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MEASURED AND TRUE PRECIPITATION AT SVALBARD

av I. HANSEN-BAUER, E.J FØRLAND and P.Ø NORDLI

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ABSTRACT

Parallel precipitation measurements from Svalbard are used in order to evaluate and adjust models for estimating true precipitation under Arctic conditions. The conclusion is that true precipitation may be estimated reasonably well when the windspeed at gaugeheigth is less than 7 m/s. At higher windspeeds, and especially when the temperature also is low (< -6 °C), the estimates are less reliable, and further research is needed.

It is still possible to give good estimates of true annual and seasonal precipitation at Svalbard, as only a small part of the precipitation is falling at windspeeds above 7 m/s. True precipitation is estimated for the period July 1993 - August 1995. The seasonal ratio between true and measured precipitation varies between 1.26 for the summer and 1.70 for the winter. If it is supposed that the seasonal ratios which were found are typical for a «normal» year in Ny-Ålesund, the true normal (1961-1990) annual precipitation would be 550 mm, i.e. 50% higher than the official uncorrected value.

As the aerodynamic effects leading to precipitation catch loss are dependent on precipitation type and temperature, scenarios involving changes in the air temperature would also affect the measured precipitation, even if the true precipitation was unchanged. Estimates are made of the «virtual» precipitation increase which would result from a general temperature increase of 2, 4 and 6 °C. The increase in the measured annual precipitation would be 6, 10 and 13%, respectively. The expected virtual precipitation increase is thus of the same magnitude as the real precipitation increase which according to IPCC may be expected in Northern Europe as a result of the doubling of the atmospheric CO_2 content.

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FOREWORD AND ACKNOWLEDGEMENT

During the years 1993-96. the Climatology Division at the Norwegian Meteorological Institute (DNMI) has performed three projects in the Norwegian Arctic. The projects are partly financed by DNMI and partly by the Norwegian Research Council (NRC).

In the project **«Climate Studies in the Norwegian Arctic»** (NRC-No 101612/410) one of the subprojects was to study the difference between measured and true precipitation at Svalbard. This report summarizes the main results from this subproject.

The second project **«Long term variations in atmospheric circulation and climate in Norwegian Arctic»** (NRC-No 112890/720) deals with *e.g.* comprehensive surveys of climatological statistics for Norwegian Arctic, and will establish a dataset of precipitation data. To interpretate the precipitation data correctly, it is crucial to quantify the measuring errors. A detailed description of the measuring errors and correction procedures for for Arctic precipitation is given in chapter 6.

In the third project, **«Climatological Scenarios in two Catchments at Svalbard»** (NRC-No 110648/730), one of the aims was to give climatological scenarios for Ny-Ålesund, Spitsbergen, with special emphasis on hydrological consequences. Some implications which the scenarios of increasing temperature will have on measured precipitation, are discussed in chapter 7.

The authors are indebted to Sverre N. Thon, Geir Åsebøstøl, Lars Inge Sæther and Even Moldstad, Norwegian Polar Institute, and to Torgeir Mørk, DNMI, for performing the parallel measurements and for general assistance in connection with the field work.

1. Introduction

In wind exposed areas in Norway, precipitation gauges may catch less than 50% of the true winter precipitation (Førland and Aune 1985). The problems of measurements of precipitation have been recognised for many years (*e.g.* Heberden 1769, Hjelström 1885). The measuring errors are especially large for solid precipitation, and in 1985 WMO (World Meteorological Organization) recommended that international comparisons of current national methods of measuring solid precipitation should be conducted in order to reduce the problems of snow measurements (WMO, 1994). Two types of test stations were recommended within the proposed «WMO Solid Precipitation Measurement Intercomparison»:

a). Evaluation station - comprehensive station including «Double Fence Intercomparison Reference» (DFIR).

b). Basic station - a simpler station without DFIR, but including national gauge and a Tretyakov gauge with windshield.

During 1987-1993, the Nordic countries cooperated in operating an Evaluation station in Jokioinen, Finland (Elomaa *et. al.*, 1993). As the weather conditions in the Norwegian Arctic areas are quite different from those in Jokioinen, it was decided to establish a «Basic station» in Ny-Ålesund, Spitsbergen, and make a comparative study based upon these measurements. There were three main motivations for this study:

Firstly, testing models developed from the Jokioinen data (Allerup *et al.* 1997) on independent data from Svalbard will hopefully increase our general knowledge on the relationship between true and measured precipitation. The aim is to investigate if the Jokioinen models may be considered as «universal», and whether they may be used for higher wind velocities than those measured in Jokioinen.

Secondly, it is of importance to know the true precipitation on Svalbard, *e.g.* as a part of the hydrological cycle. The discrepancy between precipitation measurements in Ny-Ålesund, and the runoff from a nearby catchment has been documented to exceed what could possibly be explained by melting of glaciers within the catchment (Hagen and Lefauconnier 1995). This may partly be explained by orographic effects, leading to increased precipitation in the higher parts of the catchment relatively to the precipitation in Ny-Ålesund (Førland *et al.* 1996b). However parts of the discrepancy between precipitation and runoff is probably also caused by the catch deficiency of the precipitation gauge in Ny-Ålesund. This study aims to estimate this catch deficiency and accordingly the «true» precipitation in Ny-Ålesund.

Thirdly, as the catch deficiency is different for snow and rain, and further depends on wind and temperature, changes in these latter climate elements may result in virtual changes in the precipitation. *E.g.*, a positive trend in the annual mean temperature might lead to an increased catch efficiency, and thus a virtual positive trend in the precipitation, even if the true precipitation does not change at all (Førland 1994). The potential for such artificial trends is at maximum in areas where a large percentage of the annual precipitation is solid. The present study aims to quantify the potential of this effect on Svalbard.

2. Methods

2.1 Background and basic formulas

Førland *et al.* (1996a) gave a survey of the error sources which are connected to precipitation measurements. For operational purposes, they conclude that, the real amount of precipitation («true precipitation») may be expressed as:

(2.1) $$P_C = k \cdot (P_m + \Delta P_W + \Delta P_E),$$

where $\mathbf{P_C}$ is true precipitation, **k** is the correction factor due to aerodynamic effects, $\mathbf{P_m}$ measured precipitation , $\mathbf{\Delta P_W}$ precipitation lost by wetting, and $\mathbf{\Delta P_E}$ precipitation lost by evaporation from the gauge.

At most measuring sites, wind speed is the most important environmental factor contributing to the under-measurement of precipitation. The catch deficiency is caused by the fact that wind is accelerated over the gauge. Accordingly hydrometeors that during calm would have reached the catchment area of the gauge, are deflected outside the orifice of the gauge because of wind effects. The aerodynamic error is different for different types of gauges and windshields. The wetting and evaporation errors also depend on the gauge type. Consequently, the operational corrections for wind, wetting and evaporation must be specified for each gauge type.

The wind induced catch deficiency depends on the design of the gauge, the windspeed and the characteristics of the hydrometeors. The size and structure of hydrometeors are difficult to assess at regular measuring sites. Therefore, Førland *et al.* (1996a) used rain intensity as a measure of droplet size during liquid precipitation, and air temperature to indicate the crystal structure during solid precipitation, in spite of fact that this implies rather rough approximations.

To establish relationships between measured and true precipitation, «reference gauges» are recommended (WMO, 1994). For liquid precipitation a «Pit gauge» (gauge with orifice at ground level) is recommended to get a measure of ground true precipitation. Allerup and Madsen (1980) used a comprehensive dataset including pit gauge measurements to develop a correction model for the unshielded Danish Hellmann gauge for liquid precipitation. Førland *et al.* (1996a) recommended to use a modified version of this model for all Nordic gauges. The recommended correction factor for liquid precipitation is:

(2.2) $$k_l = \exp\{-0.00101 \cdot \ln I - 0.012177 \cdot v_g \cdot \ln I + 0.034331 \cdot v_g + 0.007697 + c\},$$

where **I** is the rain intensity (mm/h), $\mathbf{v_g}$ is the wind speed (m/s) at gauge height and **c** is a gauge coefficient, which is dependent on whether the gauge has a windshield.

To establish relationships between measured and true <u>solid</u> precipitation, WMO (1994) recommended to use the «Double Fence Intercomparison Reference, DFIR», consisting of a Tretyakov gauge installed within a «double fence». At the Jokioinen field, parallel recordings of solid precipitation were made in DFIR and in different national gauges, during a period of 7 years. For each gauge, k was established as a function of wind, temperature and precipitation characteristics (Allerup *et al.* 1997). For solid precipitation at temperatures down to -12 °C, the correction factor was found to be:

(2.3) $$k_s = \exp\{\beta_0 + \beta_1 \cdot v_g + \beta_2 \cdot T + \beta_3 \cdot v_g \cdot T\} \quad \text{for } 1 < v_g < 7 \text{ m/s},$$
$$k_s = 1.0 \quad \text{for } v_g \leq 1 \text{ m/s}.$$

Here, **T** is the air temperature, while $\beta_{0\text{-}3}$ are coefficients, which are dependent on the gauge type, and which Allerup *et al.* (1997) give for a number of gauges.

Førland *et al.* (1996a) recommended that equations 2.2 and 2.3 should be used for operational correction of liquid and solid precipitation, respectively. For mixed precipitation, they suggested that the correction factor is:

(2.4) $$k_m = (r_l \cdot k_l + r_s \cdot k_s) / (r_l + r_s),$$

where $\mathbf{r_l}$ and $\mathbf{r_s}$ are the amounts of precipitation falling as rain and snow, respectively.

2.2 Comparing measurements from Tretyakov and Norwegian gauge

A first guess when estimating true precipitation in Spitsbergen would be to follow the above recommendations directly. However, it might be questioned whether equations developed from the Jokioinen data may be regarded as universal. The structure of snowflakes, and thus their aerodynamic characteristics, is affected by humidity as well as by temperature. Besides, coefficients are not given for solid precipitation for wind speed at gauge height above 7 m/s. A Basic station (cf. Introduction) was thus established in Ny-Ålesund, Spitsbergen, including a Tretyakov type gauge with a Tretyakov windshield in addition to the Norwegian gauge. The relation between these gauges can be deduced from the Jokioinen experiments (Allerup *et al.* 1997). In case similar relations were found in the present experiment, the Jokioinen formulas would be supported, and true precipitation could be estimated by these. In the opposite case, possible reasons for the differences would have to be investigated.

Using eq. 2.1, the following relationship between measurements in the Tretyakov and Norwegian gauge is valid:

(2.5) $$k_{tr} \cdot (P_{tr} + \Delta P_{Wtr} + \Delta P_{Etr}) = k_{nor} \cdot (P_{nor} + \Delta P_{Wnor} + \Delta P_{Enor}) \quad ,$$

where index **tr** means Tretyakov gauge and index **nor** means Norwegian gauge. When using the following definitions:

(2.6) $$P_{TR} \equiv (P_{tr} + \Delta P_{Wtr} + \Delta P_{Etr}) \quad \text{and} \quad P_{NOR} \equiv (P_{nor} + \Delta P_{Wnor} + \Delta P_{Enor}) \quad ,$$

eq. 2.5 gives:

(2.7) $$P_{TR} / P_{NOR} = k_{nor} / k_{tr} \quad .$$

Using equations 2.2, we have for liquid precipitation:

(2.8) $$P_{TR} / P_{NOR} = \exp\{ c_{nor} - c_{tr} \}.$$

According to Førland *et al.* (1996a) $\mathbf{c}_{\mathbf{nor}}$ and $\mathbf{c}_{\mathbf{tr}}$ are both approximated by -0.05. Consequently:

(2.9) $P_{TR} / P_{NOR} = 1$.

For solid precipitation, equation 2.3 gives:

(2.10) $P_{TR} / P_{NOR} = \exp\{ \beta_{0nor}-\beta_{0tr}+ (\beta_{1nor}-\beta_{1tr})\cdot v_g + (\beta_{2nor}-\beta_{2tr})\cdot T + (\beta_{3nor}-\beta_{3tr})\cdot v_g \cdot T \}$ for $1<v_g<7$ m/s,
$P_{TR} / P_{NOR} = 1.0$ for $v_g \leq 1$ m/s .

Gauge coefficients β based upon data from Jokioinen were estimated by Allerup *et al.* (1997). The Tretyakov gauge used in Ny-Ålesund was of the Finnish «H&H90» type. This gauge differs somewhat from the Russian Tretyakov gauge concerning wetting and evaporation characteristics (*cf.* chapter 4.2), but aerodynamically, the gauge is identical to the Russian Tretyakov gauge. As the «H&H90» gauge coefficients from Jokioinen were based upon a very limited dataset compared to the Russian gauge coefficients, the coefficients for the latter gauge are used for the Tretyakov gauge in the present study. According to Allerup *et al.* (1997), the relationship between the Tretyakov gauge and the Norwegian gauge is:

(2.11) $P_{TR} /P_{NOR} = \exp\{ -0.07343 + 0.05163\cdot v_g - 0.002146\cdot T - 0.000113\cdot v_g \cdot T \}$ for $1<v_g<7$ m/s,
$P_{TR} /P_{NOR} = 1.0$ for $v_g \leq 1$ m/s .

According to equation 2.11, it is evident that the wind speed more than air temperature accounts for the differences between the catch efficiency of the two gauges.

In the present study, the relationship between the precipitation measured in the Tretyakov gauge and in the Norwegian gauge is studied for different types of precipitation. For liquid precipitation, the relationship is studied as a function of wind speed and intensity. For solid precipitation, it is studied as a function of wind speed and temperature. The concluding relations are compared to equations 2.9 and 2.11.

