W O R L D   M E T E O R O L O G I C A L   O R G A N I Z A T I O N

COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION

INTERNATIONAL ORGANIZING COMMITTEE

for the

WMO SOLID PRECIPITATION MEASUREMENT INTERCOMPARISON

Sixth session

FINAL REPORT

Toronto, Canada

14-18 September 1992

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1. ORGANIZATION OF THE SESSION

1.1 Opening of the session

1.1.1 The International Organizing Committee (OC) for the WMO Solid Precipitation Intercomparison held its sixth session at the Headquarters of the Atmospheric Environment Service (AES) in Toronto and at the Centre for Atmospheric Research Experiments (CARE) in Egbert, Canada from 14-18 September 1992. The list of participants and the list of addresses of the participants are attached as **Appendices A and B.**

1.1.1 Dr Roger Daley, Chief Scientist, Canadian Climate Centre welcomed the participants to Toronto and to the Atmospheric Environment Service. He noted that intercomparisons such as this one are important for those working in climate research. Researchers must have confidence that climate data from around the world are compatible and suitable for time series analysis if we are to address the question of climate variability and change. In the case of precipitation, the initial driving force for the experiment was from the hydrological community. Now the strong support comes from the climate community as well. The results are important in our assessment and validation of our GCM outputs and in the successful conduct of experiments such as GEWEX. Dr. Daley wished the participants well in their deliberations and hoped that they would have an enjoyable stay in Canada.

1.1.2 Mr. Schulze, WMO Secretariat welcomed the participants on behalf of Prof. G.O.P. Obasi, Secretary General of WMO. Further he conveyed the best regards of Dr. Rasmussen, Director WWW, Department of WMO to the seminar and expressed the gratitude of WMO to the administration of the AES Canada and especially to Dr. B. Goodison and Mr. J. Metcalfe for preparing the session and hosting it in Toronto. He appreciated very much that so many national nominated precipitation experts have shown their interest in this important comparison and could arrange for their participation at the session. He underlined that this sixth session of the OC is very important for determination of further actions for finalizing the comparison in 1993 and for preparation of the final report which is intended to be published and distributed by WMO as soon as possible after termination of the comparison in 1993 and for preparation of the final report which is intended to be published and distributed by WMO as soon as possible after termination of the comparison. He wished the participants a nice stay in Toronto and its surroundings and a very efficient session.

1.1.3 Dr. Jaan Kruus (President of CIMO, AES Canada) welcomed participants to the first meeting of the OC in Canada. Dr. Kruus outlined the mission of CIMO, the importance of solid precipitation measurement and the uniqueness of this experiment. His comments are summarized in **Appendix C.** In conclusion he thanked all participants and their meteorological and hydrological services for their participation in the intercomparison and the Secretary-General of WMO for the organization of the session.

1.1.4 Dr. B. Goodison (Canada), chairman of the Organizing Committee for the Solid Precipitation Measurement Intercomparison, welcomed the participants to AES, Toronto and Canada. He noted that this was the sixth session of the intercomparison. After five seasons of data collection at the various study sites in participating countries the experiment is coming to a successful conclusion. The emphasis is now on data analysis and preparation of a report with recommendations which can be implemented by WMO member countries. The experiment is now recognized as a very important contribution to improved understanding and analysis of precipitation data for both climatological and hydrological analysis. The current need is to produce recommendations for consideration by CIMO by September 1993; the report should be completed by the end of 1993. To achieve this objective data from the 1992/93 season must be submitted in April 1993 for inclusion in the archive. Countries' analyses must be completed in early 1993. That is a challenge for all participating Members. During the past year the Organizing Committee has had the good fortune of having Dr. Daqing Yang work on the international data set. The hope is for him to continue his work at the Canadian Climate Centre. The chairman thanked him for all his work on the experiment. The challenge is for all of the participants to help the OC reach a successful completion to this intercomparison.

1.2 Adoption of the agenda

The Provisional Agenda was adopted for the work of the session with the understanding that it can be amended at the session if necessary (see page 1 of the report).

1.3 Working arrangements for the session

The working arrangements for the session have been announced by the organizers. The participants agreed on it.

2. REVIEW OF THE INTERCOMPARISON

2.1 Canada

2.1.1 Dr. B. Goodison summarized the Canadian operations. Four stations have been closed (East Baltic, Kortright, Trent and Regina). Dease Lake and Baie Comeau will continue their observation program for one more winter. The newest intercomparison station located at the Centre for Atmospheric Research Experiments (CARE) is currently planned to operate continuously over the next few years. The Canadian focus will continue to be on the impact of automation on the Canadian data base, the correction of winter precipitation measurements and data homogeneity for climate analyses. The results of recent analyses are presented in **Section 4** of this report.

2.1.2 Some additional information concerning the Canadian experience with the automation of winter precipitation measurements is contained in **Appendix E**. An overview on the Canadian assessment is enclosed as **Appendix D** to this report.

2.2 USA

2.2.1 Preliminary results show that by looking at the slopes for all data of all gauges versus the DFIR for the Danville, Vermont data, the average deviation from the DFIR is as follows:

Gauge	Slope	R^2	Compared to DFIR
Tretyakov (TRET)	0.971	0.995	3.0% undercatch
National Shielded	1.039	0.969	4.0% overcatch
National Unshielded	0.914	0.982	8.6% undercatch
8" Standard Raingauge	0.986	0.982	1.4% undercatch
Belfort (Automatic)	0.905	0.911	9.5% undercatch
Belfort Town line	0.981	0.975	1.9% undercatch

2.2.2 The highest correlation to the DFIR is with the Tretyakov gauge. This is expected because they both have 200 (cm^2) orifice areas. When we plotted the Belfort Town line gauge (all data) versus the NWS standard (both with 324.3 (cm^2) orifice areas) we get even higher correlation, a slope of .995 and an R^2 of 0.995 and an undercatch of 0.5% when compared to the standard 324.3 cm^2 orifice diameter rain gauge. All gauges are alter-shielded.

2.2.3 The wind plots are full of scatter with the TRET and National unshielded gauges showing general decreases with increasing wind speeds. CRREL has also furnished density plots calculated for all gauges (i.e. catches/the snowfall for the event) as compared to measured snow surface layer densities (g/cm^3). The comparisons are for 33 events when densities were measured immediately after the snowstorm.

2.2.4 The plots show that a grouping occurs around the 1:1 correlation line. Most of the outliers from this grouping are wet snow events. The standard Belfort 8 inch gauges and National Shield gauges seem to have the best correlation to measured density.

2.2.5 Conclusions

- In light wind regime at Danville, Vermont the data show limited differences between gauge catches for daily or storm totals.
- Greater correlation is found among the 8" (20 cm) orifice gauges than with the 6" (15 cm) orifice DFIR and Tretyakov gauges.
- Snow surface layer density measurements as compared to total snowfall depth and water equivalent measurements can be used to estimate the accuracy of gauge catch.
- Alter shielded gauges do not experience overcatch on the shield.
- Danville, Vermont results show that 8" (20 cm) alter-shielded NWS standard reference gauge is most accurate compared to measured snow surface layer density.
- Location exposure, and gauge height installation are still the most predominant factors in gauge catch accuracy.

2.2.6 The comparison results at the Sleepers River Research Watershed, Danville, Vermont can be found in **Appendix F**.

2.3 Russian Federation

2.3.1 Dr. Golubev gave his oral report in Russian, translated by B. Sevruk.

2.3.2 At the Valdai site, two additional instruments were added for the 1991-1992 winter season: A standard U.S. 8" gauge at a height 1 metre and an alter-shielded U.S. 8" gauge at a height of 1 metre. Six Tretyakov gauges were also operated at both the open site and the bush site to determine the gauge precision error. At each site, the standard deviation for monthly totals was an average of 5% for the winter months and 1% for the summer. To specify more accuracy seems unwarranted; indeed, the WMO specification of ±2% is misleading. The systematic error is in addition to this gauge precision value.

2.3.3 For the 1991-1992 winter, seven gauge configurations were installed: A bush gauge, a Tretyakov gauge, a Canadian Nipher-shielded gauge, a Tretyakov and a Canadian Nipher in a double fence, and the two 8" U.S. gauges discussed above. Present results were grouped by wind speed and surface air temperature and are given in **Appendix G.**

2.3.4 For the 1992-1993 season, an optical gauge from STI will be installed too. It was noted that the University of St. Petersburg also is developing an optical gauge to measure the snow diameter and structure.

2.4 Finland and Scandinavia

2.4.1 In Finland the intercomparison was started 1 February 1987. Nine different types of manual gauges and four different types of automated gauges are used at present. During the last winter, October 1991 - April 1992, there were 55 snowfalls, 44 rain and snow and in all 180 cases of precipitation. The catch ratios of the different gauges varied from 34 to 82% of the reference (DFIR) for snowfall only and from 63% to 87% for all cases.

2.4.1 The measurements have been made by weighing and volumetrically. The difference between the weighed and volumetrically measured values showed the wetting loss of about 0.04 - 0.12 mm/case for snow only and 0.06 - 0.17 mm/case for mixed precipitation (rain and snow) and rainfall. Wetting loss and evaporation have also been determined separately for different gauges. Evaporation was as high as 1mm/12h from some Nordic gauges in April and in summer months. High April values are due to the lack of a funnel in gauges during that month. Preliminary results using a scatterometer to measure precipitation seemed to be very promising.
Further results of the intercomparison at Jokioinen are contained in **Appendix H.**

2.5 Germany

2.5.1 Dr. Guenther provided a summary of German activities. Data of the Evaluation Station Harzgerode from six winter seasons 1986/87 - 1991/92 have been analyzed. The national standard gauge Hellmann unshielded and five other types of precipitation gauges have been compared to the Double Fence Intercomparison Reference (DFIR). All gauge measurements are corrected for wetting loss; the DFIR measurements are corrected for losses due to wind speed, using Golubev's curve of DFIR catch versus true at Valdai.

2.5.2 Initial results of the analysis are presented in **Appendix** I. The Hellmann gauge, catches between 45.5% (snow only) and 86.6% (rain only) as compared with the DFIR (see Fig. 2a,b; Table 1, **Appendix** I). The analysis of the percentage catches separated for various classes of daily snow precipitation depth reveals the following results (see Fig. 9, **Appendix** I):

Daily totals for P>1.1 mm

Hellmann unshielded	40...53%
Automatic gauge (volumetric)	38...46%

Daily totals for P≤1.0 mm

Hellmann unshielded	60...74%
Automatic gauge (volumetric)	26...31%

The percentage catch of the Hellmann unshielded gauge for snow only as a function of wind speed varies between 19% (V1≥5ms^{-1}) and 67% (V1<1ms^{-1}) (see Fig. 17, Table 3, **Appendix** I). The high losses of the automatic gauge in the case of small wind speed are caused by the heating of the gauge (evaporation loss).

2.5.3 Four different ratios of the comparison gauge to the DFIR and six factors of influence (wind speed at 1m and 10m levels, air temperature, depth, duration and intensity of precipitation) were included into the regression analysis. Starting with simple linear regressions multiple linear regressions were finally calculated. From the total of 624 regression equations only those were listed in Tables 5 and 6 (**Appendix** I) which have in each case the highest correlation coefficient (r^2). The most important factor of influence is mean wind speed (V1, V10) which forms the decisive contribution to the correlation coefficient (r^2).

2.5.4 Concluding remarks

The initial results confirm the predominant influence of the wind causing Hellmann gauge deficiencies. There is no significant influence of air temperature on the catch losses. High measuring losses of the automatic gauges in the case of small wind speeds and low intensity events are caused by heating of the gauge. Because of the planned operational use of heated automatic gauges their accuracy should be of particular concern. The correction of winter precipitation measurements in Central Europe is rather a problem, because the types of precipitation vary frequently and within short time intervals between snow and rain, particularly in flat regions. The presented preliminary results show that a correction procedure for long-term mean monthly precipitation totals must account for the mean wind conditions (e.g. a classification into wind-exposed, normal or wind-sheltered sites). An operational procedure for daily values (Hellmann unshielded) have to be taken into account as factors of influence at least various classes of mean wind speed and precipitation depth. Correction factors or regression equations should be derived separately for the different types of precipitation.

2.5.5 Future activities

Germany will continue at national level the comparison measurements in order to improve the data base (number of snow events) for the statistical analysis. Furthermore the reliability of the results presented in this report can be improved and extended investigations are possible.

2.6 People's Republic of China

2.6.1 The need for correction of precipitation measurements, particularly snowfall measurement, has been widely recognized in hydrology and glaciology studies recently in China. During 1978 to 1985, fifty-five hydrological stations across China had been involved in a precipitation measurement project initiated by the National Hydrological Bureau of Water Resources Administration. In this project, the ground level gauge and Chinese standard gauge at various heights were compared for rainfall measurements. In 1987, Tianshan Glaciological Station of Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, participated in the Solid Precipitation Measurement Intercomparison (WMO/CIMO, 1986) and started precipitation measurement experiment at 6 hydrological and climatic stations situated from the high alpine glacier area to the low land of Urumqi city in Urumqi river basin in Tainshan Mountains. A WMO reference gauge (DFIR) was installed at the highest elevation site in the upper streams and Chinese standard gauge, Tretyakov wind shield and Hellmann gauges were used.

2.6.2 All the intercomparison data up to August 1991 have been digitally archived and submitted to the Canadian Climate Centre. Preliminary analysis indicates that the Chinese standard gauge at 0.7m catches 73% of the DFIR in dry snow measurements.

2.6.3 The intercomparison will continue to the summer of 1994 and wind speed at DFIR height will be measured in order to correct the daily and monthly precipitation data. In the later summer of 1994, the DFIR will be moved down to the Daxigou climatic station, where precipitation, air temperature and wind speed at 10m have been measured since 1958. A pit gauge will be set up for rainfall measurements. Weighing method will be used to determine the average amount of trace precipitation. Further information on the preliminary results are contained in **Appendix J**.

2.7 Other countries/Switzerland (ETH)

Dr. Sevruk reported on the progress of research works done in the Department of Geography of the Swiss Institute of Technology, ETH, in Zurich. Wind tunnel investigations showed that the wind speed increase above the orifice of precipitation gauges is greater for thick orifice rims than for thinner ones. It seems that the orifice area also plays some role but particularly for thinner orifice rims. There is a slight increase of wind speed with increasing orifice areas up to 300 cm^2 (**Appendix K**). Further, an empirical model was developed to estimate the wind-induced losses of precipitation measurement. This model is characterized by a set of one parameter (wind speed) curves with increasing threshold value of rate of precipitation for increasing wind speed (**Appendix L**). In addition a map of corrections and corrected precipitation of Switzerland (on a scale of 1:500,000) have been presented. This is a part of the Hydrological Atlas of Switzerland. Finally, it was pointed out that the estimation of the exposure of a gauge side from the station history records can be made with fairly well accuracy. This is important especially for the estimation of wind-induced error at gauge sites without measurements of wind speed. Based on station history records a system of exposure classes was developed and used for the estimation of corrections over the territory of Switzerland. More information about the projects can be found in **Appendices M and N.**

3. DATA ARCHIVING

3.1 Review and update of outputs

3.1.1 Mr. J. Metcalfe reviewed the current status of the digital archive for the WMO Intercomparison. The summary of data received and entered into the archive is given in **Appendix O.** Participants were requested to check this summary and confirm that the information is correct. It was noted that data from Valdai for 1990/91 and 1991/92 had not yet been received.

3.1.2 Participants visited "PhD Associates", the contractor responsible for creating the data base. A demonstration of the format and data availability was provided to familiarize participants with data they could receive (**Appendix P**). It was decided that a copy of the data could be provided to participants who wish to use the data for analysis at this time. Each person would be responsible for extracting the data they wished to use. A copy of all the data will be provided with the final report of the Intercomparison to participants; it will be provided to others only upon request.

3.2 Data archive

There is concern about where the "archive" will be kept for future access by member countries. It should not be the responsibility of individuals or WMO. It was recommended that the Canadian Climate Centre Information Branch and the World Data Centres for Glaciology (Boulder, Moscow and Lanzhou) would be suitable repositories. The chairman will contact these groups to confirm their interest.

4. DATA ANALYSIS

4.1 Correction of the DFIR for wind effects

Dr. Golubev and Dr. Yang gave talks on the DFIR measurement accuracy at the Valdai-site in Russia. They agreed on the need for correction of DFIR measurements for wind induced error. But they debated the method of the correction. Golubev's correction equation uses station elevation, air temperature, atmospheric pressure, humidity and wind speed. Recent analysis on Valdai intercomparison data by the Canadian Climate Centre (CCC) found blowing snow occurred on one-third of the snow events greater than 3 mm. After eliminating the blowing snow, there remains a systematic difference between the measurements of the bush gauge and DFIR, with the bush gauge catching more snow than the DFIR. The most important factor in the correction procedure is mean wind speed during storm. Atmospheric pressure, air temperature and humidity have little or no influence. The equations for correcting the DFIR (Yang/CCC and Golubev) are described in **Appendix Q.** The following Yang/CCC equations using wind speed are recommended for correction DFIR:

a) Dry Snow

$$\frac{BUSH}{DFIR}(\%) = 100+1.89\times U_3+6.54E\text{-}4\times U_3^3+6.54E\text{-}5\times U_3^5, \quad (N=52, R^2=0.37) \quad (1)$$

b) Wet Snow

$$\frac{Bush}{DFIR}(\%) = Exp(4.54 + 0.032\times U_3), \quad (N=38, R^2=0.56) \quad (2)$$

c)Blowing Snow

$$\frac{BUSH}{DFIR} = 95.40+2.19\times U_3-8.47E\text{-}3\times U_3^3, \quad (N=54, R^2=0.37) \quad (3)$$

d) Rain with Snow

$$\frac{BUSH}{DFIR}(\%) = 101.67 + 0.254\times U_3^2, \quad (N=39, R^2=0.38) \quad (4)$$

e)Snow with Rain

$$\frac{BUSH}{DFIR}(\%) = 98.97 + 2.30\times U_3, \quad (N=43, R^2=0.34) \quad (5)$$

f) Rain

$$\frac{BUSH}{DFIR}(\%) = 100.35 + 1.667\times U_3 - 2.40E\text{-}3\times U_3^3, \quad (N=120, R^2=0.22) \quad (6)$$

Note: U_3 = wind speed at 3 Metre (m/s) during storm.

4.2 Report of countries' analyses of national gauges

4.2.1 Finland and Scandinavia

4.2.1 As decided in the Nordic Working Group for Precipitation an analysis of data from the experimental field of Jokioinen, Finland will be undertaken. The preliminary results from this analysis are given in **Appendix R.**

4.2.2 Canada

Canada was concerned about the difference in Canadian Nipher gauge catch to "true" (DFIR) versus wind speed for the recent intercomparison compared to previous work done in Canada. Regional analysis of differences at the six Canadian sites indicates no bias of ratio of Nipher/DFIR versus wind speed by climatic region (**Appendix S**). After correction of the DFIR for its wind induced error using the method developed by Yang et al., a more compatible relationship with previous work done in Canada was achieved. Additional analysis done on the Canadian data was presented and is included in the attached reference by Metcalfe and Goodison to be presented at the AMS Conference in January 1993 in Anaheim, California (**Appendix T**).

4.3 Report on the results of the international intercomparison

A paper on the preliminary results of the comparison (status early 1992) was presented at TECO-92 held in Vienna Austria, May 1992. It is published by WMO in the preprints of the conference (Instruments and Observing Methods Report No. 49, WMO-TD 462) and a copy is enclosed as **Appendix U** to this report for information.

5. PREPARATION OF THE FINAL ANALYSIS

5.1 Analysis procedures for solid precipitation only

5.1.1 It is first necessary to calibrate the instrument. This requires:

(1) a check for deviation of the orifice rim from a true circle;
(2) a determination of the exact elevation of the orifice from the ground level, and
(3) an evaluation of the proper tilt of the orifice.

It is presupposed that the instrument has been properly calibrated and installed as per specification (i.e., the orifice is perfectly round, parallel to the ground and elevated at the correct height above the ground). If deviations from these standards are found to exist, then the data must be corrected to ameliorate these effects.

5.1.2 Once the instrument calibration has been verified and/or accepted, a wetting loss correction is then applied to the measured precipitation data. This wetting loss is gauge-specific and has been specified for each national precipitation gauge by the Nordic and Canadian researchers.

5.1.3 The next step is to correct the DFIR data for

(1) wetting losses based on the Tretyakov gauge, and
(2) for wind speed effects using the equations developed by Yang and stratified by precipitation type.

The final step is to determine the catch ratio for each precipitation gauge included in the comparison as a function of wind speed at gauge orifice height and shelter-height air temperature. Wind speed should be the primary effect with air temperature as a secondary variable. These relationships need not be linear, however; indeed, they should be designed to maximize the explained variance in the data. Thus, the equation may include linear, exponential and power terms. To ensure that the relationship is not adversely affected by small precipitation totals which can inflate the ratio, only events in which the measured precipitation in the DFIR equals or exceeds 3mm are to be included. Additionally, blowing snow events (denoted by observer notes) are to be eliminated from this analysis. They may be considered at a later time to quantify the impact of blowing snow. It is the duty of the researchers from each nation to develop this catch ratio for the national precipitation gauge of their own country.

5.1.4 It should be noted that stratification must only be made on gauge and precipitation type (rain, dry snow, wet snow, rain followed by snow, and snow followed by rain) and the time step. Wind speed, air temperature, and precipitation amount must be treated as a continuous variable and not stratified. Time intervals considered will include once, twice, and four times a day measurements as well as for event totals. The requirements given here are minimal requirements. Additional evaluations may be undertaken at the discretion of each researcher.

5.1.5 When these equations are applied for the correction of new or existing precipitation observations, it must be remembered that the equation is valid only for the wind speed interval in which the equations were derived. Thus, it is proposed that an upper value of the wind speed be determined and corrections at higher wind speeds are to use for the correction of this threshold wind speed. This is important since the empirical equations that are derived are only valid statistically for the interval for which they were developed and should not be used for extrapolation outside of this range.

5.2 Analysis procedures for mixed precipitation

5.2.1 In cases where the precipitation event is described by the observer as "rain changing to snow" or "snow changing to rain", a separate analysis must be applied. Guidelines given in the general analysis section are to be followed with the following changes.

5.2.2 The first step is to correct the DFIR data for

(1) wetting losses based on the Tretyakov gauge, and
(2) for wind speed effects using equation 4 and 5 developed by Yang for mixed precipitation.

Then, the gauge measured precipitation should be corrected for its wetting loss. This correction has been specified by the Nordic and Canadian researchers.

5.2.3 The final step is to determine the catch ratio for each precipitation gauge included in the comparison as a function of wind speed at gauge orifice height and the mean, maximum, and/or minimum shelter-height air temperature. This analysis should be done for measurements made once, twice, and four times daily as well as for event precipitation.

5.2.4 In the case of automatic gauges, an attempt should be made to separate the rain and snow components and analyze each separately. Additionally, the timing of the precipitation event and its intensity as well as the problems of heated gauges especially during low intensity events must be addressed. Unique problems and advantages associated with certain gauges should be politely mentioned.

5.2.5 Some further ideas regarding the preparation of the final analysis of the results of the Intercomparison and a draft for a glossary are listed in **Appendix V**.

6. FINAL REPORT OF THE INTERCOMPARISON

6.1 The preparation of the final report of the Intercomparison, its outline and the assignment of tasks were discussed in detail on the basis of the proposal that was proposed at the fifth session of the OC (see item 8). The session agreed on the following outline and the responsibilities:

	Issue	Responsibility	Deadline
0.	Executive summary	Goodison	/
1.	Background / Introduction (History	Secret.,Goodison B.Sevruk)	/
2.	Methodology (see report of the first session of the OC)		
3.	Description of sites and instruments	all participants	/1.12.92
4.	Physics of gauges (incl.windtunnel)	Sevruk	/ 1.2.93
5.	Data archive	Goodison, Metcalfe	/
6.	National analysis and results		
	6.1 Preliminary results (with regard to item 5)		/ 1.4.93
	6.2 Packed and returned for final evaluation		/ 1.8.93
	6.3 Final version to be sent to the chairman		/1.10.93
7.	Comparison of the different methods	Goodison	/
8.	Demonstration and implementation of the results		
	8.1 Demonstration on one or two stations	each participant	/1.8.93
	8.2 Discussion on application	Legates	/1.10.93
9.	Conclusions and recommendations	Goodison	/
10.	References	Goodison	/
11.	Appendices		

6.2 It was agreed that the final report of the conduct and the results of the WMO Solid Precipitation Measurement Intercomparison should be published by WMO in the Instruments and Observing Methods Reports series. It is intended that the report should be distributed prior to CIMO-XI which is scheduled to be held in February 1994. In addition to the CIMO mailing list it was proposed to prepare also a GENERAL SUMMARY of the results of the Intercomparison which should be distributed to the members of CCl and CHy for information.

7 RECOMMENDATIONS FOR CIMO-XI

As result of an intensive discussion of the preliminary evaluation of the intercomparison (items 2. and 4. of the agenda) the OC decided that recommendations for improving precipitation measurements should be developed and submitted to the eleventh session of CIMO for consideration. The OC agree on the drafts of four recommendations contained in **Appendix W.**

8 OTHER BUSINESS

8.1 National and Regional Precipitation Centres

The session discussed the need of the establishment of National and Regional Precipitation Centres as a mean for improving the quality of precipitation measurements. The basis for the discussion was the corresponding issue contained in item 9 of the fifth session of the OC. It was agreed to submit two relevant draft resolutions to CIMO-XI (**Appendix W**).

8.2 Information on ASOS network

As a result of concerns raised during the fifth session of the Organizing Committee, a letter was sent from D. Legates, USA and E. Friday, Assistant Administrator for the Weather Service, USA regarding the planned precipitation measurement in ASOS. Copies of the letter and the subsequent reply are attached as **Appendix X** to this report.

8.3 Snow loads

Serious problems can arise in countries which have national snow load standards based on the measurements of snow water equivalent using precipitation gauges where the measurements have not been corrected for wind-induced losses. In such cases, snow loads will be considerably underestimated and the revision of these national standards will be necessary.

8.4 Information on CIMO-XI

The participants have been informed that the next session of the Commission will be probably held in February/March 1994 in Geneva. The session will be combined with a technical conference and an exhibition of meteorological instruments. The members of the OC and the invited participants are requested to present papers concerning precipitation measurements and preliminary results of the evaluation of national data of the Intercomparison.

8.6 Visits

The participants appreciated the introduction in the tasks of the Centre for Atmospheric Research Experiments (CARE), Egbert, given by Mr. F. Froude, Director of CARE. CARE is a regional monitoring facility of the AES which was developed as a multi-disciplinary integrated facility to promote research programmes with other federal departments, provincional governments, universities and industries to study environmental problems. The Centre was erected away from dense populated area and industry so that is suitable for background measurements especially for air pollution monitoring measurements for the Atmospheric Radiation and Turbidity Programme and other studies. Furthermore, it is used for testing of different meteorological instruments. The laboratories and the outside facilities were visited. In addition, Mr. van Cauvenberghe gave an interesting introduction in the running national comparison of different shieldings and screens applied for operational temperature measurements. At the test site of CARE there was recently also accommodated one of the Canadian precipitation station which participates as a test site in the WMO Solid Precipitation Measurement Intercomparison. Dr. Metcalfe explained the disposition of the participating instruments in field and provided all necessary information on the Canadian approach to the comparison. The participants appreciated very much this interesting introduction in the tasks of CARE and especially to have the opportunity to visit one of the canadian test sites for the Solid Precipitation comparison and thanked the host for the interesting explanations.

8.6 Next session of the International Organizing Committee

Reflecting the experience of previous WMO intercomparisons it was agreed that a last session of the OC should be convened especially to review the draft of the Final Report of the comparison. It was agreed that this session of the OC should be held not earlier than the September 1993. It would be advantageous to combine this final meeting of the OC with the International Symposium on Precipitation Evaporation which is scheduled to be held in Bratislava, Slovakia, from 20 - 24 September 1993. The precondition for a successful session of the OC is that the first draft of the report can be distributed prior to the above Symposium. If the draft report cannot be prepared in time other arrangements should be made.

9 CLOSURE OF THE SESSION

9.1 The chairman thanked the participants for their active work during the session. He wished the participants a save trip home.

9.2 Mr. Schulze thanked Dr. Goodison for his dedicated chairmanship and the members of the OC and the participating experts for their excellent contributions. He expressed his appreciation to the organizers of the session for the excellent working conditions they have provided and thanked especially the local staff for the secretarial support provided for the preparation of the report and for the hospitality extended to the participants.

9.3 The session was closed on Friday, 18 September 1992 at 2.00 pm.

LIST OF PARTICIPANTS

1. Members of the International Organizing Committee

B. Goodison	(Chairman)	Canada
V. Golubev		Russia
T. Günther		Germany
B. Sevruk		Switzerland

2. Invited experts

R. Bates	USA
Daqing Yang	China
H. Ellsworth[1)]	Canada
E. Elomaa	Finland
D. Legates	USA
H. Madsen	Denmark
J. Metcalfe	Canada
A. Tuominen	Finland

3. WMO Secretariat

K. Schulze

[1)] part time

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SUMMARY OF THE STATEMENT OF THE PRESIDENT OF CIMO AT THE OPENING CEREMONY OF THE SIXTH SESSION OF THE INTERNATIONAL ORGANIZING COMMITTEE, WMO SOLID PRECIPITATION MEASUREMENT INTERCOMPARISON

CIMO MISSION

IMOP PROGRAMME OBJECTIVES ACCORDING THE WMO THIRD LONG-TERM PLAN

1. To promote:

- the development,
- documentation and
- world-wide standardization of meteorological and related geophysical instruments and methods of observation
- to meet specified requirements
- under differing environmental conditions;

2. To ensure the effective and economic use of instruments and methods of observation:

- under varying working conditions and
- in differing technical infrastructures
- by providing technical standards, guidance material, performance specifications, technology transfer, and training assistance.

IMPORTANCE OF SOLID PRECIPITATION MEASUREMENT

- CLIMATOLOGY:CLIMATE CHANGE

  (Combines signals for temperature change and precipitation change.)

  APPLICATIONS
  (e.g. standards for construction)

- ECONOMIC IMPORTANCE:

  HYDROLOGY
  WATER RESOURCES
  AGRICULTURE
  TRANSPORTATION
  RECREATION
  WILDLIFE
  ...

- SAFETY:

  AVALANCHES
  FLOODING

THIS INTERCOMPARISON IS UNIQUE

- done in many countries
- many seasons
- common standards
- national instruments

IT HAS DEMONSTRATED THE VALUE OF THIS TYPE OF INTERCOMPARISON PROCESS FOR OTHER TYPES OF MEASUREMENTS

- great sensitivity in measurement to combinations of environmental factors;
- standard instrument(s) and methods can be made locally available;

THE WMO SOLID PRECIPITATION INTERCOMPARISON: CANADIAN ASSESSMENT

B.E. Goodison and J.R. Metcalfe
Canadian Climate Centre, Downsview, Canada

INTRODUCTION

In 1985, the World Meteorological Organization (WMO) initiated an international intercomparison to assess national methods of measuring solid precipitation. Past and current procedures as well as methods suitable for use at automatic weather and climate stations were to be assessed against a standard method whose accuracy and reliability was known (4). Canada recognized this experiment as an opportunity to investigate, and hopefully provide solutions to some of the challenges of winter precipitation measurement. In 1986, Canada initiated the installation of the first of seven evaluation stations with the WMO reference standard gauge (DFIR). These stations were situated across the country in different climatic and physiographic regions. After five years of continuous data collection, three of these stations have been terminated.

An overview on current Canadian methods of solid precipitation measurement is given in (5). Several kinds of precipitation gauges, using different types of shielding, were tested at these stations (5). This paper will focus on the accuracy and performance of the Canadian Nipher Shielded Snow Gauge System, the Atmospheric Environment Service (AES) national standard instrument for measuring snowfall precipitation at principal observing stations. It should be noted, that at climatological stations (85% of the Canadian precipitation observing network) daily snowfall precipitation is estimated from snow depth measurements using an average density of 100 kgm^{-3} for all regions. Yet, observations from the Nipher gauge provide the core data set for most meteorological, hydrological and climate change analyses. An accurate assessment of its performance is critical.

PROCEDURES AND INITIAL COMPARISONS

The DFIR, which uses the Russian Tretyakov gauge, was used as the standard against which the Canadian Nipher gauge and other gauges were compared (4). Both the Nipher and Tretyakov gauges are non-recording and require manual observation. Their contents must be melted and poured into a graduate for measurement. Systematic errors related to wind, wetting loss and evaporation must therefore be considered.

Previous experimentation (3), and recent results from the WMO Intercomparison (5), confirm an average wetting loss for the Nipher gauge collector of 0.15mm +/- 0.02mm. Canadian tests also found the wetting loss for the Tretyakov gauge averaged 0.20mm per observation. Scandinavian tests (6) have found the wetting loss for the Tretyakov gauge to be 0.1 to 0.2mm. Since 1966, Russia has routinely applied a wetting loss correction to each observation: 0.2mm for liquid precipitation, 0.1mm for solid precipitation. Based on these results, it was determined that 0.15mm should be added to each observation to correct for the wetting loss of the Nipher gauge and the DFIR (with Tretyakov).

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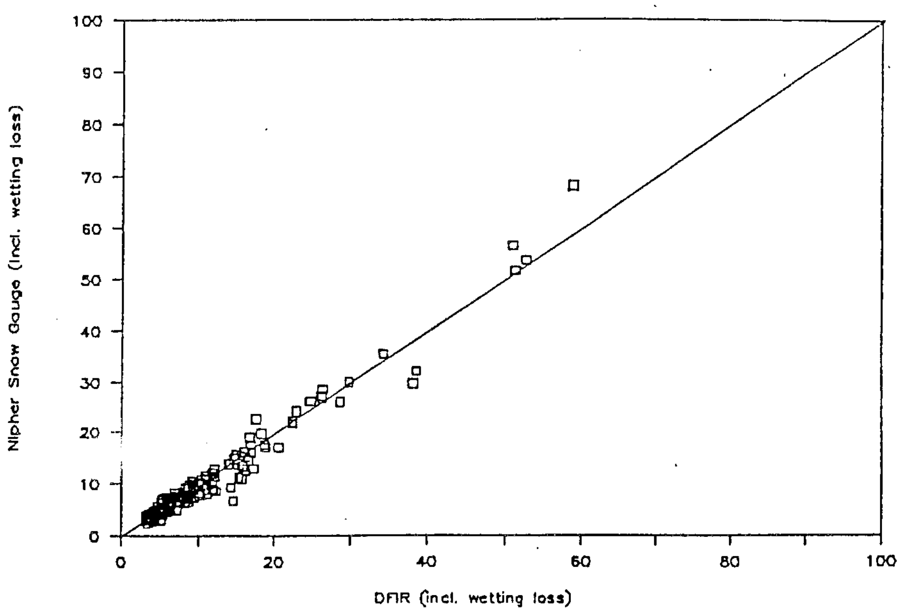

Fig. 1 Event snowfall precipitation (mm) of Nipher Snow Gauge compared to DFIR at six Canadian stations. Both gauges have been corrected for wetting loss.

First priority for analysis was "event" data, i.e. storm totals for snow only events. Since the ratio of measurements from two gauges was the basis of the analysis, consideration was given to the fact that even small measurement differences between the two gauges could produce quite variable ratios for small snowfall events. To minimize this problem, it was decided to use only snow events greater than 3.0mm in the analysis of gauge catch (Nipher/DFIR) versus wind speed. Figure 1 compares totals from the Nipher and DFIR for 156 events, after correction of each observation within the event for wetting loss. The gauge measurements are very similar; the correlation between the two is 0.98 (R^2=.97). Wind speeds at 2m (the height of the national gauge) during the events ranged from 0 to 8 m/s and mean temperatures ranged from -25°C to +1.0°C. No bias has been observed in the comparison of event totals from the different stations which could be directly related to regional wind speed or temperature effects.

In 1981, AES began using a less expensive fiberglass Nipher shield as a replacement for the original spun aluminum shield. Metcalfe and Goodison (5) outlined the corresponding design and catch differences between these two shields. Because the AES network and the Canadian Intercomparison stations have a mix of the two types of shields, an attempt was made to compensate for this difference (5).

Golubev (1) reported that the DFIR measurements are adversely affected by wind speed, and based on gauge measurements in a sheltered bush site at Valdai, require a correction for wind speed to estimate "true" snowfall precipitation. Event totals from the DFIR were therefore adjusted using the Golubev equation which considers wind speed, air pressure, mean air temperature and mean air humidity. Analysis of the Golubev equation showed that for the same site, pressure and humidity have little effect and the correction equation could be simplified to consideration of temperature and wind speed only:

$$P = P(\text{meas.}) \times (1.0+0.005 \times (273/(273+T))^2 \times W^2)$$

P(meas.)= measured DFIR including wetting loss (no.of obs x 0.15 mm)
T = mean air temperature (°C)
W = wind speed at 3 m, DFIR gauge height

This correction results in an increase in the DFIR measurements, especially at higher wind speeds; thus the ratio of Nipher to corrected DFIR decreases compared to the ratio without the DFIR correction. Figure 2 shows the ratio of Nipher to corrected DFIR plotted against mean storm wind speed. On the same graph the results from Goodison (3) of the ratio of the Nipher gauge to snowboard measurements in a sheltered site (used as "true") are plotted for comparison. For wind speeds up to 2m/s, the results are similar, generally within +/-10% of "true". However, at higher speeds, the current results indicate a catch ratio lower than that found in earlier field studies. At this time one can only suggest possible contributing factors to the difference, including: a larger data set; observations from more than one site; a different minimum threshold for analysis (Goodison (3) used 5mm as the lower limit); the need to estimate catch differences between the fiberglass and aluminum shields used in the current study; and, different instruments for measuring wind speed. Assessment of possible contributing factors to the difference is necessary before applying any correction procedure.

Similarly, snow only event data for the Tretyakov gauge were also analyzed for comparison against earlier work done in Canada (3). Figure 3 shows the results. The ratio of Tretyakov/corrected DFIR, including wetting loss for both gauges, is plotted against mean storm wind speed for three Canadian sites where these gauges were co-located. For comparison, the ratio of Nipher/corrected DFIR for the same events are plotted on this graph as well. The lower catch ratio of the Tretyakov versus Canadian Nipher gauge is consistent with previous findings (2,3).

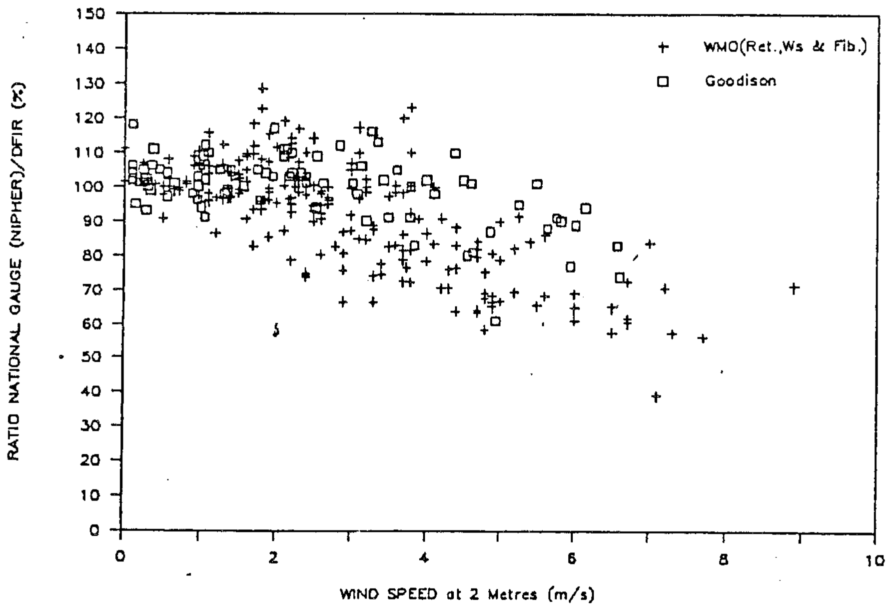

Fig. 2 Comparison of catch ratios, Canadian Nipher to "true" (corrected DFIR) for WMO Intercomparison snow only event data >3.0mm (1987-1991), including correction for fiberglass Nipher shield, and previous field results of Goodison (3).

CONCLUSIONS

Wetting loss is a systematic error which can be quantified and should be included in the correction of any "can" type gauge which must be poured out to be measured. Canada must decide how to implement this correction for both historical and new measurement. The Russian experience of applying the correction at the time of observation must be considered for its applicability in Canada, and for that matter in other countries. Although the difference in measurement between fiberglass and aluminum Nipher shields is small, it does contribute to creating an inconsistent data base for temporal and spatial analysis. Replacing all the gauges in the network now with fiberglass shields is one option to minimize the problem of a prolonged period of mixed instrumentation and creation of an artificial non-homogeneous data base which will adversely affect climate analysis.

The catch characteristics of the Canadian Nipher Shielded Snow gauge are very similar to the WMO reference standard (DFIR), for snow only event totals. Matching totals were achieved over a wide range of temperatures and wind speeds, and at a variety of sites (Fig.1). These results reinforce our previous contention that the Canadian national snow gauge is an efficient instrument for measuring solid precipitation.

The WMO reference gauge (DFIR) should be corrected using the procedures outlined above in order to best represent "true" snowfall. However, this correction does have to be re-assessed when all data from all participating countries have been collected and reviewed. The comparison of ratio of Tretyakov/corrected DFIR against mean storm wind speed lends credence to this procedure as results obtained (Table 1) are comparable to the previous work of Golubev (2) and Goodison (3). Even though Goodison used a different "true", the results indicate that the DFIR or snow boards at a sheltered site provide a suitable reference for measuring "true" snowfall.

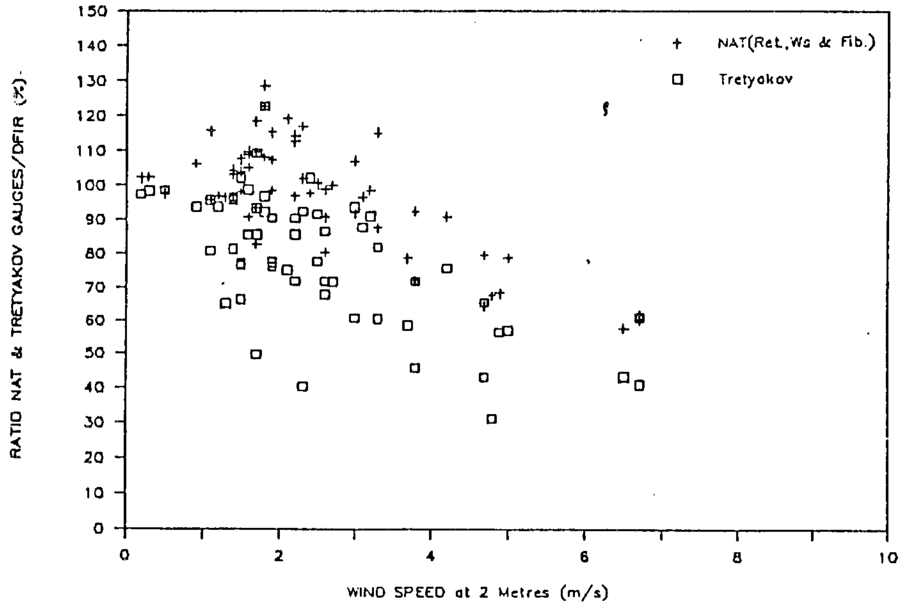

Fig 3. Comparison of catch ratios, Tretyakov to "true" for WMO Intercomparison snow only event data >3.0mm, at three Canadian stations (1987-1991) and catch ratios for Canadian Nipher to "true" for the same events.

