipitation type
Wind speed: Not observed
Temperature : Not observed
Precipitation intensity: Not observed
Precipitation type: Observed

Recommended correction procedures:

Aerodynamic error:



Alternative correction model for Finnish gauge: See chapter 4.5 and Appendix 1.

Evaporation loss: Use values in Table 5.2.

Wetting loss: Use values in Table 5.3, but note that the actual wetting loss only is equal to these wetting values if the gauge is completely dried out when it is out of position. This may be the case if the gauge is changed at the observation hour and brought indoors for melting of snow. On the other hand, during continous prepcipitation and no change of gauge, there will be no wetting error from the gauge.

5.8.1 Example of correction of precipitation at a manual precipitation station

Gauge: Norwegian gauge with Nipher wind shield
Data : Daily observations of precipitation type and precipitation amount
Month: January, Exposure class 5 (see chapter 5.3.2)

Correction factor: Liquid k=1.14, Solid k=1.80, Mixed k=(1.14+1.80)/2=1.47

Date	Precipitation type	Measured precipitation Pm (mm)	Correction factor k	Corrected precipitation $k \cdot P_m$ (mm)
01	No precipitation	-	-	-
02	No precipitation	-	-	-
03	Snow	3.2	1.80	5.76
04	No precipitation	-	-	-
05	No precipitation	-	-	-
06	Snow	5.1	1.80	9.18
07	Snow	1.2	1.80	2.16
08	Snow	5.2	1.80	9.36
09	Snow	1.1	1.80	1.98
10	Mixed	6.3	1.47	9.26
11	Rain	11.3	1.14	12.88
12	Mixed	7.6	1.47	11.17
13	Rain	11.8	1.14	13.45
14	Rain	6.5	1.14	7.41
15	Rain	1.8	1.14	2.05
16	Rain	11.0	1.14	12.54
17	Rain	13.5	1.14	15.39
18	Rain	4.6	1.14	5.24
19	Rain	14.2	1.14	16.19
20	Mixed	3.0	1.47	4.41
21	Snow	3.0	1.80	5.40
22	Rain	12.2	1.14	13.91
23	Rain	9.0	1.14	10.26
24	Mixed	16.6	1.47	24.40
25	Rain	1.6	1.14	1.82
26	Snow	3.9	1.80	7.02
27	No precipitation	-	-	-
28	No precipitation	-	-	-
29	No precipitation	-	-	-
30	No precipitation	-	-	-
31	Drizzle	0.2	1.14	0.23
Sum		153.9		201.47

Monthly correction factor $k = (\sum P_{c,i}) / (\sum P_{m,i}) = 201.47/153.9 = 1.31$

Evaporation loss (23 precip. days): $\Delta P_E \sim 23 \bullet 0.02 = 0.46$ mm (see Table 5.2)

Wetting loss (Rain: 11 days, Snow: 7 days, Mixed: 4 days, Drizzle: 1 day)

$$\Delta P_W \sim 11 \bullet 0.15 + 7 \bullet 0.05 + 4 \bullet 0.13 + 1 \bullet 0.14 = 2.66 \text{ mm (see Table 5.3)}$$

Corrected precipitation:

$$P_c = \sum P_{c,i} + k \bullet \Delta P_E + k \bullet \Delta P_W = 201.47 + 1.31 \bullet 0.46 + 1.31 \bullet 2.66 = 205.6 \text{ mm}$$

6. FUTURE DEVELOPMENTS

6.1 Overview

The results presented in this report clearly demonstrates that the conventional precipitation gauges in current use in the Nordic countries are introducing substantial measuring errors. At the majority of stations, the most serious errors are caused by aerodynamic effects around the measuring gauge, but none of the error sources mentioned in section 2 can be neglected.

There are three different alternatives to reduce the measuring errors, i.e. a). improving current gauges and measuring sites, b). optimising procedures for operational correction and c). development of new measuring techniques for precipitation.

6.2 Improvement of gauges and measuring sites

a). Wetting and Evaporation

Tables 5.2 and 5.3 show that the errors caused by wetting and evaporation are different for the various gauges used in the Nordic countries. By using the technical design for the best performing Nordic gauge, the measuring errors caused by evaporation and wetting may be reduced.

This is illustrated below, by using the values in Table 6.1 from a "typical" Nordic station.