3. Test area, instrumentation and data.

Ny-Alesund (78°56'N, 11°53'E) is a research station and a former mining town on the west coast of Spitsbergen, at the eastern side of the peninsula «Brøggerhalvøya» (figure 3.1). Weather observations were initiated in 1969, and the precipitation gauge and temperature screen is presently situated in the center of Ny-Ålesund, between 1- and 2-storied buildings (figure 3.2). Temperature and precipitation normals (1961-1990) for Ny-Ålesund are given in table 3.1 and 3.2, together with monthly temperature means and precipitation sums for the period 1993 - 1995. Further statistics from the weather station in Ny-Ålesund is given by Hanssen-Bauer *et al.* (1990).

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Figure 3.1 *Map of Spitsbergen with Ny-Ålesund.*

Table 3.1 *Monthly and annual mean temperatures during 1993-1995, and temperature normals 1961-1990 for Ny-Ålesund (Nordli et. al 1996, p 41).* ***All values are given in*** *°C.*

PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1993	-15.1	-16.0	-15.8	-12.9	-3.4	2.3	5.8	5.0	-0.8	-8.2	-2.8	-11.2	-6.1
1994	-15.0	-14.8	-11.2	-6.8	-3.6	2.4	4.4	2.4	-0.5	-8.8	-12.9	-9.2	-6.1
1995	-14.1	-14.3	-14.6	-7.1	-2.9	2.3	5.0	4.7	1.5	-7.1	-13.3	-14.3	-6.2
1961-1990	-13.9	-14.6	-14.2	-11.1	-4.0	1.5	4.9	3.9	-0.3	-5.7	-10.0	-12.5	-5.7

Table 3.2 *Monthly and annual precipitation sums during 1993-1995, and precipitation normals 1961-1990 for Ny-Ålesund (Førland 1994, p 33).* ***All values are given in mm.***

PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1993	12	49	49	36	24	17	8	64	68	19	230	101	677
1994	1	97	22	12	20	10	79	54	34	10	17	30	386
1995	3	4	27	11	16	13	15	4	21	12	17	115	258
1961-1990	27	36	38	22	17	19	29	40	46	37	32	27	370

Table 3.3 *Meteorological variables used in the present analysis.*

Description	**Symbol**
Precipitation measured by Norwegian gauge	P_{nor}
Precipitation measured by Tretyakov gauge	P_{tr}
Precipitation measured by Norwegian gauge adjusted for evaporation and wetting	P_{NOR}
Precipitation measured by Tretyakov gauge adjusted for evaporation and wetting	P_{TR}
Precipitation measured by Geonor gauge	P_{ge}
True precipitation (corrected for catch deficiency)	P_C
Temperature from the official weather station (measured 2 m above the ground)	T
Temperature from the automatic station (measured 2 m above the ground)	T_a
Ta weighted by P_{ge}	T_g
Wind speed from the official weather station (measured 10 m above the ground)	v
Wind speed from the automatic station (measured 2 m above the ground at gauge height)	v_a
v_a weighted by P_{ge}	v_g
Simplified precipitation code defined in table 3.4	SPC

In June 1993, a Tretyakov precipitation gauge with a Tretyakov wind shield was put up next to the Norwegian gauge with its Nipher shield. An automatic weather station including hourly measurements of air temperature, wind at gauge height, and precipitation was also installed. These precipitation values were recorded from a Geonor weighing gauge with an

Alter shield. The positions of the instruments are shown in figure 3.2. Table 3.3 shows a survey of the meteorological variables which were used in the present analysis. The Geonor precipitation data were in the present analysis used only as weight factors for computing weighted means of temperature and wind at gauge height valid for the precipitation episodes. These values (T_g and v_g) were use in the precipitation correction formulas.

The parallel precipitation measurements were performed by the staff of the research station during the period July 1993-August 1995. The types of precipitation were noted for every observation, and the 12 hour precipitation observations are in the present study characterized by a simplified code (SPC) which is defined table 3.4. Total precipitation measured in the Norwegian gauge for the measuring period, subtotals for the different precipitation types, and some other key information are given in table 3.5. Addition of monthly totals for July 1993 through August 1995 in table 3.2 gives 965 mm. The reason for the difference between this value and the total in table 3.5 is that measurements from days when data were missing for the Tretyakov gauge were excluded from the analysis.

The last two lines of table 3.5 give average measured 12 hr precipitation amount for cases with $P_{nor}>0.0$ in the Norwegian and Tretyakov gauge, respectively. For rain and drizzle, slightly less was at average measured in the Tretyakov gauge than in the Norwegian. For snow, sleet and mixed precipitation on the other hand, the average amount measured in the Tretyakov gauge was higher than the equivalent measured in the Norwegian gauge.

Table 3.4 *Simplified precipitation code for classification of 12 hours precipitation values.*

SPC	0	1	2	3	4	5	6	7	9
TYPE	Not given	Rain	Drizzle	Snow	Sleet	Mixed rain/snow	Hail	Drifting snow	Other

Table 3.5 *Precipitation totals and other relevant information valid for the field period July 1993- August 1995 broken down by the simplified precipitation code.*

SPC / Weather type	1 rain	2 drizzle	3 snow	4 sleet	5 mixed ra/sn	6 hail	7 drifting snow	9 other	ALL -
ΣP_{nor} (mm)	313.5	12.4	295.6	70.4	206.5	1.0	8.8	1.5	909.7
Number of events* with precipitation**	144	39	312	30	41	1	14	5	586
Mean P_{nor} for events with precipitation	2.18	0.32	0.95	2.35	5.04	1.00	0.63	0.30	1.55
Number of events with P_{nor}>0.0	122	26	249	27	37	1	10	2	474
Mean P_{nor} per event with P_{nor}>0.0 (mm)	2.57	0.48	1.19	2.61	5.58	1.00	0.88	0.75	1.92
Mean P_{tr} per event with P_{nor}>0.0 (mm)	2.54	0.45	1.28	2.83	5.77	1.00	1.47	1.05	2.00

* The term «event» means 12 hour period 07-19 or 19-07 in the present report.

**The term «precipitation» includes, only in this table, drifting snow.

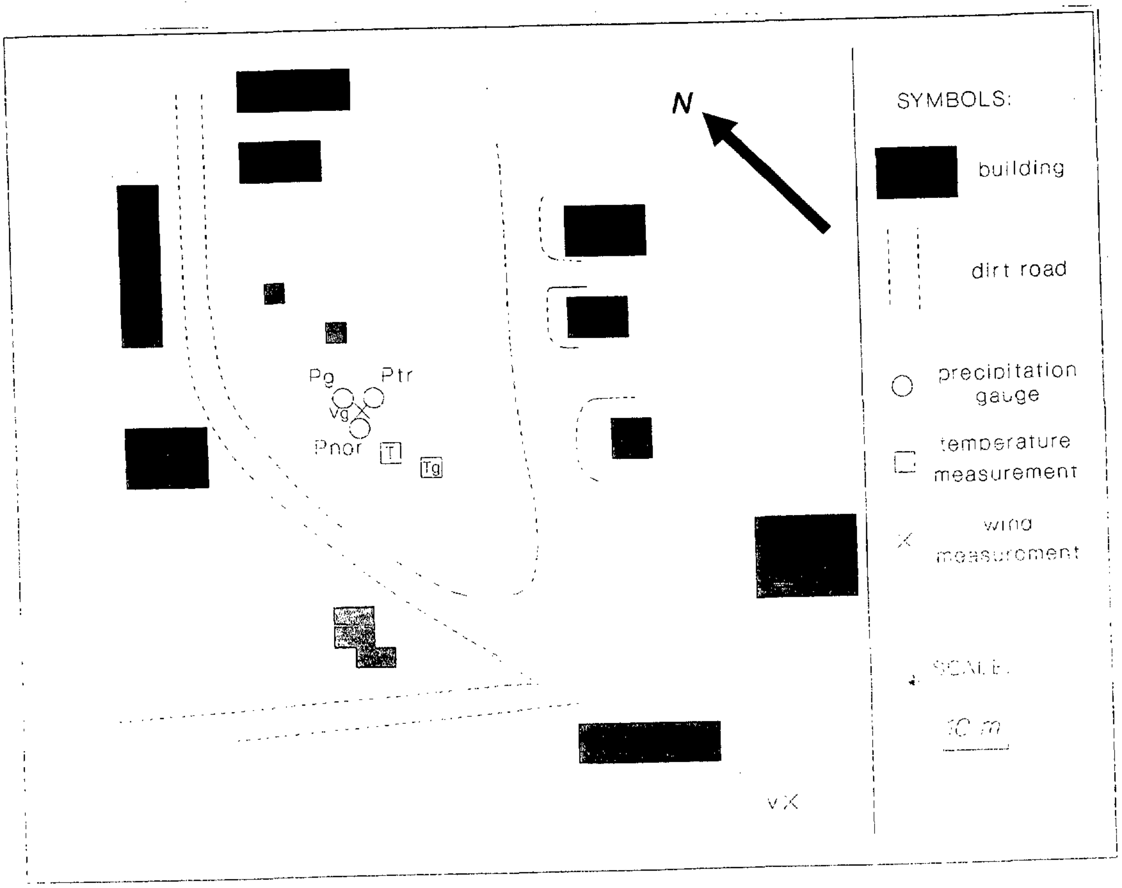

Figure 3.2 Map of the station area in Ny-Ålesund.

4. Results from the parallel measurements in Ny-Ålesund.

4.1 Basic data treatment.

The manual precipitation recordings from Ny-Ålesund were noted in separate forms, which were sent to the Norwegian Meteorological Institute (DNMI) once a month. At DNMI the forms were fed into the computer, and the datafiles were merged with data from the official weather station in Ny-Ålesund. The measurements from the Norwegian gauge and the precipitation types were checked against the official Ny-Ålesund climate data. A few errors were detected in this way. At one occasion the official precipitation value was changed. Whenever the simplified precipitation code was 0 but precipitation was measured, precipitation type was decided from the climate data. Concerning the Tretyakov measurements, a couple of obviously wrong values were removed. Missing data were not interpolated, but were left out of the analysis.

The data were grouped by the SPC (table 3.4). The groups with SPC>5 (hail, drifting snow and «other») were left out of the following analysis. According to table 3.5, these groups account for only about 1% of the «total precipitation», and most of this is drifting snow, which is not really precipitation at all. Subtracting the drifting snow, more than 99% of the measured precipitation is thus included in the analysis.

Førland *et al.* (1996a) used the term «mixed precipitation» as precipitation reported as sleet as well as real mixture of solid and liquid precipitation. The same recommendations for correction are given for these precipitation types. Group 4 and 5 in the present dataset were thus combined, and the term «mixed precipitation» will in the following chapters be used for this combined group.

4.2 Evaporation and wetting.

Equations 2.7 - 2.11 are all based upon measurements which are corrected for evaporation and wetting. Førland *et al.* (1996a) suggest to use the values given in table 4.1 and 4.2 if wetting and evaporation are not known from other sources. The wetting values should be valid for measurements anywhere. Evaporation, on the other hand, is probably lower at Spitsbergen than in southern Finland. Besides, the values in table 4.2 are quite uncertain according to the authors (Førland *et al.* 1996a). The suggestion for 12 hour evaporation values given in table 4.3 is nevertheless based upon table 4.2. It is suggested to use the same values day and night, as the differences between day and night are small most of the year at Spitsbergen. A first suggestion for corrections for wetting and evaporation, based only upon Førland *et al.* (1996a) is thus given in table 4.4, which is produced by adding up tables 4.1 and 4.3.

In Ny-Ålesund, neither evaporation loss nor wetting loss were measured, but estimates may be made of the difference between the Tretyakov gauge and the Norwegian gauge.

Table 4.1 *Recommended values of wetting amounts (mm/case) from Førland et al.(1996a).*

	Rain	Drizzle	Snow	Mixed
Tretyakov H&H90	0.13	0.09	0.05	0.11
Norwegian gauge	0.15	0.14	0.05	0.13
Difference T-N	-0.02	-0.05	0.00	-0.02

Table 4.2 *Recommended values of mean daily evaporation loss (mm/day) from Førland et al.(1996a).*

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Tretyakov H&H90	0.03	0.04	0.06	0.20	0.04	0.05	0.05	0.05	0.04	0.03	0.03	0.03
Norwegian gauge	0.02	0.02	0.03	0.16	0.04	0.06	0.06	0.05	0.03	0.02	0.02	0.02
Difference T-N	0.01	0.02	0.03	0.04	0.00	-0.01	-0.01	0.00	0.01	0.01	0.01	0.01

Table 4.3 *Suggested values of mean evaporation loss (mm/12 h) based upon table 4.2.*

	Rain	Drizzle	Snow	Mixed
Tretyakov H&H90	0.02	0.02	0.01	0.02
Norwegian gauge	0.02	0.02	0.01	0.01
Difference T-N	0.00	0.00	0.00	0.01

Table 4.4 *Values for wetting + evaporation (mm/case) based upon tables 4.1 and 4.3 .*

	Rain	Drizzle	Snow	Mixed
Tretyakov H&H90	0.15	0.11	0.06	0.13
Norwegian gauge	0.17	0.16	0.06	0.14
Difference T-N	-0.02	-0.05	0.00	-0.01

For wind speeds smaller than 1 m/s at gauge height, the aerodynamic effects are small even for solid precipitation (cf. eq. 2.11), and the average difference between the amounts measured in the two gauges should reflect the differences in wetting and evaporation loss only. Table 4.5 shows this difference for different precipitation types for cases with mean wind at gauge height smaller than 1 and 2 m/s respectively. The average for the cases with v_g<1m/s would give the better estimate in the long run. However, if there are few cases in the group, random variations may affect the mean value seriously. For rain, the average difference for the cases with v_g< 1m/s is about 0.10 mm, while it is 0.05 mm for drizzle. For small amounts of rain (< 1 mm/case), the difference seems to be closer to the "drizzle value" than to the "rain value", and these cases are thus treated like the drizzle cases concerning wetting and evaporation. For snow there is no systematic difference between the gauges. For mixed precipitation the average difference is slightly below zero. There are few cases in this group, and the difference is close to zero when cases with wind below 2 m/s are included. As it would also be physically difficult to explain why this value should be negative for mixed precipitation when it is positive for liquid precipitation and zero for solid precipitation, the difference is assumed to be zero for mixed precipitation.