TABLE 1.

Catch efficiency of the Tretyakov gauge versus mean wind speed based on Golubev (2), Goodison (3) and WMO Intercomparison for snow only event data at six Canadian sites.

Mean Wind Speed	Tretyakov Percent Catch
2 m/s	80%
4 m/s	60%
6 m/s	40%

If in fact the catch characteristics of the Canadian Nipher gauge and the DFIR are similar, as demonstrated above (Fig.1), then their associated correction coefficients should also be similar. However, in comparing the ratio of Nipher/corrected DFIR (Fig.2), it is obvious that the catch efficiency of the Nipher is less when the DFIR is used as "true" compared to Goodison's previous snowboard work. This is particularly noticeable at wind speeds greater than 4m/s.

When compared to Golubev's (1) catch coefficient versus wind speed for the DFIR, a similar result is observed (Table 2). The reason for the lower catch coefficient at higher wind speeds compared to the DFIR as "true" in light of the previous work is not readily apparent.

Certainly with a high degree of confidence, we can say that at mean storm wind speeds up to 2m/s no correction of the Canadian Nipher shielded snow gauge measurements, except for wetting loss, is required to achieve the best estimate of actual snowfall. Further analysis of both daily and monthly data will continue, in the hope of determining to a higher degree of certainty, correction coefficients for mean wind speeds over 4m/s. The ultimate aim over the next five years is to create a corrected historical precipitation data base and to implement correction procedures for current observations.

TABLE 2

Catch efficiency of the DFIR and Canadian Nipher Shielded Snow Gauge versus mean wind speed based on by Golubev (1), Goodison (3) and WMO Intercomparison at six Canadian sites.

Mean Wind Speed	DFIR[1]	Nipher[2]	Nipher[3]
2 m/s	100%	+100%	100%
4 m/s	95%	100%	85%
6 m/s	87%	90%	75%

1 - observed by Golubev (1) at Valdai, Russia for a vertical fence (DFIR)
2 - observed by Goodison (3) at Cold Creek, Ont., Canada
3 - observed at six Canadian sites during WMO Intercomparison

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AUTOMATION OF WINTER PRECIPITATION MEASUREMENTS: THE CANADIAN EXPERIENCE

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INTRODUCTION

In Canada, and particularly within the Atmospheric Environment Service (AES), economic pressures and technological advances, have led to an increasing trend from manned observations to automated meteorological and climatological systems and sensors. The Canadian climate presents a wide range of conditions within which alternative sensor and data acquisition systems must operate. In spite of the potential severity of the Canadian climate, advances have been made in the development of new technologies to meet the challenge of automation, notably in the field of winter precipitation measurement (2). It is critical, however, that the reliability and accuracy of these new techniques be established if we are to have a homogeneous time series of precipitation data for studies of climate variability and change and global water balance. Participation in the WMO Solid Precipitation Measurement Intercomparison (4) has offered Canada and AES an important opportunity to identify problems and provide solutions to the challenges of winter precipitation measurement.

Since the beginning of the WMO Intercomparison, Canada has operated up to six evaluation stations. All operated the designated WMO reference standard gauge (DFIR) as well as many other standard and non-standard precipitation gauges used in Canada and in other countries, particularly, the neighbouring United States. In 1989 the Canadian Climate Centre (CCC) decided to operate two long term evaluation stations which would operate both WMO precipitation standards, i.e. the DFIR for solid and the pit gauge for liquid precipitation. The first of these stations was located north of Toronto, Ontario at the AES Centre for Atmospheric Research Experiments (CARE).

INSTRUMENT ASSESSMENT

Currently, weighing-type precipitation gauges and heated tipping bucket gauges are the most widely used instruments for solid precipitation measurement on automatic stations. Non-intrusive type sensors which employ optical or small radar devices are under development, but as yet have not been successfully calibrated for winter application. In Canada, the Belfort Transmitting Precipitation Gauge (weighing type) combined with electro-optical encoder technology has proven to be the most suitable configuration for use on automatic recording systems (5).

The goal of any automation plan should be not only to provide accurate precipitation measurements, but also to provide data which would be compatible with current national methods. In an effort to meet these needs, CCC has

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developed and tested a large Nipher-type shield suitable for use on 20.7cm (8") orifice recording precipitation gauges, a system designed to be compatible with the Canadian national standard snow gauge system. Results of field and wind tunnel tests (1,5) indicate that the large Nipher-type shield can be used with recording gauges to provide winter precipitation measurements which are compatible with those obtained by the standard Canadian Nipher shielded snow gauge. Figure 1 illustrates this fact. Over the five winters, the large Nipher-type shielded Belfort gauge (lnBel) measured within 5% of the national standard Nipher gauge (NAT) and the WMO reference gauge (DFIR). This shield also provided a significant improvement in catch compared to the same type of gauge using common alternative shielding, i.e., unshielded (uBel) and Alter-shielded (aBel).

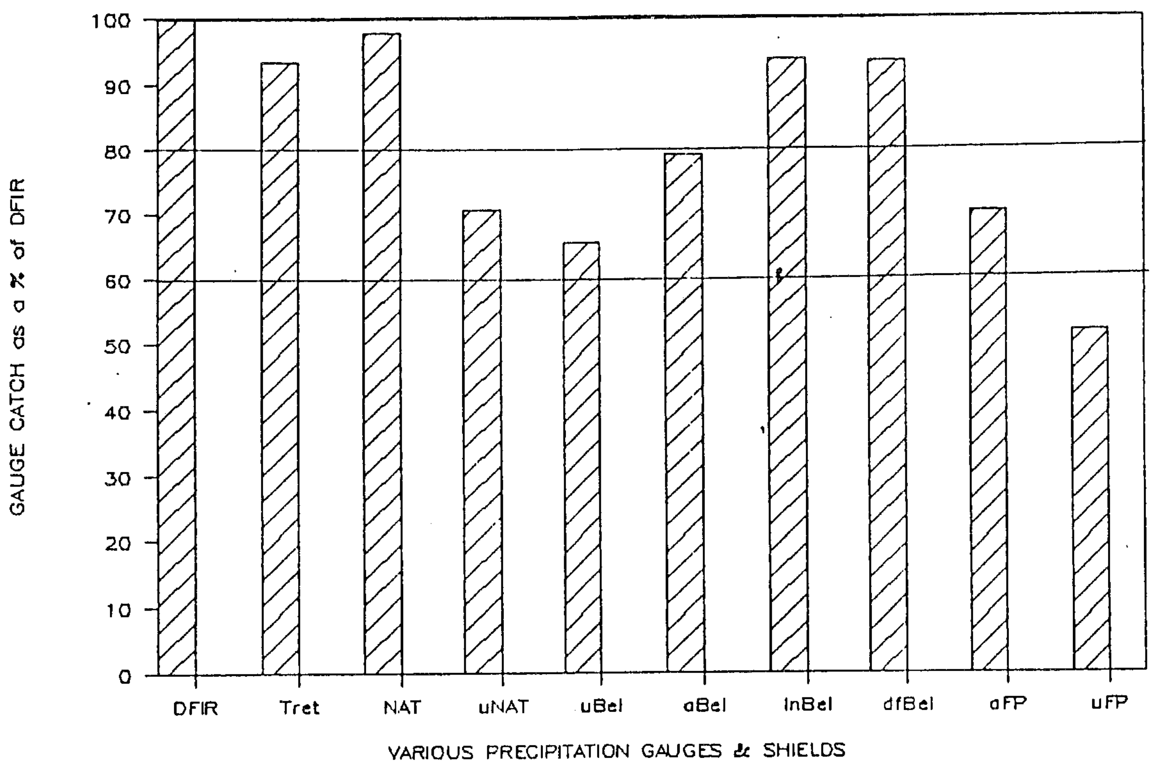

Fig. 1 Monthly Accumulated Snow Precipitation as a percent of WMO reference gauge (DFIR) at the Canadian WMO Evaluation station at Kortright, Ontario for January 1987 to March 1991 for different precipitation gauges: unshielded (uNAT, uBel, uFP), Alter shielded (aBel, aFP), Large Nipher shielded (lnBel), and double fence shielded (dfBel) Belfort Gauges; Double Fence Intercomparison Reference with Tretyakov gauge (DFIR), Tretyakov gauge (Tret) and Canadian Nipher shielded Snow Gauge System (NAT).

One serious operational problem with recording weighing gauges is that wet snow or freezing rain can stick to the inside of the orifice of the gauge and not fall into the bucket to be weighed until some time later, often after an increase in ambient air temperature. This particular problem is amplified with the large Nipher-type shield which has its orifice extended 1.2 m above the gauge to accommodate the shield. Figure 2 summarizes the differences in measured precipitation at CARE between standard climate station measurements and two different automated data collection systems, i.e. GOES Data Collection Platform (DCP) and a conventional data logger (Campbell-Scientific 21X). The auto-stations record meteorological observations hourly, but the climate station is limited to measurements twice daily, morning and afternoon. Both automatic systems use Belfort gauges with large Nipher-type shields to measure precipitation. The climate station uses a standard Nipher shielded gauge for snowfall and a Canadian Type B gauge for rainfall. The average difference between the climate station and DCP precipitation measurements was 0.04 mm, and between the climate station and 21X it was -0.02mm. However, for Julian day 50 to 120, a time normally associated with mixed precipitation events, large daily differences, of up to 10 mm, were observed between the auto-stations and the manned climate station. A significant positive difference was usually followed, within 24 hours, by a similarly significant negative value, indicating the precipitation from the weighing gauge had fallen into the gauge after the end of the precipitation event. This timing difference is important for many climatological and meteorological applications, including the correction of precipitation data, development of climatological and design statistics, meteorological forecasting verification, hydrological forecasting, etc.

Other complications, such as gauges catching blowing snow and the effects of wind induced oscillation of the weighing mechanism must also be considered. It may be possible to detect and eventually quality control some of these anomalies by using other instruments, such as an acoustic snow depth sensor to determine type and timing of precipitation (3). This would require the development and implementation of new interactive and, hopefully, automated quality control procedures by agencies; such a system has not been yet considered for implementation by the CCC in Canada.

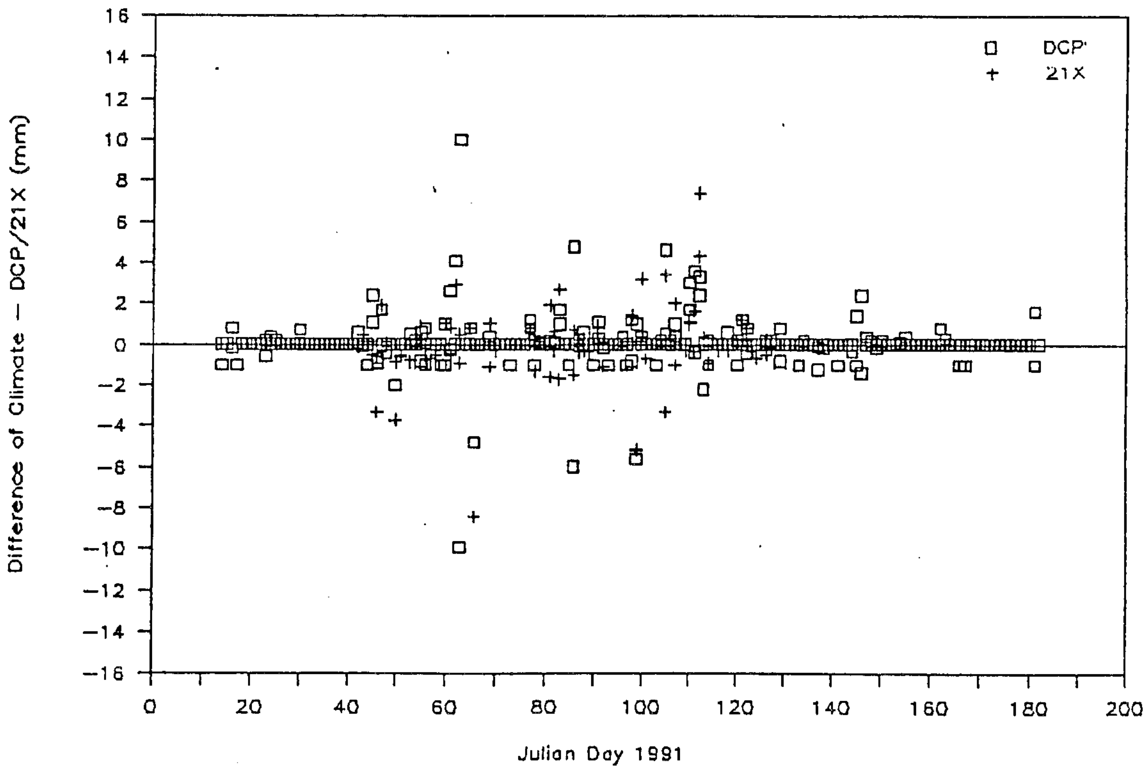

Fig 2. Difference between climate station and auto-station (DCP and 21X) precipitation observations from January to June, 1991.

The recent promotion of heated tipping bucket gauges as a viable method of measuring solid precipitation in North America (6) has led to considerable concern within the scientific community in North America and with members of the WMO Expert Committee for the Solid Precipitation Measurement Intercomparison. In an effort to investigate the accuracy of such sensors, since their use had previously been rejected in Canada several years earlier, CCC installed a Lambrecht Model 1518 heated tipping bucket at CARE in 1990. Figure 3 shows some initial results using this gauge. A time series of accumulated precipitation measured with the WMO reference gauge (DFIR) and with the heated tipping bucket gauge (T/B) during February 1991 is plotted along with hourly temperature. During warm periods, for example day 50 to 51, when rain is falling, both gauges catch similar amounts of precipitation. However, during cold periods, such as days 45 to 48, when temperatures dropped to -20°C, the heated tipping bucket severely undercaught the DFIR. In total, over the entire period, the heated tipping bucket gauge caught less than one third of the actual amount of precipitation recorded by the DFIR.

CONCLUSIONS

In Canada, the use of weighing recording gauges is presently the most practical method of measuring annual precipitation at auto-stations. Heated tipping bucket gauges are not a feasible alternative for winter precipitation measurement in areas where temperatures fall below 0°C for prolonged periods of time. The addition of the large Nipher-type shield on weighing gauges, particularly in windy environments, offers a viable method of minimizing systematic errors in catch, while providing measurements compatible with standard Canadian snow gauge observations. As well, the use of an acoustic snow depth sensor in conjunction with precipitation gauge measurements has been found to be an effective tool in providing further information on type and timing of precipitation.

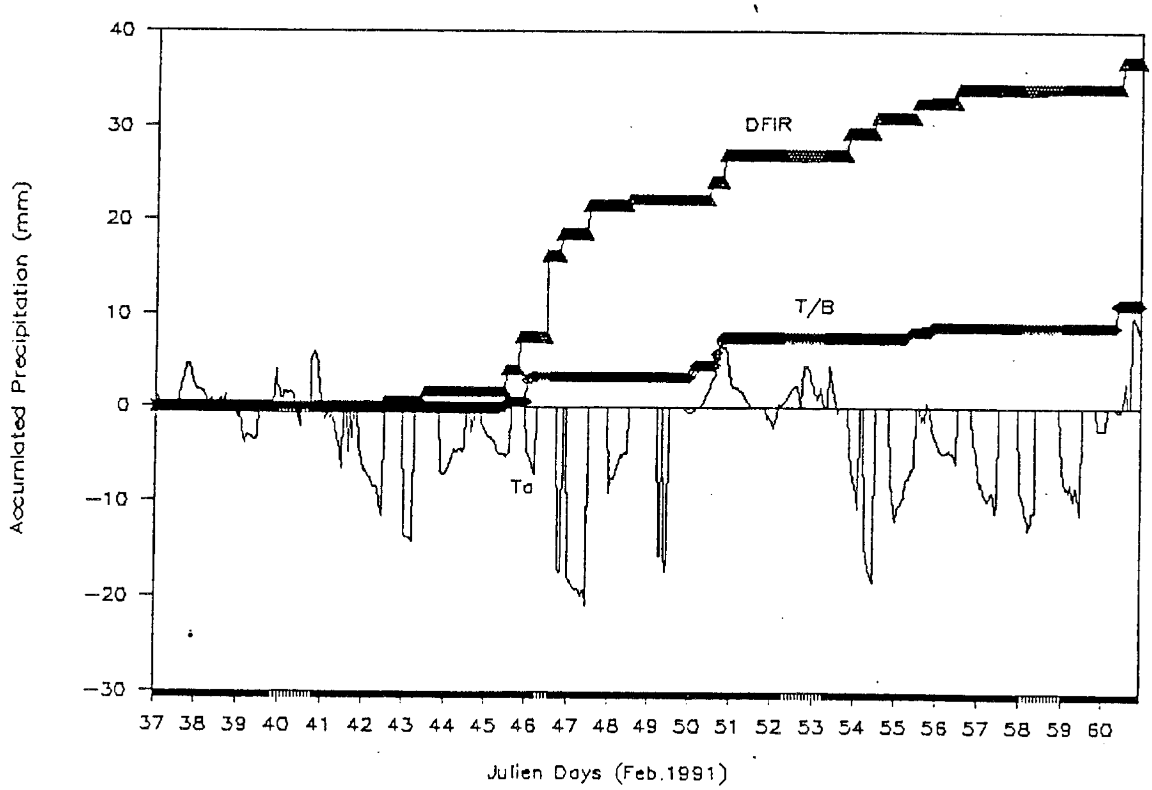

Fig. 3. Accumulated precipitation from WMO reference gauge (DFIR) and heated tipping bucket gauge (T/B) and hourly temperature (Ta) at CARE during February 1991.

Initial analysis of data from the Canadian WMO evaluation stations indicate that climatological summaries and event totals from a large Nipher-type shielded weighing recording gauge are similar to the WMO reference gauge (DFIR) and consistent with those from the Canadian standard Nipher shielded gauge. However, there is more scatter of the event data points about the regression line for the large Nipher shielded weighing gauge than for the standard Nipher gauge when plotted against wind speed. This is no doubt a reflection of the problems discussed above, particularly, the timing errors associated with freezing rain or wet snow events. Therefore, under these conditions, it is expected that the application of correction procedures for weighing gauge data on hourly or daily totals will prove more difficult than correcting data for longer time periods such as monthly climatological summaries. However, it is now recognized that precipitation measurements must be corrected for systematic errors. Identification of the characteristics and magnitude of the errors and ultimate correction of them will be a significant challenge for agencies collecting, archiving, disseminating and using winter precipitation data. The Canadian Climate Centre is now embarking on a study to develop such procedures.

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WMO SOLID PRECIPITATION INTERCOMPARISON

AT SLEEPERS RIVER RESEARCH WATERSHED
DANVILLE, VERMONT, USA
FINAL REPORT: 1986 - 1992

SUBMITTED BY

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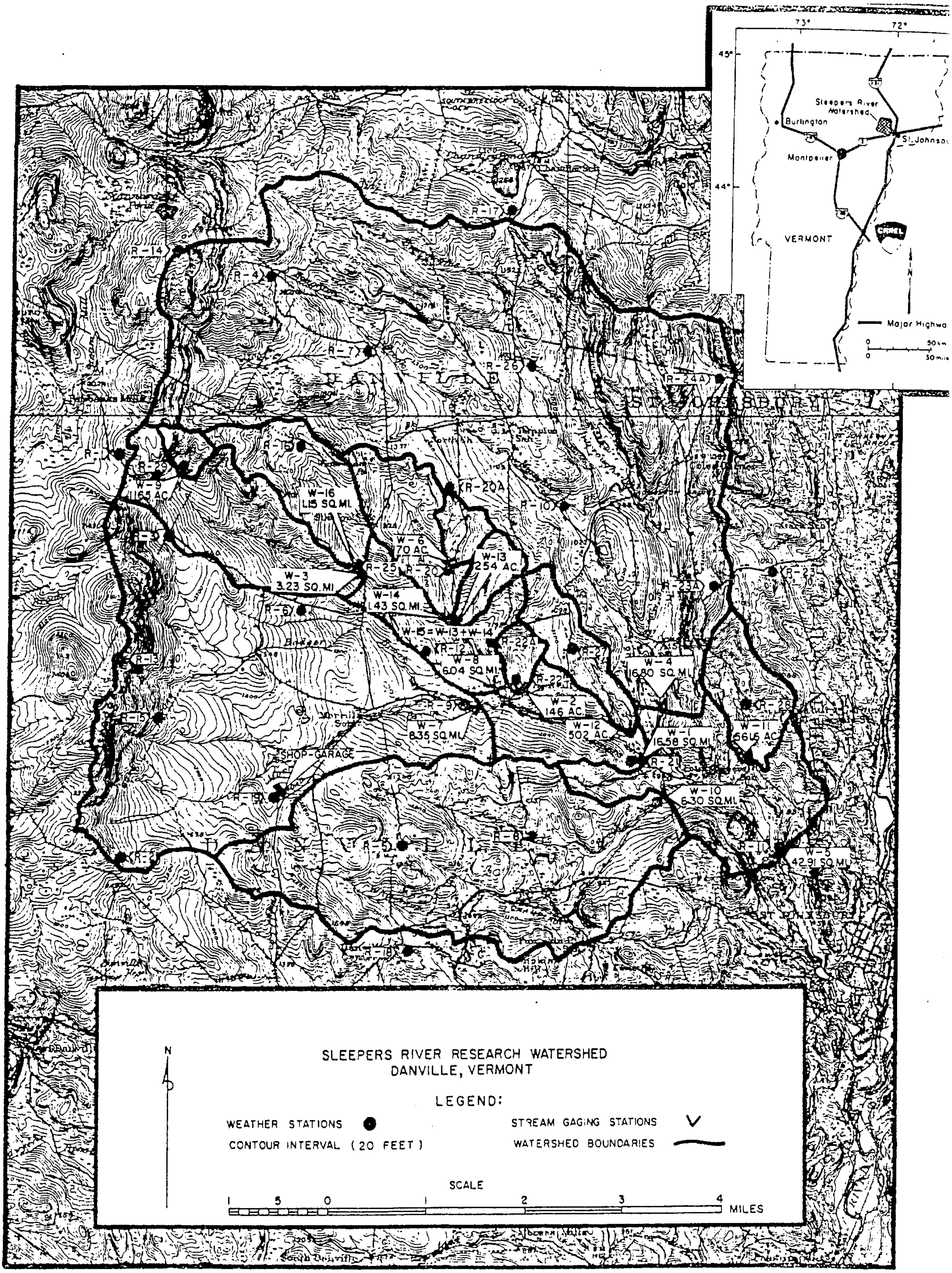
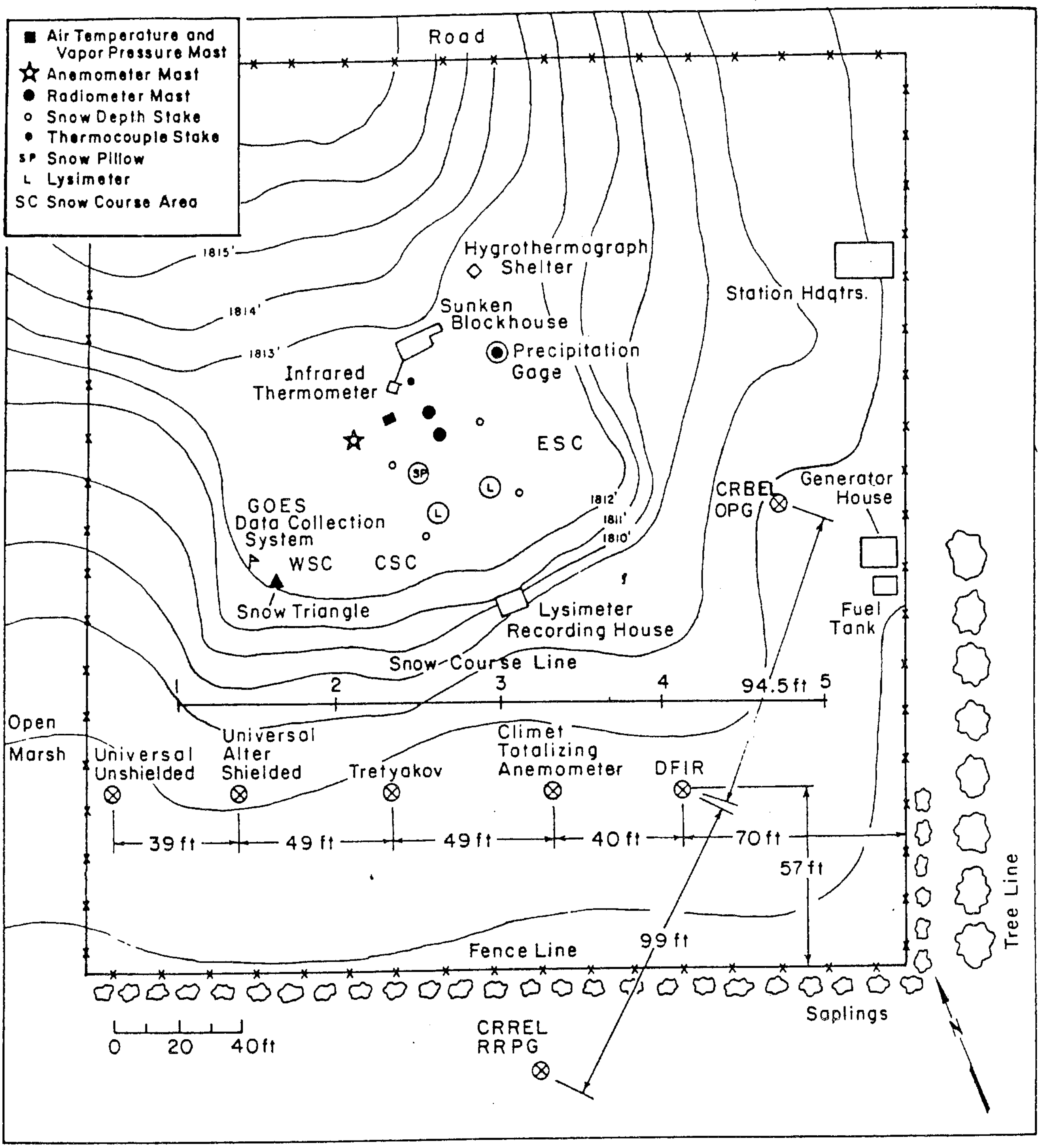
SITE DESCRIPTION

LOCATION: SLEEPERS RIVER RESEARCH WATERSHED
TOWNLINE STATION (R-3),
NORTH DANVILLE, VERMONT, USA

LATITUDE: 44°28'58"N
LONGITUDE: 72°09'56"W

GAUGE	NOMENCLATURE
DFIR	DFIR
TRETYAKOV WITH WINDSHIELD	TRET
NATIONAL SHIELDED-BELFORT UNIVERSAL ALTER SHIELDED	NATSHLD
NATIONAL UNSHIELDED-BELFORT UNIVERSAL	NATUNSHLD
8" NWS STANDARD REFERENCE GAUGE	8"SRG
BELFORT UNIVERSAL WITH POTENTIOMETER OUTPUT	BLFTAUTO
BELFORT UNIVERSAL ALTER SHIELDED (2)	BLFTTL


SLEEPERS RIVER RESEARCH WATERSHED
DANVILLE, VERMONT
LEGEND:
WEATHER STATIONS
CONTOUR INTERVAL (20 FEET)
STREAM GAGING STATIONS
WATERSHED BOUNDARIES
SCALE
MILES
N
Sleepers River Watershed
Burlington
Montpelier
St. Johnsbury
VERMONT
Major Highway
W-16 1.15 SQ.MI.
W-9 1.65 AC.
W-6 70 AC.
W-13 254 AC.
W-3 3.23 SQ.MI.
W-14 1.43 SQ.MI.
W-15=W-13+W-14
W-8 6.04 SQ.MI.
W-4 16.80 SQ.MI.
W-2 146 AC.
W-12 502 AC.
W-7 8.35 SQ.MI.
W-1 16.58 SQ.MI.
W-11 5615 AC.
W-10 6.30 SQ.MI.
W-5 42.91 SQ.MI.
SHOP-GARAGE



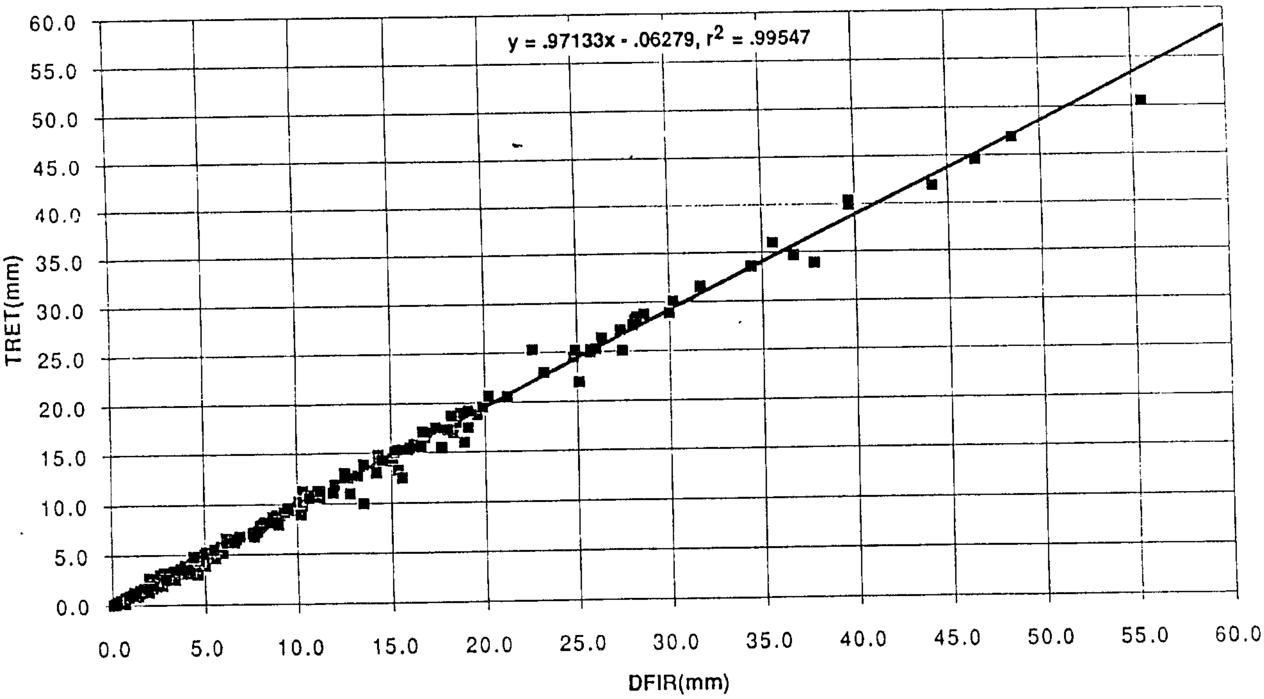
TOWNLINE STATION (R3)

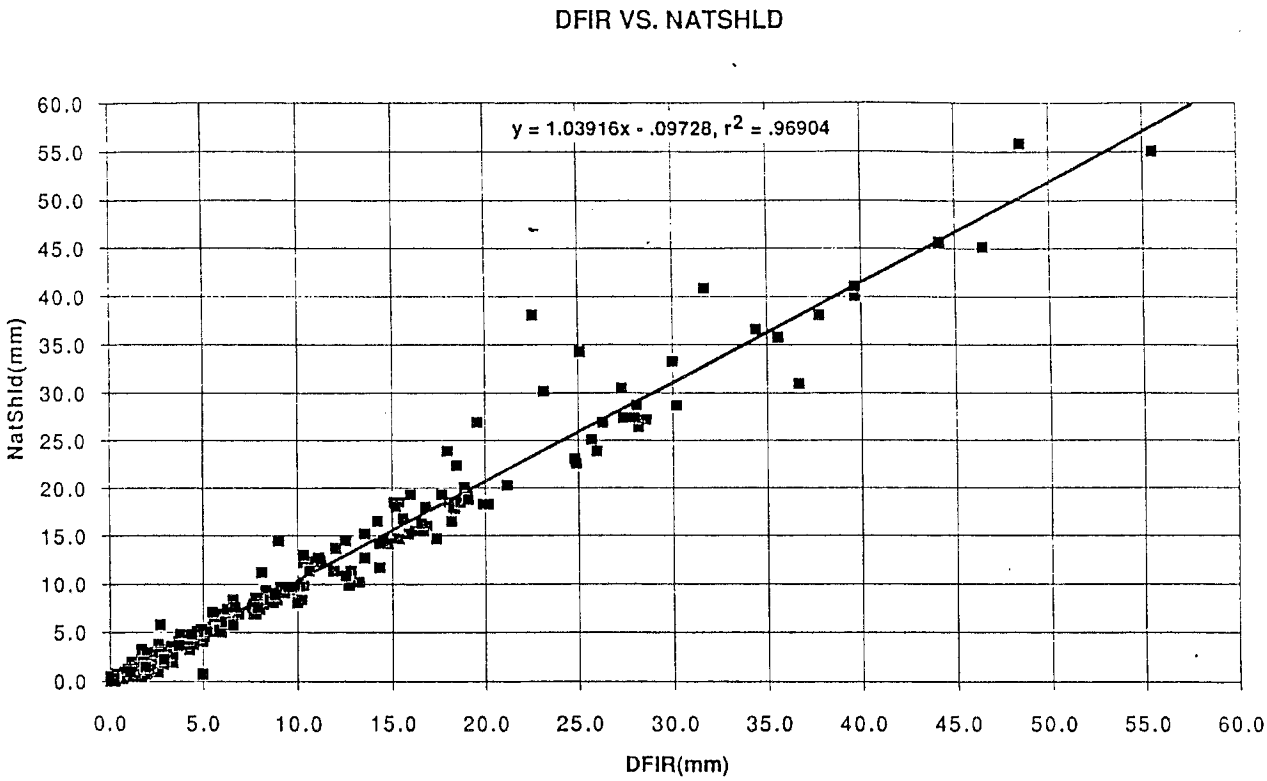
WMO SOLID PRECIPITATION INTERCOMPARISON, DANVILLE VT
WINTERS 1986-1992

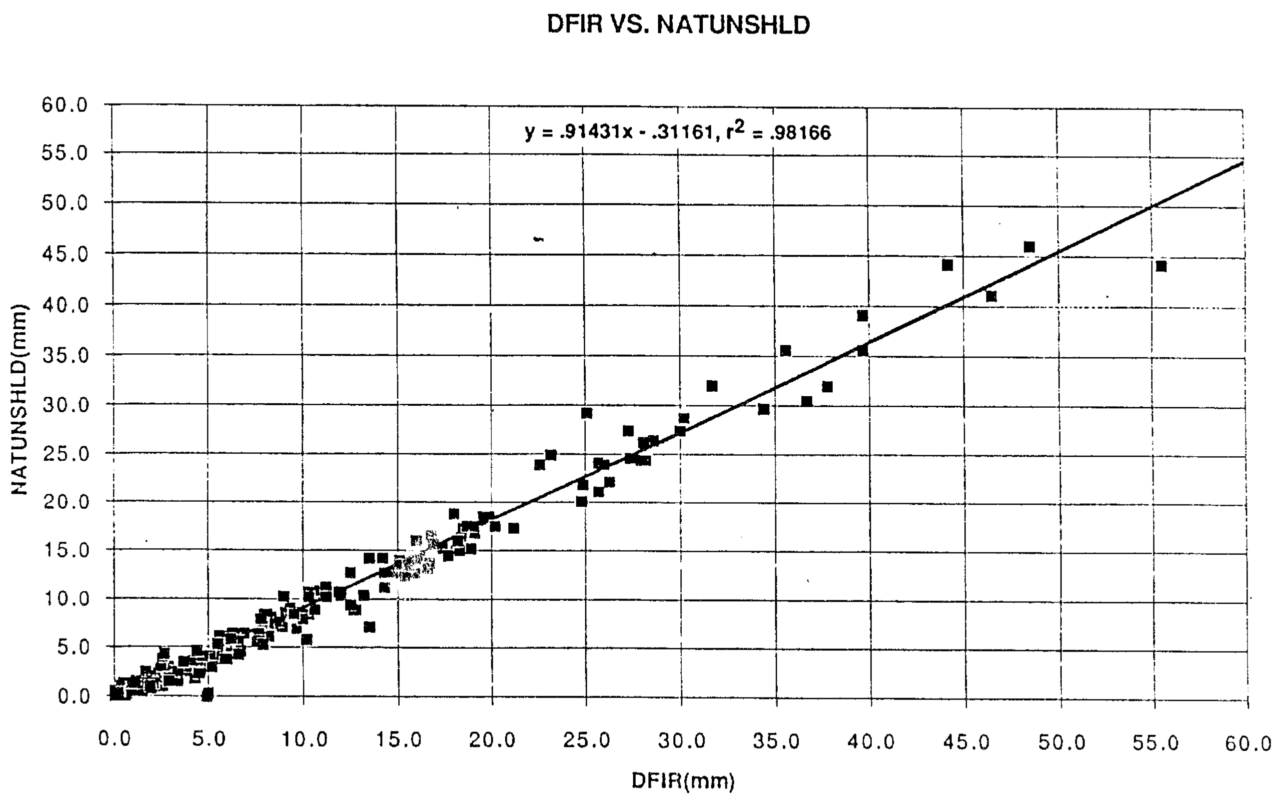
Summary of Events

Precip. Type	No. of Events
Rain	26
Rain with Snow	18
Snow	'183
Snow with Rain	18
Freezing Rain	7
Total	252

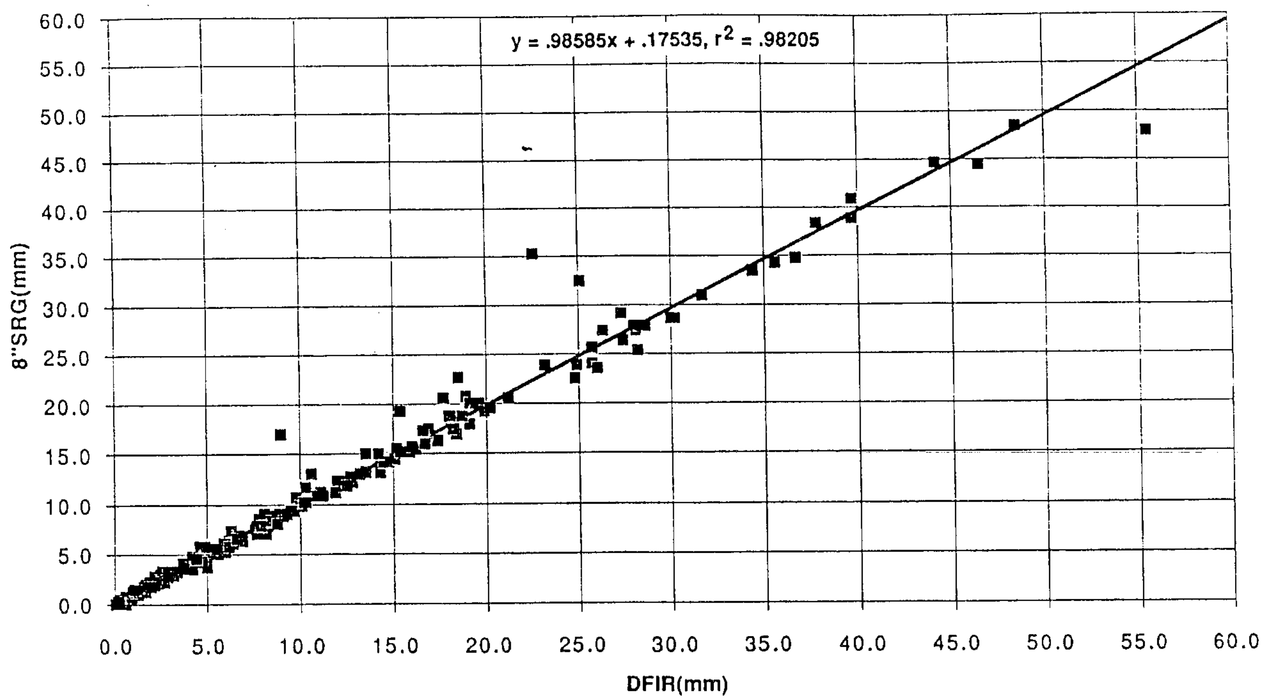
DFIR VS. TRET



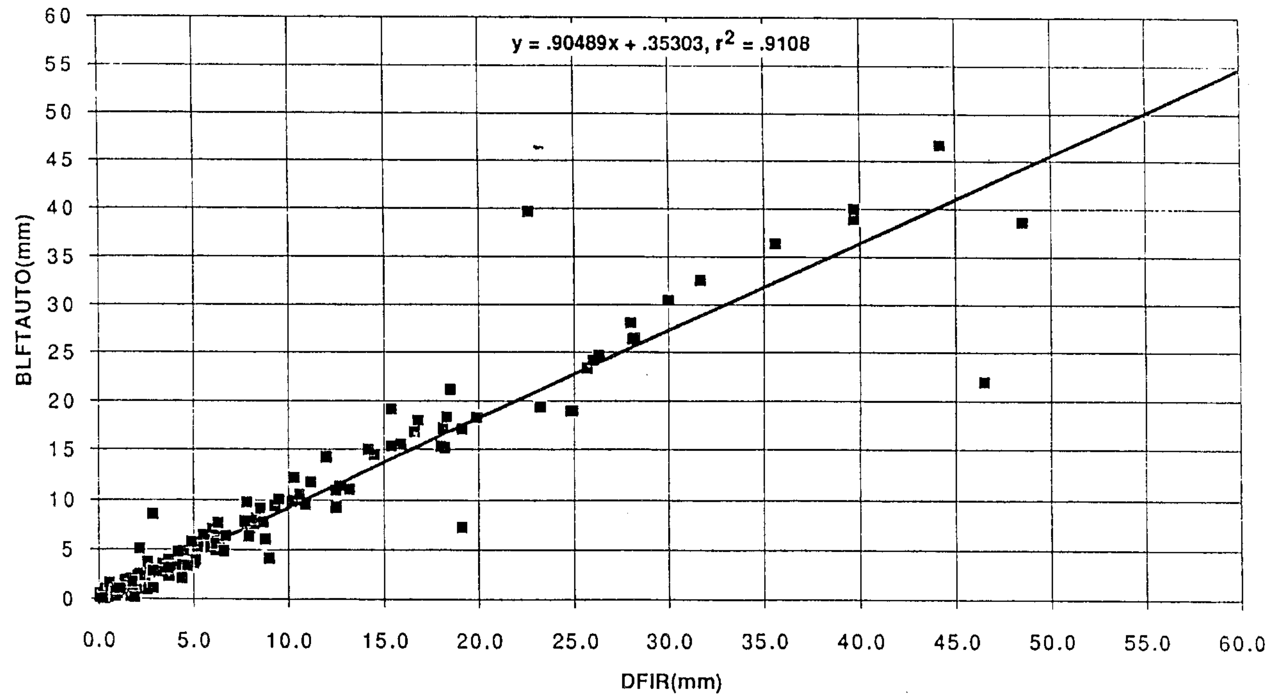

DFIR VS. NATSHLD
y = 1.03916x - .09728, r2 = .96904
NatShld(mm)
DFIR(mm)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0