Table 6.1 Precipitation data from a "typical" Nordic station

Annual precipitation: 700 mm				
PRECIPITATION DAYS				
Spring	Summer	Autumn	Winter	Year
35	40	45	45	165
Rain	Snow	Mixed	Drizzle	Total
80	50	25	10	165

By using the values in table 6.1 combined with Table 5.2 and 5.3, it is possible to get an estimate of evaporation and wetting loss, as illustrated in Table 6.2

Table 6.2 Optimal improvement of Nordic precipitation gauges for evaporation and wetting

	EVAPORATION		WETTING			TOTAL		
	mm1	E%	D1%	mm2	%	D2%	DT	DT%
"Best gauge"	6.9	1.0	0.0	8.7	1.2	0.0	2.2	0.0
Danish	8.3	1.2	0.2	22.0	3.1	1.9	4.3	2.1
Swedish	11.0	1.6	0.6	8.7	1.2	0.0	2.8	0.6
Finnish	8.5	1.2	0.2	16.6	2.4	1.2	3.6	1.4
Norwegian	6.9	1.0	0.0	19.2	2.7	1.5	3.7	1.5
Tretyakov	13.2	1.9	0.9	20.4	2.9	1.7	4.8	2.6

mm1 = evaporation loss (mm)
E% = evaporation loss (%) (mm1 in percent of 700 mm)
D1% = difference between national gauge and "best" gauge (percent of 700 mm)
mm2 = wetting loss (mm)
W% = wetting loss (%) (percent of 700 mm)
D2% = difference between national gauge and "best" gauge (percent of 700 mm)
DT = sum [E% + W%] (mm)
DT% = total difference between national gauge and "best" gauge (percent of 700 mm)

Table 6.2 indicates that by choosing the "best" Nordic solution concerning evaporation and wetting, the "typical" measuring error would be reduced by 1-2 % for the Nordic gauges. Although this value will vary for stations with different precipitation conditions within the Nordic region, the table indicates that the potential improvement against wetting and evaporation errors is marginal.

b). Aerodynamical effects

By far the most serious errors are caused by aerodynamical effects around the gauge, but Table 3.6-3.9 and Table 5.6 shows that the magnitude of this error source is different for the various gauges used in the Nordic countries. Similar to section a) above, by using the technical design for the best performing Nordic gauge, the measuring errors caused by wind effects can be reduced.

This is illustrated in Table 6.3 by data from a "typical" Nordic station, with an anticipated annual precipitation of 700 mm, and with a 25/75 percentage of solid / liquid precipitation. As a measure of catch deficiency, the results from Jokioinen (Table 3.6 and 3.7) are used.

Table 6.3 Optimal improvement of Nordic precipitation gauges for aerodynamical effects

	SNOW (700x0.25=175 mm)				RAIN (700x0.75=525 mm)				TOTAL	
	mm1	%	D1	D1%	mm2	%	D2	D2%	DT	DT%
"Best gauge"	130	74	0	0.0	510	97	0.0	0.0	0.0	0.0
Danish unshielded	84	48	46	6.6	479	92	31	4.4	77	11.0
Tretyakov unshielded	85	49	45	6.4	480	91	30	4.3	75	10.7
Swedish	120	69	10	1.4	502	96	8	1.1	18	2.6
Finnish	130	74	0	0.0	510	97	0	0.0	0	0.0
Norwegian	115	65	15	2.1	478	91	32	4.6	47	6.7
Tretyakov	129	74	1	0.1	502	96	8	1.1	9	1.3

mm1 = "measured" solid precipitation (mm)
% = catch ratio for solid precipitation (from Table 3.6) (%)
D1 = difference (mm) between national gauge and "best" gauge
D1% = difference D1 in % (percent of 700 mm)
mm2 = "measured" liquid precipitation (mm)
% = catch ratio for liquid precipitation (from Table 3.7) (%)
D2 = difference (mm) between national gauge and "best" gauge
D2% = difference D2 in % (percent of 700 mm)
DT = sum [D1 + D2] (mm)
DT% = sum DT in % (percent of 700 mm)

The results in Table 6.3 show that by changing from unshielded Danish gauge to the shielded Finnish gauge, the total annual gauge catch at a "typical" Nordic station would increase by 11%. But still it should be kept in mind that even the "best" gauge just catches 74% of the true solid precipitation, and the Danish gauge merely 48%.

The aerodynamical catch deficiency could also be reduced by moving gauges to less wind exposed sites. By reducing the mean windspeed at gauge level from e.g. 4 to 3 m/s, Figure 5.1 shows that the correction factor for solid precipitation and T=-10°C would be reduced from 2.2 to 1.7. I.e. the gauge catch would be increased by 30% by reducing the windspeed by just 1 m/s. However, to reduce leeward effects and local turbulence, the distance from the gauge to nearby objects should be 2-4 times the height of the objects.