The magnitude of the wetting and evaporation for the Norwegian gauge (Table 4.4) is confirmed by previous national studies (*e.g.* Dahlström et al. 1986), and is therefore adopted also in the present study. To keep the consistency from Table 4.5 between the gauges, the values from Table 4.4 were adjusted according to the observed differences between the precipitation measured by the two gauges at low wind speeds. To indicate that these are rough estimates, the values are rounded off to the nearest 0.05 mm/case. The values in Table 4.6 were used to correct the present dataset for wetting and evaporation loss.

Table 4.5 *Average difference between precipitation measured by Norwegian gauge (P_{nor}) and precipitation measured by Tretyakov gauge (P_{tr}) at low wind speeds.*

	RAIN,all SPC=1	RAIN≥1mm SPC=1	RAIN<1mm SPC=1	DRIZZLE SPC=2	SNOW SPC=3	MIXED SPC=4 - 5	ALL SPC=1 - 5
(P_{nor}-P_{tr}),v_g<1m/s	0.09	0.11	0.07	0.05	0.00	-0.03	0.03
N, v_g<1m/s	39	20	19	15	73	11	138
(P_{nor}-P_{tr}),v_g<2m/s	0.08	0.09	0.07	0.05	-0.02	-0.01	0.02
N, v_g<2m/s	69	31	38	23	138	19	249

Table 4.6 *Values of wetting + evaporation (mm/case) used in the present analysis.*

	Rain ≥ 1mm	Drizzle + Rain<1mm	Snow	Mixed
Tretyakov H&H90	0.25	0.20	0.10	0.15
Norwegian gauge	0.15	0.15	0.10	0.15
Difference T-N	0.10	0.05	0.00	0.00

Table 4.7 *Precipitation totals (ΣP_{nor} and ΣP_{TR}) and averages for days with $P_{nor} > 0.0$ during the field period July 1993- August 1995 broken down by precipitation code.*

	RAIN SPC=1	DRIZZLE SPC=2	SNOW SPC=3	MIXED SPC∈ (4 , 5)	TOTAL SPC∈ (1, 5)
ΣP_{nor}	313.5	12.4	295.6	276.9	898.4
ΣP_{NOR}	331.8	16.3	320.5	286.5	955.1
ΣP_{TR}	337.8	16.8	343.5	299.6	997.7
Number of events with $P_{nor}>0.0$	122	26	249	64	461
Mean P_{nor} for events with $P_{nor}>0.0$	2.57	0.48	1.19	4.33	1.95
Mean P_{NOR} for events with $P_{nor}>0.0$	2.72	0.63	1.29	4.48	2.07
Mean P_{TR} for events with $P_{nor}>0.0$	2.77	0.65	1.38	4.68	2.16

Table 4.7 shows, for both gauges, the precipitation totals and averages pr. case corrected for evaporation and wetting by using the values in table 4.6. The uncorrected totals from the Norwegian gauge are shown as well. For all precipitation types, the corrected amounts from the Tretyakov gauge are larger than the equivalent from the Norwegian gauge.

It should be noted that only mesurements where $P_{nor}>0$ are included in the present study. Table 3.5 shows that «trace amounts» ($P_{nor}= 0$) were reported in almost 20% of the totally reported precipitation events. In these cases all precipitation is lost as evaporation or wetting. At some Canadian Arctic stations, 80% of the observations have been reported as trace amounts (Goodison *et al.* 1996). Inclusion of the trace events in analyses of catch efficiency is then important. For adjustment purposes, trace amounts reported during 6-hour periods at Canadian Arctic stations have thus been assigned a value of 0.07mm. In the present analysis, it would be reasonable to add half the values given in table 4.6 to the trace events in order to adjust for wetting and evaporation. This would increase ΣP_{NOR} and ΣP_{TR} in table 4.7 by less than 1% (6 and 7 mm, respectively). The further comparisons and analyses would not be seriously affected by this.

4.3 Aerodynamic effects, general

For all cases with $P_{nor}>0$, the ratio P_{TR}/P_{NOR} was calculated. The relationship between this ratio and the wind speed at gauge height was then investigated for different precipitation types, intensities and temperatures. The noise in the ratio caused by random errors is at maximum for small amounts of precipitation. It is thus common to use a lower threshold of a few mm/case in studies like this. In the WMO Intercomparison analysis, only daily totals when the DFIR measurement is >3.0 mm are included (Goodison *et al.* 1996). The low annual precipitation and low precipitation intensities in the Arctic, however, made us reluctant to skip any of the data. Besides, introduction of a threshold might bias the dataset, as the precipitation intensity is more likely to be low when the 12 hour precipitation total is small. Preliminary regression analyses were therefore accomplished with and without a threshold of P_{nor}= 1mm. Comparison of the result showed no major differences for solid precipitation. The correlations were slightly higher when skipping the small precipitation amounts, but the regression coefficients were very similar. For liquid precipitation on the other hand, the regression coefficients were seriously affected by skipping small precipitation amounts. The results presented in the following sections are thus from the regression analyses based upon all cases.

The advantage of this is that all data are included in the analysis. The disadvantages are that inclusion of values with low P_{nor} increases the noise level, and that all cases get the same weight (*e.g.* a case with P_{nor} = 0.1 mm counts as much as a case with P_{nor}= 10 mm). Both these disadvantages may be reduced by grouping together precipitation from similar weather situations. Two approaches were thus made to study the relationship between the ratio P_{TR}/P_{NOR} and the wind speed v_g :

i) regression analyses based upon P_{TR}/P_{NOR} for all single cases;

ii) regression analyses based upon the ratio between precipitation totals for defined wind speed intervals ($\Sigma P_{TR}/\Sigma P_{NOR}$ for cases with $v_g \in \{v_1, v_2\}$).

The advantages of approach ii) is that noise from single cases is reduced by adding all precipitation within given wind speed intervals. A disadvantage is that all wind intervals get the same weight, independently of precipitation amount and number of cases included in each of them. Two efforts were made in order to compensate for this. The values were weighted by total amount of precipitation (ΣP_{nor}) within the interval, and lower limits were put on number of cases per interval. The results showed that weighting increased the noise level, while the introduction of a lower limit of number of cases pr wind speed interval reduced it, as long as number of wind speed intervals was not reduced too much. Consequently, the results presented in the following sections are from runs without weighting, but with a lower limit of 2 cases per wind speed interval. The width of the wind speed intervals was defined as 1m/s. Intervals including 1 case only were added to a neighbouring interval, preferably the subsequent one.

4.4 Aerodynamic effects, liquid precipitation

According to eq. 2.9 there is no difference between the two gauges concerning the catch efficiency of liquid precipitation. The hypothesis of differences between the gauges were investigated anyway, as it seems to be illogical that there should be differences for solid precipitation but not for liquid. If there are differences between the gauges in aerodynamic characteristics under solid precipitation, these differences should also affect the catch efficiency during rain, even if the effect might be smaller. It is thus assumed that the relation between precipitation measured in the two gauges is of the same form as eq. 2.2, i.e. it is dependent on wind speed and rain intensity. For precipitation of a certain intensity, this gives:

(4.1) $$P_{TR}/P_{NOR} = \exp\{\, a_0 + b_0 \cdot v_g \} \, .$$

This leads to the linear model:

(4.2) $$\ln\{P_{TR}/P_{NOR}\} = a_0 + b_0 \cdot v_g \ ,$$

where $\mathbf{a_0}$ and $\mathbf{b_0}$ may be dependent on intensity only. For $\mathbf{v_g}=0$, the aerodynamic effects should not cause any differences between the gauges, and one might thus expect following connection for a given intensity:

(4.3) $$\ln\{P_{TR}/P_{NOR}\} = b_1 \cdot v_g .$$

Regression analyses were made in order to test both these models.

The precipitation intensity recorded by the Geonor weighing pluviograph was too unreliable for low precipitation intensities. Instead, the total precipitation amount over 12 hours was used to give a rough estimate of intensity. In the present analyses the rain data were divided into 3 groups: $P_{nor} < 1$mm, 1mm $\leq P_{nor} <$ 4mm and $P_{nor} \geq 4$ mm. Assuming that the precipitation at average fell during 8 of the 12 hours, the corresponding intensities would be: $I < 0.125$mm/hr , 0.125mm/hr $\leq I <$ 0.5mm/hr and $P_{nor} \geq 0.5$ mm/hr. The drizzle data were not divided into groups, as the intensity during drizzle is always low.

The complete results from the regression analyses based upon single cases (approach i, p.18) of rain and drizzle are shown in table A.1 in Appendix. The results corresponding to equation 4.3 are also presented in the first columns of table 4.8. Results are shown for the rain and drizzle groups, as well as for the 3 rain intensity subgroups. The correlation coefficients are low, and the regression coefficients corresponding to equation 4.2 vary randomly from group to group (table A.1). The regression coefficient corresponding to equation 4.3, on the other hand, increases gradually from 0.009 for the «high intensity» rain group, to higher values for lower intensities, and to a maximum of 0.033 for the drizzle group. The b_1 values in table 4.8 indicate that the aerodynamic behaviour of rain when $P_{nor} < 1$mm is more like the behaviour of drizzle than the behavior of rain of higher intensities. The last two lines of table 4.8 show the results from moving the low intensity rain cases from the «rain group» to the «drizzle group».

Ratios between the precipitation sums measured by the two gauges within defined wind speed intervals are given in table A.2 (Appendix) for all intervals and for all groups referred to in table 4.8. Representative wind speeds $<v_g>$ for each interval were calculated as weighted means of the wind speed during the precipitation events within the interval. The complete results from regression analyses based upon these ratios and wind speeds (approach ii, p.18) are given in table A.3 (Appendix). The results corresponding to equation 4.3 are also given in the last columns of table 4.8. While the two approaches, for many groups, gave quite different values of the regression coefficients corresponding to eq. 4.2, table 4.8 illustrates that the coefficient corresponding to equation 4.3 shows the same pattern.

Table 4.8 *Main results from regression analyses, liquid precipitation.*
N=number of cases in approach i) / number of intervals in approach ii);
b_l = regression coefficients corresponding to eq. 4.3;
R_l = redefined correlation coefficient corresponding to the no intercept model.

	approach i): single cases			approach ii): wind intervals		
	N	b_l	R_l^2	N	b_l	R_l^2
RAIN, ALL (SPC=1)	122	0.015	0.044	6	0.012	0.792
DRIZZLE, ALL (SPC=2)	26	0.033	0.102	3	0.032	0.779
RAIN, $P_{nor} \geq 4mm$	18	0.009	0.281	5	0.011	0.606
RAIN, $1 \leq P_{nor} < 4mm$	48	0.014	0.094	6	0.015	0.754
RAIN, $P_{nor} < 1mm$	56	0.025	0.045	5	0.026	0.709
RAIN, $P_{nor} \geq 1mm$	66	0.011	0.082	6	0.012	0.774
DRIZZLE / RAIN, $P_{nor} < 1$	82	0.027	0.056	5	0.029	0.831

Table 4.8 also show that the correlation improves substantially when ratios between precipitation totals within 1 m/s wind intervals are used rather than single values. Based upon the regression coefficients corresponding to eq. 4.3, following conclusions can be drawn concerning liquid precipitation:

* Differences between the gauges concerning aerodynamic effects leads to better catch of rain and drizzle in the Tretyakov gauge than in the Norwegian gauge.

* The difference is at maximum for low rain intensities (P_{nor} <1mm/case) and for drizzle. For these groups, the regression coefficient b_l is about 0.030.

* For rain at higher intensities, the regression coefficient b_l is 0.010 - 0.015.

4.5 Aerodynamic effects, solid and mixed precipitation

According to equation 2.11. the ratio between snowfall caught in the Tretyakov gauge and in the Norwegian gauge is an exponential function of both the wind speed at gaugeheight and the air temperature. However, a change in wind speed of 1 m/s is more important than a change in temperature of 15°C, and we are thus basically looking for a connection on the form shown in eqs. 4.2 or 4.3. In the present analysis the snow data were divided into 3 groups: $T_g \leq -6$ °C, $-6°C < T_g \leq -2°C$ and $T_g > -2$ °C. The sleet/mixed data were not divided into groups, as the temperature during these cases was always above -2 °C.

Results from approach i (p.18) for snow and mixed precipitation are shown in table A.4 in Appendix, while the results from approach ii (p.18) are summarized in tables A.5 and A.6. The correlation coefficients were generally higher than for liquid precipitation, but they were still very low in the single case approach. As for liquid precipitation, the regression coefficients corresponding to equation 4.2 (particularly a_0) vary somewhat randomly between the groups, while the regression coefficient corresponding to equation 4.3 shows a more regular variation. The ratio between precipitation caught by the two gauges is thus suggested to be related to the wind speed as described by equation 4.3. The main results corresponding to equation 4.3 are, for both approaches, presented in table 4.9. Results from the single case approach (first columns of table 4.9) indicate that snowfall at temperatures above -2 °C behave more like mixed precipitation than like snowfall at lower temperatures.