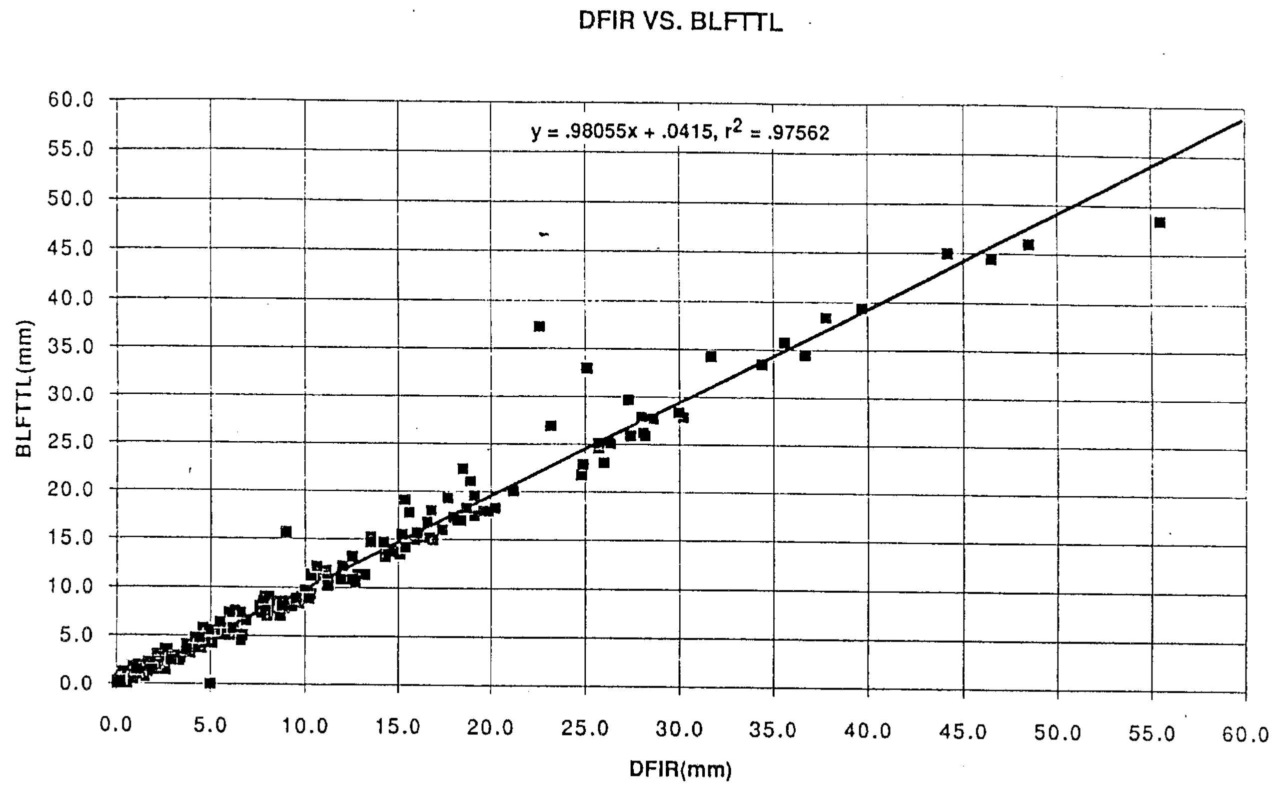

DFIR VS. NATUNSHLD
y = .91431x - .31161, r2 = .98166
NATUNSHLD(mm)
DFIR(mm)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0

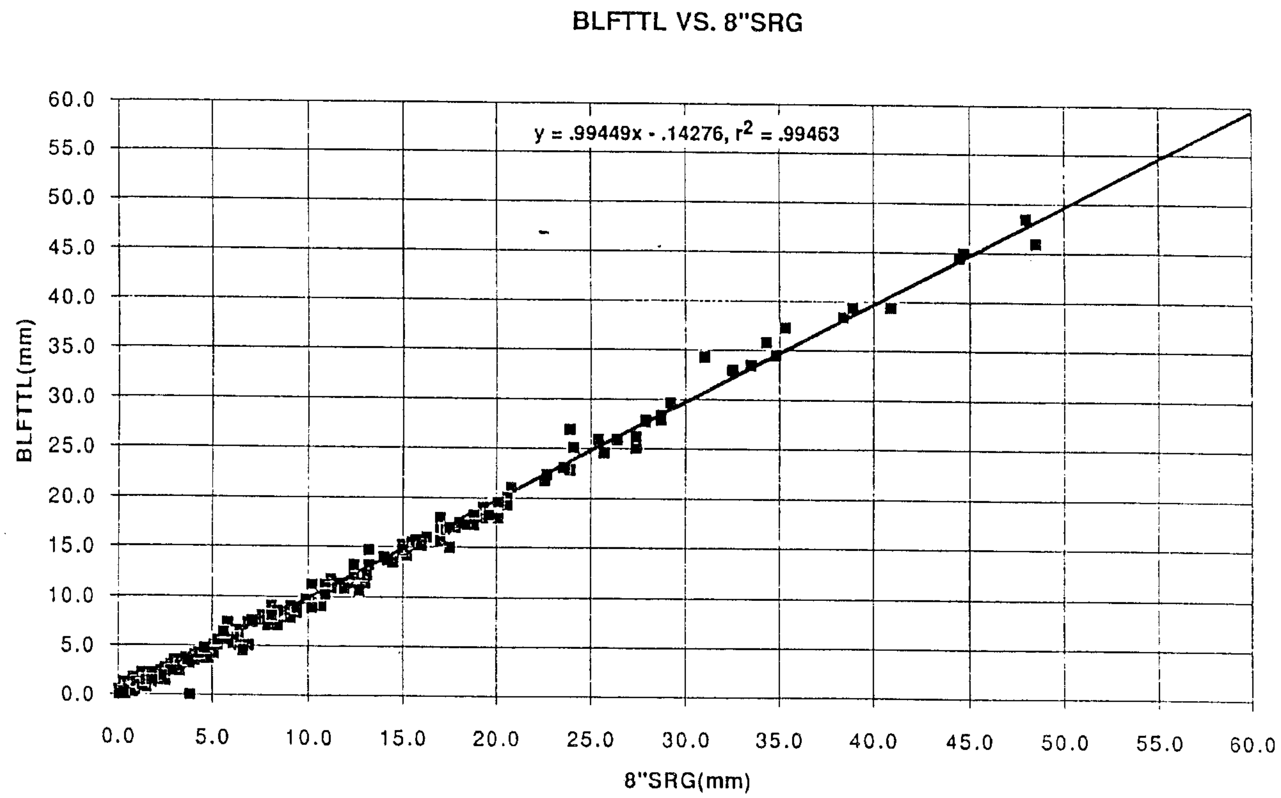
DFIR VS. 8"SRG

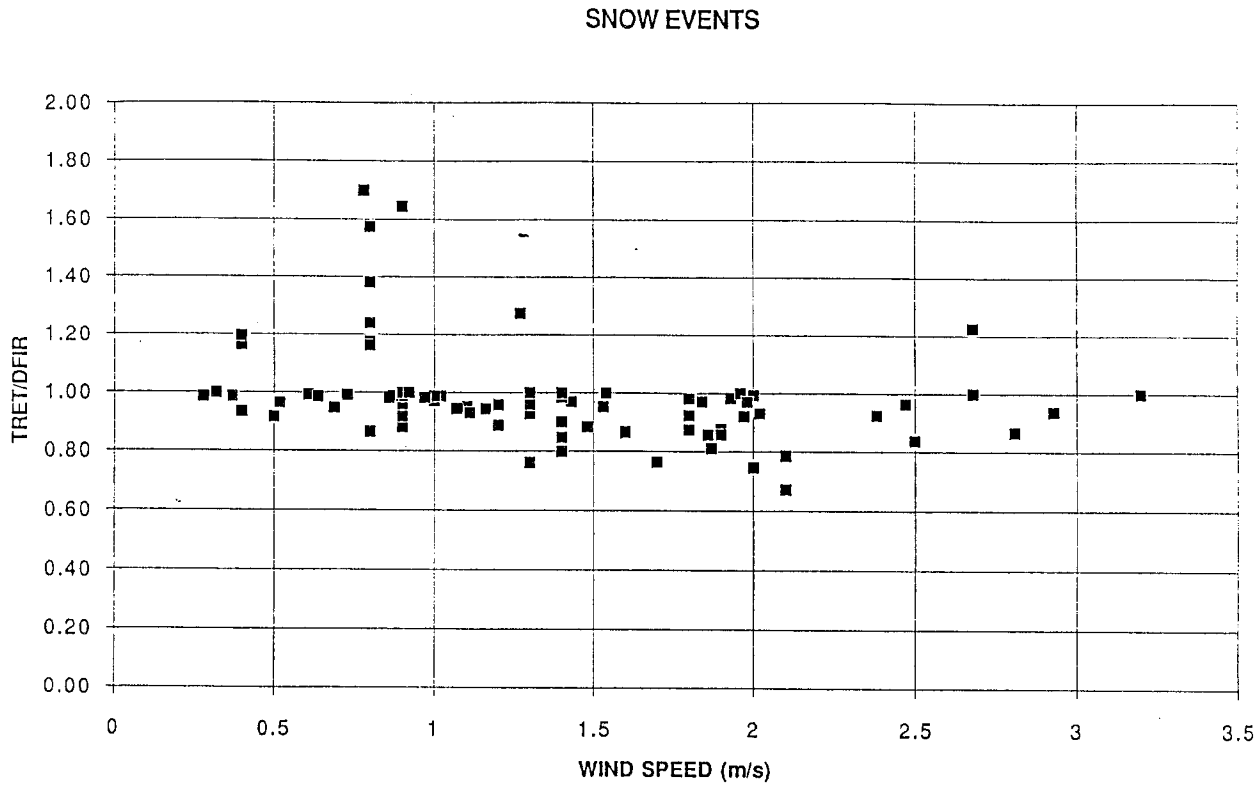


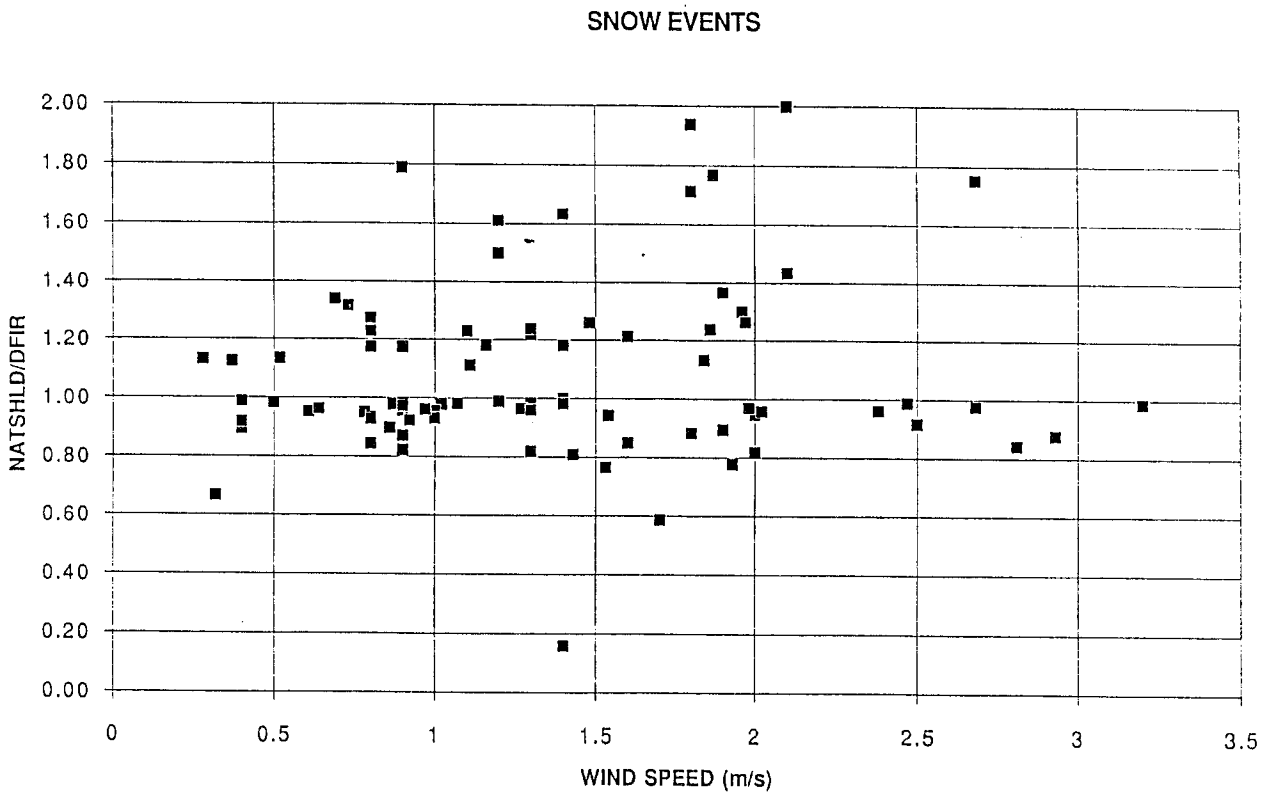
DFIR VS.BLFTAUTO

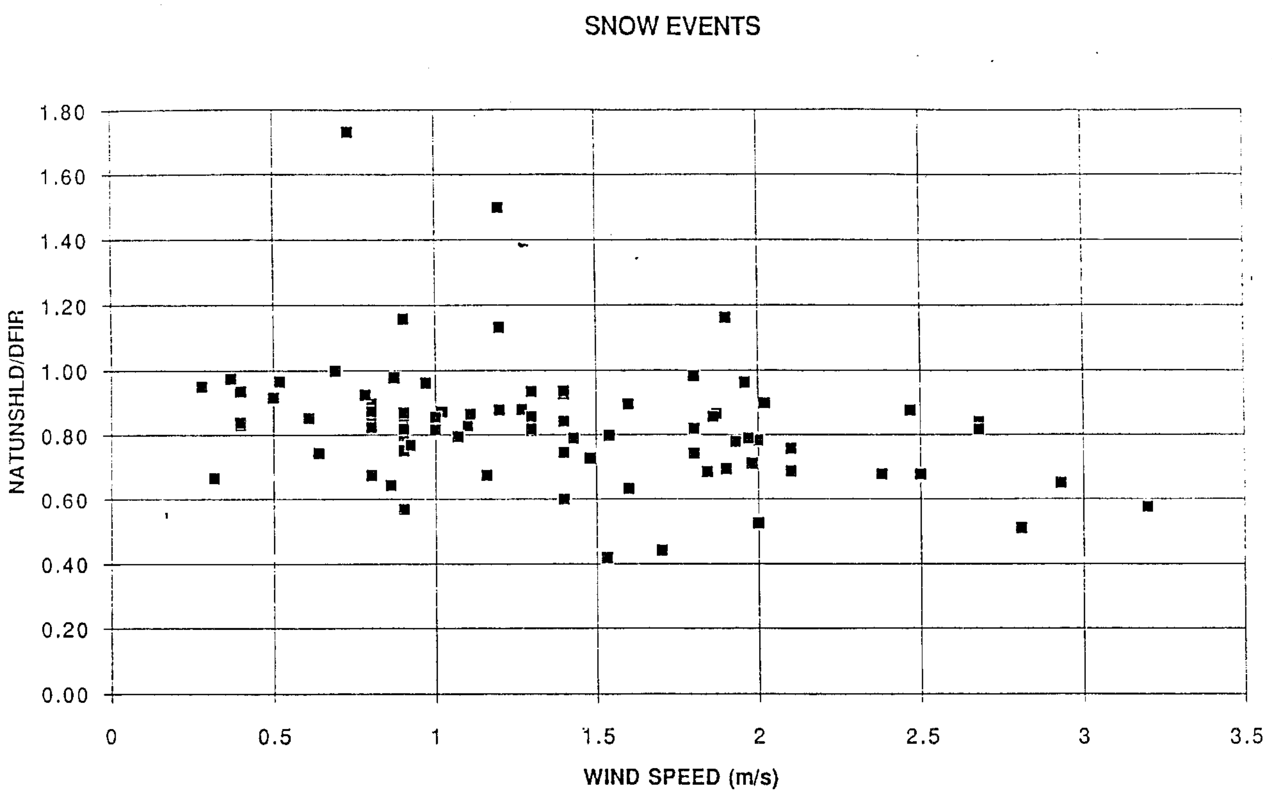


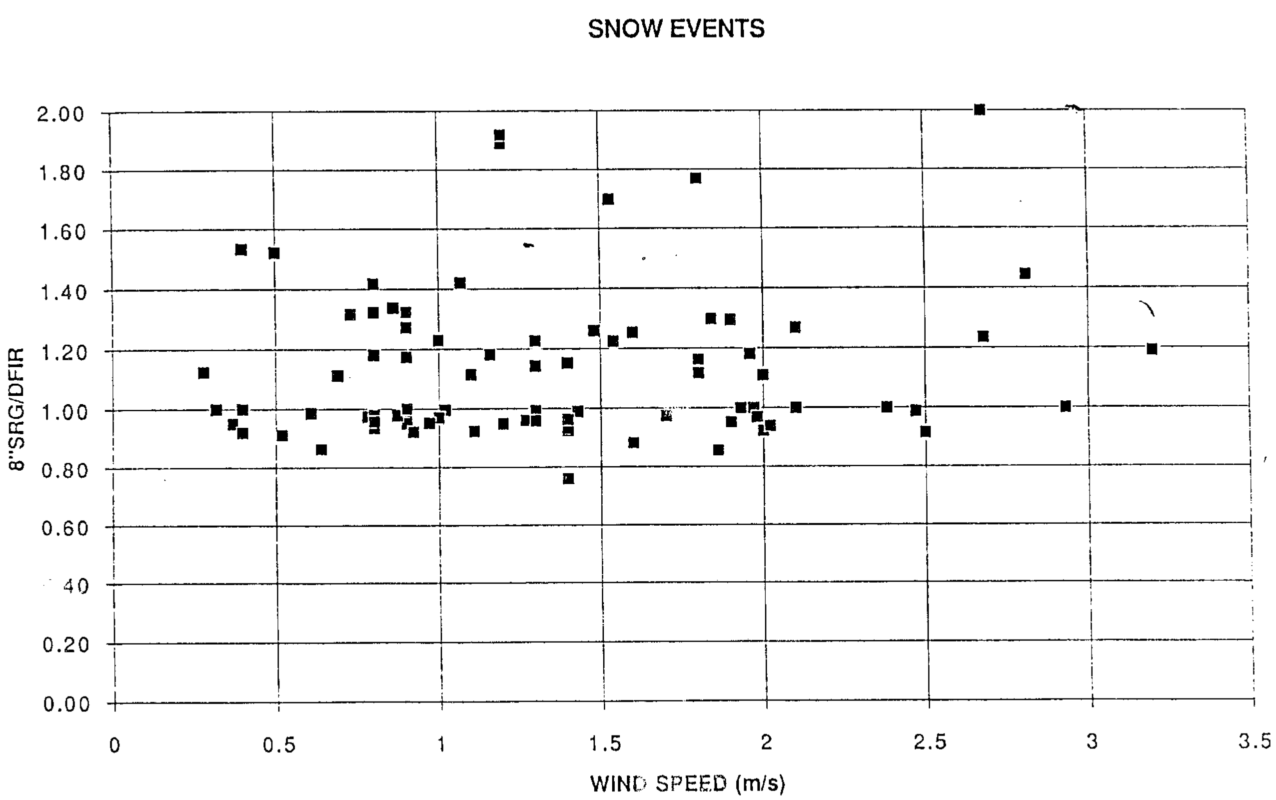

DFIR VS. BLFTTL
y = .98055x + .0415, r2 = .97562
BLFTTL(mm)
DFIR(mm)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0

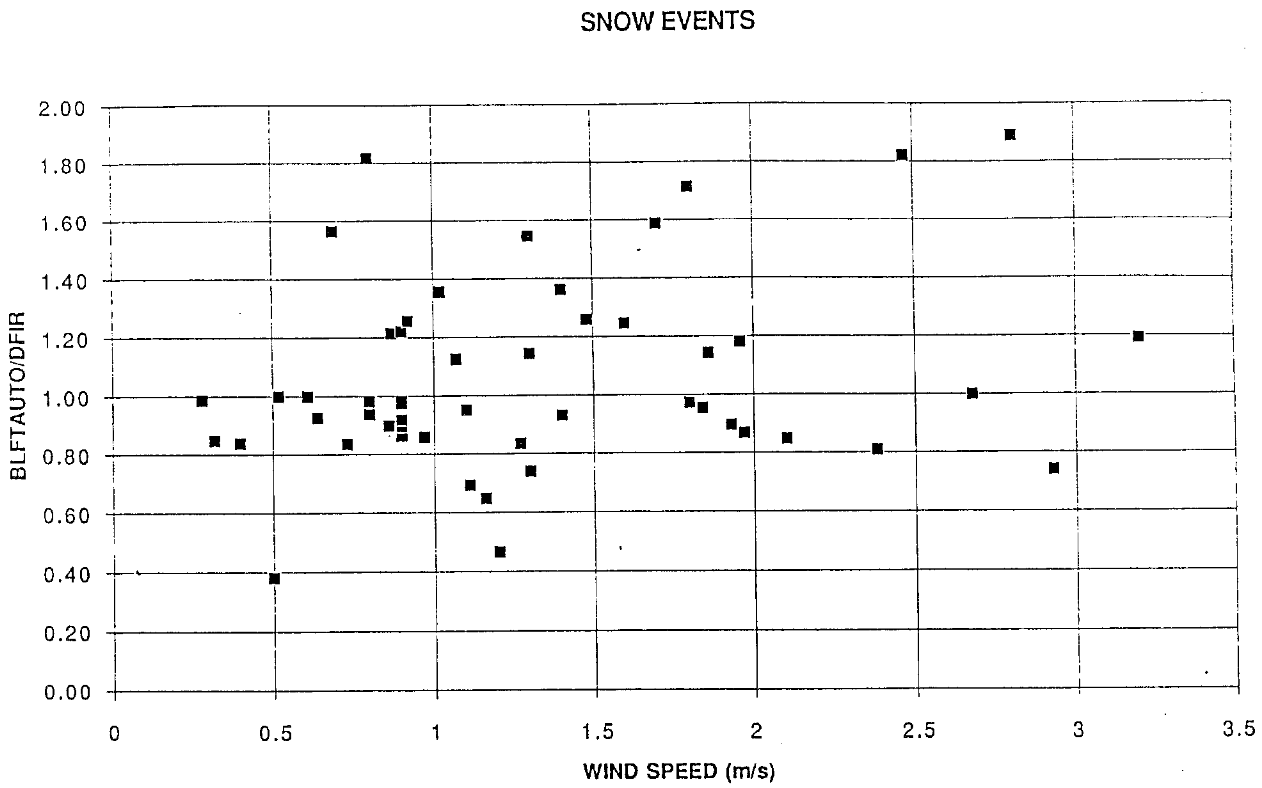

BLFTTL VS. 8"SRG
y = .99449x - .14276, r2 = .99463
BLFTTL(mm)
8"SRG(mm)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0

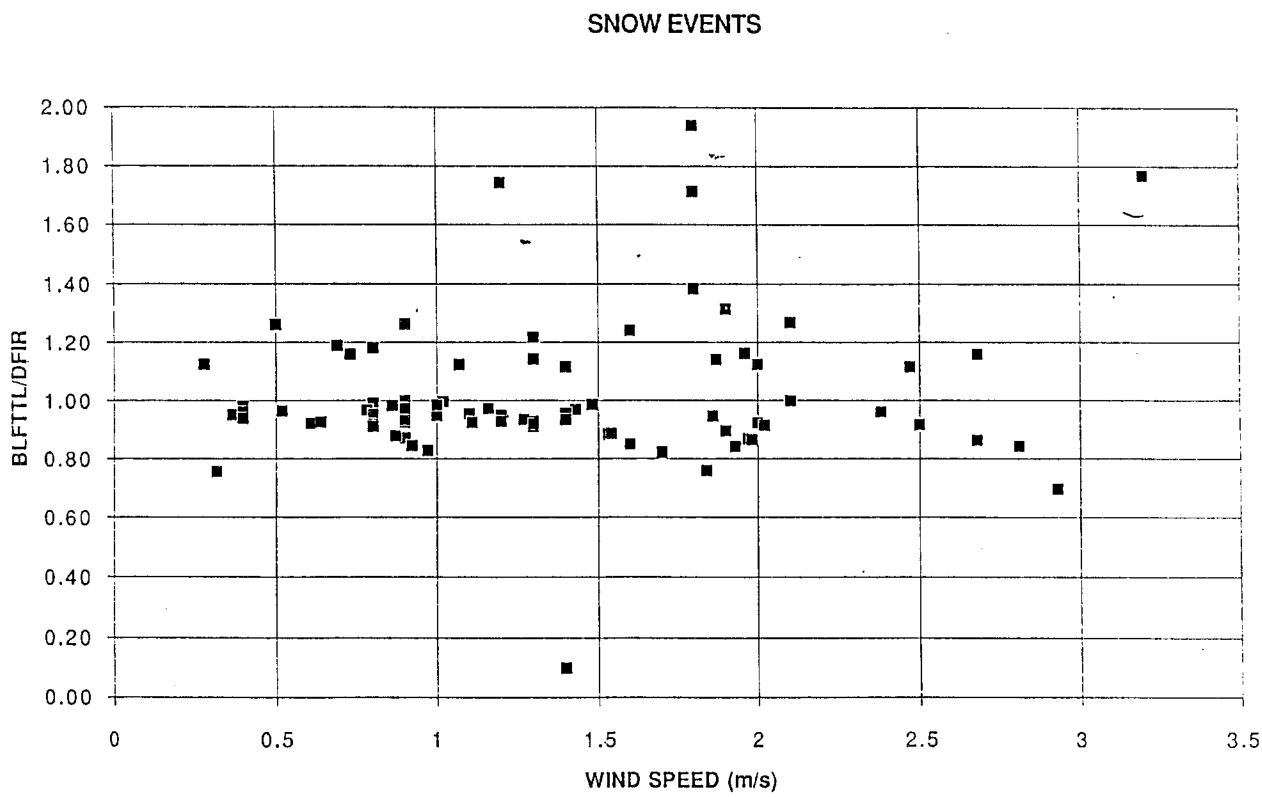

SNOW EVENTS
TRET/DFIR
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
0.5
1
1.5
2
2.5
3
3.5
WIND SPEED (m/s)


SNOW EVENTS
NATSHLD/DFIR
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
0.5
1
1.5
2
2.5
3
3.5
WIND SPEED (m/s)

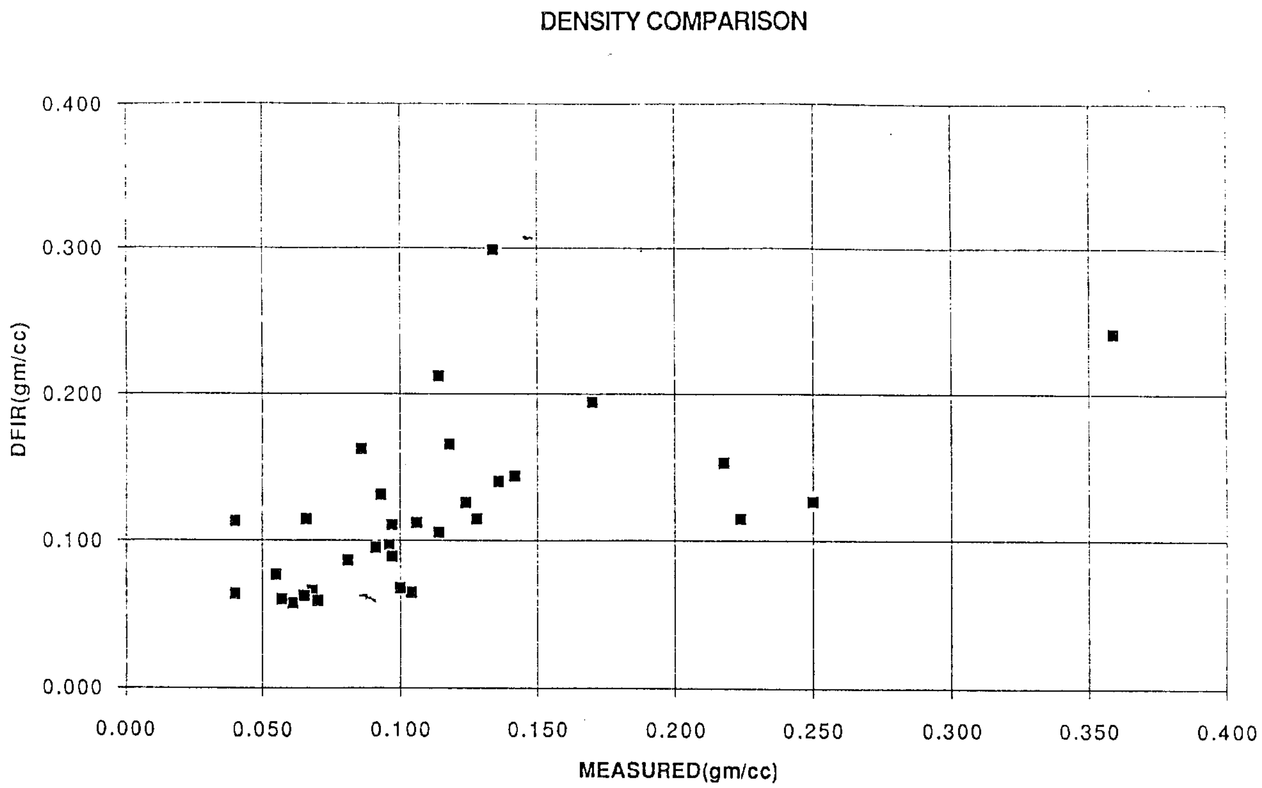

SNOW EVENTS
NATUNSHLD/DFIR
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
0.5
1
1.5
2
2.5
3
3.5
WIND SPEED (m/s)

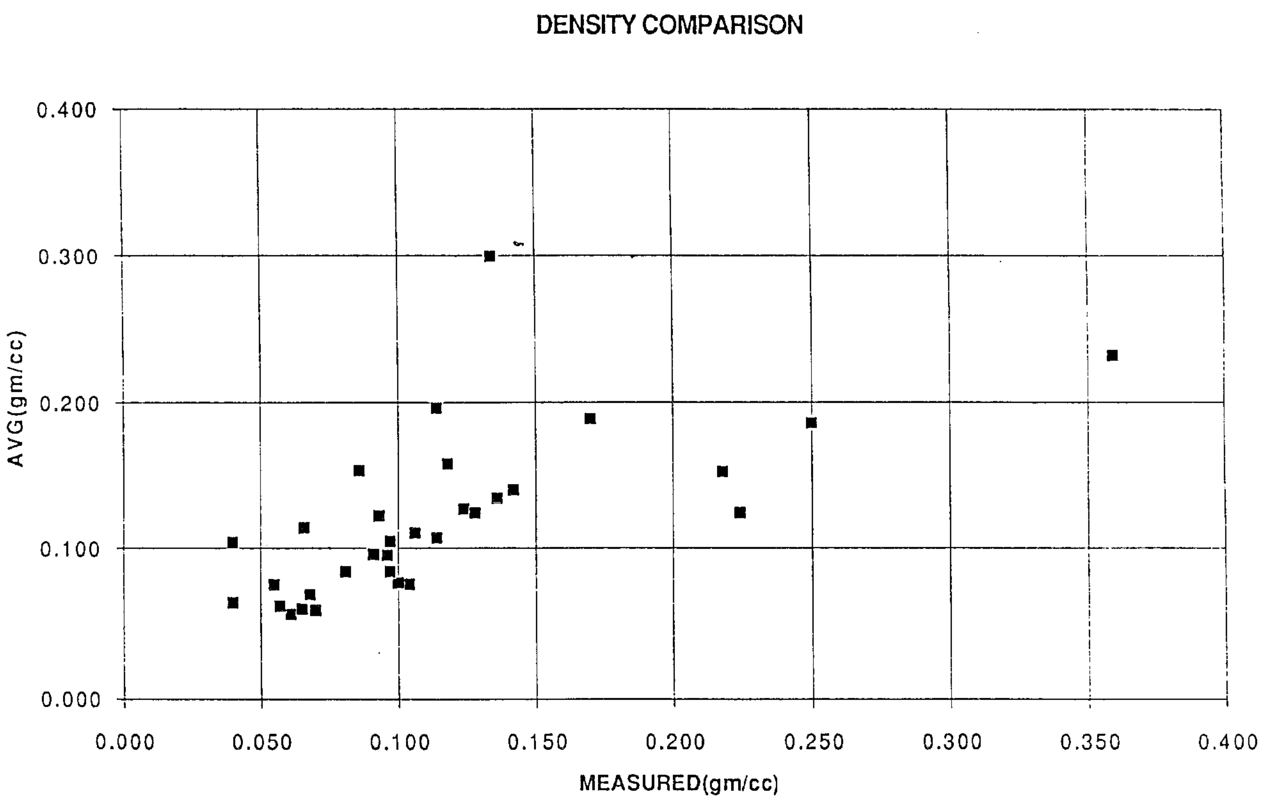

SNOW EVENTS
8"SRG/DFIR
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
40
0.20
0.00
0
0.5
1
1.5
2
2.5
3
3.5
WIND SPEED (m/s)

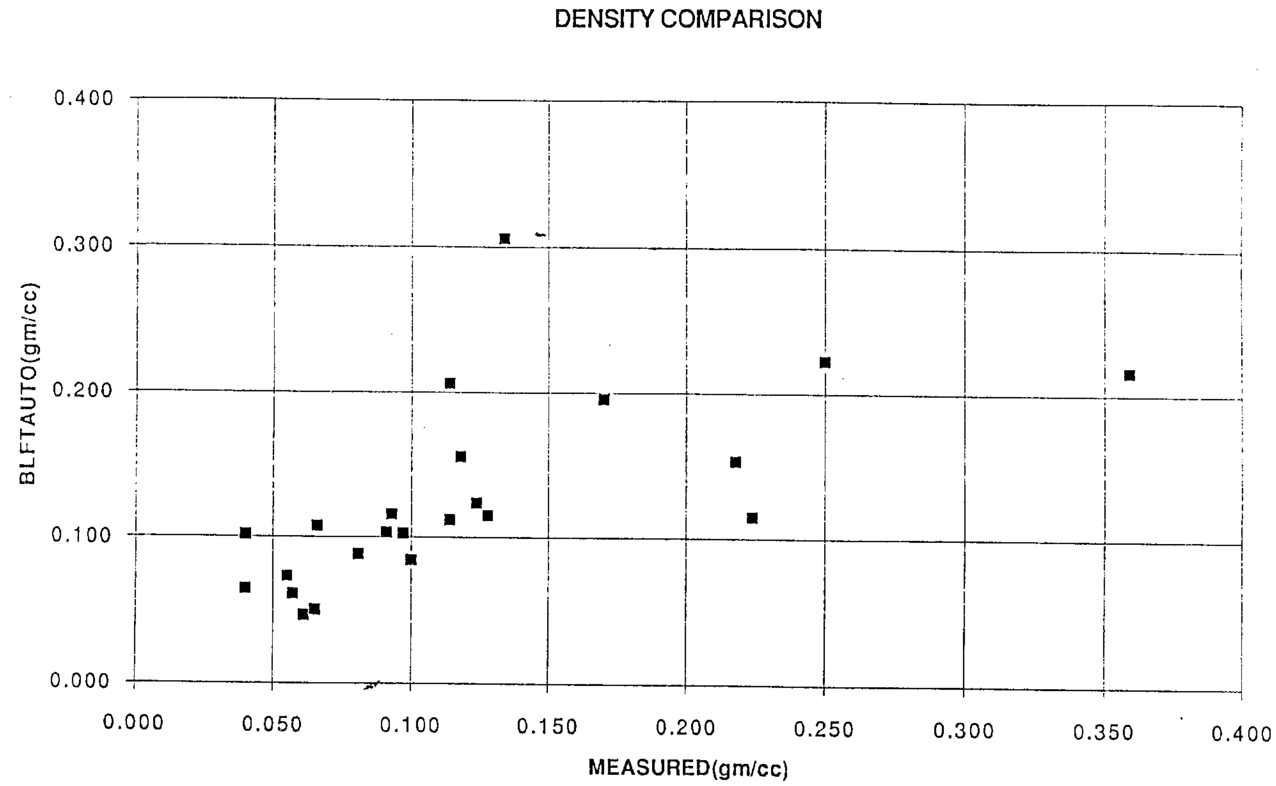

SNOW EVENTS
BLFTAUTO/DFIR
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
0.5
1
1.5
2
2.5
3
3.5
WIND SPEED (m/s)

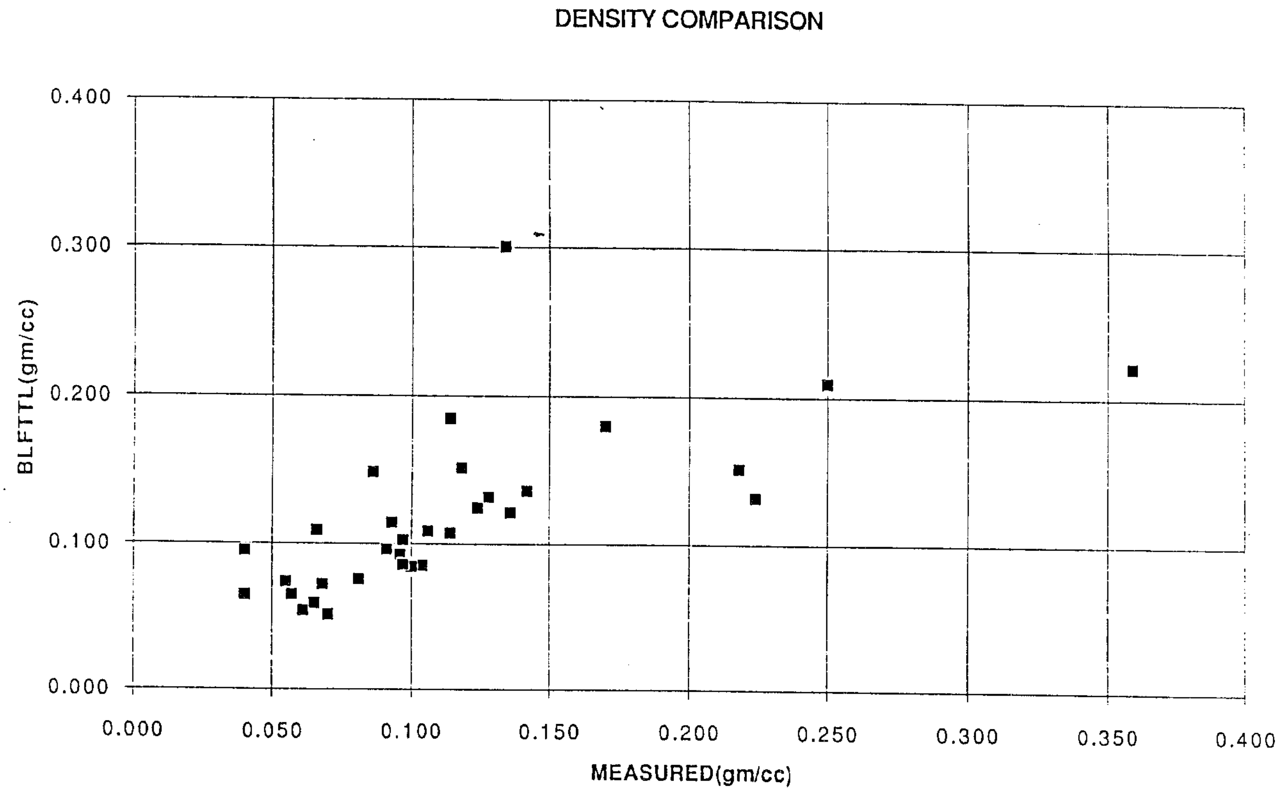

SNOW EVENTS
BLFTTL/DFIR
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
0.5
1
1.5
2
2.5
3
3.5
WIND SPEED (m/s)