6.3 Optimising procedures for operational correction

The quality of the operational precipitation corrections will be best for stations with direct measurements of the elements needed in the dynamical correction model in section 4.3. Consequently the estimates of true precipitation can be improved by trying to fullfill the following data requiery:

Hourly values of:
* precipitation intensity
* windspeed at gauge level
* air temperature
* precipitation type

6.4 New measuring techniques.

During the last years, optical rain gauges have been introduced at an increasing number of automatic weather stations. These instruments give a measure of precipitation intensity as well as precipitation type. In principle these optical sensors offer major improvements to conventional "bucket" gauges: no wetting, no evaporation, substantially reduced aerodynamic effects around the sensors. Also the sensors may be placed in a height above the ground reducing the influence of blowing/drifting snow.

Several different optical gauges are in operation, e.g. Scientific Technology Inc Optical Rain Gauge ORG-700, HSS Inc. Present Weather Sensor PW-402, Scientific Technology Inc. LEDWI OWI-240 and Vaisala O.Y. Present Weather Sensor FD12P. The Vaisala FD12P has been tested in the experimental field at Jokioinen, and in the following some technical details and test results for this sensor will be referred.

The Vaisala FD12P Weather Sensor (Figure 6.1) consists of a transmitter, a receiver and a capacitive rain detector (Vaisala, 1995) and combines signals from:

a). An optical forward-scatter sensor that detects fog and distinguishes different types of precipitation particles.
b). A heated capacitive surface sensor that detects the amount of water falling on it.
c). A temperature sensor is used to increase the reliability of precipitation type assessment
d). An "artificial intelligence type algorithm" running in a built-in micro-processor for estimating Present Weather, Visibility and Precipitation Intensity from the combined data of sensors a)-c). In this way 11 different precipitation types are detected.

To distinguish between solid and liquid precipitation, the ratio between optical measurement and amount of water on the capacitive sensor, is used. Controlled heating of sensing surfaces turns frozen precipitation into liquid. Thus a measurement of liquid equivalent of water is obtained.

Precipitation detection:
above 0.05 mm/h within 10 minutes

Precipitation intensity:
range 0.00-999 mm/h

Accuracy:
±30% (0.5-20 mm/h)

Operating temperature:
-40 to +55 degC

Figure 6.1 Vaisala FD12P Present weather sensor

For liquid precipitation, where the droplets are almost ball-shaped, there is a constant proportionality between the scattered light and the volume of the particles (Hedegaard, 1994). For solid precipitation the shape of the particles are varying, but the scattering seems to be proportional to the average volume of the particles. For liquid precipitation it is thus possible to estimate the precipitation intensity in mm/h just from the optical signal. For solid precipitation the water volume deviates from the precipitation intensity by a factor of about 10. Therefore a separate capacity surface sensor is used in combination with the optical signal to estimate the precipitation intensity of solid precipitation.

The optical precipitation gauges are tested in some experimental fields, but up to now the evaluation is based on rather limited datasets. It is therefore difficult to give a final judgement of the functionality of the optical gauges. In Figure 6.2 some results for the Vaisala FD12P are presented. In Jægersborg in Denmark, the recordings from FD12P was compared to the 12h precipitation in a Hellmann gauge. Hedegaard (1994) concluded that the FD12P functioned almost perfectly for liquid precipitation (cf. Figure 6.2a). In the Jokioinen test field a Vaisala FD12P sensor (gauge 23 in Figure 3.4) was tested from May 1992 to April 1993 (Aaltonen et al., 1993). For liquid precipitation (Figure 6.2b) there was good correspondance between the optical gauge and a pit gauge (gauge 17 in Figure 3.4). For solid precipitation (Figure 6.2c) however, there was a rather big scatter between the results from FD12P and the corrected double fence measurements.