Table 4.9 *Main results from regression analyses, solid and mixed precipitation.*
N=number of cases in approach i) / number of intervals in approach ii);
b_1 = regression coefficients corresponding to eq. 4.3;
R_1 = redefined correlation coefficient corresponding to the no intercept model.

	approach i): single cases			approach ii): wind intervals		
	N	b_1	R_1^2	N	b_1	R_1^2
SNOW, ALL (SPC=3)	249	0.022	0.178	11	0.022	0.926
SLEET OR MIXED (SPC=4,5)	64	0.017	0.192	8	0.009	0.791
SNOW, $T_g \leq -6°C$	94	0.023	0.228	8	0.029	0.815
SNOW, $-6°C < T_g \leq -2°C$	79	0.027	0.328	8	0.021	0.926
SNOW, $T_g > -2°C$	76	0.015	0.068	9	0.017	0.884
SNOW, $T_g \leq -2°C$	173	0.025	0.276	10	0.029	0.873
SLEET/MIX /SNOW, $T_g > -2°C$	140	0.016	0.100	9	0.015	0.873

Regressions were therefore calculated also for a combination of the «mild snow group» and the «mixed precipitation group» and for a «medium to cold snow group». The results from the wind interval approach (last columns of table 4.9) though indicate that there is a difference between «mild snow» and «mixed precipitation», and that these groups should be treated separately. Following conclusions are drawn from table 4.9:

* Differences between the gauges concerning aerodynamic effects leads to better catch of snow and mixed precipitation in the Tretyakov gauge than in the Norwegian gauge.

* The difference is at maximum for snow falling at low temperatures.
For the group with $T \leq -6$ °C , the regression coefficient b_1 about 0.030.

* For sleet and mixed precipitation, the regression coefficient b_1 is 0.010.

4.6 Model for relationship Tretyakov / Norwegian gauge in Ny-Ålesund

From the parallel measurements in Ny-Ålesund, we conclude that the ratio between the precipitation measured in the Tretyakov gauge and in the Norwegian gauge is fairly well described by the equation

$$(4.4) \qquad P_{TR} / P_{NOR} = \exp\{ b \cdot v_g \} .$$

Suggested values of b are given in table 4.10 for different precipitation types, intensities and temperatures.

Table 4.10 Suggested values of the coefficient b in eq 4.4 for different types of precipitation in Ny Ålesund, total amount of each type measured during the period of parallel measurements, and average intensity for the rain groups and temperature for the snow groups .

	RAIN $I \geq 0.5$mm /hr	RAIN $I \in 0.125 - 0.5$mm/hr	RAIN+DRIZZLE $I < 0.125$mm/hr	SNOW T<-6	SNOW -6<T<-2	SNOW T > -2	MIXED
b	0.010	0.015	0.030	0.030	0.025	0.015	0.010
ΣP_{nor}	191.7 mm	100.3 mm	33.9 mm	75.7 mm	113.7 mm	106.2 mm	276.9 mm
<I>or <T>	1.35 mm/hr	0.28 mm/hr	0.07 mm/hr	-10.0 °C	-4.0 °C	-0.1 °C	0.56 mm/hr 1.23°C

In order to make the «intensity groups» in table 4.10 comparable to equations based upon rain intensity given in mm/hr, it is assumed that it at average is raining 8 of the 12 hours within the measuring period. The reason for combining the «low intensity rain group» and the «drizzle group» is that small amounts of precipitation are included in both these groups.

The virtually smooth variation of b with intensity for liquid , and with temperature for solid precipitation, makes it convenient to express these relationships by equations. As it is the logarithm of the intensity which is used in the estimate of true precipitation in equation 2.2, following relationships were suggested:

(4.5) $b = x_l + y_l \cdot \ln(I)$ for liquid precipitation,

(4.6) $b = x_s + y_s \cdot T_g$ for solid precipitation.

Values of $\mathbf{x_l}$, $\mathbf{y_l}$, $\mathbf{x_s}$ and $\mathbf{y_s}$ were found by adaption to the group means of I and T given in table 4.10. Introducing them in equation 4.4 we may suggest:

(4.7) $P_{TR}/P_{NOR} = \exp\{ 0.0096 \cdot v_g + 0.0060 \cdot \ln(I) \cdot v_g \}$ for liquid precipitation,

(4.8) $P_{TR}/P_{NOR} = \exp\{ 0.0150 \cdot v_g + 0.0020 \cdot T_g \cdot v_g \}$ for solid precipitation.

For sleet end mixed precipitation, it is suggested to use equation 2.4.

5. Results from Ny-Ålesund compared to results from Jokioinen

The ratio between precipitation measured by Tretyakov gauge and by Norwegian gauge may now be estimated in 3 different ways:

- by using equation 4.4 with the coefficients given in table 4.10 (model 1a) ;
- by using equations 4.7 and 4.8 (model 1b);
- by using the suggestions from Førland *et al.*(1996a) as expressed in equations 2.9 and 2 .11 (model 2).

Figures 5.1 a-g show P_{TR}/P_{NOR} as function of wind speed when using model 1a and model 2, for each of the precipitation types given in table 4.10. The observed values based upon precipitation sums in wind intervals (from tables A.2 and A.5) are also plotted in the figure. For rain (fig. 5.1 a-c), model 2 (which says it is no difference between the gauges) clearly underestimates the ratio. For snow and mixed precipitation(fig. 5.1 d-g) on the other hand, model 2 seems to overestimate the ratio, at least for wind speeds > 3m/s.

The amounts of precipitation included in each of the observations in figure 5.1 varies from less than 1 to more than 90 mm. In order to quantify the discrepancy between the precipitation measured in the Tretyakov gauge and the precipitation estimated by using the different models in combination with the precipitation measured in the Norwegian gauge, one should thus consult table 5.1. Note that the differences between model 1a and 1b are small. They are both slightly overestimating precipitation in the rain groups and in the coldest snow group, while the precipitation in the other groups are slightly underestimated. The deviations are however < 5 mm for all groups as well as for the total precipitation. Model 2, on the other hand, overestimates the precipitation in the solid and mixed groups, while the precipitation in the liquid groups is slightly underestimated. The deviations from the measured precipitation are, for most groups as well as for total precipitation, larger than for model 1a and 1b. We conclude that model 1a or 1b should be used rather than model 2 to describe the ratio between measurements in Tretyakov gauge and measurements in Norwegian gauge at Spitsbergen. Further we conclude that model 1b very well may be used instead of model 1a. This will be done in the following calculations.

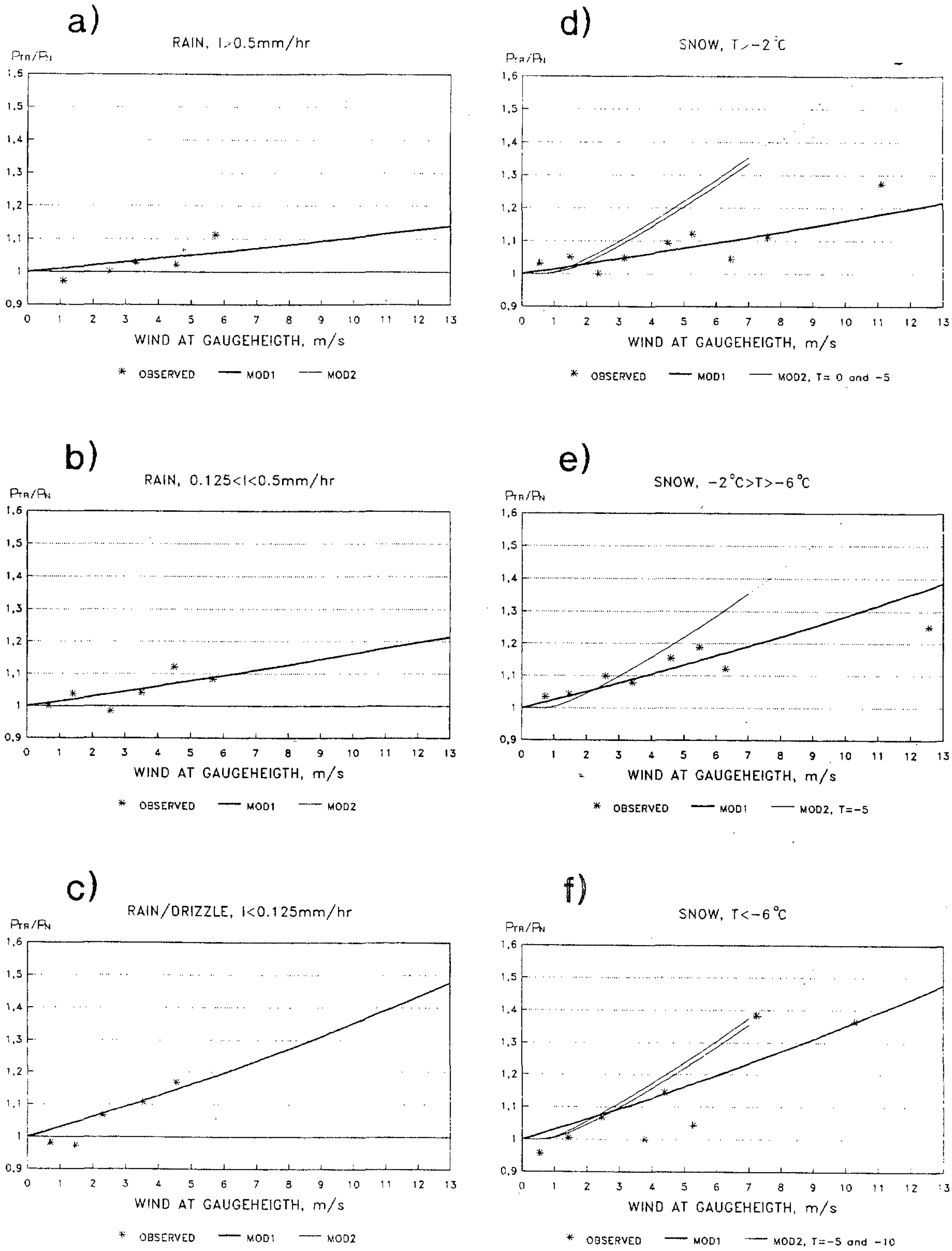

Figure 5.1. *Observed and modelled ratio between precipitation in Tretyakov gauge and in Norwegian gauge as a function of wind speed at gauge height. « Mod 1» is the model developed presently. «Mod 2» is the ratio based upon Allerup et al. (1997) and Førland et al. (1996a). a-c: Rain in 3 intensity classes. d-f: Solid precipitation in 3 temperature classes.*

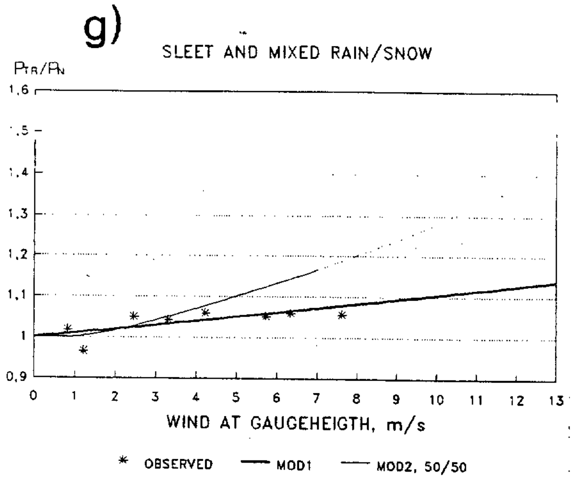

Figure 5.1 *continued. g: Sleet and mixed solid/liquid precipitation.*

Table 5.1 Measured and modelled precipitation in the Tretyakov gauge in Ny-Ålesund.
Observed values: N =number of events ΣP_{TR} *= measured precipitation adjusted for wetting/evaporation.*
Model values: ΣP_{TR} *= modelled precipitation, rms= root of mean square deviation between observed and modelled precipitation, dev=deviation between modelled total and observed total, corr.= correlation coefficient between observed and modelled precipitation.*

	OBSERVED		Model 1 a				Model 1 b				Model 2			
	N	ΣP_{TR} mm	ΣP_{TR} mm	rms mm	dev mm	corr.	ΣP_{TR} mm	rms mm	dev mm	corr.	ΣP_{TR} mm	rms mm	dev mm	corr.
RAIN, I ≥ 0.5	18	197.8	200.7	0.39	+2.9	.999	198.0	0.51	+0.2	.999	194.4	0.55	- 3.4	.999
-»- 0.5> I ≥0.125	48	109.9	110.9	0.22	+1.0	.968	111.2	0.22	+1.3	.969	107.5	0.22	- 2.4	.967
DR/RAIN,I<0.125	82	46.9	48.6	0.13	+1.7	.956	48.1	0.12	+1.2	.954	46.2	0.12	- 0.7	.949
SLEET/MIXED	64	299.6	298.1	0.24	- 1.5	.999	297.3	0.19	- 2.3	1.00	306.8	0.50	+7.2	.999
SNOW T > -2	76	120.9	119.3	0.19	- 1.6	.996	119.2	0.20	- 1.7	.996	126.5	0.34	+5.6	.990
SNOW -6<T<-2	79	133.4	131.4	0.14	- 2.0	.998	130.4	0.15	- 3.0	.998	134.7	0.20	+1.3	.997
SNOW T<-6	94	89.2	92.5	0.17	+3.3	.993	93.6	0.17	+4.4	.993	94.6	0.19	+5.4	.993
ALL	461	997.7	1001.5	0.19	+3.8	.999	997.9	0.20	+0.2	.999	1010.7	0.30	+13.0	.998

Possible reason for the relatively poor adaption of model 2 to the Ny-Ålesund data is discussed in connection with the estimation of true precipitation in chapter 6.