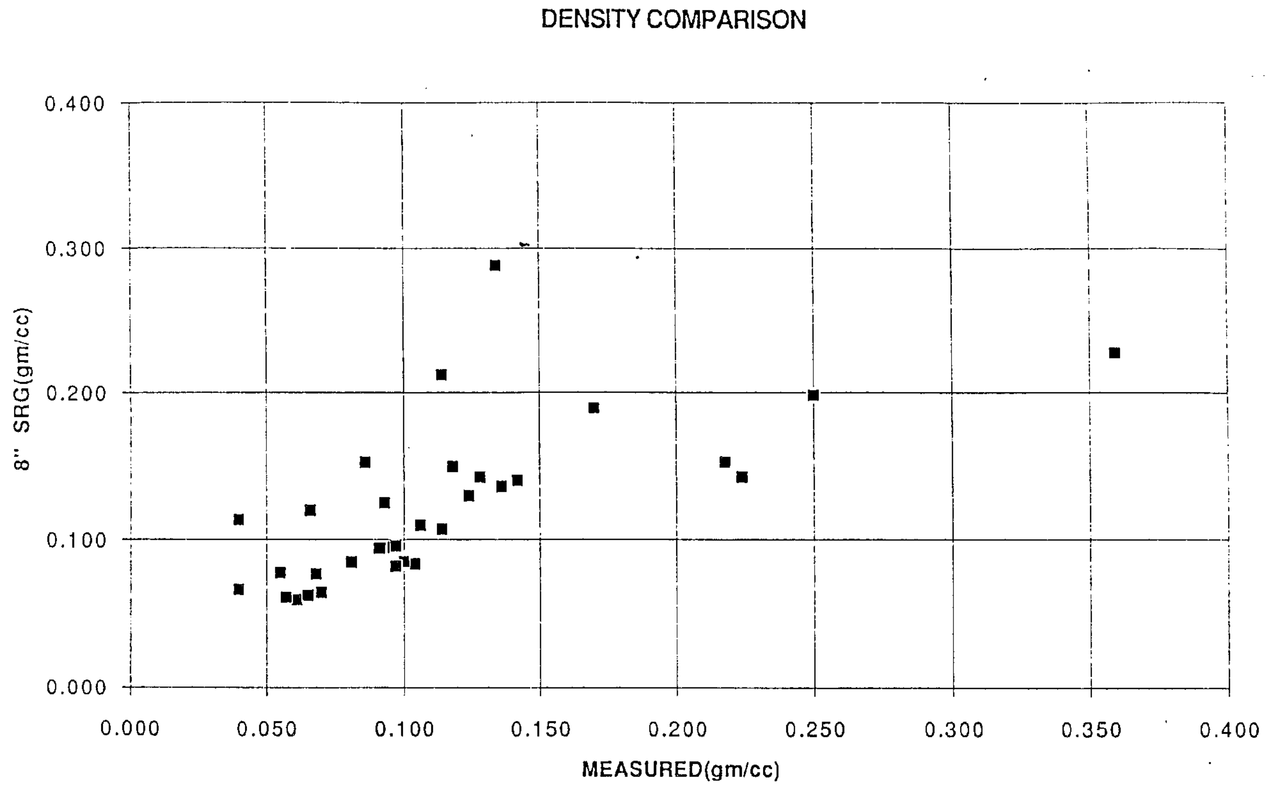
WMO Station :	Danville, Vermont, U.S.A.																		
			Snow	Precipitation Amount (mm)							DENSITY								
Year	Month	Day	New (cm)	DFIR	Tret	Nat Shld	Nat Unshld	8" SRG	BLFT AUTO	BLFT TL									
1	2	3	9	10	11	12	13	14	15	16	MEASURED	DFIR	TRET	NATSHLD	NATUNSHLD	8"SRG	BLFTAUTO	BLFTTL	AVERAGE
86-87	Jan87	12	38.6	25.1	22.0	34.3	29.2	32.5		33.0	0.104	0.065	0.057	0.089	0.076	0.084		0.085	0.076
86-87	Mar87	02	10.7	17.4	17.5	14.7	15.2	16.3		16.0	0.086	0.163	0.164	0.137	0.142	0.152		0.150	0.153
87-88	Dec87	16	22.9	26.3	26.4	26.9	22.1	27.4	24.7	25.1	0.066	0.115	0.115	0.117	0.097	0.120	0.108	0.110	0.114
87-88	Jan88	04	10.7	6.2	6.6	6.1	5.1	6.4	5.0	5.8	0.061	0.058	0.062	0.057	0.048	0.060	0.047	0.054	0.056
87-88	Jan88	26	22.6	15.4	13.3	18.5	13.8	19.3	19.2	19.1	0.100	0.068	0.059	0.082	0.061	0.085	0.085	0.085	0.077
87-88	Feb88	04	23.4	18.1	17.2	18.5	15.0	18.3	17.2	17.3	0.055	0.077	0.074	0.079	0.064	0.078	0.074	0.074	0.076
87-88	Feb88	12	14.7	21.2	20.6	20.3	17.3	20.6		20.1	0.142	0.144	0.140	0.138	0.118	0.140		0.137	[illegible]
87-88	Feb88	13	26.7	17.7	15.5	19.3	14.5	20.6		19.3	0.068	0.066	0.058	0.072	0.054	0.077		0.072	[illegible]
87-88	Feb88	22	9.4	18.3	17.0	18.0	15.0	17.8	18.4	17.0	0.170	0.195	0.181	0.191	0.160	0.189	0.196	0.181	0.189
88-89	Dec-88	15	10.4	10.1	10.2	9.7	8.4	9.9		9.7	0.096	0.097	0.098	0.093	0.081	0.095		0.093	0.095
88-89	Jan-89	26	6.9	9.7	9.4	9.4	6.9	9.4		8.4	0.136	0.141	0.136	0.136	0.100	0.136		0.122	0.134
88-89	Jan-89	27	7.4	4.4	4.5	4.3	3.6	4.8		3.8	0.070	0.059	0.061	0.058	0.049	0.065		0.051	0.059
88-89	Feb-89	21	7.9	19.1	19.2	19.1	16.8	18.0	17.1	17.5	0.359	0.242	0.243	0.242	0.213	0.228	0.216	0.222	0.232
88-89	Mar-89	21	10.7	9.3	9.2	9.1	9.1	9.1	9.5	8.1	0.081	0.087	0.086	0.085	0.085	0.085	0.089	0.076	0.085
89-90	Dec-89	26	8.1	5.1	5.2	4.6	4.1	5.1	4.1	4.8	0.065	0.063	0.064	0.057	0.051	0.063	0.051	0.059	0.059
89-90	Jan-90	12	7.4	8.2	8.1	7.9	6.1	7.1	7.6	7.6	0.097	0.111	0.109	0.107	0.082	0.096	0.103	0.103	0.105
89-90	Jan-90	30	31.5	39.7	40.4	40.1	35.6	40.9	39.0	39.4	0.124	0.126	0.128	0.127	0.113	0.130	0.124	0.125	0.127
89-90	Feb-90	15	8.6	7.7	7.2	6.9	6.4	7.1		7.4	0.097	0.090	0.084	0.080	0.074	0.083		0.086	0.084
89-90	Mar-90	21	41.7	44.2	41.9	45.7	44.2	44.7	46.7	45	0.114	0.106	0.100	0.110	0.106	0.107	0.112	0.108	0.107
90-91	Jan91	14	25.4	28.6	28.8	27.2	26.4	27.9		27.7	0.106	0.113	0.113	0.107	0.104	0.110		0.109	0.110
90-91	Jan91	31	11.2	12.7	12.5	9.9	8.9	12.7	11.4	10.7	0.040	0.113	0.112	0.088	0.079	0.113	0.102	0.096	0.104
90-91	Feb91	15	9.5	12.5	12.5	10.9	9.4	11.9	11	10.9	0.093	0.132	0.132	0.115	0.099	0.125	0.116	0.115	0.122
90-91	Feb91	25	4.8	10.2	9	8.4	5.8	10.2	9.9	8.9	0.114	0.213	0.188	0.175	0.121	0.213	0.206	0.185	0.197
90-91	Mar91	25	17	28.2	28.5	26.4	24.4	25.4	26.5	25.9	0.118	0.166	0.168	0.155	0.144	0.149	0.156	0.152	0.158
91-92	Dec91	18	8.6	5.2	5.2	5.1	3.0	5.3	5.3	5.6	0.057	0.060	0.060	0.059	0.035	0.062	0.062	0.065	0.061
91-92	Feb92	6	9.2	10.6	10.6	11.4	8.9	13.1	10.6	12.2	0.128	0.115	0.115	0.124	0.097	0.142	0.115	0.133	0.124
91-92	Feb92	17	18.3	28.0	27.7	27.4	24.4	27.9	28.1	27.9	0.218	0.153	0.151	0.150	0.133	0.152	0.154	0.152	0.152
91-92	Feb92	28	8.9	8.5	8.2	8.4	7.4	8.4	9.2	8.6	0.091	0.096	0.092	0.094	0.083	0.094	0.103	0.097	0.096
91-92	Mar92	2	25.9	16.6	15.7	16.3	13.2	17.3	16.8	16.8	0.040	0.064	0.061	0.063	0.051	0.067	0.065	0.065	0.064
91-92	Mar92	30	17.8	22.6	25.3	38.1	23.9	35.3	39.7	37.3	0.250	0.127	0.142	0.214	0.134	0.198	0.223	0.210	0.186
91-92	Apr92	13	11.9	35.6	36.0	35.8	35.6	34.3	36.4	35.8	0.134	0.299	0.303	0.301	0.299	0.288	0.306	0.301	0.300
										AVG.=	[illegible]	0.120	0.118	0.120	0.102	0.123	0.127	0.119	0.121

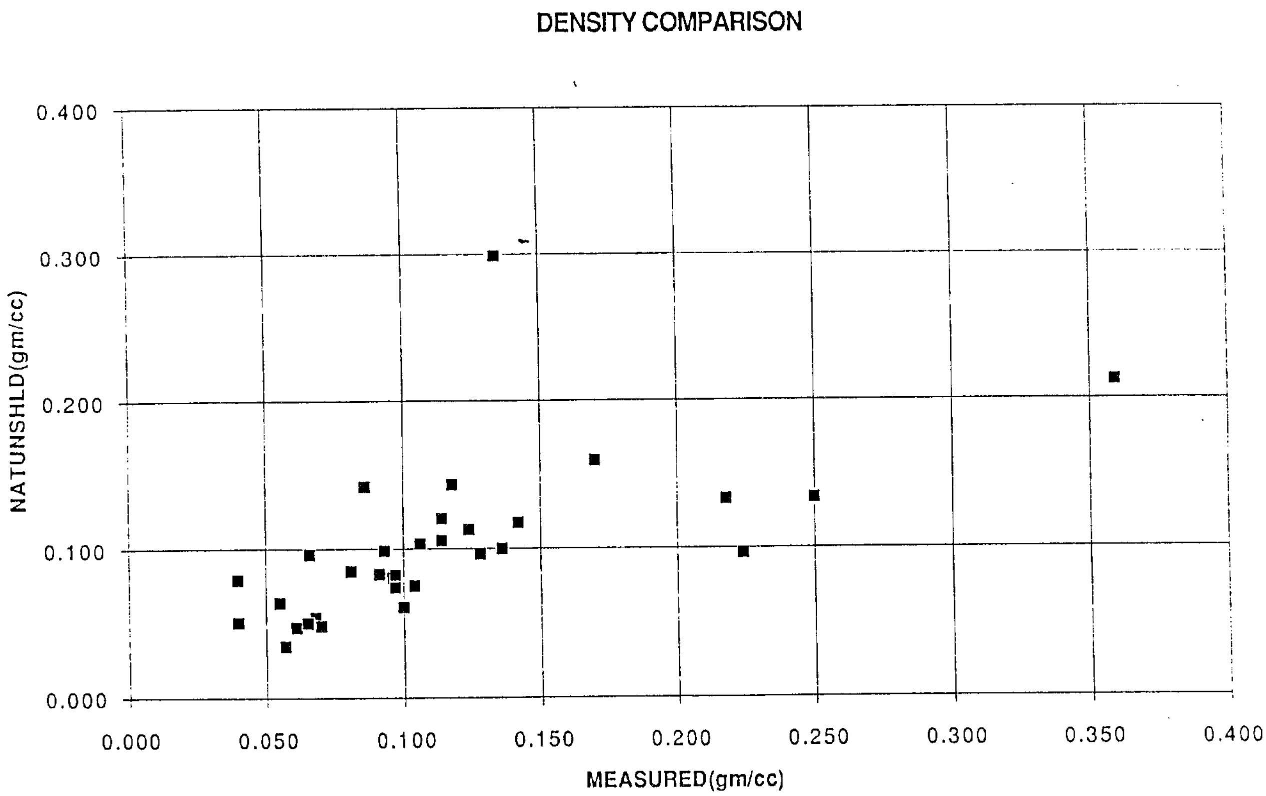

DENSITY COMPARISON
0.400
0.300
0.200
0.100
0.000
DFIR(gm/cc)
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
MEASURED(gm/cc)

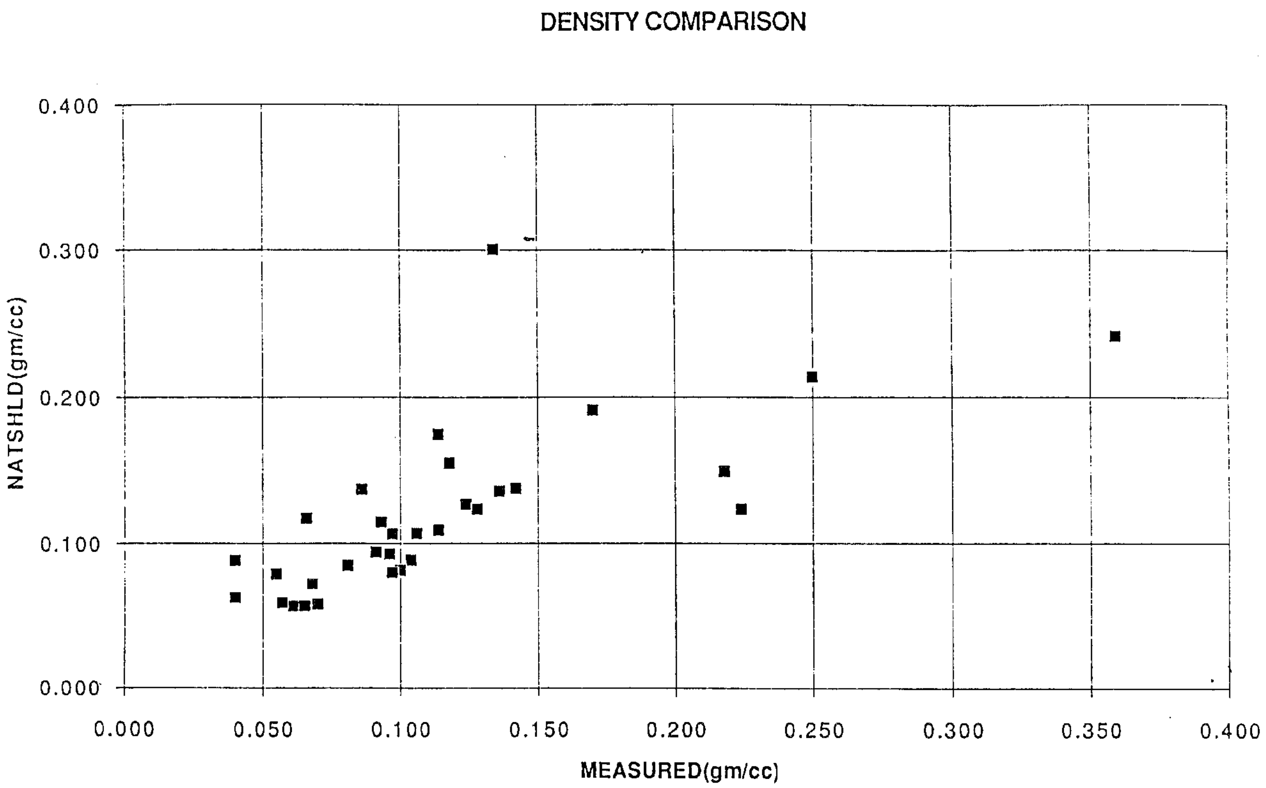

DENSITY COMPARISON
0.400
0.300
0.200
0.100
0.000
AVG(gm/cc)
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
MEASURED(gm/cc)

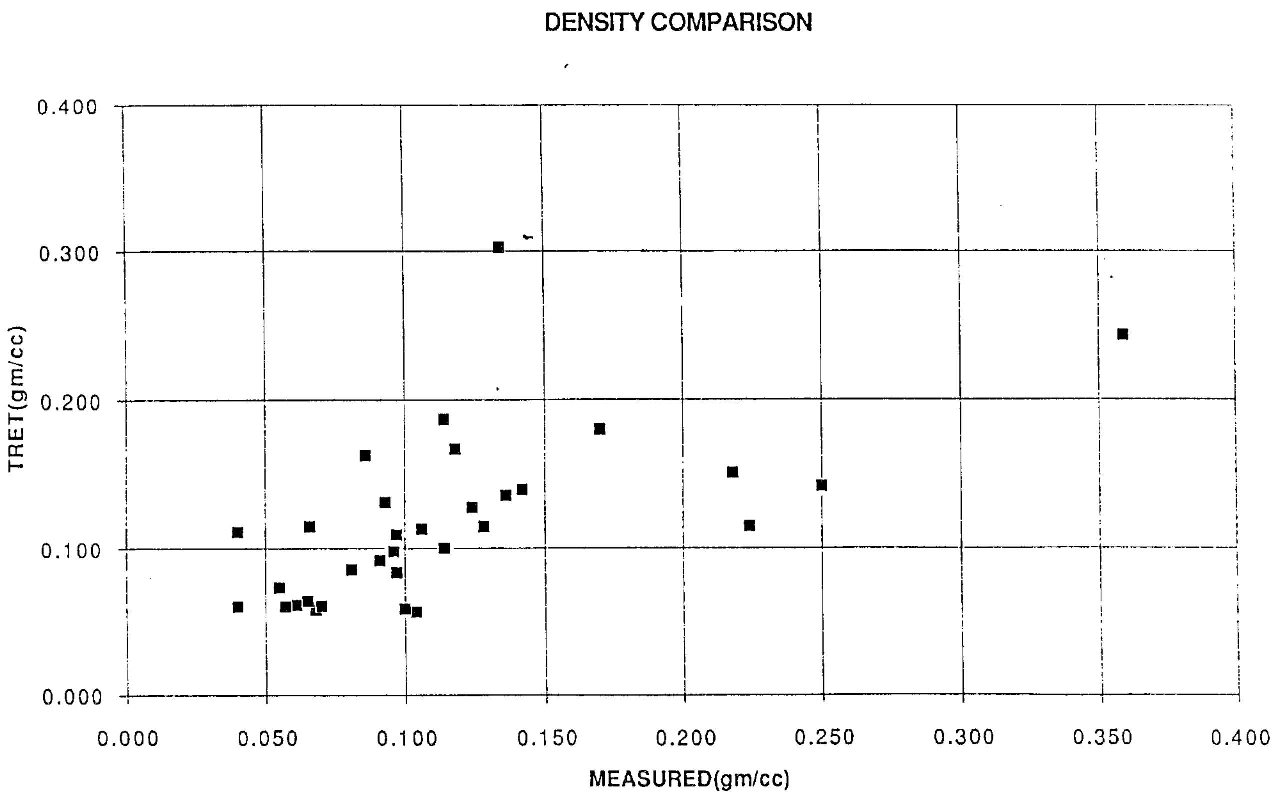

DENSITY COMPARISON
0.400
0.300
0.200
0.100
0.000
BLFTAUTO(gm/cc)
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
MEASURED(gm/cc)


DENSITY COMPARISON
0.400
0.300
0.200
0.100
0.000
BLFTTL(gm/cc)
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
MEASURED(gm/cc)


DENSITY COMPARISON
0.400
0.300
0.200
0.100
0.000
8" SRG(gm/cc)
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
MEASURED(gm/cc)


DENSITY COMPARISON
0.400
0.300
0.200
0.100
0.000
NATUNSHLD(gm/cc)
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
MEASURED(gm/cc)


DENSITY COMPARISON
0.400
0.300
0.200
0.100
0.000
NATSHLD(gm/cc)
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
MEASURED(gm/cc)


DENSITY COMPARISON
0.400
0.300
0.200
0.100
0.000
TRET(gm/cc)
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
MEASURED(gm/cc)

REVIEW OF THE INTERCOMPARISON AT VALDAI, RUSSIAN FEDERATION

Nov

TABLE 1

MONTHLY PRECIPITATION (RAIN AND SNOW) TOTALS (mm) MEASURED BY DIFFERENT GAUGES AT VALDAI, RUSSIA, 1991-1992

Gauge type	1991 Sept.	Oct.	Nov.	Dec.	1992 Jan.	Feb.	March	April	May	Total%	Nov. Mar
Tret.in bushes	41.4	28.9	62.6	85.6	137.1	44.3	37.8 367.8	70.9	59.1	100	100
DFIR (Tret.)	40.1	28.0	56.8	79.1	122.9	43.3	36.9 339	68.2	56.8	94	92
DFIR (Can.N)	39.2	27.8	58.2	77.3	124.5	45.7	36.7 342.4	68.2	55.4	94	93
Can. N	38.9	27.7	55.6	72.7	109.1	42.0	34.9 314.3	63.0	54.8	88	86
Tret.	39.1	28.0	45.5	53.5	95.3	31.1	32.9 258.3	59.1	55.3	78	70
$" USA sh	37.3	24.4	48.9	60.4	99.1	34.2	31.2 273.8	58.5	52.5	79	75
$" USA unsh	35.3	23.0	38.4	40.4	80.2	21.9	26.9 207.8	48.9	49.0	64	57

TABLE 2

CATCH RATIO

Gauge type	t°/C -15.1••-10.0	t°/C -10.0••-2.0	t°/C -2.0••2.0	t°/C 2.0••10.0	t°/C 10.0••21.7
Tret.in bushes (mm)	5.6	98.3	249.7	165.1	43.1
DFIR (Tret.) (% to bushes)	105	97	94	98	101
DFIR (Can.N) (% to bushes)	120	97	92	97	98
Can.N (% to bushes)	104	74	88	95	98
Tret. (% to bushes)	73	58	73	93	97
$" USA shielded (% to bushes)	66	62	79	88	92
$" USA unsh. (% to bushes)	30	36	63	80	89

TABLE 3

CATCH RATIO

	t°/C -10.0 .... -2.0			t°/C -2.0 .... 2.0			t°/C 2.0 .... 10.0		
	U_2 <2	U_2 2.0••4.9	U_2 ≥5.0	U_2 <2	U_2 2.0••4.9	U_2 ≥5.0	U_2 <2	U_2 2.0••4.9	U_2 ≥5.0
Tret. in bushes (mm)	0.4	82.2	15.7	8.6	152.2	86.7	4.1	138.0	29.1
DFIR (Tret.) (% to bushes)	-	97	98	98	94	93	83	95	94
DFIR (Can.N)	-	97	98	105	94	88	83	95	88
Can.N, %	-	72	83	102	90	84	88	93	87
Tret. %	-	58	56	97	83	65	88	92	82
$" USA sh (%)	-	61	66	94	80	73	80	86	83
$" USA unsh (%)	-	36	34	85	63	59	73	78	70

TABLE 4

ESTIMATION OF CHARACTERISTICS FOR ACCURACY DFIR

Characteristic	BKC	Formula for correction: Yang/ Goodison's	Golubev's f(P, U)	Golubev's f(P,U,t)	Golubev's total
N	100.00	100.00	100.00	100.00	100.00
Pi min, mm	0.33	0.34	0.35	0.35	0.35
Pi max, mm	13.90	13.40	13.61	13.69	13.62
Pi avg, mm	4.41	4.38	4.53	4.56	4.54
std, mm	3.11	3.12	3.31	3.33	3.31
r		0.976	0.97	0.97	0.969
Qi, mm		-0.03	0.12	0.15	0.13
di, mm	0.12	0.68	0.81	0.83	0.81
Qi/di		0.04	0.15	0.18	0.16
Qi/D		0.24	1.06	1.25	1.08
di/D		5.79	6.91	7.10	6.93
Qi/F, %		-0.64	2.82	3.32	2.89
di/P, %	2.66	15.42	18.41	18.92	18.46
di/STD	0.04	0.22	0.26	0.27	0.26

TABLE 5

AVERAGE LAYERS (P) AND SPATIAL VARIABILITY (δa) OF MONTHLY AND ANNUAL SUMS OF ATMOSPHERIC PRECIPITATION ON A TERRITORY OF OPEN AND PROTECT SITES OF PRECIPITATION POLYGON IN VALDAI

Month/ Year	Open site: Average layer P /mm	Open site: Variability δa /mm	%	Protected site: Average layer P /mm	Protected site: Variability δa /mm	%
January	21	1.1	5	37	1.5	4
February	25	1.1	5	39	1.5	4
March	28	0.9	3	40	2.1	5
April	36	0.7	2	44	2.7	6
May	40	0.8	2	46	0.7	2
June	86	0.9	1	90	0.8	1
July	78	1.1	1	84	0.5	1
August	52	0.7	1	56	0,8	1
September	62	0.8	1	68	0.7	1
October	69	0.9	1	79	1.4	2
November	63	1.2	2	84	2.6	3
December	38	1.6	5	58	1.7	3
Year	598	4.8	1	724	12.5	2

TABLE 6

AVERAGE LAYERS (P AND P) AND SPATIAL VARIABILITY (δa) OF HARD ATMOSPHERIC PRECIPITATIONS ON A TERRITORY OF OPEN AND PROTECT SITES OF PRECIPITATION POLYGON IN VALDAI

Range of precipitation sums(P/mm) for 12 h intervals: From	To	Open site: Average layer P /mm	Open site: Variability δa /mm	%	Protected site: Average layer P /mm	Protected site: Variability δa /mm	%
	<1.0	0.5	0.2	39	0.6	0.1	22
1.0	1.9	1.5	0.3	17	1.4	0.2	13
2.0	2.9	2.5	0.4	18	2.4	0.1	6
3.0	4.9	3.8	0.4	10	3.9	0.2	5
>5.0		6.4	0.6	9	7.7	0.3	4

20 August 1992

A REVIEW OF THE INTERCOMPARISON AT JOKIOINEN, FINLAND

Finnish report presented at the Sixth Session of the International Organizing Committee for the WMO Solid Precipitation Measurement Intercomparison, Toronto 14.-18. September 1992

1 PRECIPITATION GAUGES

Measurement started on the 1st of February 1987 with the following gauges (Fig. 1):

No. of gauge in the field

1	Tretyakov with a wind shield
2	Tretyakov without a wind shield
7	Wild without a wind shield
9	Tretyakov with a wind shield
11	Swedish gauge (SMHI)
13	Tretyakov with a wind shield
14	Wild with a Nipher wind shield
16	Tretyakov with a wind shield in a Valdai double fence

Later on measurements were started with the following gauges:

15	Danish Hellman	6th February 1987
8	Norwegian	7th April 1987
12	Geonor	26th August 1987
18	Geonor in a double fence	26th August 1987
4	Friedrich´s tipping bucket (a heated gauge from Sweden)	19th January 1988
10	Finnish prototype	1st February 1988
6	Hungarian Hellman	1st May 1988
19	Danish tipping bucket (a heated gauge Rain-o-matic-H)	21th February 1988 - 6th March 1990
	RIMCO (a heated tipping bucket from Denmark)	6th March 1990
20	Canadian gauge with a Nipher wind shield	23th February 1989
5	Wilska	1st January 1989
21	BT-60	8th February 1990
22	Tretyakov H & H -90	1st March 1991
23	FD 12P weather sensor	9th April 1992

The gauges in operation only during the summer (May - September) were as follows:

3	Tipping bucket	26th August 1987
17	Pit gauge	12th May 1987

2. PRECIPITATION SUMS FOR OCTOBER 1991 - APRIL 1992

During the measuring period 1st October 1991-30th April 1992 there were 55 snowfall cases, 44 rain and snow cases and in all 180 precipitation cases measured in 12 h intervals. The lowest catching ratios of the different gauges were for snowfall 30-50 % and the highest ones 70-80 % compared with the reference gauge 16 (Tretyakov in DFIR). (Table 1.).

3. WETTING LOSS AND EVAPORATION FROM THE GAUGES

Wetting loss was determined in May - July 1992 with 9 different gauge-types making 30 measurements with a water amount of 0.5, 5 and 10 mm. The same procedure has been used in the previous determinations in 1987 and in 1989 (Huovila et al. 1988). Wetting losses seemed to be almost independent of the water amount used in the tests (Figure 2.). Mean values of wetting losses were 0.1-0.2 mm. An application of these values to individual precipitation measurements does not agree on the weighted sums for all type of gauges (Table 2.).

Wetting loss for the whole winter period 1991-1992 varied from 2.7. to 9.4 % when calculated from the difference between the weighing & volymetric measurement of precipitation.

Evaporation measurements were made with 6 types of gauges using a digital balance. 2-3 cm snow was put into the vessels in the morning and evaporation was calculated as lost weight of the vessel if no precipitation occurred during the day. In summer 2-3 mm of water was used in each vessel.

Evaporation was as high as 1 mm even in April when some gauges does not have a funnel. During summer evaporation with funnel was at the highest about 1 mm (Figure 3.).

4. AUTOMATED MEASUREMENTS

On the 9th April 1992 a weather sensor FD 12P was installed on the intercomparison field (Figure 1.) The same kind of instrument has been already tested at Helsinki Airport weather station over one year. The results has been very promising.

5. OTHER PROCEDURES

5.1. Calibration of anemometers

The cup anemometers has been calibrated and maintained once a year. The latest calibration period was in July-August 1992. The sensors were calibrated in two different phases (8 + 8 sensors). The starting threshold speed of the anemometer W16 was as high as 3.6 m/s and in all for 20 % of the anemometers it was higher than 1 m/s.

After maintaining the anemometers it was typically 0.3-0.5 m/s (Table 3).

5.2. Instrumentation of the third mast

The instrumentation of the 26 m high mast has been started. Anemometers have been installed at the levels of 2, 4, 10 and 27 m.

Table 1. Precipitation sums for October 1991-April 1992. Orifice area corrected values, mm and % of the gauge 16. I snow fall cases (n=55) II Rain and snow cases (n=44) III All cases (n=180) (12 h measuring interval) a) by weighing b) volymetric.

No	9 Tret	8 Nor	7 Wild	6 Hun	5 Wilska	2 Tret	1 Tret	16 Tret	11 SMHI	20 Can	13 Tret	21 BT-60	14 Wild	15 Dan	22 HeH-90
I a) mm	115.7	100.7	53.7	65.8	75.4	74.0	120.4	157.0	106.3	128.2	117.0	90.9	87.1	69.7	119.7
%	74	64	34	42	48	47	77	100	68	82	75	58	55	44	76
b) mm	109.3	97.7	50.4	61.0	72.9	68.1	113.3	152.5	103.7	122.5	109.7	85.9	86.1	63.1	117.0
%	72	64	33	40	48	45	74	100	68	80	72	56	56	41	77
II a) mm	90.4	84.9	74.5	80.5	77.2	79.3	94.6	107.6	92.3	96.7	94.1	83.5	80.7	76.7	97.8
	84	79	69	75	72	74	88	100	86	90	87	78	80	71	91
b) mm	83.3	79.6	71.2	74.4	71.3	71.9	86.7	101.1	88.5	90.0	86.9	77.8	78.5	69.1	92.2
%	82	79	70	74	71	71	86	100	88	89	86	77	78	68	91
III a) mm	338.9	314.5	256.9	280.5	277.0	280.2	352.3	408.9	334.2	355.7	347.0	304.5	298.2	273.4	357.2
%	83	77	63	69	68	69	86	100	82	87	85	74	73	67	87
b) mm	314.4	293.8	242.9	258.3	257.9	253.8	323.2	385.9	320.4	330.6	318.8	282.8	290.2	246.5	337.5
%	81	76	63	67	67	66	84	100	83	86	83	73	75	64	87
$\frac{(a-b)}{a}$ * 100%	7.2	6.6	5.4	7.9	6.9	9.4	8.3	5.6	4.1	7.1	8.1	7.1	2.7	9.8	5.5

Table 2. Comparison of the differences a-b from the table 1 and the sum of wetting loss for 180 cases of different types of gauges (c), (the mean wetting loss values have been used).

	8	7	6	1	11	20	15	22
a-b mm	20.7	14.0.	22.2	29.1	13.8	25.1	26.9	19.7
c mm	46.8	16.2	21.6	45.0	34.2	54.0	23.4	41.4

Table 3. The starting threshold speed of the anemometers of the Jokioinen intercomparison field before (a) and after (b) maintaining them (m/s).

no	a	b
W16	3.6	0.3
W1	0.3	0.3
W14	0.4	0.3
W11	2.4	0.3
W12	0.3	0.3
W7	1.9	0.3
W13	0.5	0.5
W15	0.4	0.6
W2	0.3	0.3
W5	0.4	0.3
W3	0.5	0.4
W9	0.5	0.4
W4	0.3	0.3
W8	0.4	0.3
W6	0.3	0.3
W10	0.6	0.3

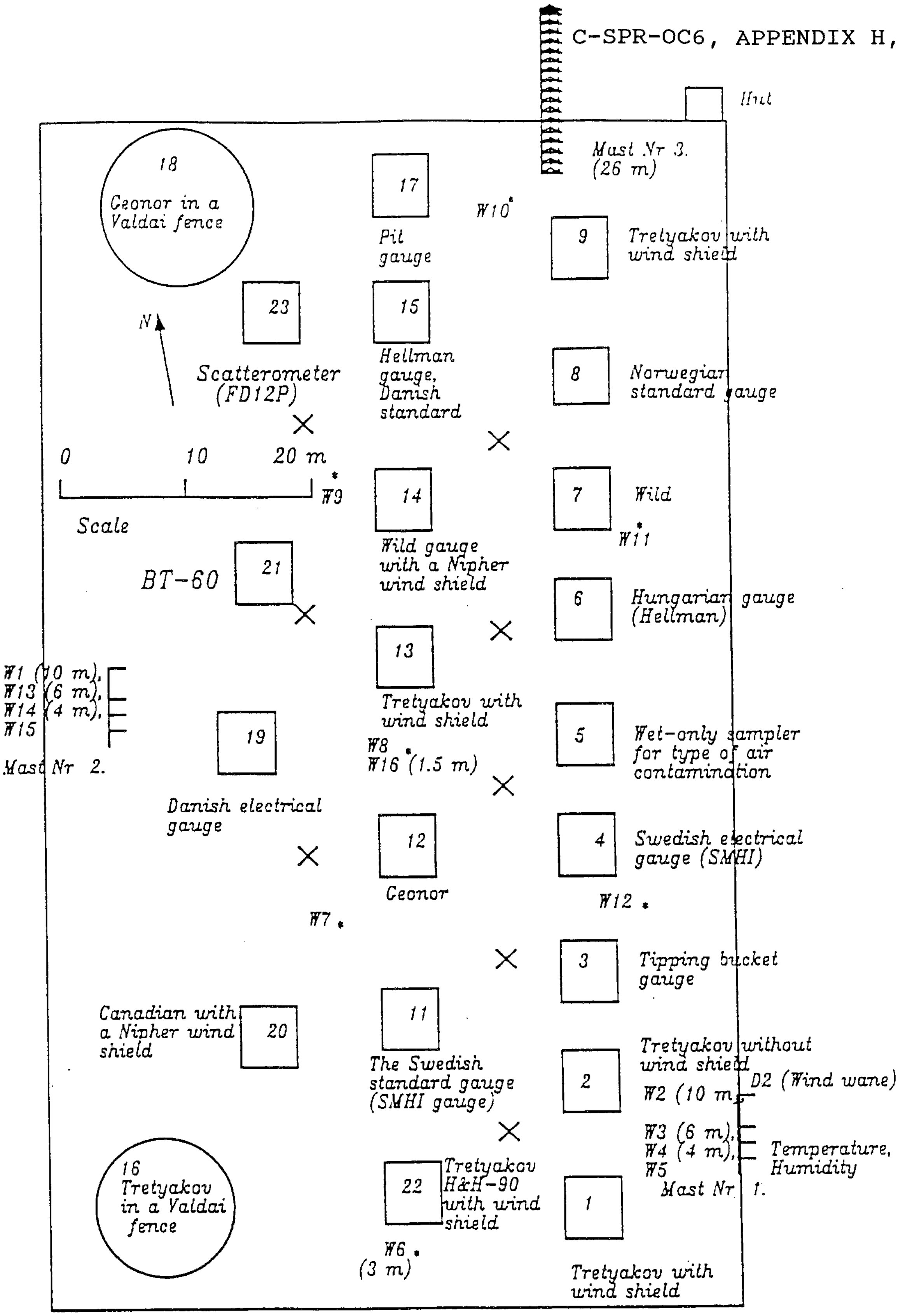


Figure 1. Location of the gauges on the Jokioinen solid precipitation intercomparison field on 9th April 1992. Snow gauges 1...22, anemometers W1...W16. Anemometers are at 2 m height if not explicitly shown. Snow stakes represented by x.

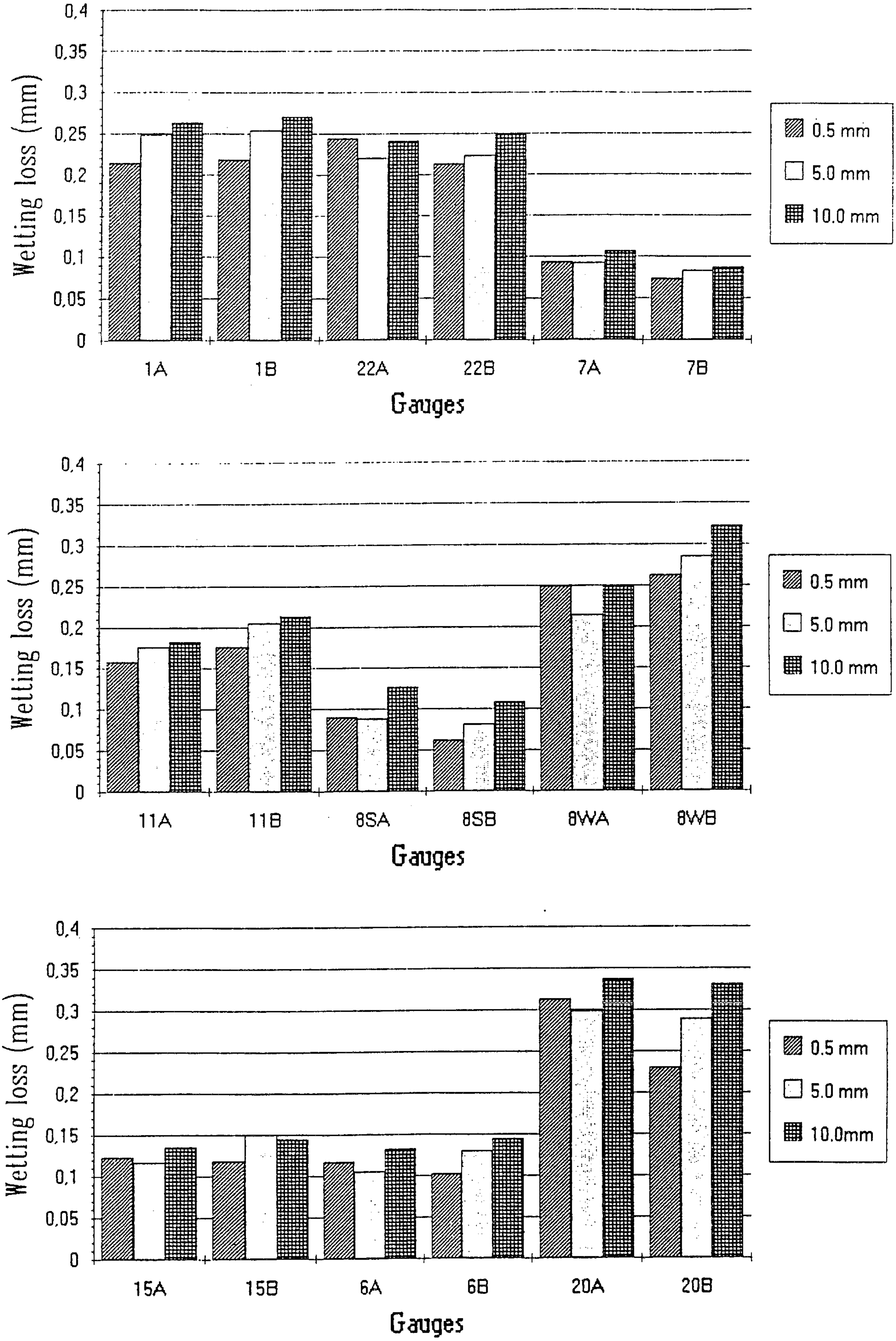
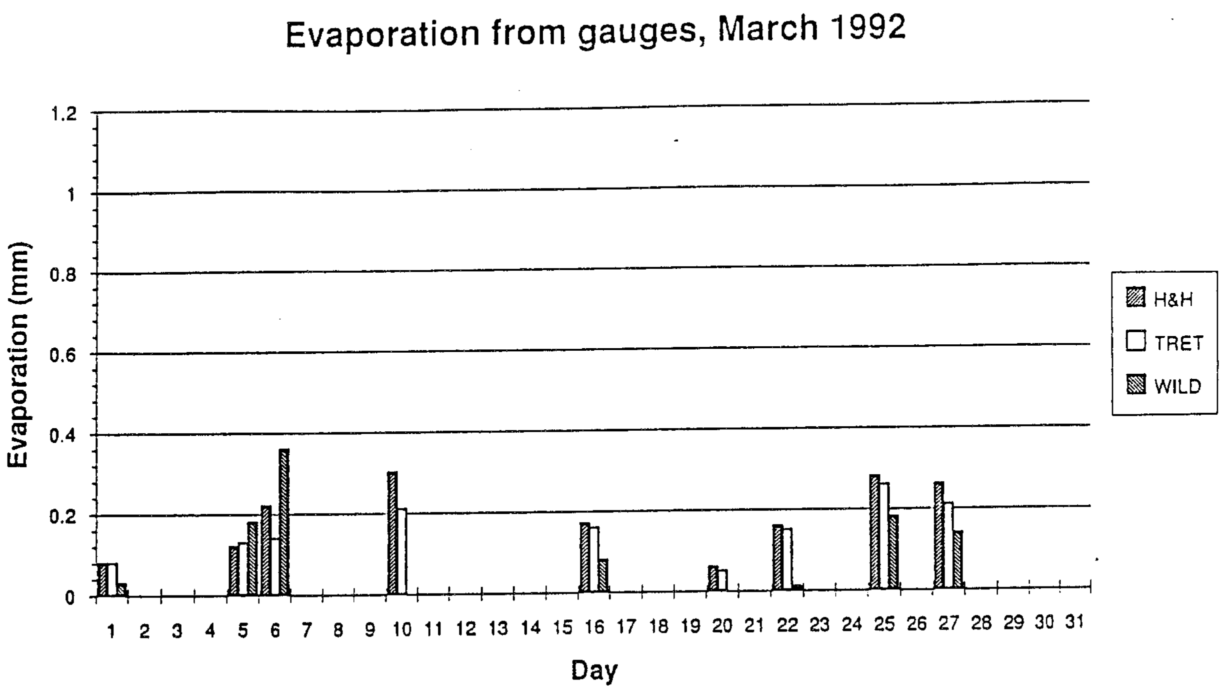
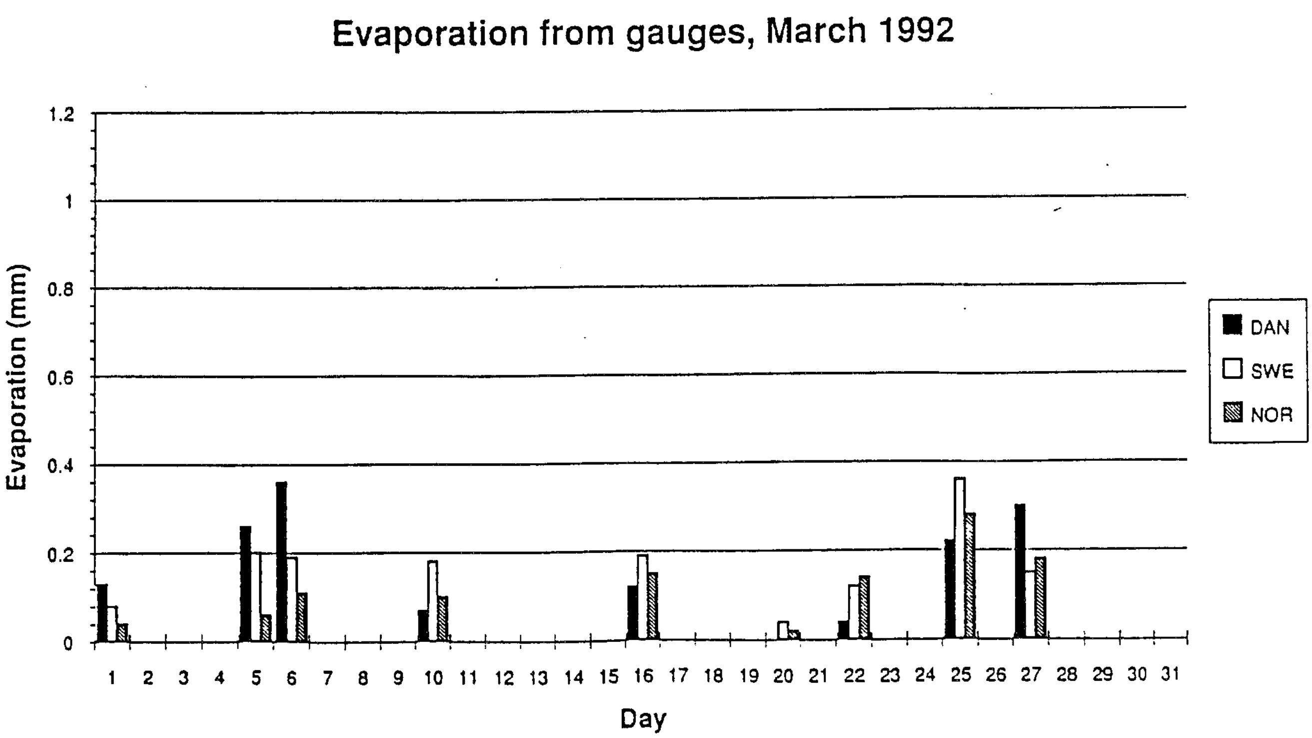
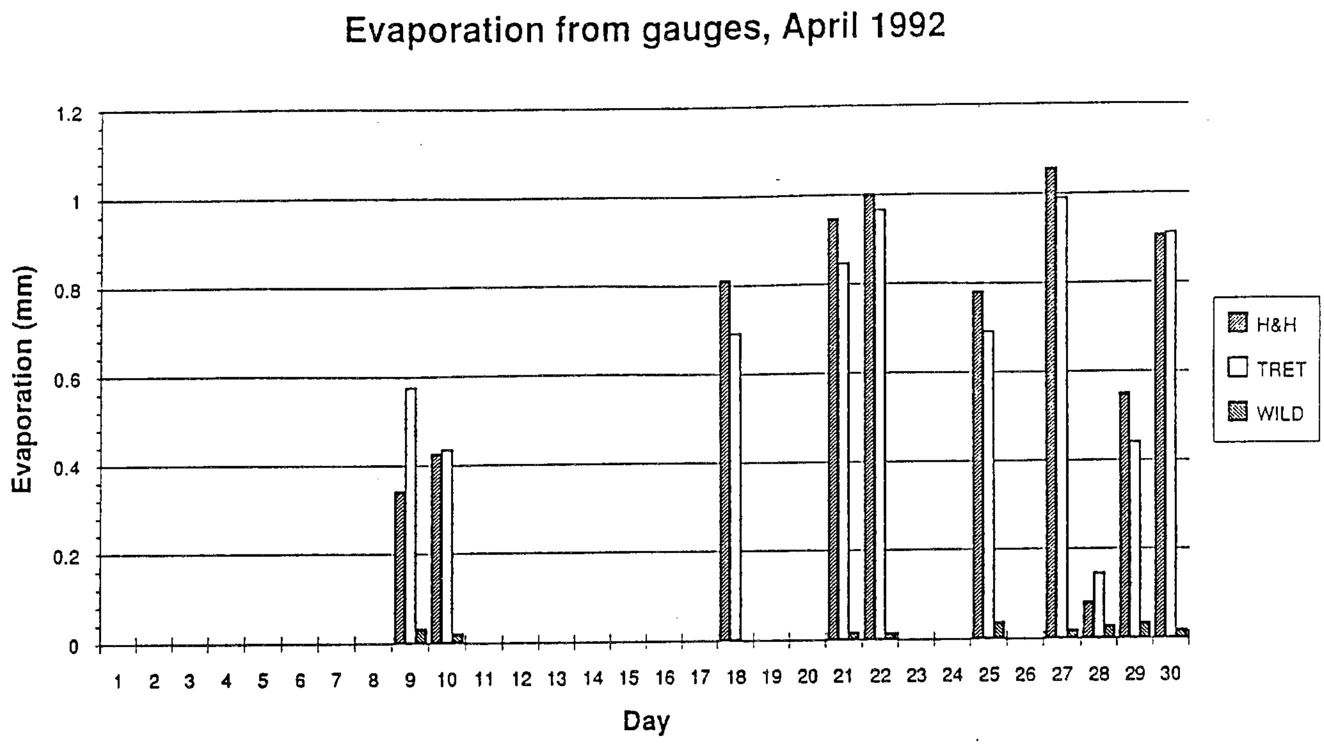