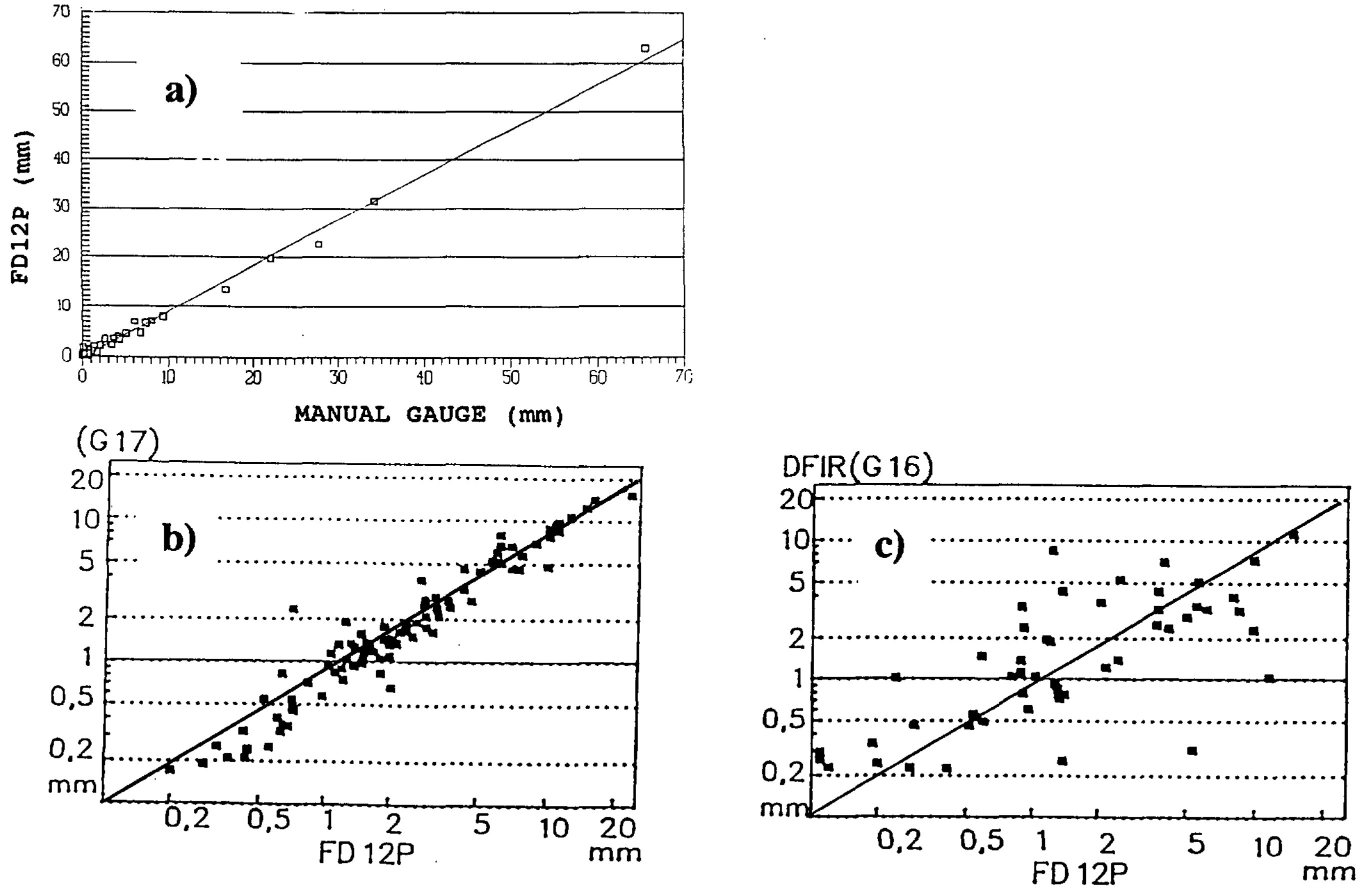


Figure 6.2 Evaluation of precipitation amounts in Vaisala FD12P Present weather sensor

a). Liquid precipitation (12 h values), Jægersborg, Denmark, spring 1994 (from Hedegaard, 1994)

b). Liquid precipitation (12 h values), Jokioinen, Finland, 1993 (from Aaltonen et al., 1993)

c). Solid precipitation (12 h values), Jokioinen, Finland, 1993 (from Aaltonen et al., 1993)

7. RECOMMENDATIONS

The Nordic NHP Working Group on Precipitation

considering that

- the Jokioinen field experiment, although not covering the full range of meteorological conditions found in the Nordic countries, has resulted in a high-quality dataset for development and validation of correction methods for solid precipitation

- the correction models outlined in this report have a substantial potential for operational use

recommends that

- the following actions should be undertaken to ensure improved quality of point precipitation values:

- Improved siting of instruments
  Precipitation gauges should whenever possible be placed at wind protected sites (cf. Table 4.1), ensuring reduction of deficits in precipitation caused by wind losses. However, the distance to nearby objects should be large enough to prevent losses due to interception of precipitation by nearby objects. Generally the minimum distance between the gauge and the surrounding objects can be selected to be 1-2 times the height of the object.

- Improved instrumentation
  Precipitation gauges should be provided with windshields, especially in areas where a major part of the precipitation falls as snow. For operational correction, supplementary measurements of wind speed at gauge level, precipitation intensity and temperature are needed. To reduce evaporation, it is of crucial importance that the loose funnel in the gauges is inserted during the warm season.