6. True precipitation

6. 1 Models for correction of aerodynamic errors

True precipitation in Ny-Ålesund was estimated by the 5 models given in table 6.1.

Model 0 is the model suggested by Førland *et al.* (1996a) for estimating true precipitation from measurements in a Tretyakov gauge. It includes equation 2.2 for liquid precipitation and the Allerup *et al.* (1997) model for solid precipitation measured by Tretyakov gauge. Model 0 is regarded as the reference model, because this connection between true precipitation and Tretyakov measurements is developed from a large, high quality dataset.

Model I combines equations 4.7 and 4.8 with Model 0 in order to get from measurements in Norwegian gauge to true precipitation. Model I is the model suggested by the present analysis, for estimating true precipitation from measurements in the Norwegian gauge under Arctic conditions.

Model II is the model suggested by Førland *et al.* (1996a) for estimating true precipitation from the measurements in Norwegian gauge. It includes the Allerup *et al.* (1997) model for solid precipitation measured by Norwegian gauge, while the model for liquid precipitation is identical to model 0.

Table 6.1 *Models for estimating true precipitation (*P_C*) in Ny-Ålesund..*

Model	solid/ liquid	input in model	Equation for aerodynamic correction factor*
Model 0	solid	P_{TR}	$k_s = \exp\{-0.04816 + 0.13383 \cdot v_g + 0.009064 \cdot T_g - 0.005147 \cdot v_g \cdot T_g\}$
Model 0	liquid	P_{TR}	$k_l = \exp\{-0.042303 - 0.00101 \cdot \ln(I) - 0.012177 \cdot v_g \cdot \ln(I) + 0.034331 \cdot v_g\}$
Model I	solid	P_{NOR}	$k_s = \exp\{-0.04816 + 0.14883 \cdot v_g + 0.009064 \cdot T_g - 0.007147 \cdot v_g \cdot T_g\}$
Model I	liquid	P_{NOR}	$k_l = \exp\{-0.042303 - 0.00101 \cdot \ln(I) - 0.018177 \cdot v_g \cdot \ln(I) + 0.043931 \cdot v_g\}$
Model II	solid	P_{NOR}	$k_s = \exp\{-0.12159 + 0.18546 \cdot v_g + 0.006918 \cdot T_g - 0.005254 \cdot v_g \cdot T_g\}$
Model II	liquid	P_{NOR}	$k_l = \exp\{-0.042303 - 0.00101 \cdot \ln(I) - 0.012177 \cdot v_g \cdot \ln(I) + 0.034331 \cdot v_g\}$
Model III	solid	P_{NOR}	$k_s = \exp\{-0.08871 + 0.16146 \cdot v_g + 0.011276 \cdot T_g - 0.008770 \cdot v_g \cdot T_g\}$
Model III	liquid	P_{NOR}	$k_l = \exp\{-0.042303 - 0.00101 \cdot \ln(I) - 0.012177 \cdot v_g \cdot \ln(I) + 0.034331 \cdot v_g\}$
Model IV	solid	P_{TR}	$k_s = 1 + \{0.35 - 0.25 \cdot \exp(0.045 \cdot T_g)\} \cdot v_g^{1.2}$

* *NB! For models 0, I, II and III the correction factor is* $\max\{k, 1\}$.

Table 6.2 *True precipitation(Pc) in Ny-Ålesund estimated by the models presented in table 6.1.*

	OBSERVED		MODEL 0		MODEL I		MODEL II		MODEL III		MODEL IV	
	ΣP_{NOR} mm	N	ΣP_C mm	$\frac{\Sigma P_C}{\Sigma P_{NOR}}$	ΣP_C mm	$\frac{\Sigma P_C}{\Sigma P_{NOR}}$	ΣP_C mm	$\frac{\Sigma P_C}{\Sigma P_{NOR}}$	ΣP_C mm	$\frac{\Sigma P_C}{\Sigma P_{NOR}}$	ΣP_C mm	$\frac{\Sigma P_C}{\Sigma P_{NOR}}$
RAIN, $I \geq 0.5$	194.4	18	205.6	1.06	205.8	1.06	202.2	1.04	202.2	1.04	-	-
-»- $0.5 > I \geq 0.125$	107.5	48	116.9	1.09	118.1	1.10	114.0	1.06	114.0	1.06	-	-
DR/RAIN,$I<0.125$	46.2	82	50.4	1.09	51.5	1.11	49.4	1.06	49.4	1.06	-	-
SLEET/MIXED	286.5	64	403.0	1.41	400.2	1.40	420.2	1.47	396.2	1.38	-	-
SNOW $T > -2$	113.8	76	185.1	1.63	182.2	1.60	198.7	1.75	184.0	1.62	168.8	1.48
SNOW $-6<T<-2$	121.6	79	206.5	1.70	201.7	1.66	211.1	1.74	206.0	1.69	209.2	1.72
SNOW $T<-6$	85.1	94	165.3	1.94	171.6	2.02	180.3	2.12	189.5	2.23	157.5	1.85
RAIN+DR/ALL	348.1	148	372.9	1.07	375.4	1.08	365.5	1.05	365.5	1.05	-	-
SNOW/ALL	320.5	249	556.9	1.74	555.4	1.73	590.2	1.84	579.5	1.81	535.4	1.67
ALL	955.1	461	1332.9	1.40	1331.0	1.39	1375.9	1.44	1341.1	1.40	-	-

Model III is the model suggested by Førland *et al.* (1996a) for estimating true precipitation from the measurements in Swedish gauge. It includes the Allerup *et al.* (1997) model for solid precipitation measured by Swedish gauge, while again the model for liquid precipitation is identical to model 0. The model is used on precipitation measured by the Norwegian gauge.

Model IV is a model suggested by Golubev and Bogdanova (1996) for estimating true solid precipitation from measurements in a Tretyakov gauge. It is based on a Russian dataset and it is applied in order to compare the above models to a totally independent model.

The results from applying these models to the precipitation measurements in Ny-Ålesund are presented in table 6.2. Estimates for true precipitation during periods of pure solid or liquid precipitation were found by using the equations given in table 6.1. For mixed precipitation and sleet, the correction factor was supposed to be the mean value of the solid precipitation and liquid precipitation correction factors.

6.2 Comparison of the «reference model» and the «Ny-Ålesund model».

Table 6.2 shows that the results from models 0 and I are quite similar, both for liquid and for solid precipitation. This is what one should expect, as model I was developed to match model 0 for this dataset. In order to test model I properly, the models should be tested on an independent dataset. However, the results from the present analysis indicate that the model developed for estimating true precipitation from precipitation measured in Norwegian gauge at Svalbard (model I) is a reasonably good model provided that the Jokioinen model for the Tretyakov gauge is a good and fairly «universal» model, which also may be used for windspeeds > 7m/s.

6.3 Comparing model 0 and model II for liquid precipitataion.

Førland *et al.* (1996a) suggested, as a rough estimate, to use the same model to estimate true liquid precipitation for all nordic gauges, provided that they had a windshield (cf. table 6.1, model 0, model II and model III). The measurements from Ny-Ålesund, however, indicate that the Tretyakov gauge catches more liquid precipitation than the Norwegian gauge (cf. table 4.7 and eq. 4.7). The estimates of true liquid precipitation in Ny-Ålesund are thus larger for model 0 than for model II (table 6.2). This does not mean that the results from models 0 necessarily is more trustworthy than the results from model II. It depends on what gauge (or windshield) that has the correction factor that is best approximated by the one suggested by Førland *et al.* (1996a). The differences between the estimates thus express an uncertainty of the models. One may conclude that for the Norwegian gauge, the average aerodynamic correction factor for liquid precipitation at Svalbard is between 1.05 and 1.10.

6.4 Comparing model 0 and model II for solid precipitation.

Table 6.2 shows that model II gives higher estimates of true solid precipitation than model 0 for all temperature groups. This reflects differences between Jokioinen and Ny-Ålesund concerning the ratio between precipitation measured in Norwegian gauge and in Tretyakov gauge for given windspeeds and temperatures. These differences may be caused either by real differences in this relationship (*e.g.* diffenences in the adaption to a simplified model under different climatic conditions), or they can be caused by systematic differences between the exposure of the two gauges in one of the two testfields.

The first explanation implies that the Jokioinen equations are not «universal». This might be caused by differences between locations in the connection between temperature at gauge heigth and structure and size of the snowflakes. Alternatively, it might be caused by erroneous suggestions about the correction factors' dependency of the wind speed. *E.g.* if the correction factors are not excactly exponential functions of the wind speed, the coefficients estimated by adaption to different datasets would be dependent on the wind speed distributions which were represented in the datasets. If the Jokioinen equations, for either of these reasons are not universal, the estimates of true precipitation made by model 0 (and thus by model I) are also questionable. A good model for true precipitation in Ny-Ålesund and other Svalbard stations would then have to be developed from measurements made at an evaluation station (WMO 1994), situated in a climate similar to that of Ny-Ålesund.

The other explanation implies that there, at one of the locations were systematic differences in the exposure of the gauges. If this is the case, it is still possible that one of the Jokionen models is fairly «universal» and thus gives a good estimate of true solid precipitation in Ny-Ålesund. The other Jokioinen model would, however, give a poor estimate, either because the model was poor (in case the Jokioinen data from the gauge corresponding to this model were poor) or because the data from the corresponding gauge in Ny-Ålesund were poor.

6.5 Gauge locations in Jokioinen and Ny-Ålesund.

In order to investigate the possible reasons for the differences between Jokioinen and Ny-Ålesund concerning measurements in Tretyakov contra Norwegian gauge, the setups of the testfields were analysed. In Ny-Ålesund, the gauges were only 5 m apart in flat terrain (figure 3.2). The wind was measured between them, and should thus be representative for both. It is not likely that differences in the exposure of these two gauges should result in discrepancies of the size which are observed.

In Jokioinen, on the other hand, the windspeed was measured at a distance of 35 m from the Norwegian gauge. As a systematic gradient in wind speed was documented within the field

(Førland *et al.* 1996a, p.18) , the catch deficiency for the Norwegian gauge may very well have been overestimated because of differences on exposure of the gauges.

A rough estimate of how much this might influence the results in this report, may be found by comparing the present models to the model developed for the Swedish precipitation gauge in Jokioinen. Parallel measurements from other locations than Jokioinen indicate that the Swedish and Norwegian gauges are quite similar concerning catch efficiency (Førland *et al.* 1996a, appendix). As the Swedish gauge was placed closer to the reference wind speed sensor, the model based upon these measurements (model III) may be more trustworthy than model II, which is based upon the measurements in the Norwegian gauge. Figure 6.1 shows the model for the Swedish gauge together with model I and model II for temperatures of 0, -5 and -10 °C. At 0 °C, model I is very close to model III, and they are both giving considerably lower estimates of true precipitation than model II for wind speeds above 4 m/s. Table 6.2 also shows good agreement between the results from model I and model III for the mixed precipitation group and the snow group with T>- 2 °C. At -5 °C, and model III also gives results between models I and II. Use of model III instead of model II for the snow group with $T \in (-2, -6\ ^{\circ}C)$ thus removes more than half the deviation from model I (table 6.2). At -10 °C, however, model III gives even higher estimates than model II. Use of model III for the snow group with T<-6 °C thus increases the discrepancy to model I. However, this is a small group, and totally, use of the Jokioinen model for the Swedish gauge instead of model II reduces the difference from the model I estimate considerably.

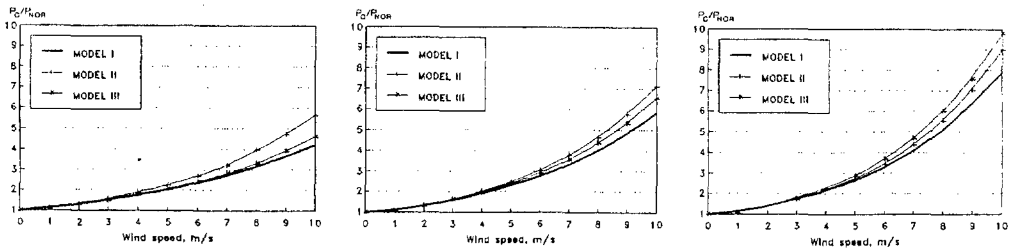

Figure 6.1 *Ratio P_C/P_{NOR} estimated from models I, II and III for solid precipitation (see table 6.1) at T=0 °C, T=-5 °C and T=-10 °C.*

The conclusion is that the unfavourable position of the Norwegian gauge within the Jokioinen field has led to systematic differences between the measuring conditions for this gauge on the one side, and the conditions for the Tretyakov gauge, the Swedish gauge and the DFIR on the other hand. Model II (which is based upon the measurements of solid precipitation in the Norwegian gauge in Jokioinen) is thus not trustworthy, and it is suggested that model III is used rather than model II for estimating true solid precipitation from measurements in Norwegian gauges. However, neither of the models are reliable at low temperatures and high wind speeds. The differences between model I and model II in the low temperature group may thus be caused by lack of universality in the models.