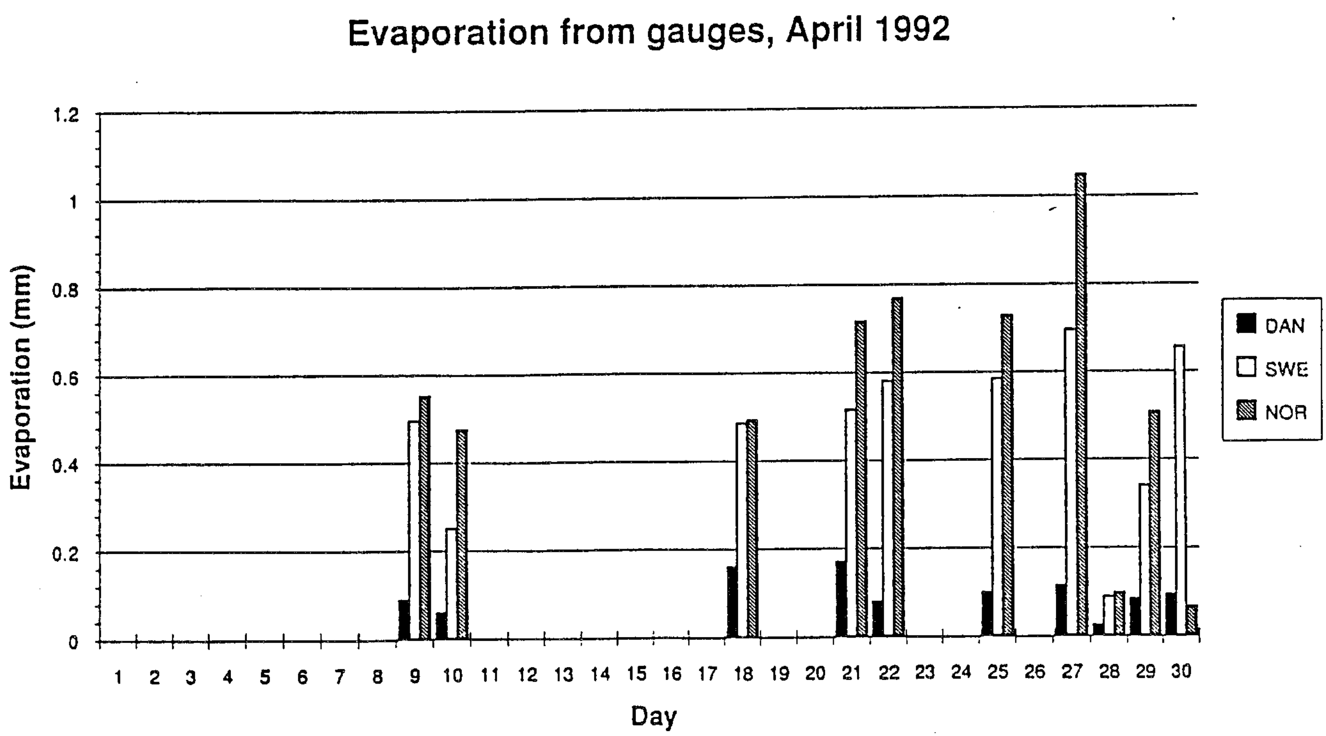
Figure 2. The Average Wetting loss of different gauges in 1992, mm.

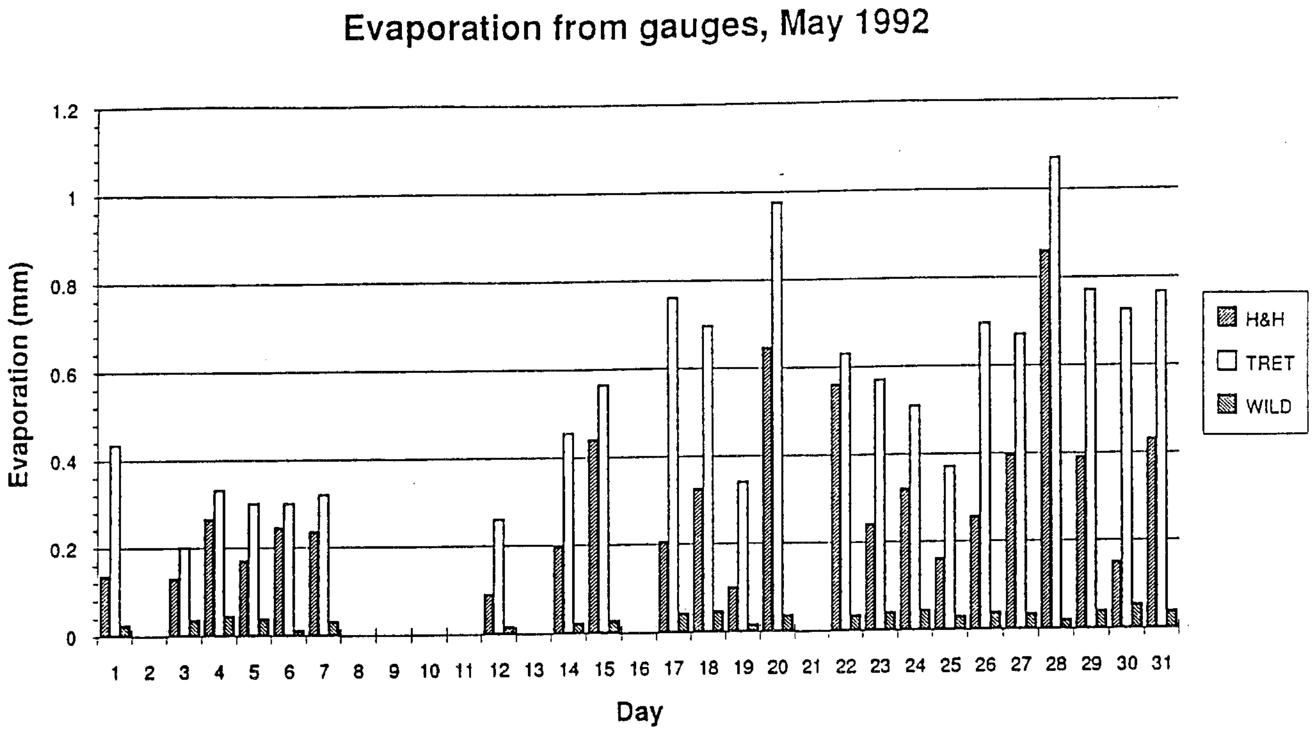
Figure 3. Evaporation (mm/12h) from different type of gauges for different months in 1992.

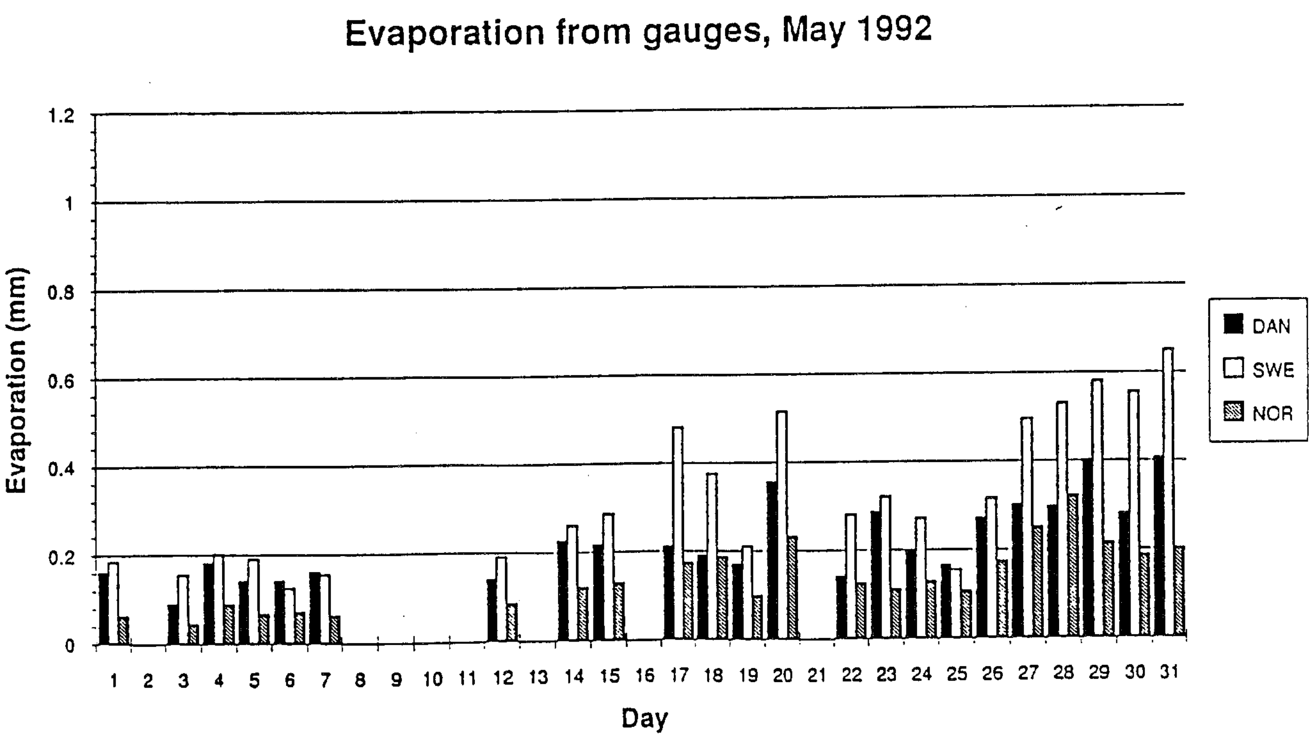


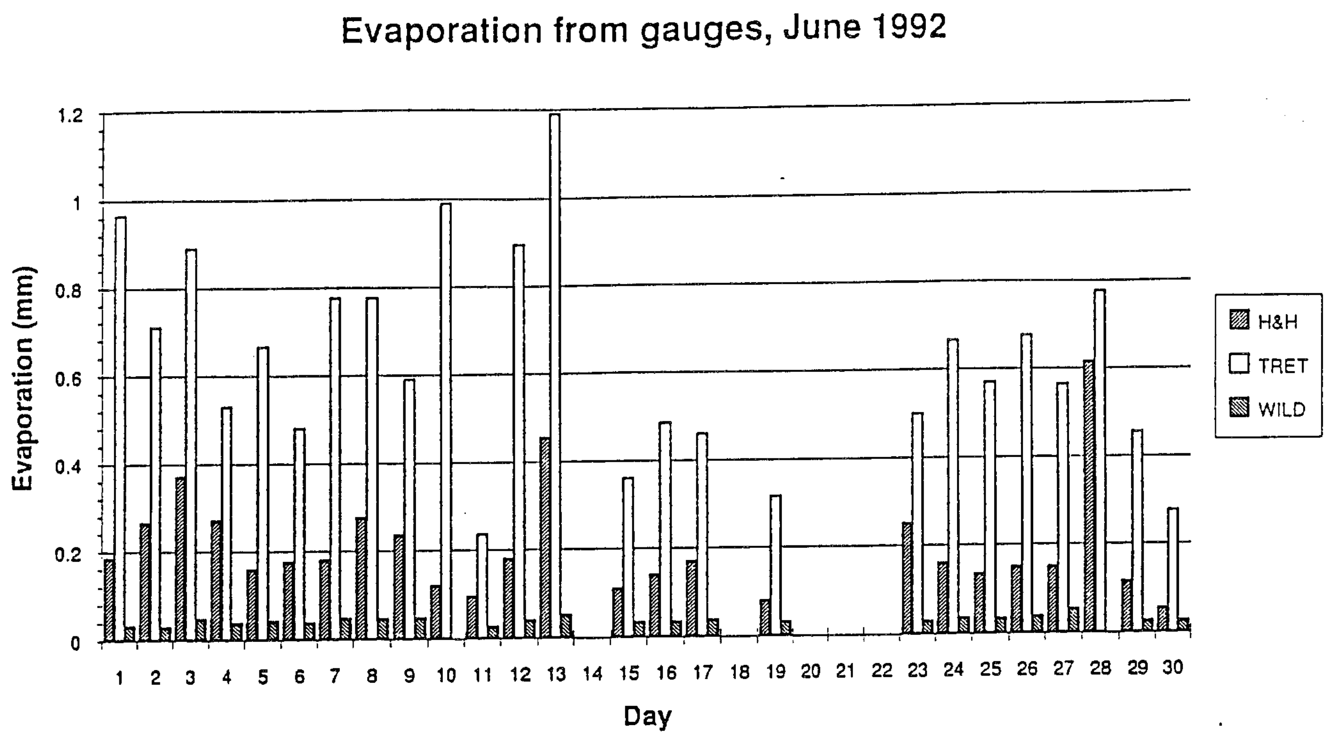


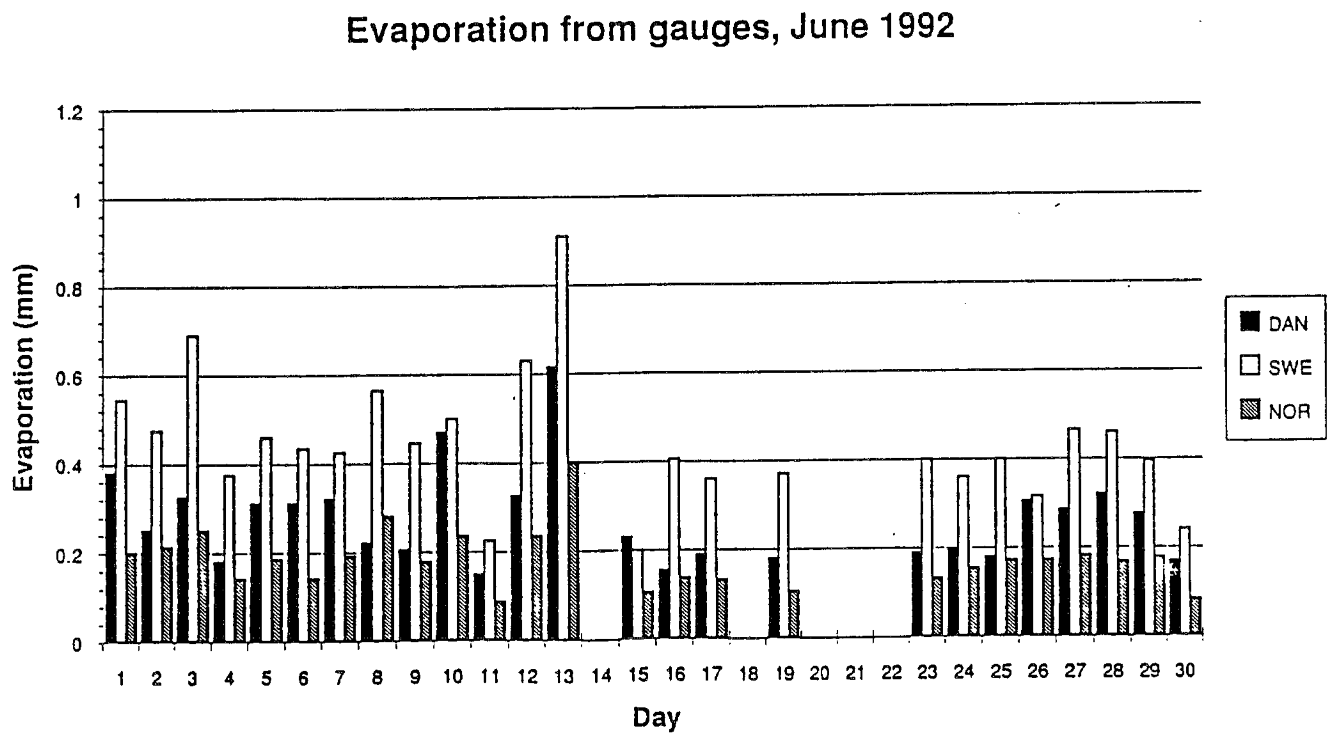

Evaporation from gauges, April 1992
1.2
1
0.8
0.6
0.4
0.2
0
Evaporation (mm)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Day
H&H
TRET
WILD

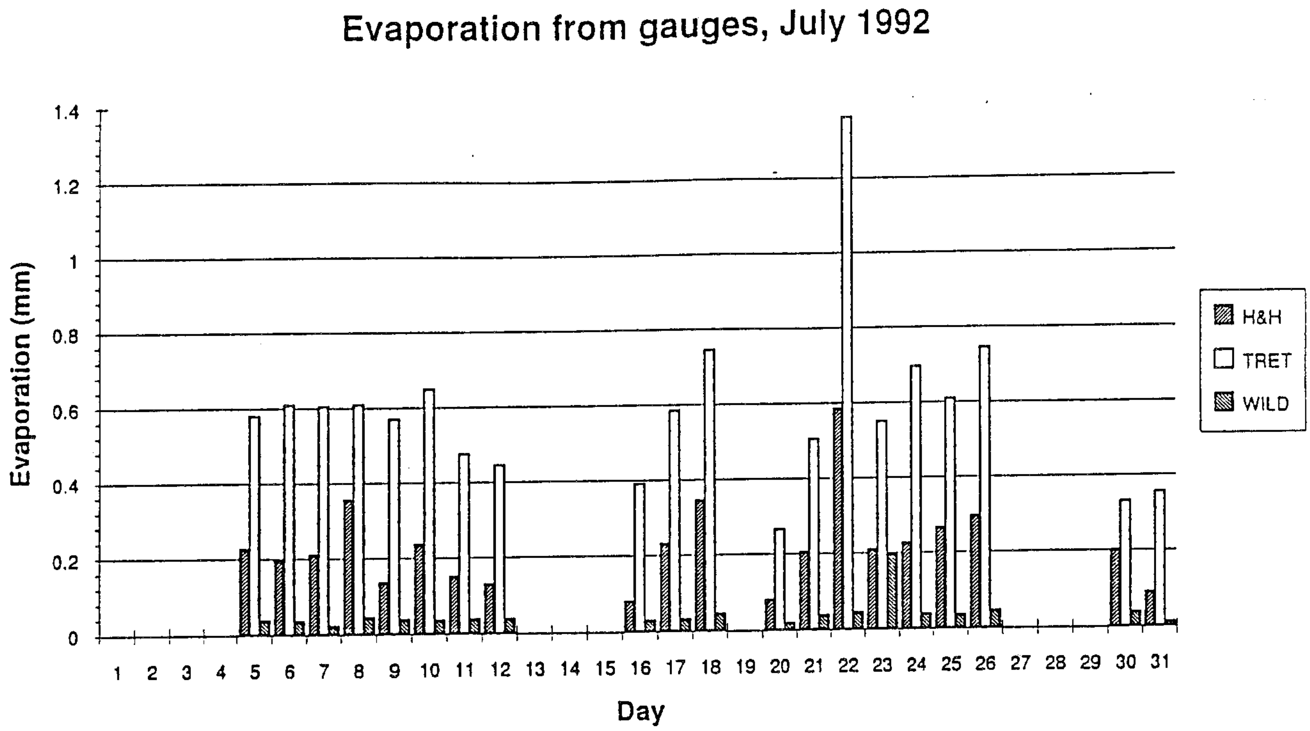

Evaporation from gauges, April 1992
1.2
1
0.8
0.6
0.4
0.2
0
Evaporation (mm)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Day
DAN
SWE
NOR

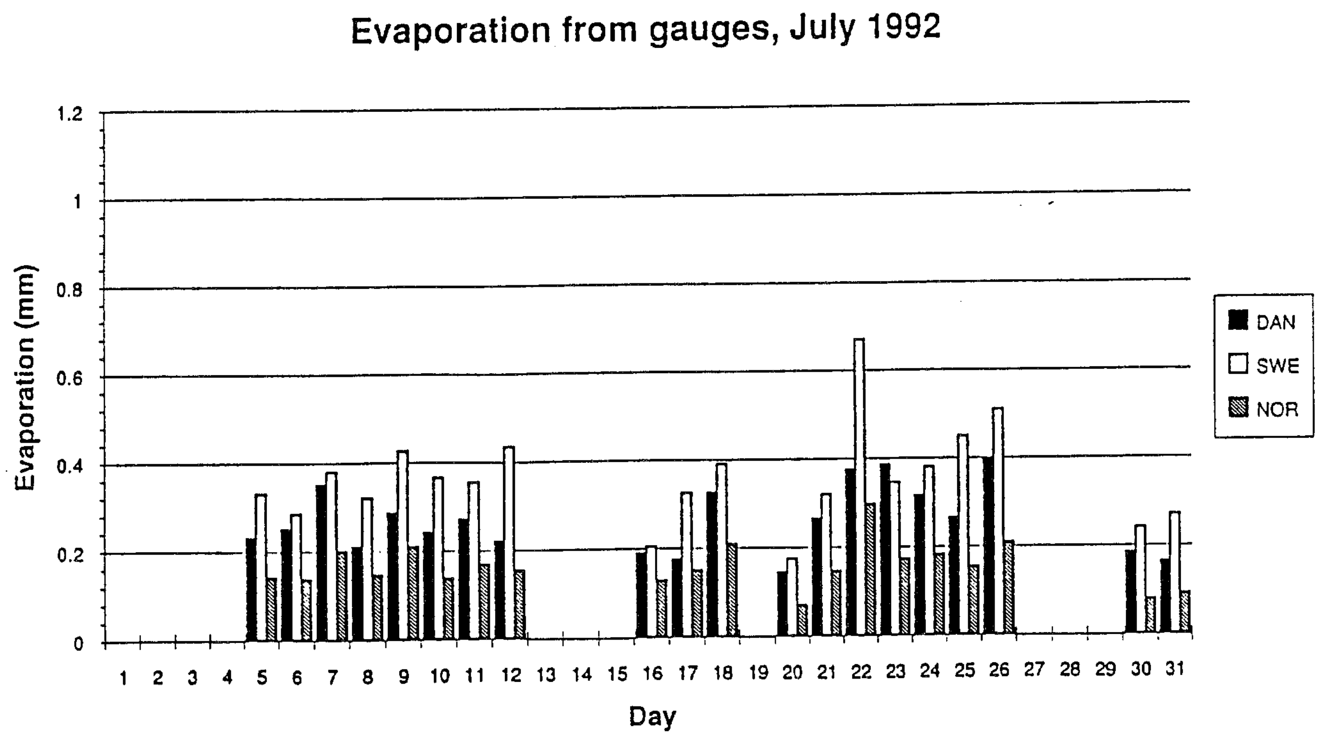

Evaporation from gauges, May 1992
Evaporation (mm)
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day
H&H
TRET
WILD

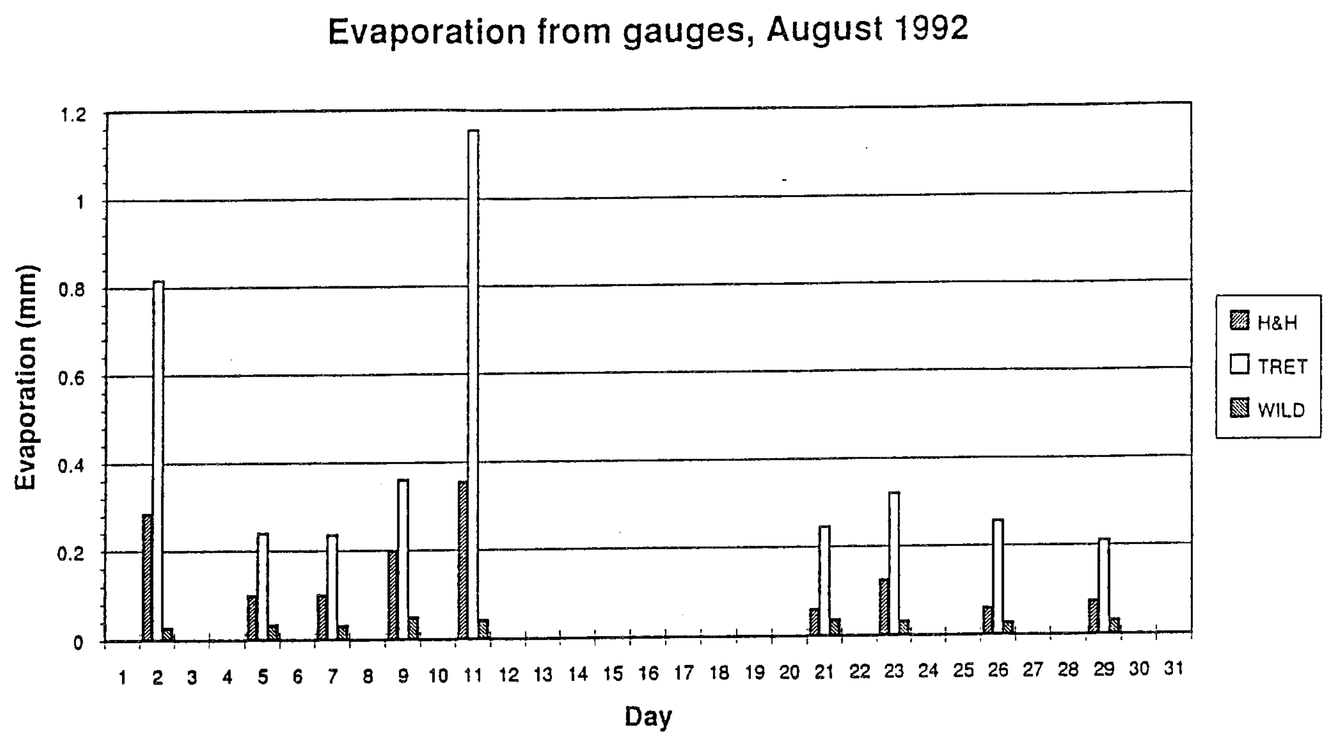

Evaporation from gauges, May 1992
Evaporation (mm)
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day
DAN
SWE
NOR

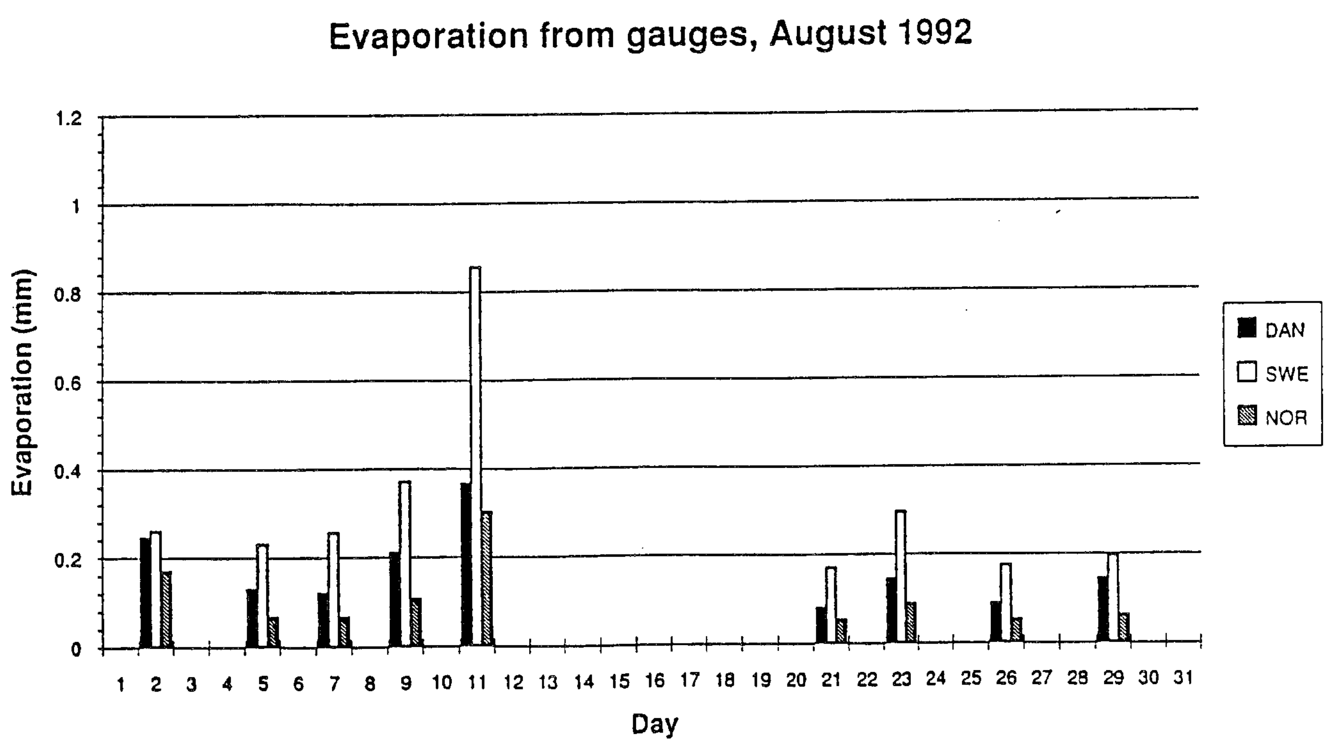

Evaporation from gauges, June 1992
Evaporation (mm)
0
0.2
0.4
0.6
0.8
1
1.2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Day
H&H
TRET
WILD

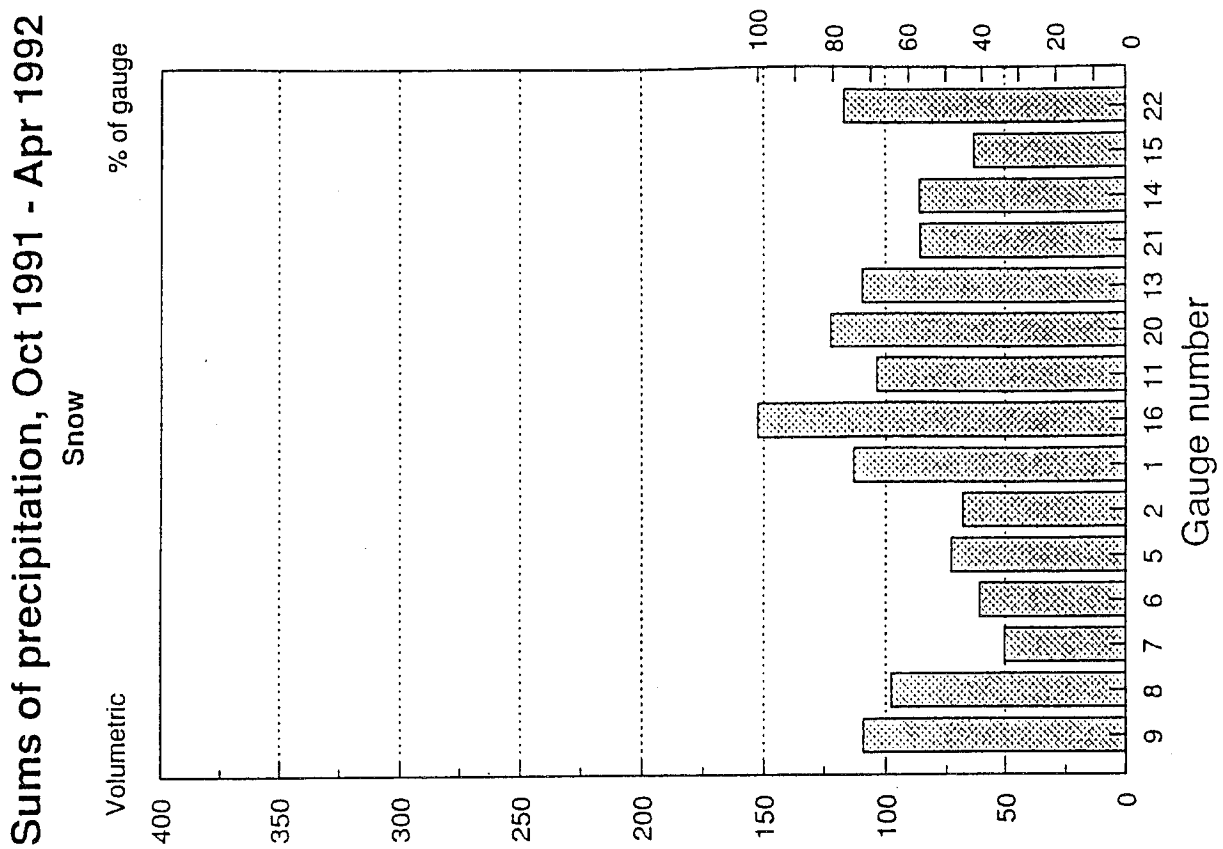

Evaporation from gauges, June 1992
Evaporation (mm)
0
0.2
0.4
0.6
0.8
1
1.2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Day
DAN
SWE
NOR

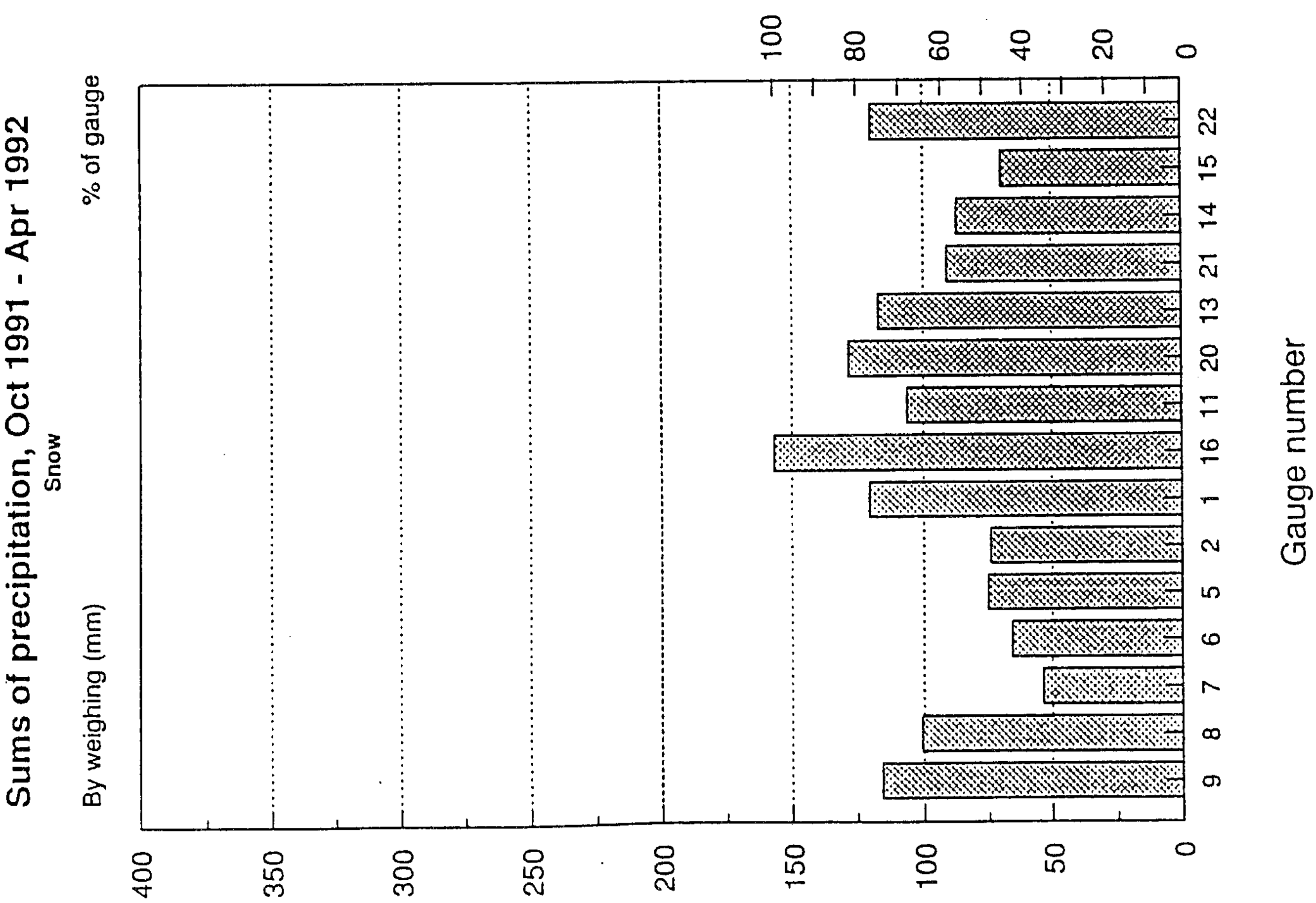

Evaporation from gauges, July 1992
Evaporation (mm)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day
H&H
TRET
WILD