- Starting of operational correction
  The correction models outlined in this report should be used for operational correction of measured precipitation. Both measured and corrected precipitation values should be kept in the data archives.

- Creation of long-term corrected point precipitation series
  In each Nordic country, some long-term series of *corrected* precipitation should be established. Merely such corrected series will show the real long-term precipitation trends.

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APPENDIX 1

Examples of correcting precipitation by using the Finnish exposure method

In Table A.1 a summary of 5 snow fall cases are presented. Wetting error and orifice area correction has been done to all gauges. DFIR acts as a reference gauge in Valdai fence and it is corrected by Golubev correction. The synop site is well sheltered against SW, W, NW, and N winds but quite exposed to other directions. Anyway for the synop site it is quite difficult to define the exposure factor due to surrounding forest and bushes. The test field is very exposed to all directions.

Temperature and wind speed values denote mean values during precipitation. On the synop site of Jokioinen precipitation is measured with Tretyakov or H&H-90 gauges. In corrections for the synop site weather and wind data from Jokioinen are used. In corrections for the test field weather and wind data either from Jokioinen (Jok) or Tampere airport (Tam) are used. When weather and wind data from Tampere are used, Jokioinen test field acts as a precipitation station.

Table A.1 Summary of 5 snow fall cases for different gauges when measured precipitation values (obs) are corrected (corr) with weather data from Jokioinen (Jok) and Tampere airport (Tam).

PRECIPITATION

	Temperature (deg Celcius)		Wind speed (m/s)		Precipitation (mm)							
					Synop site		Test field					
	Jok	Tam	Jok	Tam	TRET		WILD		TRET & H&H			DFIR
Date					obs	corr	obs	corr	obs	corr	corr	
								Jok		Jok	Tam	
16.01.92	-4.0	-4.9	4.6	3.5	16.3	19.4	0.9	1.5	12.8	18.7	17.1	19.0
30.12.88	-0.5	-1.0	5.1	4.9	13.9	14.5	7.6	11.4	11.9	15.1	17.6	15.2
31.10.92	-3.1	-5.3	2.9	3.0	7.6	8.7	3.3	4.9	6.9	8.9	8.9	8.9
15.01.93	-0.4	-0.7	5.6	5.3	3.8	3.8	4.2	5.7	6.3	7.5	7.0	7.9
30.03.91	0.6	0.9	6.4	8.6	5.3	5.3	5.3	5.8	6.3	6.5	8.9	7.0
SUM					46.9	51.7	21.3	29.3	44.2	56.7	59.5	58.0
% of DFIR					81	89	37	51	76	98	103	100

Wild gauge caught only 37 % from the precipitation compared to DFIR. It is obvious that wind blows quite easily snow out from Wild gauge. Correction did not help very much, only 51 % level was reached. On the synop site gauges caught 81 % and correction improved values up to 89 % compared to DFIR. There may be some difficulties in defining the exposure of the synop site.

On the test field Tretyakov or H&H-90 gauges caught 76 % of the precipitation compared to DFIR. This is 5 % less than on the synop site, because the test field is more exposed. But the correction improved final results up to 98 % when weather and wind data from Jokioinen were used. When weather and wind data from Tampere airport were used, corrected values were 103 % from the precipitation compared to DFIR.

When the exposure of the site is known well, exposure method gives quite good results when it is possible to use weather and wind data of the site itself or when the nearest synoptic station is located quite near. Coast areas or where the nearest synoptic station is located far away arise problems.

APPENDIX 2

Parallel measurements in Norwegian (DNMI) and Swedish (SMHI) precipitation gauges

Site	Snow			Rain		
Location	SMHI mm	DNMI mm	Ratio SMHI/DNMI	SMHI mm	DNMI mm	Ratio SMHI/DNMI
Test period 1						
Gardermoen	113	115	0.98	318	315	1.01
Fokstua	174	166	1.05	208	210	0.99
Oslo-Blindern	90	90	1.00	348	349	1.00
Kjevik	66	73	1.00	1321	1329	0.99
Sola	14	13	-	924	902	1.02
Bergen	26	22	-	1925	1932	1.00
Værnes	140	135	1.04	672	660	1.02
Ørland	83	89	0.94	844	894	0.95
Bodø	261	255	1.03	1292	1246	1.04
Test period 2						
Oslo-Blindern	228	224	1.02	410	418	0.98
Kjøremsgrendi	249	243	1.03	114	119	0.96
Dønski	324	331	0.98	1005	1041	0.97
Mean value	-	-	0.998	-	-	0.994
Standard dev.	-	-	0.046	-	-	0.026
WMO-test Finland						
Jokioinen	601	573	1.05	653	622	1.05