6.6 Comparison of model 0 and model IV for solid precipitation - is model 0 universal?

Model 0 for estimating true solid precipitation from measurements in Tretyakov gauge is based upon large amounts of high quality data, and if any of the Jokioinen models is universal, it is most likely to be model 0. In order to test this properly, it would be necessary to use data from evaluation stations situated in climatically different regions (*e.g.* in the Arctic). However, as the Tretyakov gauge is one of the reference gauges recommended by WMO (1994), several models have been developed for estimating true precipitation from measurements in this gauge. Models developed from different datasets may thus be regarded as different simplifications of the «true universal connection». When comparing the results from applying different models at the same dataset, one may thus get an idea about the magnitude of the deviations which may be expected because of lack of universality. For this reason, the Golubev model (Golubev and Bogdanova 1996) was applied on the solid precipitation measured in the Tretyakov gauge in Ny-Ålesund. A reason for choosing this model is that it is different from the Jokioinen models concerning the dependency of wind and temperature.

The results from estimating true solid precipitation by the Golubev model (model IV) are presented in table 6.2. Model IV gives a somewhat lower estimate of the total true solid

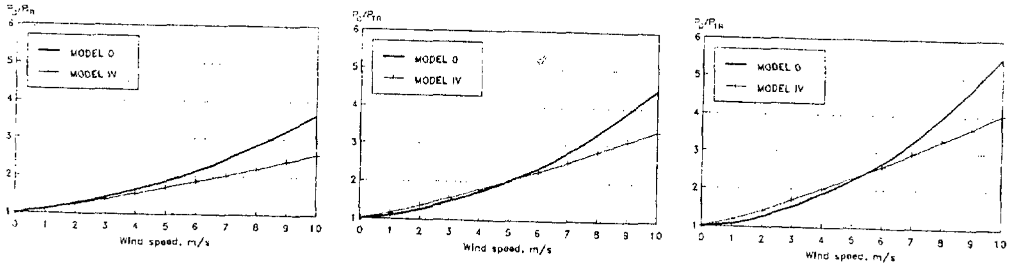

Figure 6.2 *Ratio P_C/P_{TR} estimated from models 0 and IV for solid precipitation (see table 6.1) at T=0 °C, T=-5 °C and T=-10 °C.*

precipitations than models 0 and I. For the middle temperature group, the estimate is slightly above the other two. For the other groups, the model IV estimates are definitely below the model 0 and I estimates. One might believe that this was only an effect of differences in the inclusion of temperature in the models. However, figure 6.2, which shows correction factors for model 0 and model IV for 3 different temperatures, illustrates that a main discrepancy between these models is connencted to the wind speed. For wind speeds below 6 m/s, the estimates from the two models are quite similar. At wind speeds above 6 - 7 m/s, model I (which actually is outside its original area of validity) gives estimates much higher than model IV. This discrepancy has affected the temperature groups differently, mainly because of differences between the groups concerning the wind speed distributions. In the group with $T \in (-2,-6^{o}C)$, only 2% of the precipitation fell at wind speeds above 6 m/s. For the warmer group, 5% of the precipitation fell at such wind speeds, while 10% of the precipitation in the colder group fell at wind speeds >6 m/s.

The models thus seem to be working fairly well for wind speeds < 6 m/s. For higher wind speeds, at least one of the models is giving bad estimates: Either model 0 is overestimating true precipitation, or model IV is underestimating true precipitation. Figure 5.1 illustrates that the «Jokioinen models» (Allerup et. al 1997) overestimates the differences between the Tretyakov and the Norwegian gauge at high wind speeds. It has been demonstrated that this partly, but not totally, is explainable by the location of the Norwegian gauge in Jokioinen. It is thus indicated that the «Jokioinen models» at high wind speeds exaggerates the differences between the gauges. A likely consequence of this would be that the «Jokioinen models» at high wind speeds overestimate true solid precipitation, and that at least some of the discrepancy between model I and the Golubev model (figure 6.2) is explained by this.

The conclusion is that model 0 (and thus model I) overestimates true precipitation at high windspeeds. Consequently, the «Jokioinen models» should not be used in areas where the wind speed frequently is outside the wind speed intervall for which they are defined. With this respect, the Jokioinen models are not «universal», and it may be questioned whether the connection between the correction factor and the wind speed is best approximated by the exponential function, even if this is a good approximation for a certain wind speed interval. Concerning the models' dependency on temperature, the present comparison does not give reason to support one of the models before the other. Still, we do not feel quite confident with the «Jokioinen models» with this respect, as it is difficult to explain physically why one gauge should be the better at -5 °C, while another is the better at -10 °C (cf. fig. 6.1). In order to look closer into this problem, data from an Arctic evaluation station would be needed.

Nevertheless, the estimates of total true solid precipitation from model 0 and the Golubev model are quite similar, as the percentage of precipitation at high wind speeds, all in all, is low. The estimated total true solid precipitation from model 0, 1 and 3 are thus supposed to be reasonably good. At average, the aerodynamic correction factor for solid precipitation measured in the Norwegian gauge is thus estimated to be 1.70 ±0.05.

6.7 Correction for aerodynamic errors in Ny-Ålesund - conclusions.

Using the parallel measurements from Ny-Ålesund as input in different models for estimating true precipitation, has led to following conclusions:

* For windspeeds < 7 m/s at gaugeheight, true precipitation at Svalbard is estimated reasonably well from measurements in a Tretyakov gauge by using Model 0 (cf. table 6.1) to correct for aerodynamic effects

- For the same windspeeds, true precipitation at Svalbard is estimated reasonably well from measurements in a Norwegian gauge by using Model I (cf. table 6.1) to correct for aerodynamic effects.

- For windspeeds > 7 m/s, both Model 0 and Model I probably overestimate true solid precipitation at Svalbard.

- As the percentage of the precipitation falling at windspeeds > 7m/s is low when considering a period of several months, total true precipitation in Ny-Ålesund within such a period may be estimated from measurements in the Norwegian gauge by using Model I.

- For solid precipitation, a typical aerodynamic correction factor in Ny-Ålesund would be 1.65 - 1.75, for liquid precipitation, it would be 1.05-1.10, and for sleet and mixed precipitation, it would be around 1.40.

- MODEL II (*cf.* section 6.1 and table 6.1) should not be used for estimating true precipitation from measurements in the Norwegian gauge.

6.8 Estimating true precipitation in Ny-Ålesund - an example.

Note that the models and correction factors given so far in the present chapter, are for aerodynamic effects only, and should be applied on measurements which are adjusted for evaporation and wetting (P_{NOR}). The ratio between true precipitation (P_C) and actually measured precipitation (P_{nor}) do not only depend on aerodynamic effects, and would thus not be a «universal» function of windspeed, temperature and intensity, even if **k** was «universal». Based upon equation 2.1 and the results from the present report, true precipitation may be estimated by:

(6.1) $$P_C = k \cdot (P_{nor} + \Delta P_W + \Delta P_E),$$

where **k** is given by model I in table 6.1 and ($\Delta P_W + \Delta P_E$) is given by table 4.6 (for the Norwegian gauge). The measured 12h precipitation amounts in Ny-Ålesund during the July 1993 - August 1995 were corrected according to equation 6.1. Table 6.3 gives total observed and estimated true precipitation for different precipitation types. Both ($\Sigma P_C / \Sigma P_{nor}$) and ($\Sigma P_C / \Sigma P_{NOR}$) is given in this table, in order to illustrate the difference between comparing true precipitation directly to measured precipitation and comparing to measured precipitation which is adjusted for wetting and evaporation. For solid precipitation, the estimated true precipitation is almost 190% of the measured, while the similar number for liquid precipitation is 115%.

Time series of the monthly totals of measured and corrected («true») precipitation (Figure 6.3) emphasise the large differences in corrections during winter resp. summer months. The extremely high measured precipitation in November 1993 (Table 3.2) becomes even more impressive when corrected for measuring errors.

The seasonal values of measured and true precipitation (Figure 6.4), confirm the importance of correcting the Arctic precipitation measurements. For the test period, the ratio between true and measured precipitation ($\Sigma P_C / \Sigma P_{nor}$) varied between 1.26 for the summer season to 1.70 for the winter season. If it is supposed that the seasonal ratios in Figure 6.4 are typical for a «normal» year in Ny-Ålesund, the true normal (1961-1990) annual precipitation would be 550 mm, i.e. 50% higher than the official uncorrected value in table 3.2.

Table 6.3 *Observed and true precipitation in Ny-Ålesund during the testperiod. True precipitation is estimated by using eq. 6.1 with k from model I (table 6.1) and ($\Delta P_W + \Delta P_E$) from table 4.6.*

PRECIPITATION TYPE	N	ΣP_{nor} mm	ΣP_{NOR} mm	ΣP_C mm	$\frac{\Sigma P_C}{\Sigma P_{nor}}$	$\frac{\Sigma P_C}{\Sigma P_{NOR}}$
LIQUID	148	325.9	348.1	375.4	1.15	1.08
SLEET/MIXED	64	276.9	286.5	400.2	1.45	1.40
SOLID	249	295.6	320.5	555.4	1.88	1.73
ALL	461	898.4	955.1	1331.0	1.48	1.39

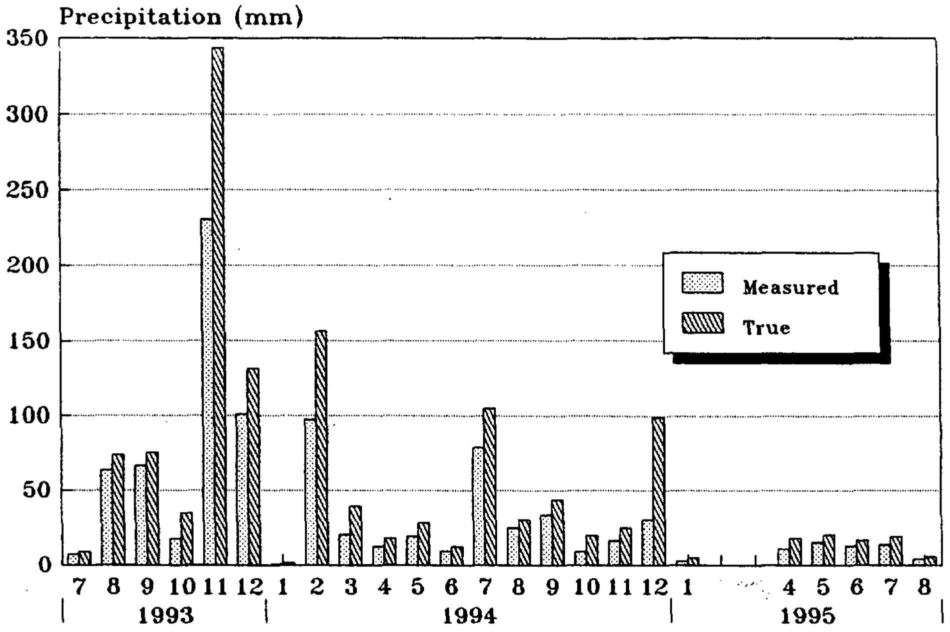

Figure 6.3 *Monthly values of measured and «true» precipitation in Ny-Ålesund. Note that the values for February and March 1995 are missing.*

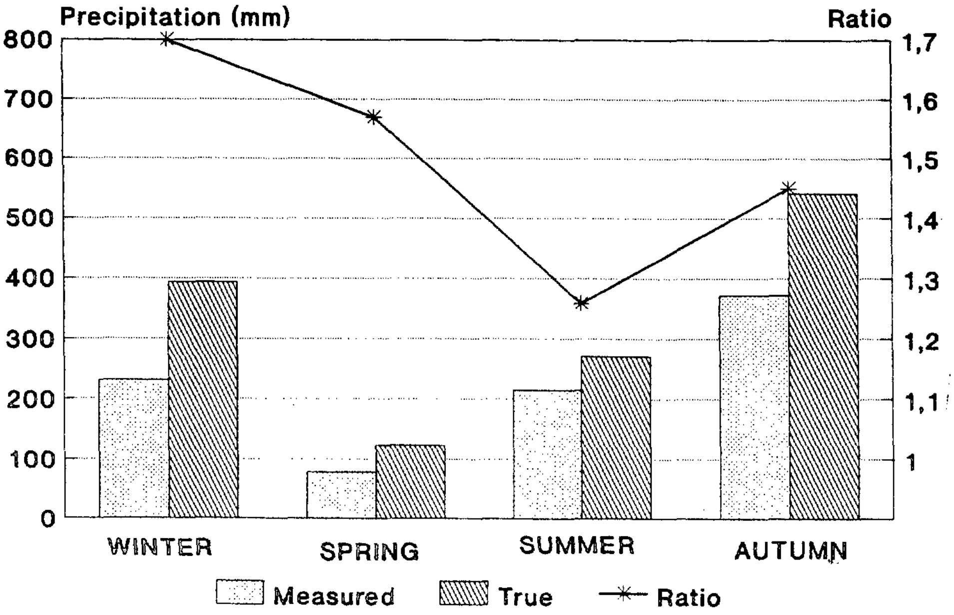

Figure 6.4 *Seasonal values of measured and «true» precipitation in Ny-Ålesund for the period July 1993 to August 1995. The ratios between true and measured precipitation are also indicated.*

7. Virtual changes in precipitation caused by temperature changes

Table 6.2 shows that, for all models, the correction factors for solid precipitation decrease when the temperature increases. Further, the correction factors for rain are smaller than those for snow. I.e. if the temperature generally was increasing, such that the percentage of the annual precipitation falling as rain increased, the measured precipitation would increase even if the true precipitation was unchanged. This was suggested by Førland (1994), and it is now possible to quantify this «virtual precipitation increase» by making some assumptions concerning the connenction between temperature and precipitation type, and by using some simple temperature scenarios.