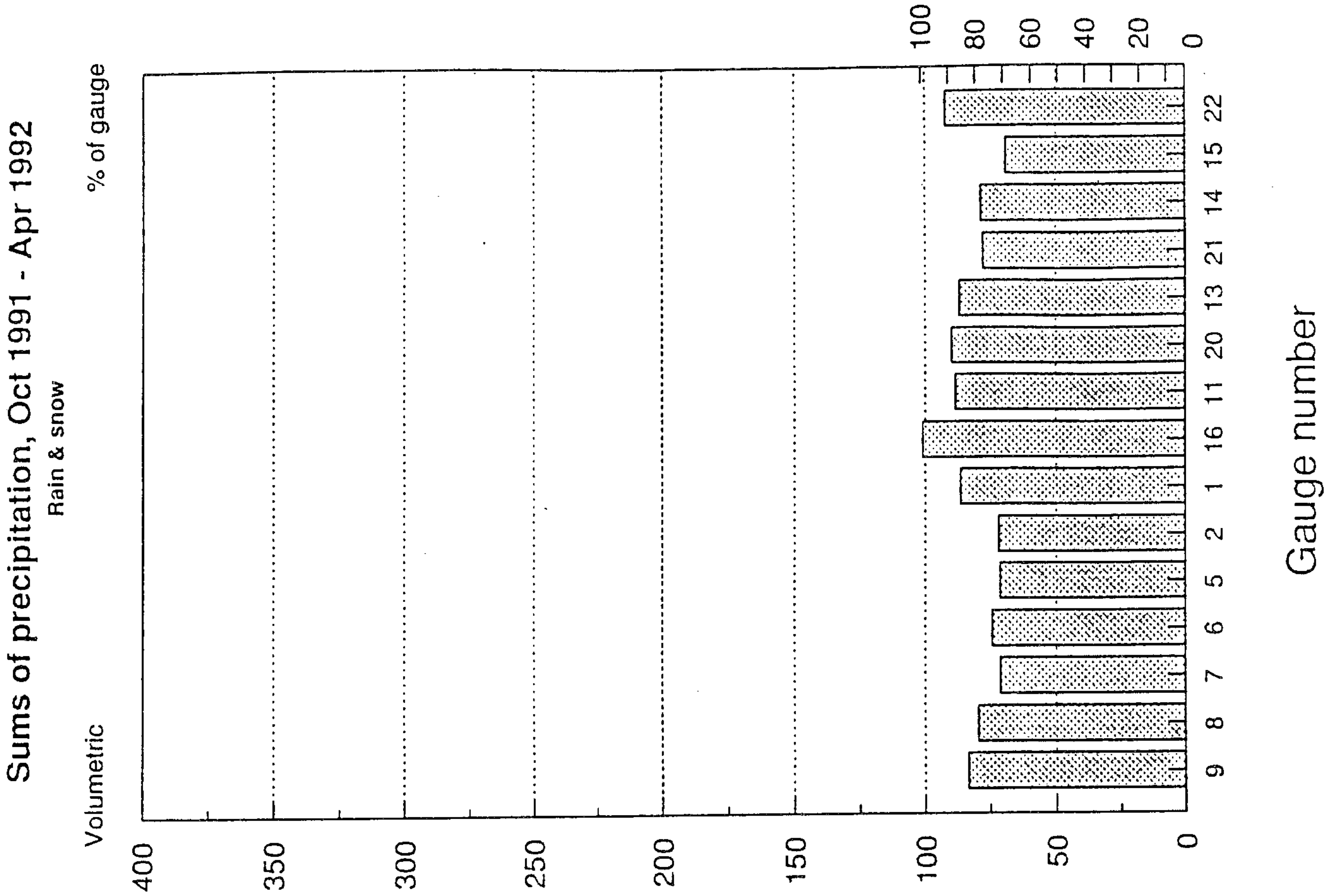

Evaporation from gauges, July 1992
Evaporation (mm)
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day
DAN
SWE
NOR

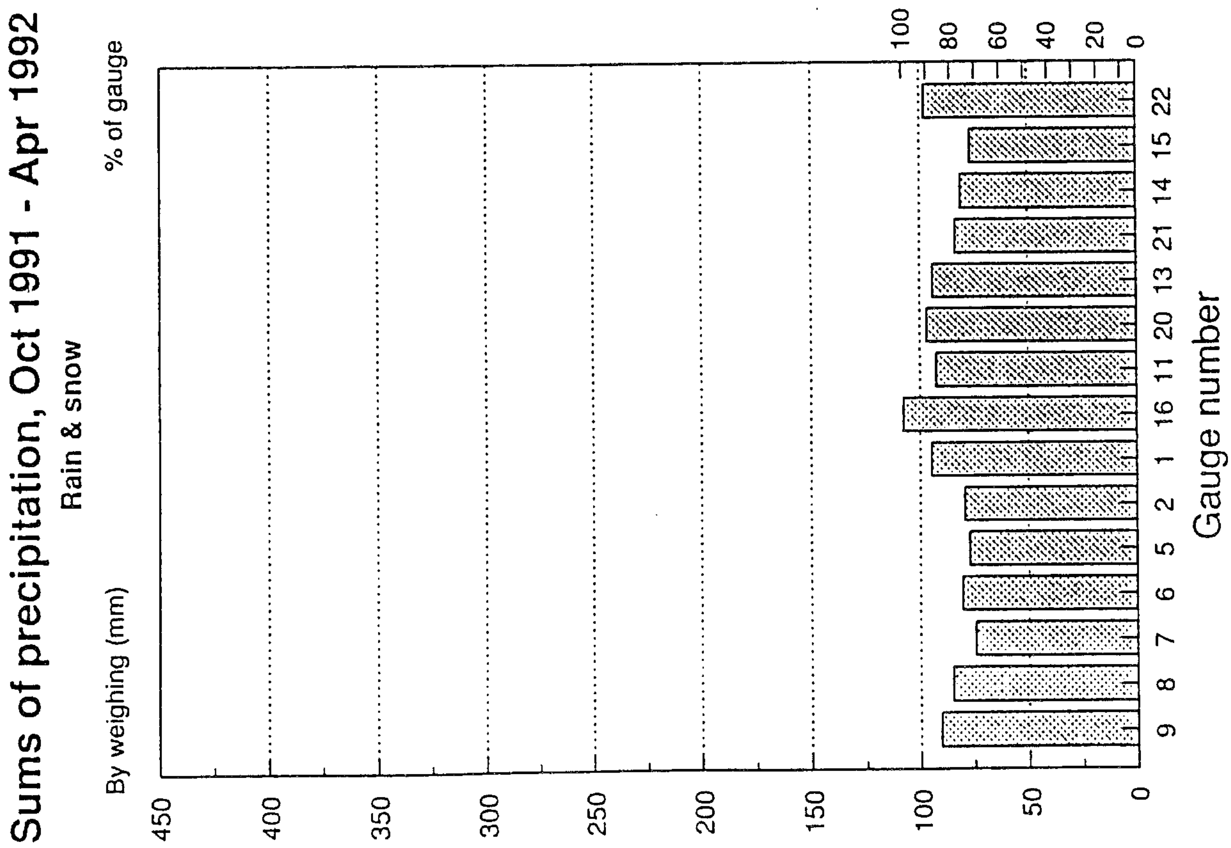

Evaporation from gauges, August 1992
1.2
1
0.8
0.6
0.4
0.2
0
Evaporation (mm)
H&H
TRET
WILD
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day

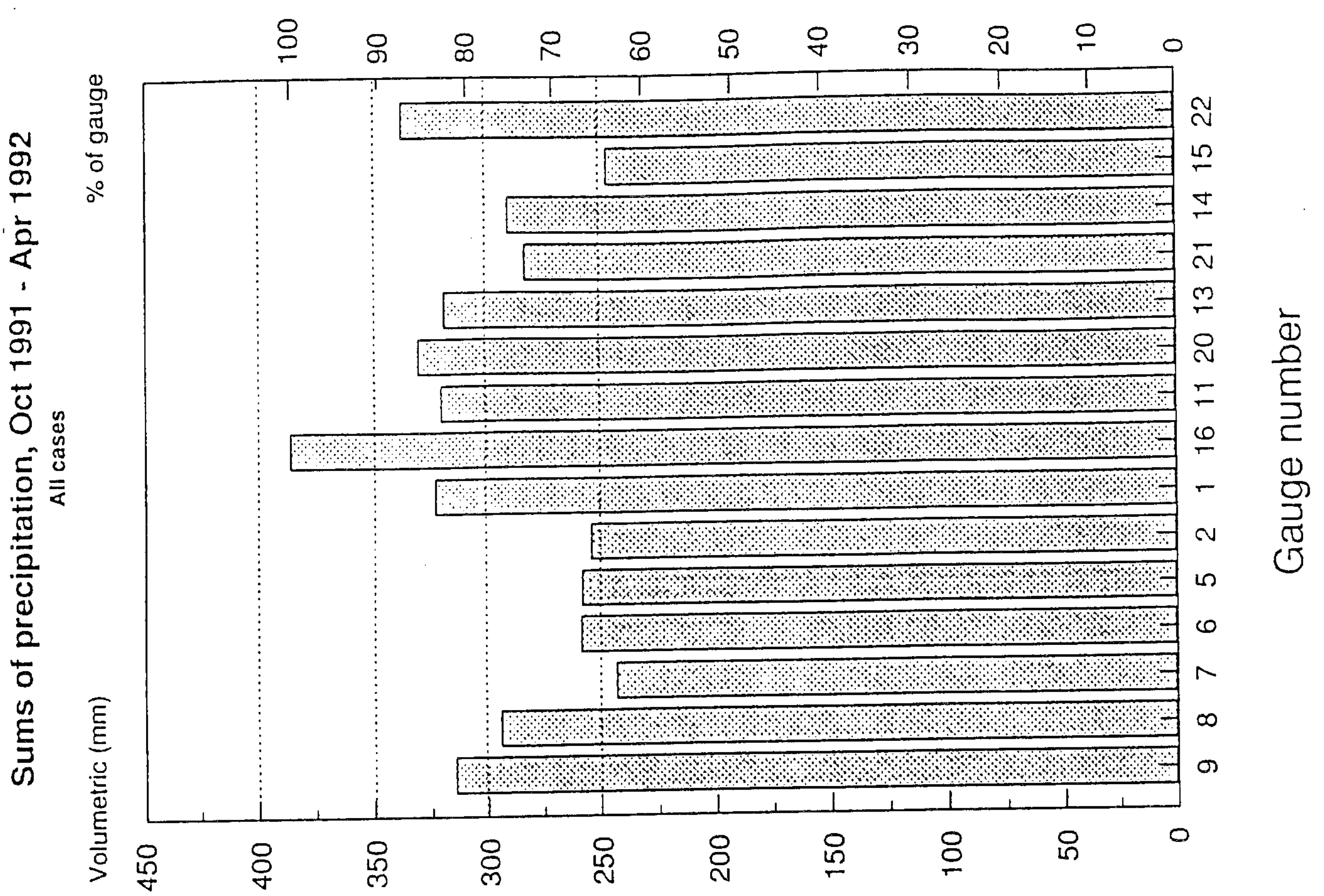

Evaporation from gauges, August 1992
1.2
1
0.8
0.6
0.4
0.2
0
Evaporation (mm)
DAN
SWE
NOR
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day

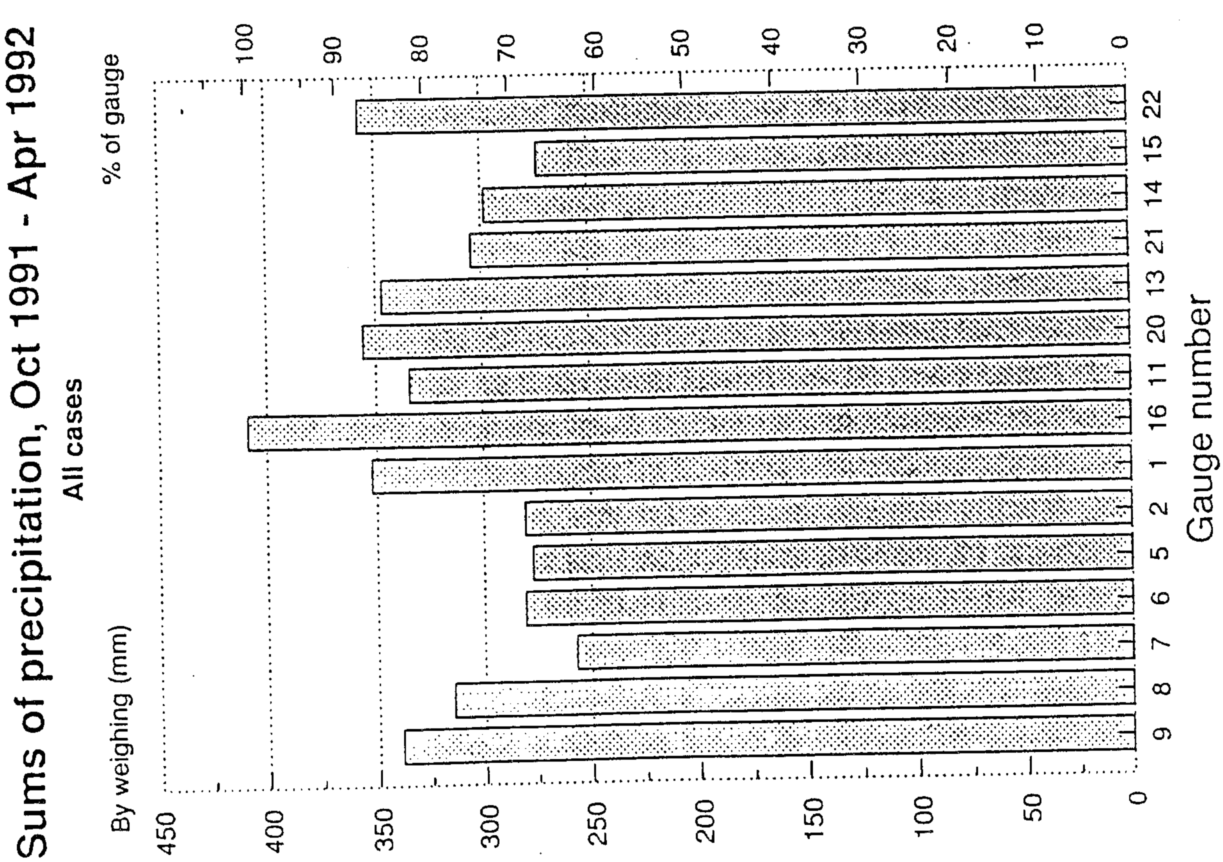

Sums of precipitation, Oct 1991 - Apr 1992
Snow
Volumetric
% of gauge
0
50
100
150
200
250
300
350
400
0
20
40
60
80
100
9
8
7
6
5
2
1
16
11
20
13
21
14
15
22
Gauge number


Sums of precipitation, Oct 1991 - Apr 1992
Snow
By weighing (mm)
% of gauge
0
50
100
150
200
250
300
350
400
0
20
40
60
80
100
9
8
7
6
5
2
1
16
11
20
13
21
14
15
22
Gauge number


Sums of precipitation, Oct 1991 - Apr 1992
Rain & snow
Volumetric
% of gauge
400
350
300
250
200
150
100
50
0
100
80
60
40
20
0
9
8
7
6
5
2
1
16
11
20
13
21
14
15
22
Gauge number


Sums of precipitation, Oct 1991 - Apr 1992
Rain & snow
By weighing (mm)
% of gauge
450
400
350
300
250
200
150
100
50
0
100
80
60
40
20
0
9
8
7
6
5
2
1
16
11
20
13
21
14
15
22
Gauge number


Sums of precipitation, Oct 1991 - Apr 1992
All cases
Volumetric (mm)
% of gauge
Gauge number
9 8 7 6 5 2 1 16 11 20 13 21 14 15 22
0 50 100 150 200 250 300 350 400 450
0 10 20 30 40 50 60 70 80 90 100


Sums of precipitation, Oct 1991 - Apr 1992
All cases
By weighing (mm)
% of gauge
Gauge number
9 8 7 6 5 2 1 16 11 20 13 21 14 15 22
0 50 100 150 200 250 300 350 400 450
0 10 20 30 40 50 60 70 80 90 100

WORLD METEOROLOGICAL ORGANIZATION

25. VIII. 1992

INTERNATIONAL ORGANIZING COMMITTEE
FOR THE WMO SOLID PRECIPITATION
MEASUREMENT INTERCOMPARISON

Sixth Session
Toronto, Canada, 14-18 Sept. 1992

INITIAL ANALYSIS OF DATA - EVALUATION STATION HARZGERODE

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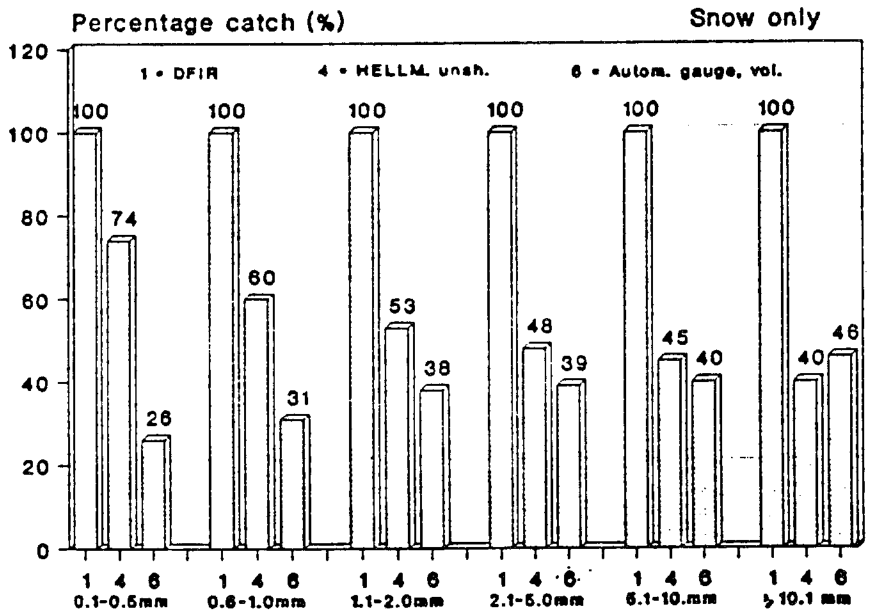

WMO Solid Precipitation Measurement Intercomparison
Initial Analysis of Data - Evaluation Station Harzgerode

Introduction

This brief report presents first results of a statistical analysis on the basis of the Harzgerode data set. The intercomparison measurements at the Evaluation station Harzgerode were started on 1 December, 1986 with 12 different types of precipitation gauges. At first the following gauges have been included in the national analysis:

- Hellmann, unshielded - National Standard
- Hellmann, shielded
- Automatic gauge/AFMS 2 (volumetric)
- Automatic gauge (tipping bucket)
- Tretyakov
- Metra
- Double Fence Intercomparison Reference (DFIR)

Results

The ratios comparison gauge/DFIR of the above listed gauges were calculated. Now the available six year data set provides the basis for a more detailed investigation of the gauge catch ratios in dependence on different factors (air temperature, wind speed; depth, duration and intensity of precipitation). According to the report of WMO/CIMO (1985) the various types of precipitation - snow only, snow with rain, rain with snow, rain - should be taken into account.
A sample of results are presented in the tables 1 - 6 and the figures 1 - 22. In the following some characteristic facts are given:

- The Hellmann gauge, unshielded, catches
  - . 45,5 % Snow only (n = 99)
  - . 61,1 % Snow with rain (n = 69)
  - . 81,9 % Rain with snow (n = 93)
  - . 86,6 % Rain only (n = 196)

  compared with the DFIR (100 %) - cf. Fig. 1, 2a, b; Table 1.
  The catch ratio Hellmann unsh./DFIR is even less for snow events, when only the days with DFIR $\geqslant$ 2,0 mm are taken into consideration (cf. Fig. 3a).

- The scatter diagram in Fig. 7 indicates that the monthly totals of the comparison gauges relate significantly to the monthly totals of the DFIR. The systematic differences are higher with the automatic gauges (especially with the tipping bucket) compared with the Hellmann gauge unshielded. The reason for that may be the increased evaporation losses caused by heating.
The following linear regression equations were calculated (Monthly totals):

Snow only $DFIR = 2.3246\ HELLM_{unsh.} - 0.7605$ ($n = 19$ $r^2 = 0.88$)

$DFIR = 2.3602\ AFMS_{vol.} + 0.3639$ ($n = 19$ $r^2 = 0.94$)

Mixed precip. $DFIR = 1.4026\ HELLM_{unsh.} - 0.9086$ ($n = 23$ $r^2 = 0,97$)

$DFIR = 1.4501\ AFMS_{vol.} - 0.4986$ ($n = 23$ $r^2 = 0.97$)

Rain $DFIR = 1.1511\ HELLM_{unsh.} + 0.1100$ ($n = 23$ $r^2 = 0.99$)

$DFIR = 1.1344\ AFMS_{vol.} + 0.9192$ ($n = 23$ $r^2 = 0.99$)

- The analysis of the percentage catches separated for various classes of daily precipitation depth (0.1 - 0.5 mm, 0.6 - 1.0 mm ...) reveals the following results:

Snow only:	Daily totals $P \geq 1.1$ mm	
	Hellmann unsh.	40....53 %
	Automatic gauge/AFMS	38....46 %
	Daily totals $P \leq 1.0$ mm	
	Hellmann unsh.	60....74 %
	Automatic gauge/AFMS	26....31 %

without essential differentiationes among the classes of higher precipitation (2.1 - 5.0 mm, 5.1 - 10.0 mm, $\geq$ 10.1 mm). The systematic losses of the Hellmann unsh. gauge is smaller for the classes of lower precipitation. On the contrary to that there are significant higher losses with the Automatic gauges for the "low precipitation classes". The losses with the automatic heated gauge are only less for the "high precipitation class" ($P \geq 10.1$ mm) (cf. Fig. 9).

- The percentage catch of the Hellmann unsh. gauge in dependence on wind speed differs in the case of snow only between

	19 %	V1 > 5.0 ms^{-1}
and		
	67 %	V1 < 1.0 ms^{-1} .

The high losses of the automatic gauges in the case of small wind speeds are purely caused by the heating of the collecting funnel (evaporation loss). In the case of higher wind speeds (V1 > 4.0 ms^{-1}) the heating prevents on the contrary the blowing out of snow. Consequently the catch ratio are higher compared with the Hellmann unsh. gauge (Fig. 17; Table 3).

- The scatter diagrams of the ratios comparison gauge/DFIR vs wind speed resp. precipitation depth show that there is a closer correlation to wind speed than to precipitation depth (cf. Fig. 18-21).

- The following ratios were included into the regression analysis:

Y1: HELLM unsh/DFIR
Y2: HELLM sh/DFIR
Y3: AFMS2/DFIR
Y4: TRETYAKOV/DFIR

in relation to:

V1: Wind speed 1 m level
V10: Wind speed 10 m level
T: Air temperature (2 m)
P: Depth of precipitation
D: Duration of precipitation
I: Intensity of precipitation

for

SNOW ONLY events
MIXED PRECIP. events (SR, RS)
RAIN events

Starting with simple linear regressions multiple linear regressions were finally calculated including two or three of the above listed variables (V1, V10, T, P, D, I). From the total of 624 regression equations only those equations were listed in Table 5 and 6 which have in each case the highest correlation coefficient (r^2). Generally the multiple linear regression (three variables) give the best results. The most important factor of influence is mean wind speed (V1, V10) which forms the decisive contribution to the correlation coefficient (r^2).

Conclusions

The initial results of the analysis confirm the predominant influence of the wind causing the HELLMANN-gauge catch deficiencies. The correction of the winter season precipitation measurements in Central Europe is rather a problem, because the types of precipitation vary frequently and within short intervals between snow and rain, particularly in flat regions. The above presented preliminary results show that a correction procedure for multi-year monthly precipitation totals will have to be derived by inclusion the type of precipitation (snow, mixed, rain) and the mean wind speed (e. g. characterized by the wind exposition of the measuring site). An operational correction procedure for daily values have to be taken into account as factors of influence at least various classes of mean wind speed and precipitation depth. Correction factors or regression equations should be derived separately for the different types of precipitation.

References

WMO/CIMO, 1985: International Organizing Committee for the WMO Solid Precipitation Measurement Intercomparison, Final Report of the First Session, WMO, Geneva, 31 pp.

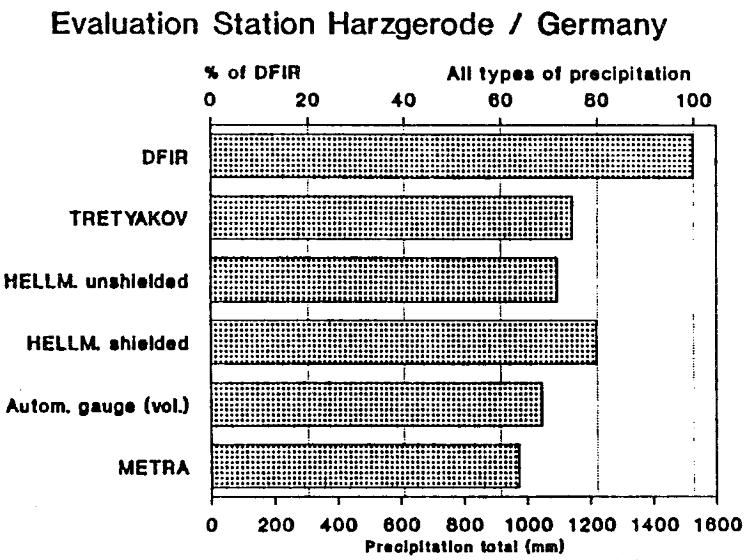

Fig.1: Precipitation totals (mm) and percentage catch (%),
all types of precipitation
Dec. - March (1986-1992); Reference gauge: DFIR = 100%

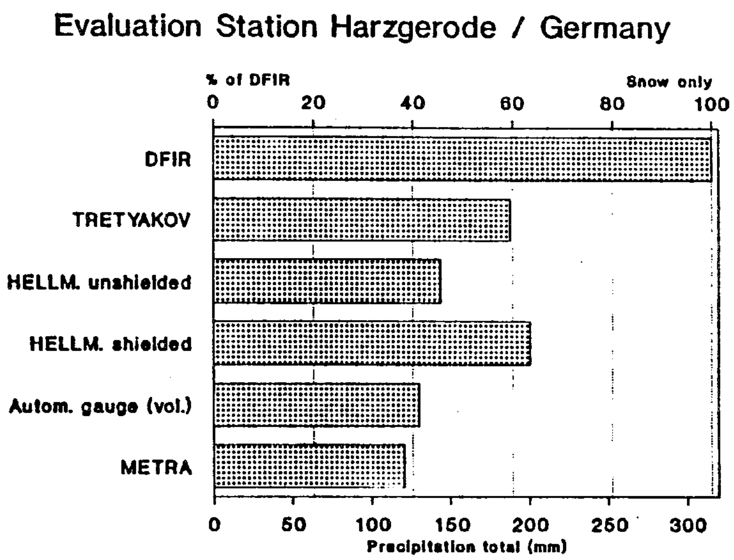

Fig.2a: Precipitation totals (mm) and percentage catch (%), snow only
Dec. - March (1986-1992); Reference gauge: DFIR = 100%

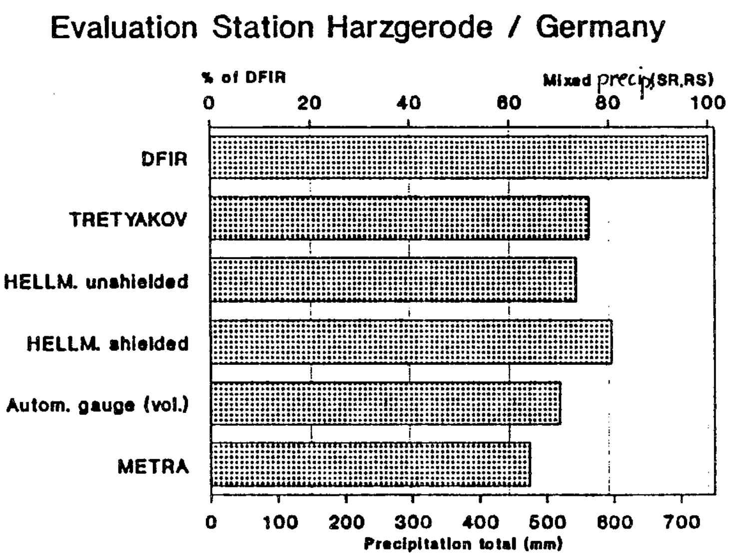

Fig.2b: Precipitation totals(mm) and percentage catch(%), mixed precip.(SR,RS)
Dec. - March (1986-1992); Reference gauge: DFIR = 100%

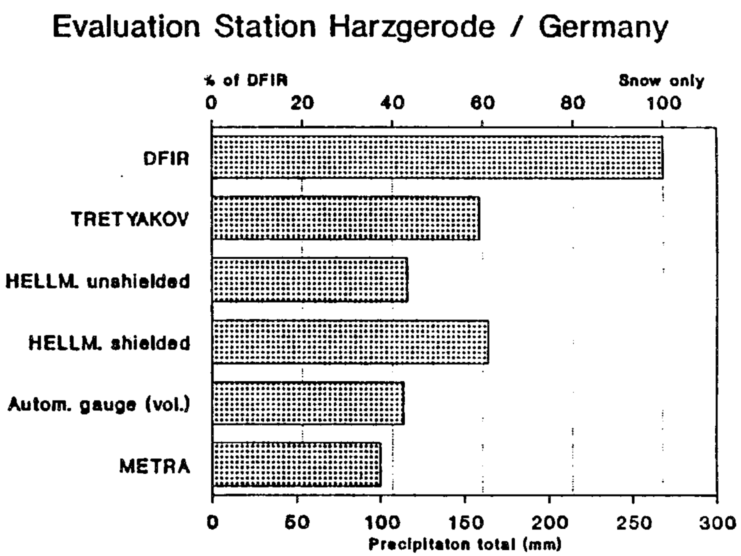

Fig.3a: Precipitation totals (mm) and percentage catch(%), snow only
(included cases: only daily totals DFIR ≥ 2.0 mm)
Dec. - March (1986-1992); Reference gauge: DFIR = 100%

Evaluation Station Harzgerode / Germany

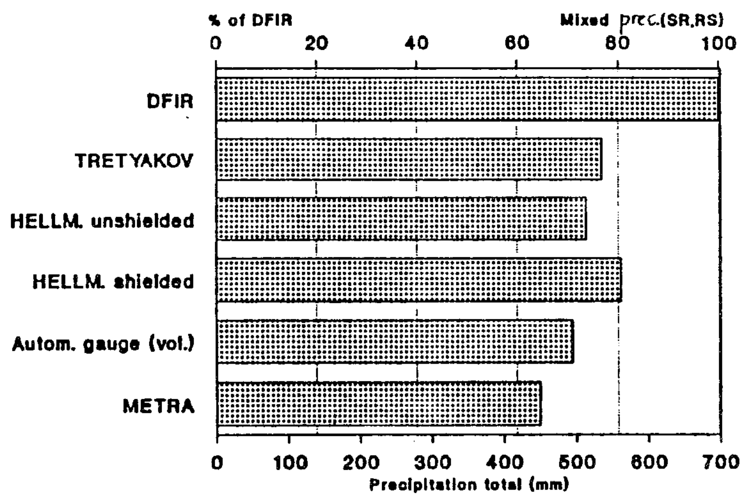

Fig.3b: Precipitation totals (mm) and percentage catch(%), mixed prec.(SR,RS) (included cases: only daily totals DFIR ≥ 2.0 mm) Dec. - March (1986-1992); Reference gauge: DFIR = 100%

Evaluation Station Harzgerode/Germany

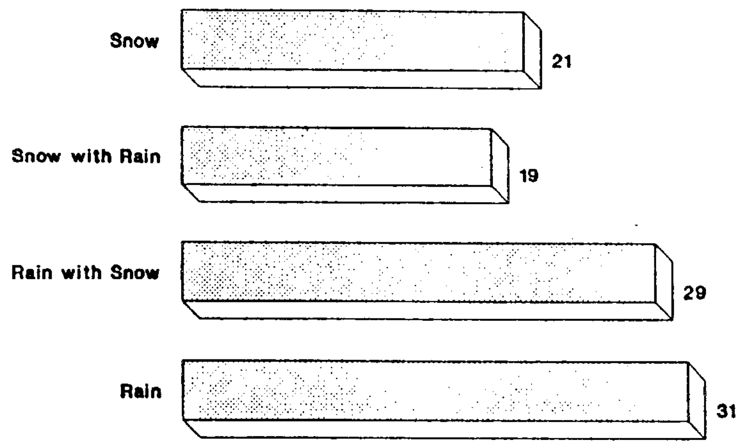

Fig.4: Portions (%) of various types of precipitation Dec. - March (1986-1992)

Evaluation Station Harzgerode / Germany

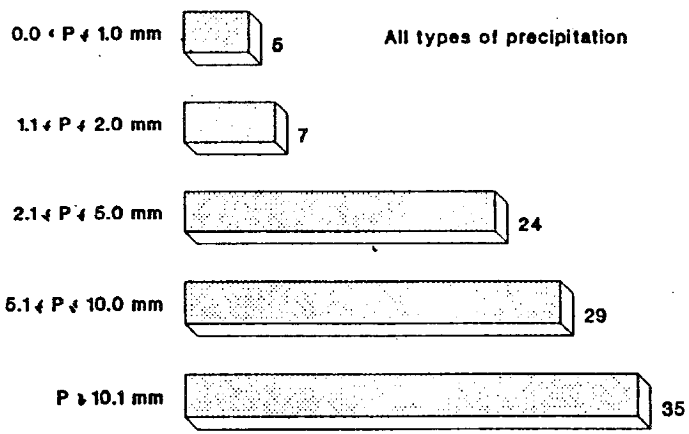

Fig.5: Portions (%) of daily totals in various classes of depth of precipitation Dec. - March (1986-1992)

Evaluation Station Harzgerode / Germany

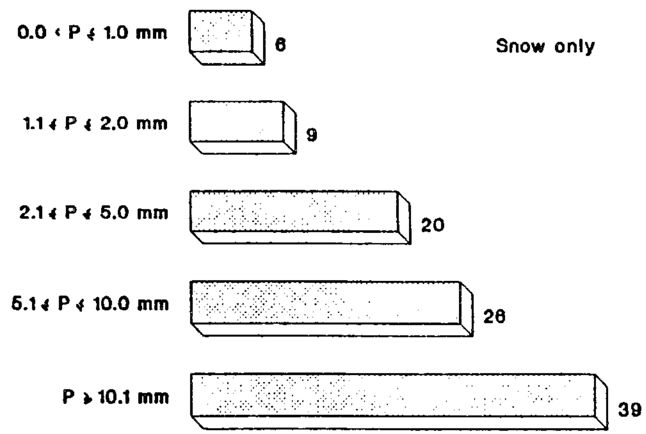

Fig.6: Portions (%) of daily totals in various classes of depth of precipitation Dec. - March (1986-1992)

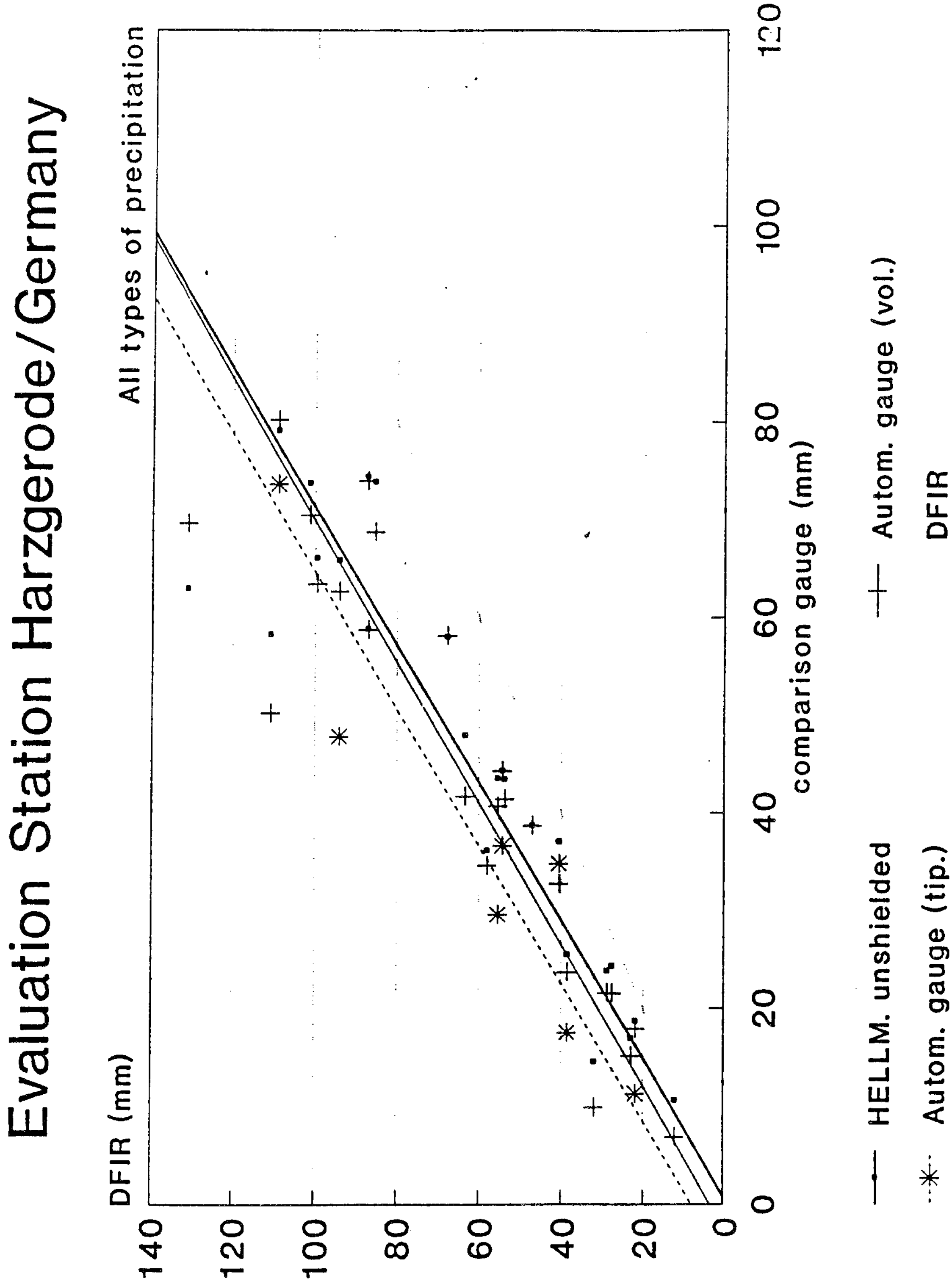

Fig.7: Monthly totals, DFIR (mm) vs comparison gauge (mm)
Dec. - March (1986-1992)

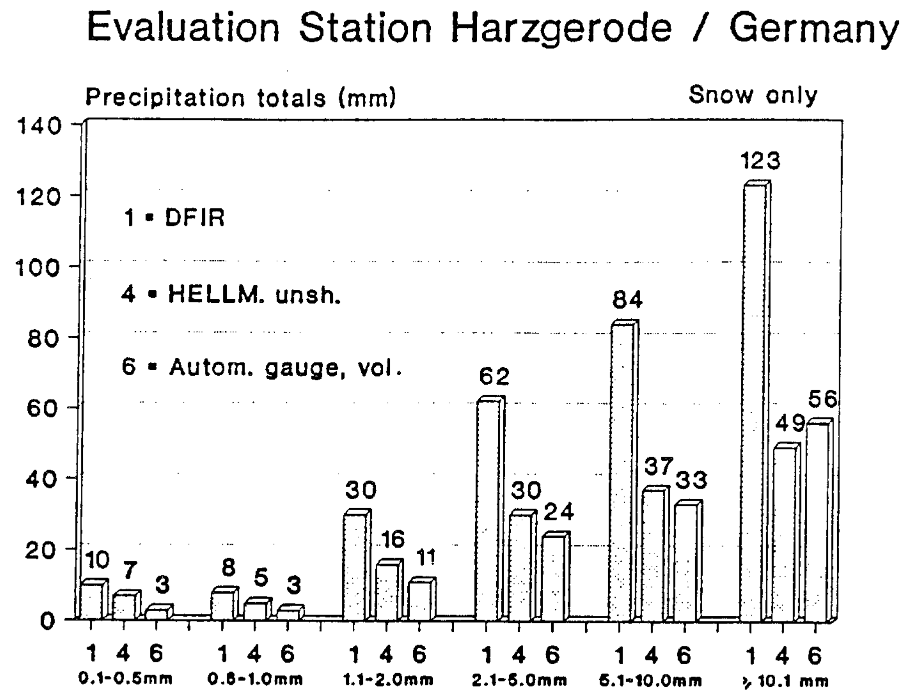

Fig.8: Precipitation totals (mm) of DFIR (1), HELLMANN unsh.(4) and Autom.gauge(6) in various classes of depth of precip. Dec. - March (1986-1992), Snow only

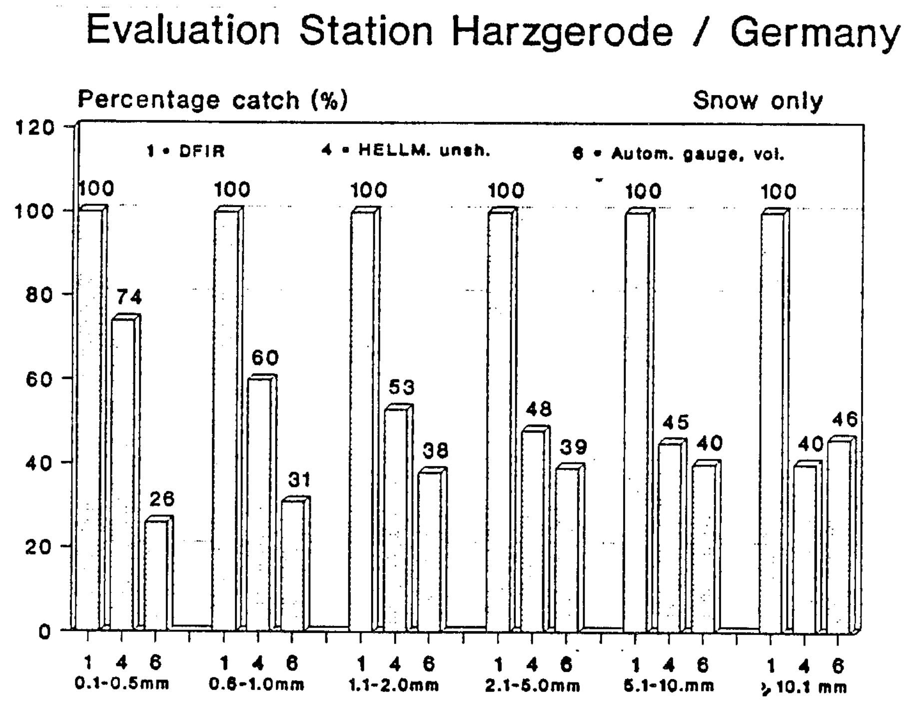

Fig.9: Percentage catch(%) of the comparison gauges (4,6) in various classes of depth of precipitation Dec.- March (1986-1992); Snow only, Reference: DFIR ▪ 100%

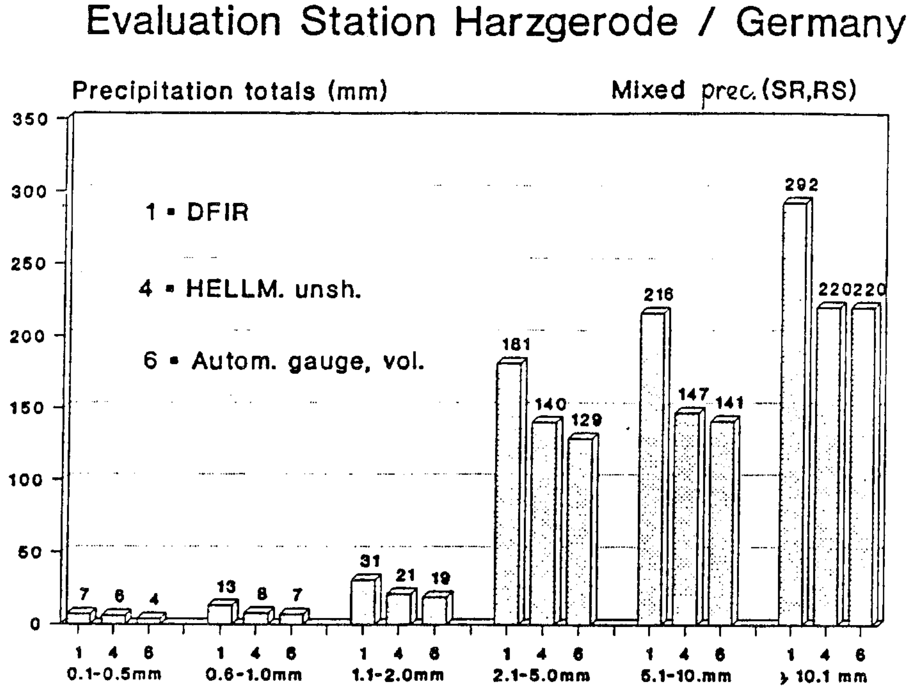

Fig.10: Precipitation totals (mm) of DFIR (1), HELLMANN unsh.(4) and Autom.gauge (6) in Various classes of depth of precip. Dec. - March (1986-1992); Mixed prec.

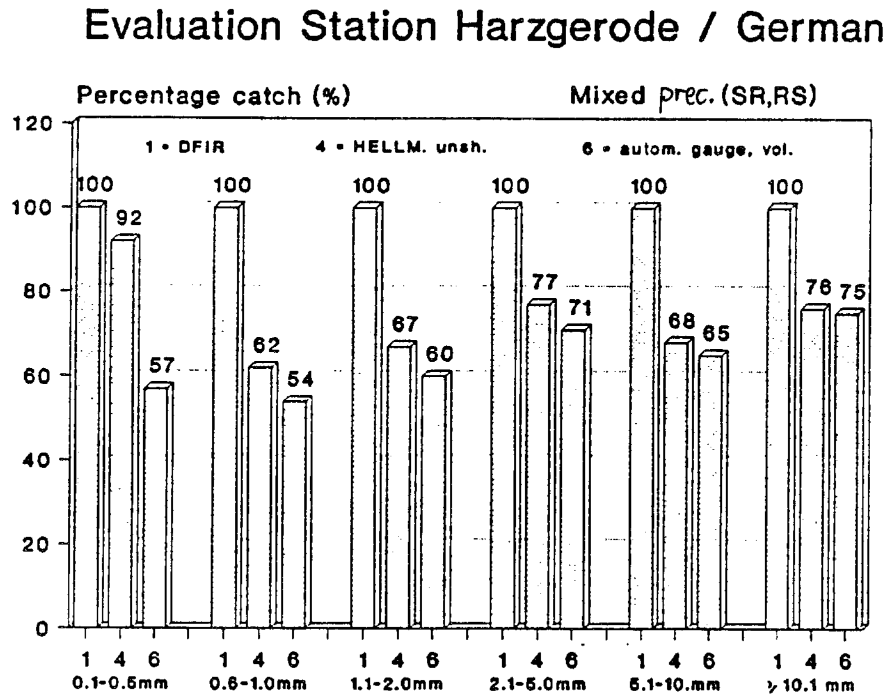

Fig.11: Percentage catch (%) of the comparison gauges (4,6) in various classes of depth of precipitation Dec. - March (1986-1992)

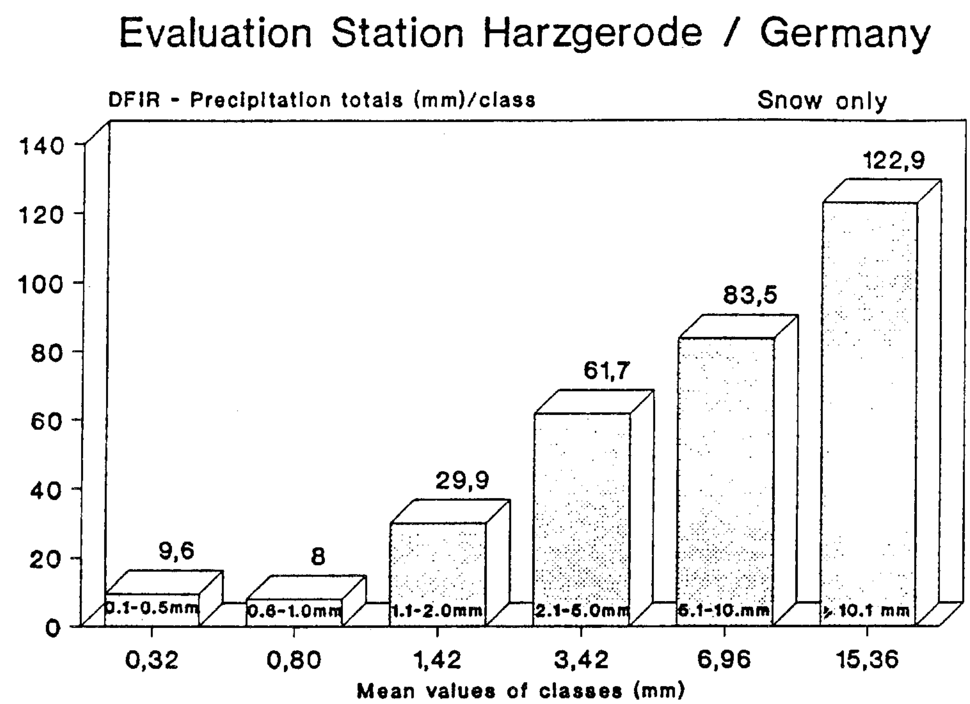

Fig.12: Precipitation totals (mm,DFIR) and the mean values of the various classes of depth of precipitation Dec. - March (1986-1992), Snow only

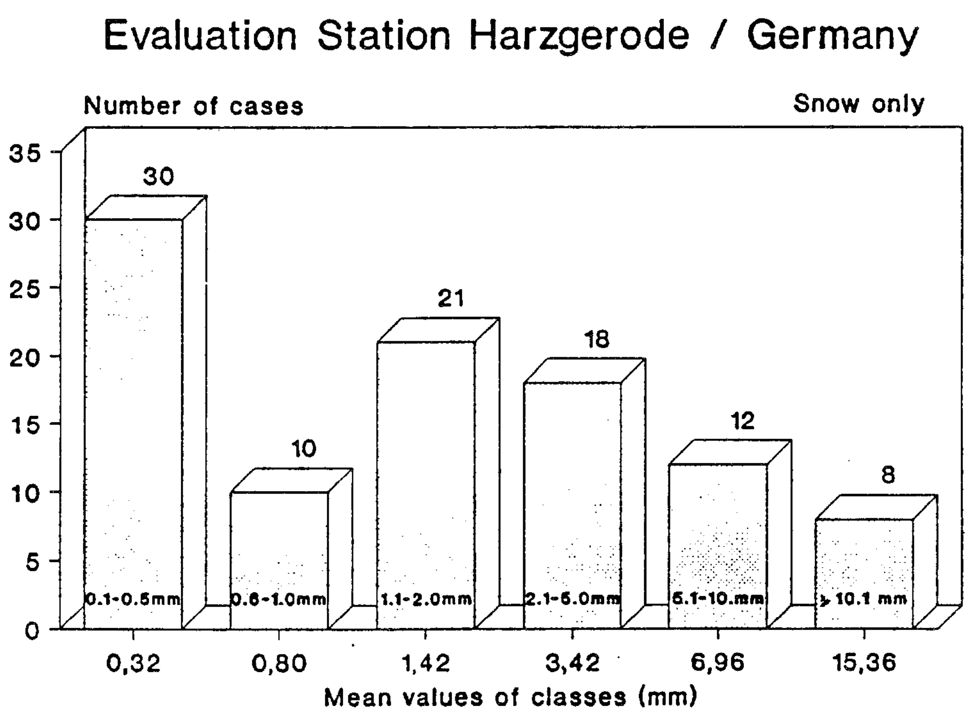

Fig.13: Number of cases (snow only) in various classes of depth of precipitation (DFIR) Dec. - March (1986-1992)

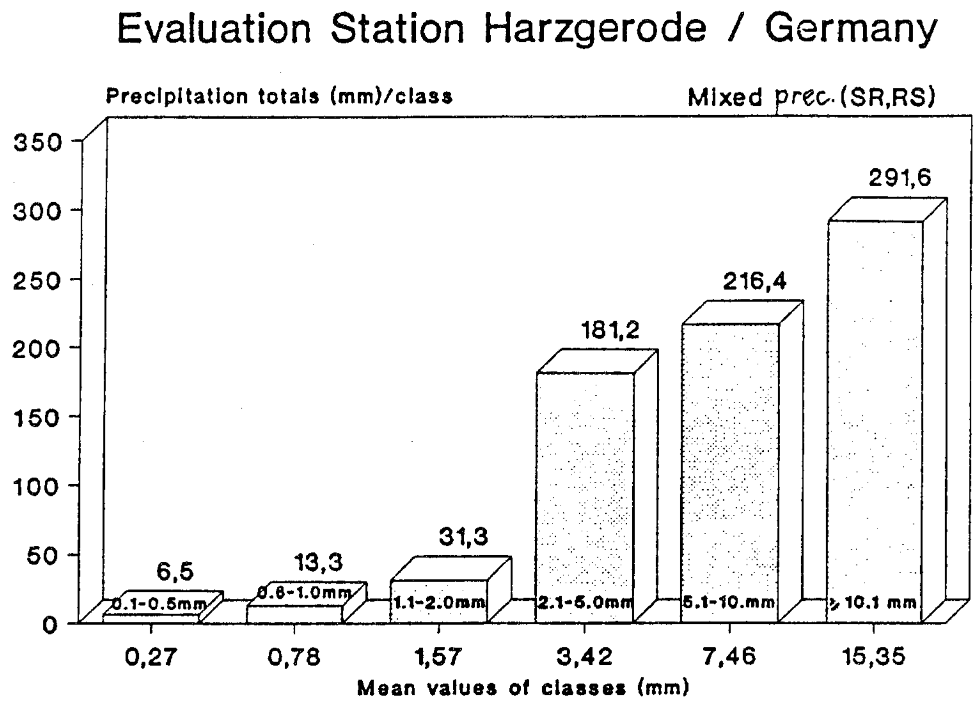

Fig.14: Precipitation totals (mm,DFIR) and the mean values of the various classes of depth of precipitation Dec. - March (1986-1992)

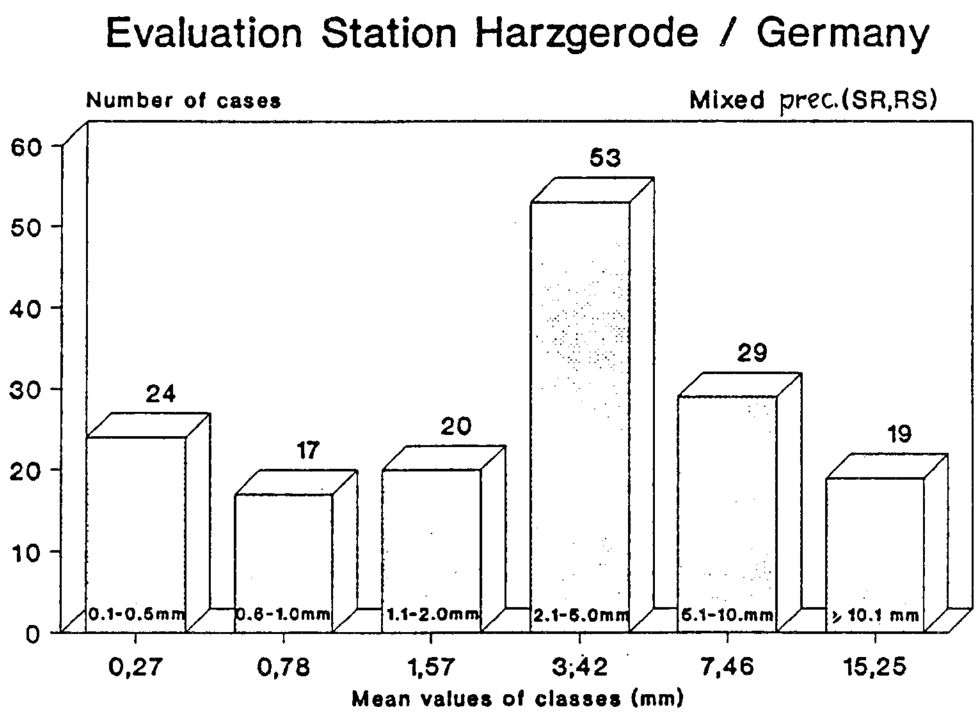

Fig.15: Number of cases (Mixed prec.) in various classes of depth of precipitation (DFIR) Dec. - March (1986-1992)

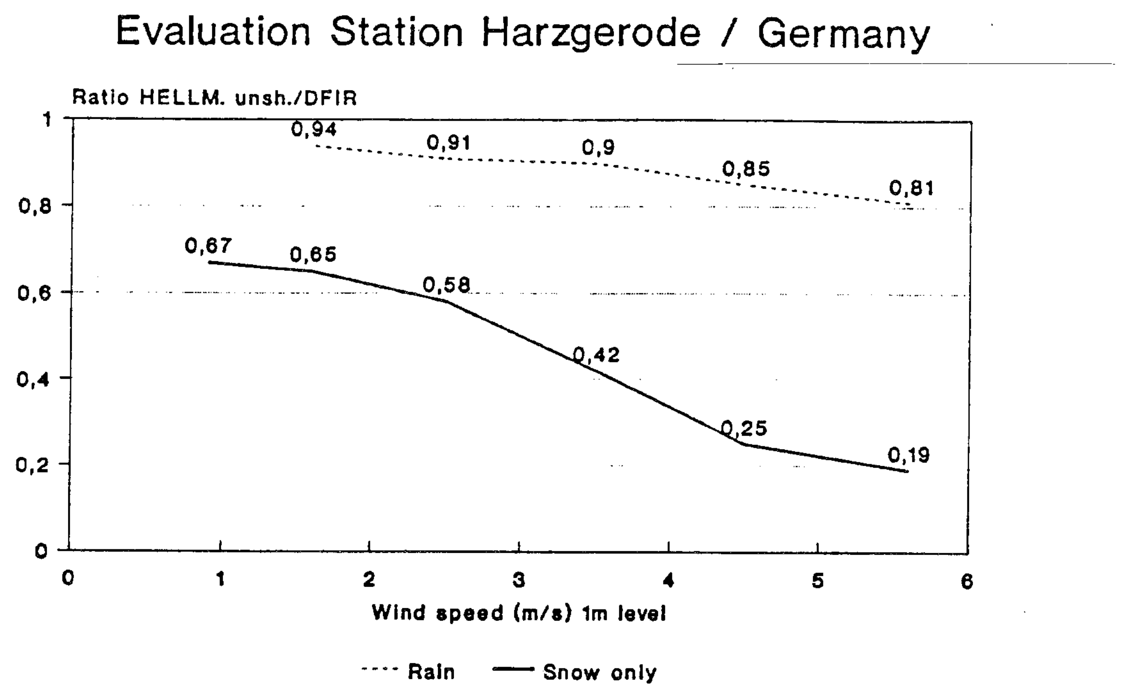

Fig.16: Gauge catch ratios HELLMANN unsh./DFIR in dependence on wind speed (1m level) Dec. - March (1986-1992)

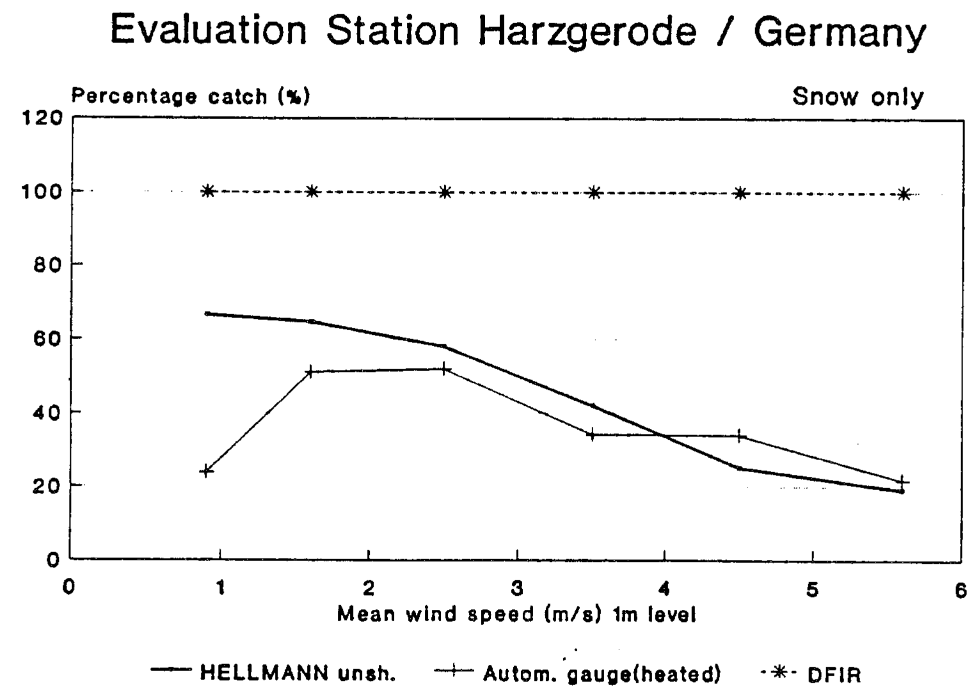

Fig.17: Percentage catch (%) of the HELLMANN unsh. and the Autom. gauge(heated), Snow only, Reference gauge: DFIR = 100% Dec. - March (1986-1992)

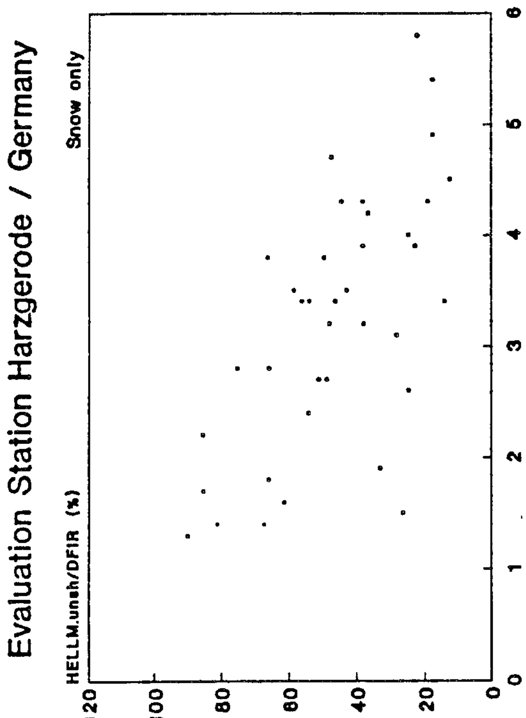

Fig.18: Percentage catch (%) of the HELLMANN unsh. in dependence on wind speed (DFIR ≥ 2.0 mm) Dec. - March (1986-1992)

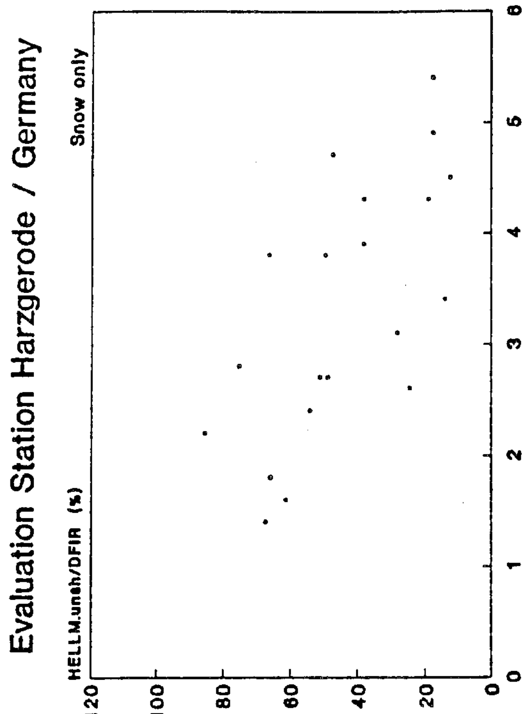

Fig.19: Percentage catch (%) of the HELLMANN unsh. in dependence on wind speed (DFIR ≥ 5.0 mm) Dec. - March (1986-1992)

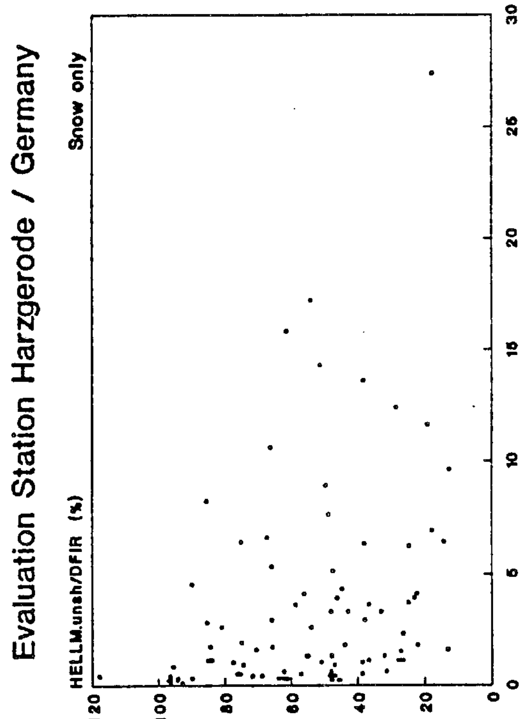

Fig.20: Percentage catch (%) of the HELLMANN unsh. in dependence on daily total (DFIR,mm) Dec. - March (1986-1992)

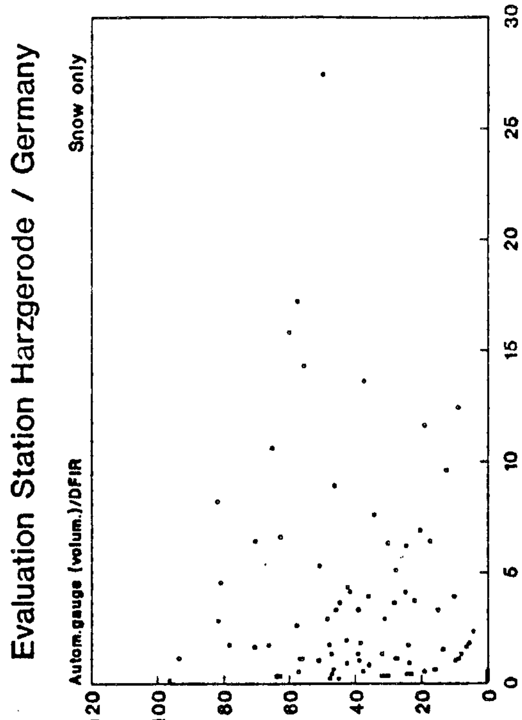

Fig.21: Percentage catch (%) of the Autom.gauge(volum.) in dependence on daily total (DFIR,mm) Dec. - March (1986-1992)

Table : 1

Evaluation Station Harzgerode / Germany
Precipitation totals (mm) and percentage catch of the comparison gauges

Reference gauge : DFIR = 100%

Type of precipitation	Precipitation totals						Number of cases	Precipitation in percent				
	DFIR	TRET	HELLM. unsh.	HELLM. sh.	Autom. gauge	METRA		TRET	HELLM. unsh.	HELLM. sh.	Autom. gauge	METRA
Month : December 1986-1991												
Snow	29.0	18.3	15.8	20.5	10.8	13.1	20	63.1	54.5	70.7	37.2	45.2
Snow with rain	101.7	67.8	59.1	73.1	54.5	49.5	20	66.7	58.1	71.9	53.6	48.7
Rain with snow	152.2	131.6	128.9	132.5	125.0	116.3	26	86.5	84.7	87.1	82.1	76.4
Rain	165.8	140.6	143.9	150.4	140.5	133.8	58	84.8	86.8	90.7	84.7	80.7
All types of precipitation	448.7	358.3	347.7	376.5	330.8	312.7	124	79.9	77.5	83.9	73.7	69.7
Month : January 1987-1992												
Snow	68.1	37.8	30.3	43.1	22.8	25.1	20	55.5	44.5	63.3	33.5	36.9
Snow with rain	64.3	49.0	43.7	49.9	40.3	36.8	15	76.2	68.0	77.6	62.7	57.2
Rain with snow	60.5	48.3	50.3	51.9	48.0	42.4	19	79.8	83.1	85.8	79.3	70.1
Rain	106.0	84.4	89.6	92.3	88.3	80.5	58	79.6	84.5	87.1	83.3	75.9
All types of precipitation	298.9	219.5	213.9	237.2	199.4	184.8	112	73.4	71.6	79.4	66.7	61.8
Month : February 1987-1992												
Snow	127.8	73.9	49.1	74.5	51.8	43.7	31	57.8	38.4	58.3	40.5	34.2
Snow with rain	87.6	54.7	53.1	64.2	46.5	43.2	21	62.4	60.6	73.3	53.1	49.3
Rain with snow	111.2	86.7	85.2	92.4	82.7	77.8	25	78.0	76.6	83.1	74.4	70.0
Rain	54.2	43.7	46.0	48.0	44.2	42.5	33	80.6	84.9	88.6	81.5	78.4
All types of precipitation	380.8	259.0	233.4	279.1	225.2	207.2	110	68.0	61.3	73.3	59.1	54.4
Month : March 1987-1992												
Snow	90.7	58.0	48.5	62.2	44.7	38.8	28	63.9	53.5	68.6	49.3	42.8
Snow with rain	46.3	26.6	27.3	31.9	26.7	20.3	13	57.5	59.0	68.9	57.7	43.8
Rain with snow	116.5	98.0	96.3	100.5	95.6	88.5	23	84.1	82.7	86.3	82.1	76.0
Rain	145.6	123.9	128.7	131.5	124.1	121.0	47	85.1	88.4	90.3	85.2	83.1
All types of precipitation	399.1	306.5	300.8	326.1	291.1	268.6	111	76.8	75.4	81.7	72.9	67.3
Month : December-March 1986-1992												
Snow	315.6	188.0	143.7	200.3	130.1	120.7	99	59.6	45.5	63.5	41.2	38.2
Snow with rain	299.9	198.1	183.2	219.1	168.0	149.8	69	66.1	61.1	73.1	56.0	49.9
Rain with snow	440.4	364.6	360.7	377.3	351.3	325.0	93	82.8	81.9	85.7	79.8	73.8
Rain	471.6	392.6	408.2	422.2	397.1	377.8	196	83.2	86.6	89.5	84.2	80.1
All types of precipitation	1527.5	1143.3	1095.8	1218.9	1046.5	973.3	457	74.8	71.7	79.8	68.5	63.7

Table : 2

Evaluation Station Harzgerode / Germany
Precipitation totals (mm) December - March 1986-1992

Type of precipitation : Snow

Daily totals of prec.(mm)	Number of cases	DFIR	TRET	HELLM. unsh.	HELLM. sh.	Autom. gauge	METRA
.1 - .5	30	9.6	6.8	7.1	9.0	2.5	5.8
.6 - 1.0	10	8.0	5.0	4.8	6.4	2.5	3.5
1.1 - 2.0	21	29.9	17.2	15.7	20.9	11.4	11.4
2.1 - 5.0	18	61.7	36.5	29.7	42.0	24.3	24.1
5.1 - 10.0	12	83.5	47.1	37.4	52.7	33.2	34.0
10.1 - 100.0	8	122.9	75.4	49.0	69.3	56.2	41.9
.1 - 100.0	99	315.6	188.0	143.7	200.3	130.1	120.7

Type of precipitation : Snow with rain

Daily totals of prec.(mm)	Number of cases	DFIR	TRET	HELLM. unsh.	HELLM. sh.	Autom. gauge	METRA
.1 - .5	12	3.7	3.3	3.2	4.3	1.5	2.8
.6 - 1.0	7	5.6	1.9	2.5	3.4	2.1	1.7
1.1 - 2.0	9	13.6	8.4	7.8	9.7	5.8	6.6
2.1 - 5.0	20	70.5	50.8	49.3	57.2	45.6	39.9
5.1 - 10.0	14	106.9	64.3	56.9	72.3	51.5	46.2
10.1 - 100.0	7	99.6	69.4	63.5	72.2	61.5	52.6
.1 - 100.0	69	299.9	198.1	183.2	219.1	168.0	149.8

Type of precipitation : Rain with snow

Daily totals of prec.(mm)	Number of cases	DFIR	TRET	HELLM. unsh.	HELLM. sh.	Autom. gauge	METRA
.1 - .5	12	2.8	2.3	2.8	2.9	2.2	2.4
.6 - 1.0	10	7.7	4.9	5.8	6.9	5.1	4.5
1.1 - 2.0	11	17.7	13.4	14.3	15.0	13.0	12.5
2.1 - 5.0	33	110.7	88.9	91.0	96.6	83.6	76.0
5.1 - 10.0	15	109.5	93.1	90.1	93.6	89.1	81.2
10.1 - 100.0	12	192.0	162.0	156.7	162.3	158.3	148.4
.1 - 100.0	93	440.4	364.6	360.7	377.3	351.3	325.0

Type of precipitation : Rain

Daily totals of prec.(mm)	Number of cases	DFIR	TRET	HELLM. unsh.	HELLM. sh.	Autom. gauge	METRA
.1 - .5	73	16.2	13.0	17.1	19.7	8.4	14.0
.6 - 1.0	29	22.1	15.8	17.9	19.4	13.7	15.5
1.1 - 2.0	31	47.1	36.7	39.7	41.6	37.4	35.4
2.1 - 5.0	36	120.4	101.7	104.7	107.4	102.3	95.6
5.1 - 10.0	19	138.0	114.3	118.7	121.6	122.1	111.7
10.1 - 100.0	8	127.8	111.1	110.1	112.5	113.2	105.6
.1 - 100.0	196	471.6	392.6	408.2	422.2	397.1	377.8

All types of precipitation

Daily totals of prec.(mm)	Number of cases	DFIR	TRET	HELLM. unsh.	HELLM. sh.	Autom. gauge	METRA
.1 - .5	127	32.3	25.4	30.2	35.9	14.6	25.0
.6 - 1.0	56	43.4	27.6	31.0	36.1	23.4	25.2
1.1 - 2.0	72	108.3	75.7	77.5	87.2	67.6	65.9
2.1 - 5.0	107	363.3	277.9	274.7	303.2	255.8	235.6
5.1 - 10.0	60	437.9	318.8	303.1	340.2	295.9	273.1
10.1 - 100.0	35	542.3	417.9	379.3	416.3	389.2	348.5
.1 - 100.0	457	1527.5	1143.3	1095.8	1218.9	1046.5	973.3

Table : 3

Evaluation Station Harzgerode / Germany
Percentage catch of the comparison gauges in dependence on wind speed (1m level) and type of precipitation
December-March 1986-1992

Mean wind speed (m/sec)	Number of cases	Mean air temp. (°C)	DFIR total (mm)	TRET/DFIR %	HELLM/DFIR unsh. %	HELLM./DFIR sh. %	Autom./DFIR gauge %	METRA/DFIR %
	Type of precipitation : Snow							
.0 - 1.0	4	-9.2	2.1	85.7	66.7	90.5	23.8	57.1
1.1 - 2.0	29	-6.3	61.5	81.0	64.7	85.4	51.2	57.2
2.1 - 3.0	28	-3.7	76.3	69.5	58.2	71.8	52.0	49.1
3.1 - 4.0	25	-2.7	85.0	49.5	42.1	62.8	34.1	33.2
4.1 - 5.0	11	-2.0	79.7	48.1	25.3	41.8	33.9	21.1
5.1 - 20.0	2	.6	11.0	27.3	19.1	40.0	21.8	16.4
.0 - 20.0	99	-4.2	315.6	59.6	45.5	63.5	41.2	38.2
	Type of precipitation : Snow with rain							
.0 - 1.0	1	-2.0	9.2	68.5	63.0	84.8	50.0	44.6
1.1 - 2.0	16	-1.9	74.1	84.3	79.2	88.7	71.5	69.1
2.1 - 3.0	20	-.8	48.3	70.8	66.3	80.7	54.0	52.4
3.1 - 4.0	11	.5	63.2	62.8	57.9	67.9	53.8	45.9
4.1 - 5.0	14	.6	63.6	53.1	48.1	62.3	47.5	37.7
5.1 - 20.0	7	1.2	41.5	52.0	47.0	58.1	48.4	39.0
.0 - 20.0	69	-.4	299.9	66.1	61.1	73.1	56.0	49.9
	Type of precipitation : Rain with snow							
.0 - 1.0	1	-4.0	.1	100.0	100.0	100.0	100.0	200.0
1.1 - 2.0	11	.3	33.9	89.7	84.7	90.9	73.2	78.2
2.1 - 3.0	12	1.3	43.2	85.2	84.5	89.6	79.6	75.7
3.1 - 4.0	35	2.0	149.8	84.2	83.0	86.4	79.7	76.2
4.1 - 5.0	22	2.5	103.7	81.5	84.9	86.2	83.4	73.8
5.1 - 20.0	12	3.5	109.7	78.9	75.7	80.9	78.5	68.4
.0 - 20.0	93	2.0	440.4	82.8	81.9	85.7	79.8	73.8
	Type of precipitation : Rain							
.0 - 1.0	3	-1.1	1.6	93.8	75.0	93.8	31.3	75.0
1.1 - 2.0	50	2.0	52.3	88.5	92.9	98.3	76.1	85.5
2.1 - 3.0	50	3.3	83.7	87.2	90.8	93.7	83.8	84.5
3.1 - 4.0	34	5.5	98.8	87.7	89.9	92.4	86.8	83.1
4.1 - 5.0	34	5.1	91.8	80.9	84.6	87.0	85.3	80.0
5.1 - 20.0	25	5.5	143.4	77.3	80.8	83.5	85.5	73.7
.0 - 20.0	196	3.9	471.6	83.2	86.6	89.5	84.2	80.1

Table : 4

Evaluation Station Harzgerode / Germany
Mean values of the percentage catch and losses in various classes of depth of precipitation

Gauge: Hellmann, unshielded Reference: DFIR

Snow only

class (mm)	Number of cases	Mean of the class (mm)	Mean percentage catch (%)	Standard deviation	losses/class mm of the total	%
0.1 - 0.5	30	0.32	74	23	2.5	26
0.6 - 1.0	10	0.80	60	21	3.2	40
1.1 - 2.0	21	1.42	53	24	14.2	47
2.1 - 5.0	18	3.24	48	21	32.0	52
5.1 - 10.0	12	6.96	45	25	46.1	55
10.1 -100.0	8	15.36	40	19	73.9	60
0.1 -100.0	99	3.19	46	26	171.9	54

Mixed prec. (SR,RS)

0.1 - 0.5	24	0.27	92	32	0.5	8
0.6 - 1.0	17	0.78	62	22	5.0	38
1.1 - 2.0	20	1.57	71	22	9.2	29
2.1 - 5.0	53	3.42	77	15	40.9	23
5.1 - 10.0	29	7.46	68	22	69.4	32
10.1 -100.0	19	15.35	76	16	71.4	24
0.1 -100.0	162	4.57	73	31	196.4	27

Gauge: Automatic gauge (volumetric measurement) Reference: DFIR

Snow only

0.1 - 0.5	30	0.32	26	26	7.1	74
0.6 - 1.0	10	0.80	31	16	5.5	69
1.1 - 2.0	21	1.42	38	24	18.5	62
2.1 - 5.0	18	3.24	39	21	37.4	61
5.1 - 10.0	12	6.96	40	22	50.3	60
10.1 -100.0	8	15.36	46	21	66.7	54
0.1 -100.0	99	3.19	41	23	185.5	59

Mixed prec. (SR,RS)

0.1 - 0.5	24	0.27	57	61	2.8	43
0.6 - 1.0	17	0.78	54	28	6.1	46
1.1 - 2.0	20	1.57	60	24	12.5	40
2.1 - 5.0	53	3.42	71	18	52.0	29
5.1 - 10.0	29	7.46	65	23	75.8	35
10.1 -100.0	19	15.35	75	17	71.8	25
0.1 -100.0	162	4.57	70	31	221.0	30

Table : 5

Evaluation Station Harzgerode / Germany
Results of the regression analysis - SNOW ONLY
Dec. - March (1986-1992) - Totals per day (DFIR ≥ 2.0mm); n = 38

Y1 : HELLMANN unsh. / DFIR
Y2 : HELLMANN sh. / DFIR
Y3 : AFMS2 / DFIR
Y4 : TRETYAKOV / DFIR

V1, V10 : wind speed (1m, 10m level);
P : precipitation depth; D : precipitation duration;
T : air temperature; I : intensity of precipitation

Y1 = -0.101 V10 + 0.028 T + 1.108 (r^2 = 0.59)
Y2 = -0.095 V10 + 0.023 T + 1.249 (r^2 = 0.66)
Y3 = -0.139 V1 + 0.030 T + 0.961 (r^2 = 0.44)
Y4 = -0.098 V10 + 0.019 T + 1.191 (r^2 = 0.58)

Y1 = -0.089 V10 + 0.019 T - 0.013 D + 1.201 (r^2 = 0.66)
Y2 = -0.091 V10 + 0.022 T - 0.005 P + 1.262 (r^2 = 0.66)
Y3 = -0.080 V10 + 0.029 T + 0.256 I + 0.813 (r^2 = 0.60)
Y4 = -0.097 V10 + 0.018 T - 0.001 D + 1.196 (r^2 = 0.60)

Table : 6

Evaluation Station Harzgerode / Germany
Results of the regression analysis - MIXED PREC. (SR,RS)
Dec. - March (1986-1992) - Totals per day (DFIR ≥ 2.0mm); n = 104

Yi; V1; V10; P; D; I; T see Table 5

Y1 = -0.047 V10 + 0.061 T + 0.955 (r^2 = 0.41)
Y2 = -0.040 V10 + 0.037 T + 1.017 (r^2 = 0.36)
Y3 = -0.029 V10 + 0.068 T + 0.791 (r^2 = 0.37)
Y4 = -0.045 V10 + 0.042 T + 0.980 (r^2 = 0.37)

Y1 = -0.048 V10 + 0.060 T - 0.004 D + 1.014 (r^2 = 0.43)
Y2 = -0.040 V10 + 0.036 T - 0.004 D + 1.070 (r^2 = 0.38)
Y3 = -0.031 V10 + 0.067 T + 0.070 I + 0.767 (r^2 = 0.40)
Y4 = -0.044 V10 + 0.043 T + 0.004 D + 0.930 (r^2 = 0.40)

PRELIMINARY RESULTS OF WMO SOLID PRECIPITATION MEASUREMENT INTERCOMPARISON AT TIANSHAN GLACIOLOGICAL STATION, XINJIAN, CHINA

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INTRODUCTION

Correction of precipitation measurement, particularly snowfall measurement, is widely recognized in hydrology and glaciology studies recently in China. During 1978 to 1985, fifty-five hydrological stations across China had been involved in a precipitation measurement project initiated by the National Hydrological Bureau of Water Resources Administration (Chen, et al., 1989). In this project, ground level gauge and Chinese standard gauge at various heights were compared in rainfall measurements. In 1987, Tianshan Glaciological Station of Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, participated in the WMO Solid Precipitation Measurement Intercomparison (WMO/CIMO, 1986) and started precipitation measurement experiment at 6 hydrological and climatic stations situated from the high alpine glacier area to the low land of Urumqi city in Urumqi river basin in Tainshan Mountains. A WMO reference gauge (DFIR) was installed at the highest elevation site in the upper streams and Chinese standard gauge, Tretyakov wind shield and Hellmann gauges were used (Yang, et al., 1989). This report discusses the relation of Chinese standard gauge to the DFIR in the high mountains.

SITE AND INSTRUMENTATION

According to the record of Daxigou climatic station (43.06 N, 86.50 E; 3539m a.s.l.) in the source area of the river basin, the annual-averaged air temperature and annual total precipitation measured are -5.4 c and 420mm, respectively. Eighty percent of the total precipitation is concentrated in the period of May through August and because of the high altitude of the study area, 43% and 35% of the summer precipitation occur as wet snow and snow mixed with rain. Therefore, measuring precipitation in this area mostly deals with snowfall. In July 1987, an intercomparison site at the flat bottom (43.06 N, 87.15 E; 3720m a.s.l.) of the river valley in front of glacier No.1, surrounded by mountain hills in south and north directions, was selected. The instruments were installed as follows:

a) Chinese standard precipitation (rain and snow) gauge. It is a cylinder of galvanized iron, 65cm long and 20cm in diameter. The standard elevation of the gauge's orifice is 0.7 m, and no wind shield is used even in snowfall measurement. Two Chinese standard gauge were mounted at 0.7m and 2m at the site.

b) Hellmann gauge. One unshielded Hellmann (Switzerland) gauge was placed at 2m high above the ground during July to August 1987.

c) DFIR. A DFIR was set up at 2.5m high since the maximum snow depth in winter was less than 1m generally. A Chinese standard gauge shielded with a Tretyakov wind shield was placed within the double fences.

d) Screen. Air temperature and relative humidity were recorded automatically.

All the gauges were measured by volumetric method at 8:00 am each day. Unfortunately, wind speed measurement at this site was not available.

RESULTS

During July 1987 through August 1991, 230 daily precipitation greater than 2mm were collected. All gauge measurements are corrected for wetting loss, e.g. 0.35 mm/event for rainfall and 0.30 mm/event for snowfall, according to the wetting loss experiments of weighing method of Chinese standard gauge (Yang, et al., 1989). The knowledge of the accuracy of DFIR measurements is critical important for the intercomparison. Recently analysis of Russian Valdai intercomparison data at Canadian Climate Centre indicates the necessity of correcting DFIR measurements for the wind induced error (Yang, Metcalfe and Goodison, 1992). The study shows that the most important factor to the correction is mean wind speed during the storm and atmospheric pressure, air temperature and humidity have little or no influence. Unfortunately wind speed at the Tianshan site was not measured. Therefore, after investigating the similarity of wind pattern of nearby Daxigou climatic station to six Canadian intercomparison sites (Goodison and Metcalfe 1992), the correction ratio of 5.7% at Kortright was applied to the snow event at Tianshan and no wind correction was made to rainfall and rain mixed with snow cases (Tab.1).

Table 1 Summary of event data at Tianshan WMO intercomparison site

Type Precip.	Nr. of Event	CSG(.7m) Total	CSG(.7m) Ratio(%)	CSG(2m) Total	CSG(2m) Ratio(%)	DFIR Total(mm)
Rain	13	123.8	95.82	117.3	90.78	129.2
Rain+Snow	67	427.8	89.03	389.4	81.04	480.5
Wet Snow	112	847.5	83.62	788.1	77.76	1013.5
Dry Snow	38	198.4	72.62	187.3	68.56	273.2
All Types	230	1597.5	84.24	1482.1	78.15	1896.4

The catch ratio of the Chinese standard gauge changes significantly with type of precipitation. For the dry snow cases, on the average, Chinese gauge at 0.7m catches 72.3% of the DFIR. Snow survey in Dry Cirque watershed near the intercomparison site indicated that the average catch ratio of a Chinese gauge in the small basin was about 73% for dry snow measurements in the winter of 1989/1990 (Yang, et al., 1992). This result implies the appropriate correction of the DFIR measurement at the intercomparison site. Generally, the catch ratios of the Chinese gauge at 2m are 5 to 8% lower than that of the Chinese gauge at 0.7m.