There is no general connection between the air temperature 2 m above the ground and the precipitation type. Table 7.1 shows that a reasonably good agreement is achieved with the observed precipitation amounts and number of events within the different types by suggesting that precipitation falling at temperatures >2.5 °C is liquid, while precipitation falling at $0.5 < T \leq 2.5$ °C is mixed precipitation or sleet, and precipitation falling at lower temperatures is solid. This classification gives a greater number of mixed precipitation cases than what was observed based upon the simplified precipitation code (SPC). On the other hand, the total amount falling as mixed precipitation is smaller for the temperature classification than for the SPC. The estimated ratios between true and observed precipitation (adjusted for evaporation and wetting) for a given precipitation type, are similar for the temperature classification and the SPC. This is also true for the entire dataset. The average aerodynamic correction factor for the test period July 1993 - August 1995 is 1.39 when using SPC, and 1.37 when using the temperature classification.

Table 7.1 Observed and true precipitation in Ny-Ålesund during the testperiod using alternative precipitation classifications. Model I (table 6.1) is used to calculate true precipitation.

	PRECIPITATION TYPE GIVEN BY SPC					PREC.TYPE DEDUCED FROM TEMPERATURE				
PRECIPITATION TYPE	CLASSIFI-CATION	N	ΣP_{NOR} mm	ΣP_C mm	$\frac{\Sigma P_C}{\Sigma P_{NOR}}$	CLASSIFI-CATION	N	ΣP_{NOR} mm	ΣP_C mm	$\frac{\Sigma P_C}{\Sigma P_{NOR}}$
LIQUID	SPC = 1 OR 2	148	348.1	375.4	1.08	$T > 2.5$ °C	133	395.6	427.5	1.08
SLEET/MIXED	SPC = 4 OR 5	64	286.5	400.2	1.40	$0.5 < T \leq 2.5$ °C	85	222.8	306.7	1.38
SOLID	SPC = 3	249	320.5	555.4	1.73	$T \leq 0.5$ °C	243	336.8	572.8	1.70
ALL	-	461	955.1	1331.0	1.39	-	461	995.1	1307.1	1.37

Three temperature scenarios are suggested: +2°C (scenario1), +4°C (scenario2) and +6°C (scenario3). Scenarios 1 and 2 are comparable to the temperature scenarios suggested by IPCC (1996) for Northern Europe as a consequence of a doubling of the preindustrial CO_2 concentration in the atmosphere. For simplicity, the same temperature increase is suggested for night and day and for all seasons, and it is supposed that the true precipitation and the wind speed during the precipitation events are unchanged. Using the precipitation classification by temperature given in table 7.1, it is possible to estimate the distribution of the total true precipitation between solid, mixed and liquid precipitation for the different scenarios based upon any dataset.

The present scenario calculations were based upon data from 1994. Concerning annual mean temperature and precipitation sum, this year is quite close to the 1961-1990 normals (tables 3.1 and 3.2). Figure 7.1 shows the 1994 true precipitation subdivided into solid, mixed and liquid precipitation for the temperature distribution observed in 1994 and for the three scenarios. The actual percentage of solid precipitation was 60, but a temperature increase of 6°C would reduce it to 26. Likewise, the percentage of liquid precipitation would increase from 25 to 64.

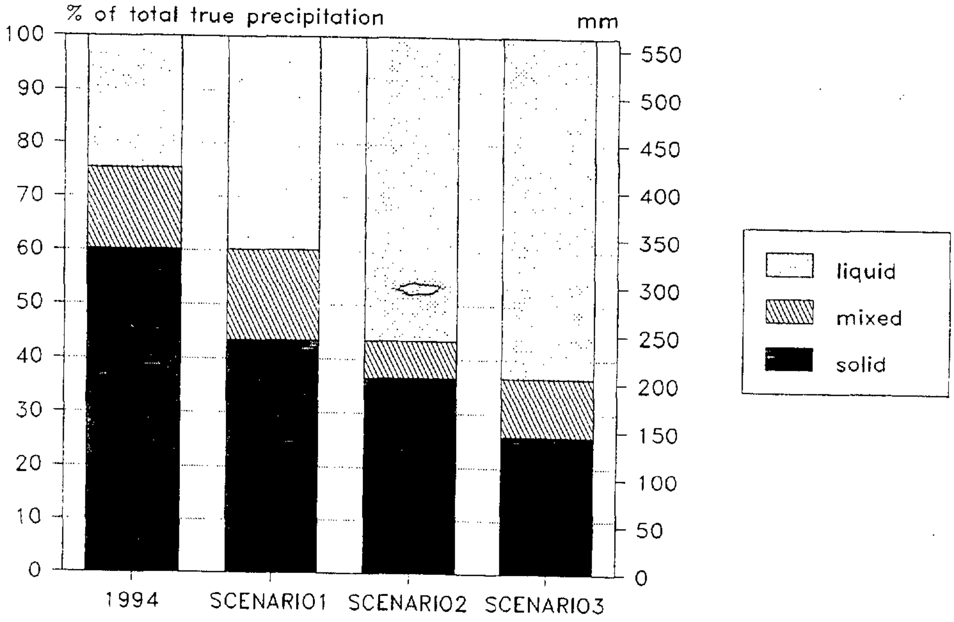

Figure 7.1 «True precipitation» (P_C) distributed on solid, mixed and liquid precipitation for 1994 and three temperature scenarios.

***Table** 7.2 Estimates of the precipitation which would have been measured in Ny-Ålesund during 1994 if the temperatures were higher, but true precipitation and wind speeds were unchanged. Scenario1: T+ 2 °C ll year, Scenario2: T+4 °C all year, Scenario3: T+6 °C all year.*
Number of cases (N), precipitation measured in the Norwegian gauge (P_{nor}), measured precipitation adjusted for evaporation and wetting (P_{NOR}) and true precipitation (P_C) are given for all precipitation types. Subscript 0 is used for 1994 values, while subscripts 1-3 are user for the scenarios.

	1994				SCENARIO 1				SCENARIO 2				SCENARIO 3			
PRECIP. TYPE	N_0	ΣP_{nor0} mm	ΣP_{NOR0} mm	ΣP_{C0} mm	N_1	ΣP_{nor1} mm	ΣP_{NOR1} mm	ΣP_{C1} mm	N_2	ΣP_{nor2} mm	ΣP_{NOR2} mm	ΣP_{C2} mm	N_3	ΣP_{nor3} mm	ΣP_{NOR3} mm	ΣP_{C3} mm
LIQUID	60	118.1	127.0	138.1	99	187.2	202.1	223.7	132	263.4	283.2	318.1	152	293.5	316.3	357.1
MIXED	39	60.0	65.5	85.6	33	65.6	70.6	94.3	20	26.3	29.3	39.0	24	37.6	41.2	60.2
SOLID	150	174.3	189.7	338.5	117	119.2	130.8	244.2	97	98.1	107.8	205.1	73	67.9	75.2	144.9
ALL	249	352.4	382.1	562.2	249	372.0	403.5	562.2	249	387.9	420.3	562.2	249	399.0	432.7	562.2

Knowing the true precipitation and the precipitation type (based on the temperature), model I (table 6.1) in combination with wetting and evaporation values from table 4.6 made it possible to estimate the precipitation which would have been measured during the different scenarios. Table 7.2 shows, for all scenarios and all precipitation types, number of cases, «measured» precipitation, «precipitation adjusted for evaporation and wetting» and «true precipitation». The «measured» precipitation is also shown in figure 7.2.

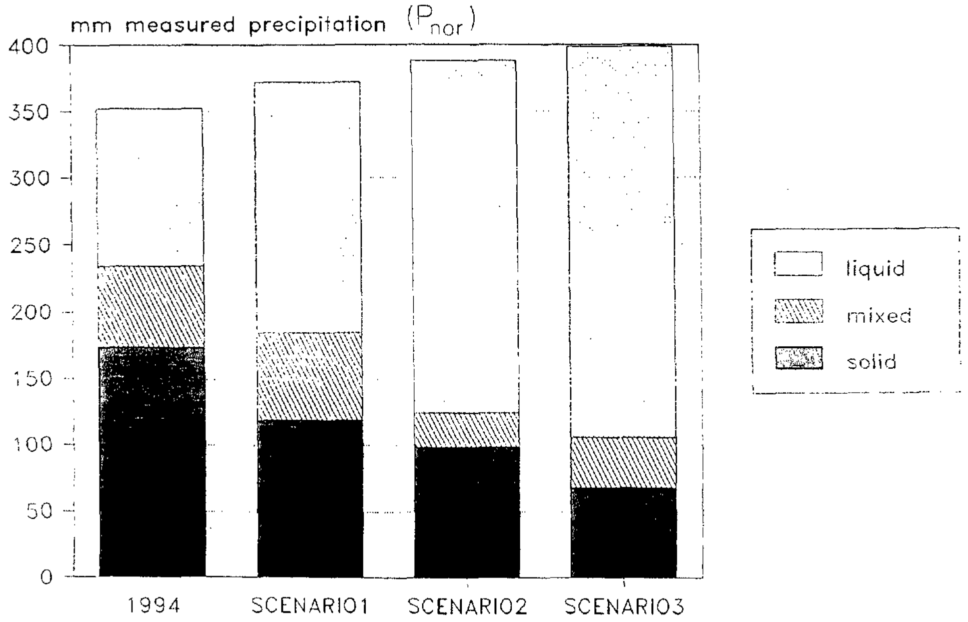

***Figure** 7.2 «Measured precipitation» (P_{nor}) distributed on solid, mixed and liquid precipitation for 1994 and three temperature scenarios.*

***Table** 7.3 Estimates of average ratio between «true» and «observed» precipitation and «average aerodynamic correction factor» during 1994 and for the different scenarios. Scenario1: T+ 2 °C, Scenario2: T+ 4 °C, Scenario3: T+ 6 °C.*

	1994		SCENARIO 1		SCENARIO 2		SCENARIO 3	
PRECIP. TYPE	$\frac{\sum_{N0} P_{C0}}{\sum_{N0} P_{nor0}}$	$\frac{\sum_{N0} P_{C0}}{\sum_{N0} P_{NOR0}}$	$\frac{\sum_{N1} P_{C1}}{\sum_{N1} P_{nor1}}$	$\frac{\sum_{N1} P_{C1}}{\sum_{N1} P_{NOR1}}$	$\frac{\sum_{N2} P_{C2}}{\sum_{N2} P_{nor2}}$	$\frac{\sum_{N2} P_{C2}}{\sum_{N2} P_{NOR2}}$	$\frac{\sum_{N3} P_{C3}}{\sum_{N3} P_{nor3}}$	$\frac{\sum_{N3} P_{C3}}{\sum_{N3} P_{NOR3}}$
LIQUID	1.17	1.09	1.20	1.11	1.21	1.12	1.22	1.13
MIXED	1.43	1.31	1.44	1.34	1.48	1.33	1.60	1.46
SOLID	1.94	1.78	2.05	1.87	2.09	1.90	2.13	1.93
ALL	1.60	1.47	1.51	1.39	1.45	1.34	1.41	1.30

Totally, «measured». precipitation increases from the 1994 situation to scenario 3 by almost 50 mm, even if the true precipitation is constant. Table 7.3 shows for each scenario and precipitation type the ratio between «true» and «measured» precipitation (P_C / P_{nor}) as well as the «average» aerodynamic correction factor (P_C / P_{NOR}). Note that the decrease in the average correction factor for the entire dataset (and thus the increase in «measured» precipitation) not at all is explained by decreasing «average correction factors» for the individual precipitation types. For a given precipitation type, the tendency is actually that the «average corrections factors» are higher for the scenarios than for the original dataset. This is caused by the distribution of wind speed and precipitation intensity within the dataset. The frequency of high wind speeds in the dataset is higher for lower temperatures. The precipitation intesity is also usually lower at low temperatures. Thus increasing the temperature brings cases with higher average windspeed and lower intensity over in the rain and mixed precipitation group. At the same time, the average wind speed in the snow group is increasing, as the average windspeed of the remaining cases is even higher than for those which changed group. Nevertheless, the «average correction factor» for the whole dataset decreases, as the total amount of snow decreases and the total amont of rain increases.

Table 7.3 thus gives the impression that the increase in the «measured» precipitation is entirely caused by the transition from snow via sleet and mixed precipitation to rain. This is not true, which becomes clear when following a given group of events from the present climate to a scenario. Table 7.4 shows the ratio between the scenario total «measured precipitation» and the total precipitation which actually was measured in 1994 *for the same events*. This ratio is thus a measure for how the scenario has changed the total measured

Table 7.4 *Estimates of the virtual change in precipitation caused by different scenarios. I.e. the ratio between the precipitation which would have been measured in Ny-Ålesund during the test period under different scenarios, and the precipitation which actually has been measured for the same group of events. Scenario1: T+ 2 °C all year, Scenario2: T+ 4 °C all year, Scenario3: T+ 6 °C.*

	SCENARIO 1		SCENARIO 2		SCENARIO 2	
PRECIP. TYPE	N1	$\frac{\sum_{N1} P_{nor1}}{\sum_{N1} P_{nor0}}$	N2	$\frac{\sum_{N2} P_{nor2}}{\sum_{N2} P_{nor0}}$	N3	$\frac{\sum_{N3} P_{nor3}}{\sum_{N3} P_{nor0}}$
LIQUID	99	1.05	132	1.11	152	1.13
MIXED	33	1.12	20	1.13	24	1.27
SOLID	117	1.03	97	1.06	73	1.08
ALL	249	1.06	249	1.10	249	1.13

precipitation for a given group of events. For solid precipitation under scenario 1, the ratio is 1.03, which implies that the measured precipitation would increase by 3% for the 184 cases which still would be snow under scenario 1. This increase is entirely caused by the estimated temperature effect on the structure of the snowflakes. The virtual change in the snow group is even higher for the other scenarios. This is because the temperature difference from the original climate is greater. The number of snow events naturally decreases. Under scenario 3, the virtual precipitation increase is 8% for the 73 snow cases which still are snow. The virtual changes for the liquid and mixed groups are larger than for the snow group. These virtual changes are mainly caused by the transition from snow to mixed precipitation and from mixed precipitation to liquid.

The virtual addition to the annual precipitation will increase with increasing scenario temperature until all precipitation is liquid. Table 7.4 shows that the virtual addition for the whole year for scenarios 1-3 are 6 %, 10 % and 13 % respectively. This increase, which is caused by changes in measuring errors alone, will be measured in addition to an eventual real increase in the precipitation which *e.g.* may be the consequence of the intensified hydrological cycle in a warmer atmosphere. According to IPCC (1996) the expected real precipitation increase connected to a doubling of the atmospheric CO_2 concentration would be 5 - 15% in Northern Europe. It is thus important to be aware of the fact that the magnitude of the expected **virtual** changes in Arctic areas is the same as the magnitude of the expected **real** changes.

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Appendix: Results from regression analyses of parallel measurements in Ny-Ålesund

Table 4.1 Regression coefficients based upon single cases, liquid precipitation.

N=number of cases,

a_0 and b_0 = regression coefficients corresponding to eq. 4.2

R_0 = correlation coefficient between $\ln \{P_{TR}/P_{NOR}\}$ and v_g

b_1 = regression coefficients corresponding to eq. 4.3

R_1 = redefined correlation coefficient corresponding to the no intercept model.

CHARACTERISTICS	N	a_0	b_0	R_0^2	b_1	R_1^2
SPC=1 (RAIN)	122	-0.028	0.025	0.037	0.015	0.044
SPC=2 (DRIZZLE)	26	0.023	0.023	0.021	0.033	0.102
SPC=1, $P_{nor} \geq$ 4mm	18	-0.057	0.021	0.265	0.009	0.281
SPC=1, $1 \leq P_{nor} <$ 4mm	48	-0.019	0.021	0.069	0.014	0.094
SPC=1, $P_{nor} <$ 1mm	56	-0.053	0.047	0.048	0.025	0.045
SPC=1, $P_{nor} \geq$ 1mm	66	-0.022	0.017	0.067	0.011	0.082
SPC=2 / SPC=1,$P_{nor} <$ 1	82	-0.023	0.037	0.035	0.027	0.056

Table A.2 Precipitation sums and other relevant information for wind intervals. Liquid precipitation.

Column 1: Wind interval

Column 2: Number of precipitation events within the interval

Column 3: Sum of precipitation measured in the Norwegian gauge

Column 4: Ratio between sums of precipitation, corrected for evaporation and wetting, measured in the Tretyakov and Norwegian gauge, respectively.

Column 5: Weighted average of wind speed under precipitation

a) Rain, all cases (SPC=1)

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	36	45.7	0.988	0.68
1 - 2 m/s	33	41.4	1.006	1.38
2 - 3 m/s	24	92.8	1.002	2.44
3 - 4 m/s	17	79.6	1.030	3.43
4 - 5 m/s	8	36.0	1.044	4.47
5 - 7 m/s	4	18.0	1.108	5.56

b) Drizzle (SPC=2)

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	14	5.5	1.013	0.68
1 - 2 m/s	9	4.2	0.972	1.38
3 - 5 m/s	3	2.7	1.175	4.26

c) Rain, $P_{nor} \geq 4mm$

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 2 m/s	3	17.4	0.972	1.08
2 - 3 m/s	7	69.5	1.000	2.50
3 - 4 m/s	4	61.3	1.026	3.30
4 - 5 m/s	2	28.8	1.021	4.52
5 - 6 m/s	2	14.7	1.113	5.72

d) Rain, $1 \leq P_{nor} < 4mm$

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	17	34.0	1.000	0.66
1 - 2 m/s	11	21.8	1.038	1.39
2 - 3 m/s	8	18.8	0.985	2.55
3 - 4 m/s	7	16.2	1.041	3.49
4 - 5 m/s	3	6.2	1.120	4.48
5 - 7 m/s	2	3.3	1.083	5.66

e) Rain, P_{nor}<1mm

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	18	6.4	0.956	0.68
1 - 2 m/s	20	7.5	0.971	1.40
2 - 3 m/s	9	4.5	1.077	2.28
3 - 4 m/s	6	2.1	1.067	3.46
4 - 5 m/s	3	1.0	1.172	4.43

f) Rain, $P_{nor} \geq 1mm$

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	18	39.3	0.995	0.67
1 - 2 m/s	13	33.9	1.017	1.36
2 - 3 m/s	15	88.3	0.997	2.53
3 - 4 m/s	11	77.5	1.029	3.42
4 - 5 m/s	5	35.0	1.039	4.49
5 - 7 m/s	4	18.0	1.108	5.56

g) Rain and P_{nor}<1mm, or drizzle.

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	32	11.9	0.982	0.69
1 - 2 m/s	29	11.7	0.972	1.43
2 - 3 m/s	9	4.5	1.077	2.28
3 - 4 m/s	8	3.4	1.109	3.52
4 - 5 m/s	4	2.4	1.167	4.53

Table A.3 Regression coefficients, precipitation sums in wind intervals, liquid precipitation

N=number of intervals,

a_0 *and* b_0 *= regression coefficients corresponding to eq. 4.2*

R_0 *= correlation coefficient between* $\ln \{\Sigma P_{TR}/\Sigma P_{NOR}\}$ *and* $< v_g >$

b_1 *= regression coefficients corresponding to eq. 4.3*

R_1 *= redefined correlation coefficient corresponding to the no intercept model.*

CHARACTERISTICS	N	a_0	b_0	R_0^2	b_1	R_1^2
SPC=1 (RAIN)	6	-0.034	0.020	0.865	0.012	0.792
SPC=2 (DRIZZLE)	3	-0.054	0.049	0.853	0.032	0.779
SPC=1, $P_{nor} \geq 4$mm	5	-0.064	0.026	0.839	0.011	0.606
SPC=1, $1 \leq P_{nor} < 4$mm	6	-0.015	0.019	0.551	0.015	0.754
SPC=1, $P_{nor} < 1$mm	5	-0.082	0.052	0.891	0.026	0.709
SPC=1, $P_{nor} \geq 1$mm	6	-0.025	0.018	0.739	0.012	0.774
SPC=2 / SPC=1, $P_{nor} < 1$	5	-0.064	0.049	0.917	0.029	0.831

Table A.4 Regression coefficients, single cases, solid and mixed precipitation.

N=number of cases,

a_0 *and* b_0 *= regression coefficients corresponding to eq. 4.2*

R_0 *= correlation coefficient between* $\ln \{P_{TR}/P_{NOR}\}$ *and* v_g

b_1 *= regression coefficients corresponding to eq. 4.3*

R_1 *= redefined correlation coefficient corresponding to the no intercept model.*

CHARACTERISTICS	N	a_0	b_0	R_0^2	b_1	R_1^2
SPC=3 (SNOW)	249	-0.013	0.025	0.110	0.022	0.178
SPC=4.5 (SLEET,MIXED)	64	-0.016	0.021	0.087	0.017	0.192
SPC=3. $T_g \leq -6$°C	94	-0.040	0.032	0.224	0.023	0.228
SPC=3, $-6°C < T_g \leq -2°C$	79	0.008	0.026	0.155	0.027	0.328
SPC=3, $T_g > -2$°C	76	0.001	0.015	0.029	0.015	0.068
SPC=3, $T_g \leq -2$°C	173	-0.020	0.029	0.195	0.025	0.276
SPC=4.5 / SPC=3, $T_g > -2$°C	140	-0.004	0.017	0.043	0.016	0.100

Table A.5 Precipitation sums and other relevant information for wind intervals. Solid and mixed precipitation

Column 1: Wind interval

Column 2: Number of precipitation events within the interval

Column 3: Sum of precipitation measured in the Norwegian gauge

Column 4: Ratio between sums of precipitation, corrected for evaporation and wetting, measured in the Tretyakov and Norwegian gauge, respectively.

Column 5: Weighted average of wind speed under precipitation

a) Snow, all cases (SPC=3)

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	73	67.3	1.003	0.58
1 - 2 m/s	65	69.1	1.034	1.45
2 - 3 m/s	32	28.1	1.058	2.47
3 - 4 m/s	13	23.2	1.065	3.39
4 - 5 m/s	31	54.9	1.138	4.48
5 - 6 m/s	16	27.5	1.121	5.30
6 - 7 m/s	6	11.2	1.059	6.38
7 - 8 m/s	6	6.2	1.250	7.42
8 - 9 m/s	3	2.3	1.192	8.38
11 -12 m/s	2	5.6	1.397	11.54
12 -13 m/s	2	0.2	1.250	12.55

b) Sleet or mixed snow and rain. (SPC=4 or 5)

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	10	27.5	1.017	0.82
1 - 2 m/s	9	10.0	0.965	1.20
2 - 3 m/s	15	39.0	1.051	2.45
3 - 4 m/s	11	42.9	1.043	3.30
4 - 5 m/s	8	74.3	1.060	4.22
5 - 6 m/s	7	64.9	1.052	5.72
6 - 7 m/s	2	15.0	1.059	6.32
7 - 9 m/s	2	3.3	1.056	7.60

c) Snow, $T_g \leq -6$ °C

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	31	26.1	0.955	0.53
1 - 2 m/s	26	19.2	1.005	1.42
2 - 3 m/s	13	7.7	1.067	2.46
3 - 4 m/s	3	1.3	1.000	3.75
4 - 5 m/s	9	6.7	1.145	4.37
5 - 6 m/s	5	6.5	1.043	5.25
6 - 8 m/s	4	3.0	1.382	7.24
8 -12 m/s	3	5.2	1.364	10.28

d) Snow, -6 °C < $T_g \leq$ -2 °C

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	20	15.4	1.034	0.72
1 - 2 m/s	22	26.1	1.042	1.46
2 - 3 m/s	11	11.0	1.099	2.58
3 - 4 m/s	5	16.0	1.079	3.41
4 - 5 m/s	12	35.2	1.154	4.57
5 - 6 m/s	4	7.6	1.188	5.46
6 - 7 m/s	3	2.2	1.120	6.28
12 -13 m/s	2	0.2	1.250	12.55

e) Snow, T_g >-2 °C

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	22	25.8	1.032	0.53
1 - 2 m/s	17	23.8	1.051	1.47
2 - 3 m/s	8	9.4	1.000	2.35
3 - 4 m/s	5	5.9	1.047	3.16
4 - 5 m/s	10	13.0	1.093	4.48
5 - 6 m/s	7	13.4	1.121	5.24
6 - 7 m/s	2	8.9	1.044	6.44
7 - 8 m/s	3	3.3	1.111	7.57
8 -12 m/s	2	2.7	1.276	11.11

f) Snow, $T_g \leq$ -2 °C

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	51	41.5	0.985	0.60
1 - 2 m/s	48	45.3	1.026	1.44
2 - 3 m/s	24	18.7	1.085	2.52
3 - 4 m/s	8	17.3	1.072	3.54
4 - 5 m/s	21	41.9	1.152	4.48
5 - 6 m/s	9	14.1	1.120	5.34
6 - 7 m/s	4	2.3	1.111	6.36
7 - 8 m/s	3	2.9	1.406	7.28
8 - 9 m/s	2	2.0	1.136	8.36
11 -13 m/s	3	3.4	1.486	11.68

Table A.5 - continued.

g) Snow, T_g >-2 °C or sleet or mixed snow and rain.

v_g	N	ΣP_{nor}	$k' = \Sigma P_{TR}/\Sigma P_{NOR}$	$< v_g >$
0 - 1 m/s	32	53.3	1.025	0.60
1 - 2 m/s	26	33.8	1.024	1.40
2 - 3 m/s	23	48.4	1.041	2.46
3 - 4 m/s	16	48.8	1.043	3.43
4 - 5 m/s	18	87.3	1.065	4.47
5 - 6 m/s	14	78.3	1.064	5.32
6 - 7 m/s	4	23.9	1.053	6.38
7 - 8 m/s	4	6.2	1.075	7.54
8 -12 m/s	3	3.1	1.261	10.70

Table A.6 Regression coefficients, precipitation sums in wind intervals, solid and mixed precipitation

N=number of intervals,

a_0 and b_0 = regression coefficients corresponding to eq. 4.2

R_0 = correlation coefficient between $ln\{\Sigma P_{TR}/\Sigma P_{NOR}\}$ and $< v_g >$

b_1 = regression coefficients corresponding to eq. 4.3

R_1 = redefined correlation coefficient corresponding to the no intercept model.

CHARACTERISTICS	N	a_0	b_0	R_0^2	b_1	R_1^2
SPC=3 (SNOW)	11	-0.005	0.023	0.796	0.022	0.926
SPC=4, 5 (SLEET,MIXED)	8	0.001	0.009	0.480	0.009	0.791
SPC=3, $T_g \leq$ -6°C	8	-0.069	0.039	0.784	0.029	0.815
SPC=3, -6°C $< T_g \leq$ -2°C	8	0.039	0.016	0.822	0.021	0.926
SPC=3, T_g >-2°C	9	-0.006	0.018	0.721	0.017	0.884
SPC=3, $T_g \leq$ -2°C	10	-0.031	0.033	0.732	0.029	0.873
SPC=4,5 / SPC=3, T_g >-2°C	9	-0.012	0.017	0.723	0.015	0.873