SUMMARY

Although the relation of wind-induced error of the Chinese gauge to wind speed has not developed at this site, the intercomparison provides a possibility to approximately correct the measured precipitation of snow and rain in the specific high alpine area. This correction is extremely important to the regional glacier mass balance and hydrological studies. The intercomparison will continue to the summer of 1994 and wind speed at DFIR height will be measured in order to correct the daily and monthly precipitation data.In the late summer of 1994, the DFIR will be moved down to the Daxigou climatic station, where precipitation, air temperature and wind speed at 10m have been measured since 1958. A pit gauge will be set up for rainfall measurements. Chinese automatic raingauge, Tretyakov wind shield, Belfort recording gauge and other new instruments will be placed at the station. Weighing method will be used to determine the average amount of trace precipitation, since trace precipitation often occur in the area, for instance, 104 trace events were recorded in 1983.

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GENERAL MODEL OF WIND-INDUCED ERROR OF PRECIPITATION MEASUREMENT

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A common precipitation gauge is raised above ground to be protected against in-splash and drifting snow. The elevation heights differ according to country from 0.2 to 2 m. An elevated precipitation gauge distorts the wind field above the gauge orifice. Due to the adverse wind action, some of the lighter precipitation particles are borne away before reaching the gauge and are lost for the measurement. The wind-induced loss amounts to 2-10% for rain and up to 50% for snow, and even more in the mountains. The diversity of error magnitudes is caused by many variables. Yet under the same environmental and observational variables, the instrumental ones play the most important role. This is documented by the fact that precipitation amounts as measured at the same site by two different gauges are usually not the same. In this context, the following gauge parameters which affect the aerodynamical properties are to be noted: The use of the wind shield, the shape of the gauge body and the orifice rim, and the thickness of the orifice rim (Sevruk et al. 1993). Slight deviations of these parameters can cause changes in characteristics of the wind-field above the gauge orifice, and consequently different precipitation values.

The wind-induced losses are not considered in the published precipitation data and need to be corrected solely by the data users. Correction models are based mainly on field intercomparison measurements. The pit gauge is used as a reference for rain and the double fence gauge for snow. Because of different aerodynamics of gauges, the field tests should be repeated for each type of gauge.

A variety of correction models exists. They attempt to estimate the difference between the precipitation values from an elevated gauge and the reference gauge using the following variables; wind speed data as related to the gauge orifice level, and intensity of precipitation or air temperature during precipitation. The last two variables are used to parametrize the structure and the form of precipitation.

Recent references on correction methods can be found in the proceedings of two international workshops on precipitation measurement and correction (Sevruk 1986, 1989a). For earlier references see Rodda (1973) and Sevruk (1981). Sevruk (1989b) reviewed correction models based either on field or wind tunnel tests or results of mathematical simulation. He developed a correction model based on a graphical relationship of the percentage differences of precipitation amounts of the pit gauge and the elevated Hellmann gauge, and the average daily intensity of precipitation and wind speed. The model used precipitation intensity as an independent variable and produced a set of one parameter (wind speed) curves with increasing threshold value of intensity for increasing wind speed. The threshold values varied between 1.5 and 3.0 mmh^{-1} for wind speeds from 0.5 to 4 mmh^{-1}. Below the threshold values the wind-induced error increases quickly, above it the increase is slow. The existence of threshold value was implicitly confirmed by different authors as cited by Sevruk (1989b). He concluded that the threshold value presents an important characteristic of the wind-induced error and consequently, correction models should reflect the similar structure.

The aim of this paper is to show a further example of the threshold value found in the intercomparison precipitation measurements of two different types of gauges; the Hellmann gauge and the tipping-bucket gauge. The former is the manual Swiss standard gauge and the latter is used at 70 Swiss automatic meteorological stations.

Both gauges were installed at the end of the runway at the Geneva airport. The distance between the gauges was 1.5 m, the installation height 1.3 and 1.5 m above ground. A cross-section of gauges can be found in Sevruk et al. (1991). The gauge site was not protected against the wind. The wind measuring instrument was installed at a distance of roughly 30 m NE from the gauge on the roof of a small station building at the height of 9.8 m above ground.

The data used in the analysis consisted of daily amounts of liquid precipitation of the Hellmann gauge, hourly amounts of precipitation of the tipping-bucket gauge and hourly values of wind speed. All in all, 576 days of the period 1980-1885 were considered. The following days were eliminated from the analysis: (i) those showing daily amounts of precipitation as measured in at least one of the gauges as being less than 0.1 mm, (ii) those when no precipitation was observed in the Hellmann gauge, (iii) days when the difference between daily precipitation amounts was greater than 60 %, (iv) days when the tipping-bucket gauge registered greater amounts than the Hellmann gauge (in total less than 30 days) and (v) days with snow (air temperature during precipitation was less than 2°C).

The analysis was the same as reported by Sevruk (1989b). The daily amount of precipitation was subdivided according to the average of daily intensity, in mmh^{-1}, into six classes as follows: 0.0-0.3; 0.3-0.6; 0.6-0.9; 0.9-1.2; 1.2-1.5 and greater than 1.5 mmh^{-1}. The average of daily intensity was defined as the total amount of precipitation of the tipping-bucket gauge, occurring during the 24-hr interval and divided by the total daily duration of precipitation, in hours. Each class was further subdivided into three classes of average wind speed, in ms^{-1}, during precipitation as follows: 0-2; 2-4 and greater than 4 ms^{-1}. The average class difference of precipitation amounts of the Hellmann gauge and the tipping-bucket gauge was expressed in percent of the amount of the Hellmann gauge. Its value for a particular intensity class was plotted separately for each class of wind speed, and fitted through a curve laid by hand. Thus the plot incorporated three one-parameter curves relating the percentage difference to intensity for a particular class of wind speed.

The plot is shown in Figure 1. The points as fitted by hand produce a set of three curves, each for an average class wind speed of 1.3; 2.9 and 5.3 ms^{-1} with increasing threshold of intensity for increasing wind speed with respective values of 1.25; 1.70 and 2.0 mmh^{-1}. The plot indicates some scatter, mainly for stronger winds. It is partly due to the relatively great wind speed intervals used in the classes, of at least 2 ms^{-1}. Despite the scatter, the overall tendency of differences is obvious. They increase with decreasing intensity and increasing wind speed. Below the threshold value and despite the practically unchanged wind speed a sharp increase of differences exists with decreasing intensity for each wind speed interval. Above the threshold value there is only a small effect of intensity and all three curves appear to run parallel.

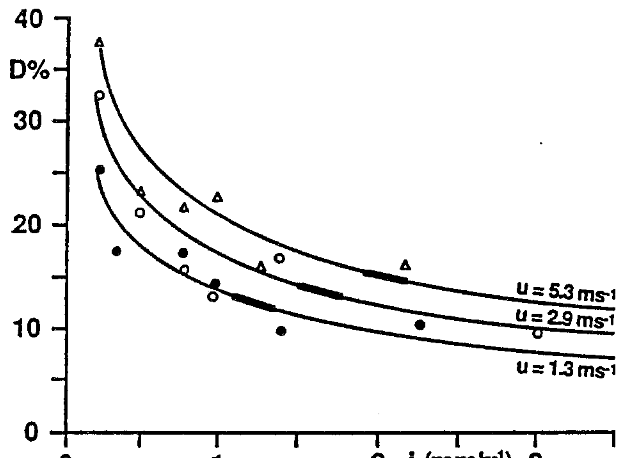

Figure 1 Plot of percentage difference, D%, between the precipitation values of the Hellmann gauge and the tipping-bucket gauge against precipitation intensity, i, for three wind speeds. Short and thick lines indicate threshold values of intensity i, below which the difference starts to increase more sharply. Class averages are based on 576 daily values from Geneva Airport, 1980-1985.

The diagrams in Figure 1 are similar to those as derived by Sevruk (1989b) for the differences of precipitation values between the Hellmann gauge and the pit gauge (reference). Yet the differences between the Hellmann gauge and the tipping-bucket gauge as presented here are essentially greater and the threshold values smaller and less obvious. The reason for the greater difference can be the thicker orifice rim of the tipping-bucket gauge and the use of bird-protecting ring on this gauge (Sevruk et al. 1992, 1993). The wind tunnel tests of both types of gauges by Sevruk et al. (1991) showed that the wind speed increase above the orifice of the tipping-bucket gauge was considerably greater as compared with the Hellmann gauge.

The previous study by the first author (Sevruk 1989b) showed that the correction model of wind-induced error of precipitation measurement had the same form as presented here. This indicates the general application of models of this type to estimate the wind effect on precipitation measurements. It can be also used to adjust inhomogeneous precipitation time series due to exchange of different types of precipitation gauge. More systematical investigations are needed to explain the variability of threshold values on physical grounds.

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PRECIPITATION GAUGE PARAMETERS AFFECTING THE WIND-INDUCED ERROR

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Precipitation measurement is plagued by a number of systematic errors mainly due to evaporation, wetting and wind. The latter originates in wind-field deformation above elevated precipitation gauge, PG, which acts as an obstacle to free airflow. It causes aerodynamical blockage, resulting in rising and accelerating airflow over the PG orifice. Consequently, a part of the small precipitation particles is taken away before it reaches the PG orifice and instead of falling into the gauge, it falls to the ground. Such a loss amounts to 2-10% for rain and up to 50% for snow.

The wind-induced loss depends on a variety of factors. Of the instrumental ones, the use of wind-shielding devices which help to reduce wind speed above the PG orifice is most important. In addition, it is the shape of the PG body and orifice rim as well as the thickness of orifice rim. Previous to the present paper, Sevruk et al. (1989) found in the wind tunnel, the maximum increase of wind speed above the centre of orifice of PGs of various design but without wind shield from 32% to 48%, and it was not quite clear what the real reason is for such a considerable disparity. The orifice area varied between 127 and 500 cm^2. There were also considerable differences concerning the size and shape of orifice rim.

The present paper focusses on the effect of the changing thickness of orifice rim on the wind speed acceleration above the gauge orifice as investigated in the wind tunnel.

Two groups of three similar models of PGs have been made from plastic and wood. In one group, there were PGs with a thin orifice rim and in other with a thick one. The shape and the slope of orifice rims and the height of PGs were always the same, but the orifice areas of three models were different, still having the same graduation in each group of 113 cm^2, 189 cm^2 and 290-300 cm^2, so that for each size of orifice area, paired PGs existed where one had a thin orifice rim and the other a thick one. In this way, it was possible to separate the effects of orifice rim thickness and area on wind speed acceleration.

The wind profiles were situated always inside the orifice rim windward and leeward and at the centre, all in the plane parallel to the direction of wind.

Typical wind profiles for PGs with thick and thin orifice rims but the same orifice areas are compared in Figure 1. Beside generally smaller values of maximum wind speed for PGs with the thin orifice rim, all wind profiles in this case look like being shifted slightly upwards.

The sudden increase of wind speed above the orifice rim from the minimum to the maximum over a vertical distance of a few millimetres is for example, one of the characteristic features of windward profiles.

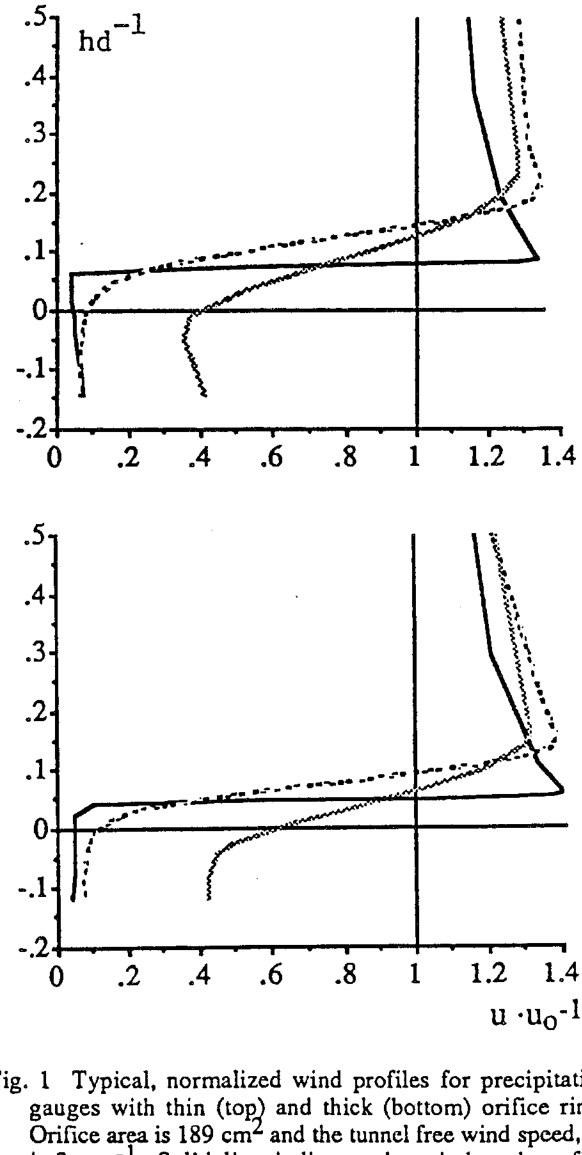

Fig. 1 Typical, normalized wind profiles for precipitation gauges with thin (top) and thick (bottom) orifice rims. Orifice area is 189 cm^2 and the tunnel free wind speed, u_o is 3 m s^{-1}. Solid line indicates the windward profile, dashed line the centre and dense point line the leeward profile. h indicates height above the orifice, d is diameter of orifice and u is profile wind speed.

The rate of increase of wind speed is smaller mainly for leeward profiles which starts at the level of orifice rim with considerably greater wind speed but does not reach the maximum values of windward and centre profiles.

Typical differences appear between the wind profiles situated in different positions, windward and leeward of orifice rim and above the centre, but the course of wind profiles is almost the same at the same position regardless of the orifice rim thickness.

It seems that with increasing horizontal distance from the windward orifice rim to the centre and further to the leeward, the wind speed at the level of orifice is increasing and the maximum profile wind speed, u_{max}, decreasing. The maximum increase is greater for thick orifice rims, that is 37% vs. 31%. The smallest values have always been measured for the leeward profiles, that is 30% vs. 27%.

The above-mentioned effect is evident also in cases where PGs are compared which have approximately the same outer diameter but different thickness of orifice rims. The respective values of u_{max} are 33 vs. 36% and 32 vs. 38%. A subdivision according to the size of the orifice area indicates that since the value of u_{max} also increases with increasing orifice area mainly above the centre, the increase is generally small and diminishing for the windward profiles and in fact not existent for the leeward ones. Moreover, the plot of the above-mentioned results in Figure 2 shows that the effect of orifice area is greater for thin orifice rims than for thick ones and grows stronger for small wind speed (2 m s^{-1}).

The results of study reveal some basic principles of the physics of precipitation gauges. Generally, thick orifice rims or bigger orifice areas can cause greater acceleration of wind speed first of all for profiles situated windward of the orifice rim or above the centre of orifice.

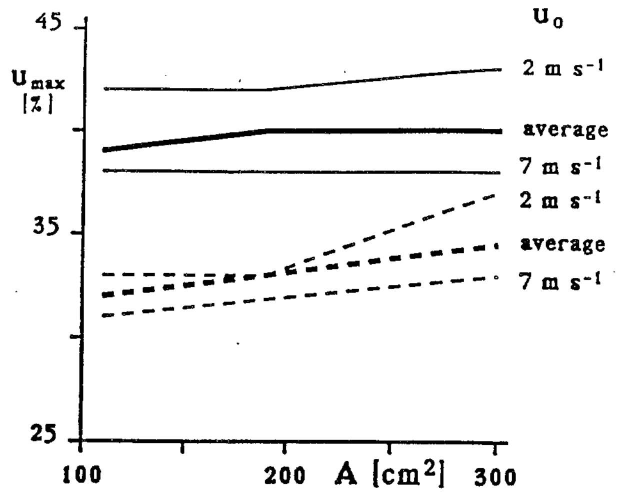

Fig. 2 Dependency of maximum wind speed increase, u_{max}, above the centre of precipitation gauge orifice on the thickness of orifice rim, the size of orifice area, A, and the tunnel free wind speed, u_o: Solid lines indicate thick orifice rim and dashed lines thin orifice rim. Fine lines indicate the dependency for a given u_o value as shown on the right.

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ACCURACY OF ASSESSMENT OF PRECIPITATION GAUGE SITE EXPOSURE CHANGES USING METADATA

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The wind-induced error of precipitation measurement at a particular site depends on more variables. The degree of protection of gauge site from the wind is especially important because precipitation gauges are installed outdoors under different conditions, in cities, airfields, gardens, parks, woods, mountains, lakeshores, etc. Thus the surrounding terrain and objects can provide different degrees of protection from the wind. The wind speed at the orifice level of a protected gauge can be reduced to one third of the value of a nearby situated, but exposed gauge. The resulting wind-induced error can differ considerably. For instance, it amounts to 2% for a protected site and to 5% for an exposed one in the summer at the altitude of 600 m a.s.l. in Switzerland. The respective figures for the winter are 7% vs. 18%. At higher altitudes the differences are even greater. Nevertheless, the gauge site exposure, GSE, was not measured in the past and is still not measured by many national meteorological services at present. There do exist indeed some recommendations for the installations of precipitation gauges with respect to the surrounding objects, but as pointed out by Sevruk (1973), they differ considerably according to the country and the author. In addition, they are practically not followed and not sufficient at all.

The GSE problem arises from the fact that the available wind speed values are routinely measured by national meteorological services at heights well above the tops of the surrounding obstacles, that is, at heights of more than 10 m above ground and not at the level of the precipitation gauge orifice. Thus the wind speed values at hand have to be reduced to the level of gauge orifice, if they are to be used for the aims of estimation of wind-induced error. The reduction of wind speed at the open sites can be made by using the simple logarithmic wind profile. Naturally, this wind profile would result in too high values for gauge sites surrounded by obstacles. The excess will depend on the situation, the density and the heights of the obstacles. To express this objectively and quantitatively, the average vertical angle α of obstacles can be applied as shown by Sevruk and Zahlavova (1993). Usually α is measured in eight directions of the wind rose using a simple optical instrument (meridian) or theodolit. More complex information can be obtained by taking a picture at the level of gauge orifice with a camera fitted with a fish-eye lens.

For the assessment of α at sites where its direct measurements are missing or are no more possible a classification of GSE was suggested by Sevruk and Zahlavova (1992). It consists of four classes 1-4 and three interim classes 1.5, 2.5 and 3.5. The classes are characterized by α as follows: Class 1 - open site (α = 0 - 5°; class 2 - partly open (α = 6 - 12°); class 3 - partly protected (α = 13 - 20°) and class 4 - protected site (α = 21 - 27°). The respective values of α for classes of 1.5, 2.5 and 3.5 are 6, 13 and 18°. In Figure 1 the four basic classes are presented in a series of drawings. The length of arrow indicates the magnitude of wind speed, u, at the level of gauge orifice and P is the precipitation amount as measured in the gauge. Figure 1 enables a conception of how a particular GSE class should look. The open site is characterized by small bushes or obstacles, and only a small group of trees. The houses are in a distance of 100 - 300 m from the gauge. Usually such sites are situated on heights, windward slopes, table-lands, passes, airfields, lakeshores, coasts, islands, in long, channelled valleys and at high altitudes. At partly open sites, there are small groups of trees or bushes or one or two small buildings. They are situated in sports places or in gardens with vegetables and flowers. Partly protected sites are to be found in parks, forest edges, village centres, farms, groups of houses, or between factory buildings. In contrast, protected sites are situated in young forests, small forest clearings, parks with big trees, city centres, closed deep valleys, strongly rugged terrain, leeward of big hills, etc.

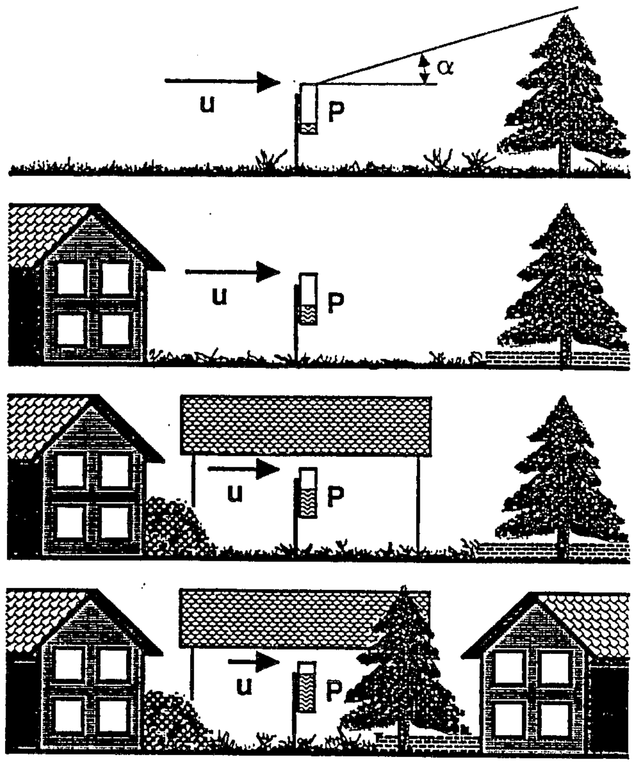

Fig. 1 From the top: Open site, partly open site, partly protected site and protected site.

The present paper suggests an indirect method of assessment of GSE classes from the station history records and compares the results with direct measurements of α in field to assess the accuracy of GSE class estimates.

The assessment of GSE classes is based on photos, sketches and written reports of gauge sites as found in the archives of the national meteorological service. The assessment was carried out by three different persons: an inexperienced student, a partly experienced, young assistant and an experienced, older assistant, two of them geographers and one a civil engineer trained in hydrology. All three persons received a brief introduction to the problem. The student started his work immediately after, without any more advice and supervising. In contrast, both assistants were carefully advised and trained on examples through the first day and consulted during the trial. The student was advised to work very quickly during no more than two days. In that short time he checked a 10-year period of 50 sites for GSE. In the case of the young and older assistants only the estimates of GSE classes were considered in the analysis, which were made after two weeks and two months of work, respectively. The results of all three persons have been compared with GSE classes as estimated from the measured values of α for the same gauge sites and the same time period. Here, the angle α was measured along the eight directions of the wind rose by an optical instrument posed immediately above the gauge orifice and averaged.

Results indicate that the degree of experience can have a considerable effect on the accuracy of GSE estimates, but the average difference is in general rather small, as can be seen from Table 1. The difference on average amounts to less than ± 2/3 of the class for an inexperienced student; ± 1/2 of the class for a less experienced young assistant, and approximately ± 1/3 of the class for an experienced, older assistant. It amounts to less than ± 4 degrees of the vertical angle α of obstacles. Small differences equal to or less than ±1/2 of class occurred in more than 80-90 percent of events in the case of experienced assistants, particularly for the more experienced one. The inexperienced student made greater errors. The differences of ± 3/4 of class were more frequent (50% of event), up to 2 classes (1 event out of 50). Moreover, almost 20 percent of all differences showed magnitudes between 1 and 2 classes (Table 1).

Table 1 Frequency and average values of differences between assessed and measured exposure classes.

Difference	Inexperienced student		Experienced assistants			
			young		older	
[class]	absolute	[%]	absolute	[%]	absolute	[%]
0	5	10	1	6	9	40
± 1/4	11	22	6	35	6	26
± 1/2	10	20	7	41	6	26
± 3/4	14	28	1	6	1	4
± 1	5	10	1	6		
± 1 1/4	2	4				
± 1 1/2	1	2			1	4
± 1 3/4	1	2	1	6		
± 2	1	2				
Σ	50	100	17	100	23	100
Average	± 2/3		± 1/2		± 1/3	

The relative high accuracy of the GSE class estimates from the station history of trained personnel of less than one half of GSE class out of four, shows the practicability of the suggested method. Brown and Peck (1962), who developed a qualitative classification system of GSE, pointed out that two meteorologists who have had the opportunity to discuss and jointly classify several gauge sites will not usually vary more than one category out of seven. This conforms with the result obtained in the present study.

Generally, the accuracy of GSE class estimates depends primarily on the quality and completeness of the station history records. The best estimates are possible in cases where there is a series of pictures of the gauge site taken from various sectors by different persons in consecutive years, complemented by drawings and written reports on the site peculiarities, noting possible effects of the surrounding objects on GSE. Even in such a case errors can still occur, when the α values of adjoining sectors vary considerably. Further possible error sources are pictures taken from the sectors which seem more to reflect the investigator's concept of how the GSE should appear, rather than the reality.

The trials showed that the assessment of precipitation gauge site exposure from the station history records by a trained person is sufficiently accurate. The accuracy can be increased when the assessment is made by the inspector who frequently visited gauge sites and when the history records are correct and complete. The suggested classification of exposure is suitable for the solution of a lot of practical problems, such as the correction of wind-induced error of precipitation measurement as shown in paper by Sevruk et al. (1993) in this volume or detection of inhomogenities of precipitation time-series (Sevruk and Zahlavova, 1992).

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Sevruk, B., W. Kirchhofer, R. Tihlarik and L. Zahlavova, 1993. 'Swiss map of precipitation corrections'. (See this volume).

SWISS MAP OF PRECIPITATION CORRECTIONS

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Corrections of the systematic error of precipitation measurement are essential for the following reasons. Precipitation is measured by can-type instruments installed above the ground and acting as an obstacle to air flow. At the same time, smaller and lighter precipitation particles-are borne away from the orifice of the precipitation gauge, and thus are withheld from measurement (Sevruk and Tettamanti 1993). Moreover, part of the precipitation adheres to the inner surfaces of the precipitation gauge and part of it evaporates. These losses need to be corrected and are not yet considered in the published precipitation data.

This paper focusses on the estimation of corrections with the aim of their mapping over a territory of Switzerland. The map of corrections is a part of the Swiss Hydrological Atlas. It shows the spatial distribution of absolute correction values of annual precipitation for the period 1951-1980 at a scale of 1:500.000 (Sevruk and Kirchhofer, 1992) and it was also used to correct the annual precipitation for the Swiss precipitation map (Kirchhofer and Sevruk, 1992). The corrections are calculated from the difference between corrected and uncorrected values of precipitation interpolated on a grid of 1 km x 1 km. Only wetting and wind-induced losses have been considered.

The correction methods are based on simplified physical concepts as presented earlier by Sevruk (1986). It is of prime importance to consider whether or not the precipitation gauge is equipped with a wind shield to reduce wind influence, and whether all the variables required for the correction are available at the gauging site. Thus the correction methods depend on the type of precipitation gauge and the measurement station; although climatological and precipitation stations are fitted with the same Hellmann precipitation gauge, they differ in the availability of meteorological data on wind and air temperature conditions required for the correction. While these data are directly available at the climatological stations analysed, they have to be inferred for the 230 precipitation stations. Only at seven exposed high altitude sites the Hellmann gauges are fitted with a wind shield. For them the wind speed was reduced 40 %, otherwise the corrections were made usually to all other Hellmann gauges (without wind shields) according to the method described in Sevruk (1986). Corrections were assessed on a monthly basis for the 10yr period 1971-1980 and used for the 30yr reference period. For the 30 storage gauges fitted with a wind shield, a different method was applied. This was based on the results of intercomparison measurements of both precipitation and water equivalent of snow cover, and of precipitation only as measured by the Hellmann gauge and the storage gauge. The correction estimates depend also on the station altitude.

Wetting losses occur with the moistening of the inner walls of the precipitation gauge. They depend on the shape and the material of the gauge, as well as on the type and frequency of precipitation. For the Hellmann gauge they amount to an average of 0.3 mm on a rainy and 0.15 mm on a snowy day.

In the case of wind influence, losses depend on wind speed and on the weight of the precipitation particles. They are also affected by the aerodynamics of the precipitation gauge and the wind exposure of the gauging site (Sevruk et al., 1993; Sevruk and Zahlavova, 1993). At protected sites (e.g. forest clearings, parks, village centres or farms) losses are normally low, whereas at exposed sites e.g. open windward slopes, mountain passes or lakeshores) they are high. The assessment of exposure class is based on site history recorded in the archives of the Swiss Meteorological Institute, documented by photos, sketches, and written reports, as well as on topographical maps at a scale of 1:25000, as shown in Sevruk and Zahlavova (1993).

Wind-induced losses are determined from the difference in the measurement values of the exposed and the protected precipitation gauges. This difference is then related to the average wind speed at the gauge orifice level during precipitation periods, as well as to the precipitation intensity or, lacking further data, to the air temperature (Sevruk and Tettamanti, 1993). Field experiments at certain selected sites are therefore required. The difference ranges from 3% for light winds and rain to 80% for strong winds and fine snow. For precipitation gauges recording only the total of precipitation, the air temperature data had to be considered to estimate the parts of rain and snow. Temperature also parameterises the precipitation intensity, the snow structure and the fraction of snow of the total precipitation. To assess the altitude dependency of the air temperature, a data set of 104 climatological stations was used (period 1971-1980). By means of this altitude dependency, the air temperature was estimated for the 230 precipitation stations. The average monthly fraction of snow was determined in a similar way, though only 54 stations for the span of 1959-1970 were available for the regression analysis.

For the storage gauges, most of them situated at higher altitude, the wind-induced loss was estimated by comparing the measured precipitation to the water equivalent of the surrounding snow cover. At altitudes of 2000-3000 m a.s.l. the wind-induced losses amount to approximately 30% during the winter half-year and approximately 15% during the summer half-year.

Problems arise when determining the wind speed. It is only measured at climatological stations, at a height of more than 10 m above ground, as in most cases only three times per day. For the remaining sites, the wind speed had therefore to be estimated. In addition, the wind speeds had to be converted into the height of the precipitation gauge as well as into the periods of precipitation.

Using the similarity principle, the average annual wind speed was transferred from measured to unmeasured sites, taking into consideration the regional wind fields and the exposure class of the gauging site. By means of the ratio of the average annual and the winter values, the seasonal wind speeds were also estimated. They were also regarded as approximate values for each month of the winter or summer half-year. Based on the logarithmic wind profile and the vertical angle of obstacles around the gauging site, the wind speed was reduced to the level of the precipitation gauge orifice. This angle characterises the average vertical elevation above the horizon of the surrounding obstacles; it can be estimated by means of the gauge site exposure class (Sevruk and Zahlavova, 1993). Empirical coefficients were used for the reduction to precipitation periods, assuming that the wind speeds during precipitation were greater than the climatic values. Ticino is an exception: average wind speeds were used for the days of precipitation.

The correction values increase absolutely and relatively with increasing altitude, from approximately 100 mm to 800 mm; this corresponds to 5-30% of the measured values. At lower altitudes, the wind speed tends to be low as a result of the greater roughness (forests and built-up areas) and the topographic barriers. The small fraction of snow and the substantial wind protection of the stations also have a positive effect. Compared to this, the correction values in the snow-rich and wind-exposed high alpine regions are excessively high. The magnitude of the corrections, however, is also influenced by the type of instrument used. For the Hellmann precipitation gauge (without wind shield) they are considerably greater than for the storage gauge fitted with a wind shield. Figure 1 emphasises the altitude dependency of the correction values for both types of gauges. Correction values are subject to the influence not only of altitude but also of regional differences. They are the result of differentiated wind speeds and precipitation intensities. For stations in the Swiss midland and in the valleys of Ticino and Valais, only small corrections need to be made, larger ones are required for stations in northern and western Switzerland, the Jura and the lower alpine regions, and major corrections are necessary for the stations in high alpine regions.

Figure 1 allows a rough estimate of the correction values at stations referring to the region (large river basin) or the station number of the Swiss Meteorological Institute and to the exposure class. It is possible to determine the curve which is likely to best represent the conditions at a given station. By means of this curve, the magnitude of the average annual correction values can then be defined as a function of station altitude.

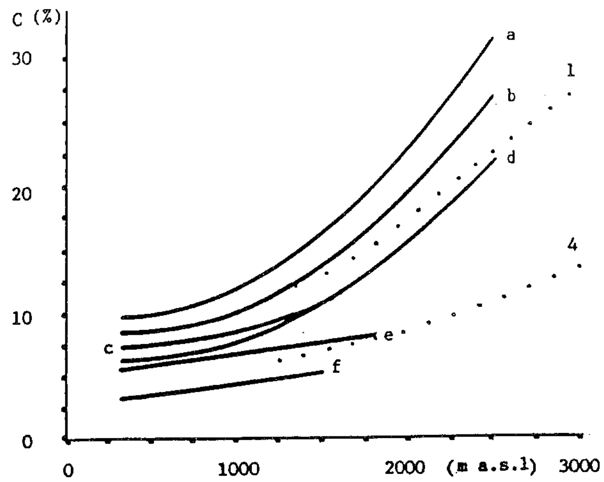

Fig. 1 Dependency of mean annual corrections, C, of precipitation on the altitude, region (a-f) and gauge site exposure(1, 4). Solid line indicates the Hellmann gauge and dotted line the storage gauge.

The results show that the correction of systematic error of precipitation measurement can be estimated even for gauge sites with missing input variables, such as wind speed, temperature and portion of snow in total precipitation. These variables can be derived by analogy and regionalized vertical gradients. Based on such procedures and kriging, the correction can be computed and isolines drawn over a territory of a country.

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STATUS OF DATA COMPILATION, WMO SOLID PRECIPITATION MEASUREMENT INTERCOMPARISON
SEPTEMBER, 1992

Country/Site	1986/87 Data Recieved	1986/87 Data Archived	1986/87 Event Summary	1987/88 Data Recieved	1987/88 Data Archived	1987/88 Event Summary	1988/89 Data Recieved	1988/89 Data Archived	1988/89 Event Summary
Canada									
Toronto(Kortright)	01/87-04/87	yes	yes	12/87-03/88	yes	yes	12/88-03/89	yes	yes
Peterborough(Trent)	12/86-03/87	yes	yes	11/87-03/88	yes	yes	12/88-02/89	yes	yes
Regina(Airport)	03/87-04/87	yes	yes	11/87-04/88	yes	yes	01/89-03/89	yes	yes
Dease Lake(Airport)	N/A	N/A	N/A	11/87-03/88	yes	yes	10/88-04/89	yes	yes
East Baltic(Climate)	N/A	N/A	N/A	12/87-03/88	yes	yes	11/88-04/89	no	yes
Baie Comeau(Airport)	N/A	N/A	N/A	N/A	N/A	N/A	01/89-04/89	no	yes
Czechoslovakia									
Bratislavia Koliba	11/86-04/87	yes	no	12/87-04/88	yes	no	11/88-04/89	no	no
Banska Bystrica	N/A	N/A	N/A	no	no	no	no	no	no
Stropkov	N/A	N/A	N/A	no	no	no	no	no	no
Finland(Denmark,Norway,Sweden)									
Jokioinen	02/87-04/87	yes	no	10/87-04/88	yes	no	11/88-12/89	yes	no
Germany									
Harzgerode	12/86-03/87	yes	yes	12/87-03/88	yes	yes	12/88-03/89	yes	yes
Croatia									
Parg	01/87-04/87	no	yes	10/87-04/88	yes	yes	12/88-03/89	yes	yes
India									
Bhang(Manali)	12/86-04/87	no	yes	12/87-04/88	no	yes	no	no	no
Solang Nala(H.P.)	12/86-04/87	no	yes	12/87-04/88	no	yes	no	no	no
Kothi(H.P.)	12/86-04/87	no	yes	12/87-04/88	no	yes	no	no	no
Verinag	12/86-04/87	no	yes	12/87-04/88	no	yes	no	no	no
United States									
Danville(CRREL)	12/86-03/87	no	no	12/87-03/88	no	no	no	no	no
Reynolds Creek(USDA)	N/A	N/A	N/A	11/87-04/88	yes	yes	11/88-03/89	yes	yes
Bismark(USGS)	N/A	N/A	N/A	N/A	N/A	N/A	11/88-03/89	yes	yes

STATUS OF DATA COMPILATION, WMO SOLID PRECIPITATION MEASUREMENT INTERCOMPARISON
SEPTEMBER, 1992

Country/Site		1989/90			1990/91			1991/92	
	Data Recieved	Data Archived	Event Summary	Data Recieved	Data Archived	Event Summary	Data Recieved	Data Archived	Event Summary
United States(cont'd)									
Rabbit Ear's Pass(USGS)	12/89-04/90	no	yes	01/91-05/91	no	yes	10/91-02/92	no	yes
United Kingdom									
Eskdalemuir	01/90-04/90	yes	no	11/90-02/91	yes	no	N/A	no	no
Lerwick	11/89-04/90	yes	no	11/90-04/91	yes	no	N/A	no	no
Argentina	N/A	N/A	N/A	no	no	no	no	no	no
People's Republic of China									
Tianshan	01/90-12/90	yes	no	01/91-08/91	yes	no	no	no	no
Russia									
Valdai	11/89-04/90	yes	no	no	no	no	no	no	no
Romania									
Joseni	no	no	no	no	no	no	no	no	no

WMO Solid Precipitation

Gauge Log

WMO Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Baie-Comeau, Can. (BC)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Baie-Comeau, Can. (BC) 01/90 - Present	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Bismarck, U.S.A. (BZ)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Bratislava, C.S.F.R. (CZ)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Dease Lake, Can. (DL)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
East Baltic, PEI, Can. (EB)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Eskdalemuir, Scotland, U.K. (ED)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Jokioinen, Finland (FN)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind @30m	Spd @30m	Wind@10m	Spd @10m	2 m	New	Ruler	DFIR	Tret
Harzgerode, Germany (GD) 12/86 - 03/87	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Harzgerode, Germany (GD) 12/87 - 03/88	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Harzgerode, Ger. (GD) 12/89 - 03/91	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Harzgerode, Ger. (GD) 12/91 - Present	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	3 m	New	Ruler	DFIR	Tret
Kortright, Canada (KT)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Lerwick Observatory, U.K. (LW)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Peterborough, Can. (PT)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Regina, Can. (RG)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Reynolds, U.S.A. (RI)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Joseni, Romania (RJ)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Valdai, USSR (UR) 01/70 - 12/78	Year	Month	Day	Local Moscow	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Valdai, USSR (UR) 01/88 - 12/90	Year	Month	Day	Local Moscow	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	3 m	New	Ruler	DFIR	Tret
Danville, USA (VT)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret
Parg, Yugo. (YG)	Year	Month	Day	GMT Time	Max. Temp	Min. Temp.	Wind Dir. (Deg.)	Nat'l Std	Nat'l Gge	DFIR	2 m	New	Ruler	DFIR	Tret

WMO Station	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
	Nat Shld	Nat Unshld	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Baie-Comeau, Can. (BC)	14	M	Other	Other	Other	10	Other	Other	Other	19	Other	Other	Other	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Baie-Comeau, Can. (BC) 01/90 - Present	14	M	Other	Other	Other	10	Other	Other	23	19	Other	Other	Other	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Bismarck, U.S.A. (BZ)	9	12	Other	Other	Other	Other	Other	Other	Other	Other	Other	9	42	8	11	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Bratislava, C.S.F.R. (CZ)	Nat Shld	Nat Unshld	Other	Other	Other	Other	Other	Other	Other	Other	Other	29	30	6	27	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Dease Lake, Can. (DL)	14	Nat Unshld	34	12	9	10	Other	Other	23	19	Other	6	7	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
East Baltic, PEI, Can. (EB)	16	M	Other	Other	Other	10	Other	Other	Other	19	18	Other	Other	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Eskdalemuir, Scotland, U.K. (ED)	44	45	34	88	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Jokioinen, Finland (FN)	2	3	2	35	20	27	40	31	20	35	39	26	32	14	1	Precip Type	Snow Type	Precip. Event (hrs)	24	24
Harzgerode, Germany (GD) 12/86 - 03/87	27	27	34	Other	Other	Other	Other	Other	Other	Other	Other	Other	30	5	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Harzgerode, Germany (GD) 12/87 - 03/88	27	27	34	Other	Other	Other	Other	Other	Other	Other	Other	Other	30	5	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Harzgerode, Ger. (GD) 12/89 - 03/91	27	27	34	5	Other	Other	Other	Other	Other	Other	Other	30	5	28	14	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Harzgerode, Ger. (GD) 12/91 - Present	27	27	34	5	Spd@15m	Dew & Frost	Cloud Type	Other	Other	Other	Other	30	5	28	14	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Kortright, Canada (KT)	16	17	Other	12	9	10	8	21	23	19	18	Other	Other	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Lerwick Observatory, U.K. (LW)	44	45	34	45	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Peterborough, Can. (PT)	16	M	Other	Other	Other	10	Other	Other	Other	Other	18	Other	Other	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Regina, Can. (RG)	14	M	Other	Other	Other	Other	Other	Other	Other	Other	Other	16	22	11	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Reynolds, U.S.A. (RI)	9	43	34	Other	Other	Other	Other	Other	Other	Other	Other	14	11	12	9	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Joseni, Romania (RJ)	Nat Shld	Nat Unshld	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Valdai, USSR (UR) 01/70 - 12/78	Nat Shld	Nat Unshld	99	4	Other	Other	3	3	3	33	33	40	40	27	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Valdai, USSR (UR) 01/88 - 12/90	Nat Shld	Nat Unshld	99	4	Other	Other	3	3	3	3	28	33	14	15	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Danville, USA (VT)	Nat Shld	Nat Unshld	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day
Parg, Yugo. (YG)	Nat Shld	Nat Unshld	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Other	Precip Type	Snow Type	Precip. Event (hrs)	Comments	Obs #/ Day

GAUGES

0-1 USSR H & H-90 (Tretyakov)	1
0-1 USSR with a wind shield (Tretyakov)	2
0-1 USSR without a wind shield (Tretyakov)	3
0-1 USSR Gauge with Bush Shield	4
Automatic Remote Transmitting Station (AFMS)	5
B.C. Transducer Standpipe Gauge with Alter Shield	6
B.C. Transducer Standpipe Gauge without Shield	7
Belfort Series 5915 in a Double Fence	8
Belfort Series 5915 with Alter shield	9
Belfort Series 5915 with Nipher shield	10
Belfort Series 5915 with Wyoming shield	11
Belfort Series 5915 without wind shield	12
BT-60	13
Canadian Nipher shielded Snow Gauge	14
Canadian Nipher shielded Snow Gauge in a Double Fence	15
Canadian Nipher shielded Snow Gauge Fixed at 2 metres	16
Canadian Nipher Snow Gauge without Shield	17
Canadian Type "B" Rain Gauge	18
CSC Acoustic Snow Depth Sensor	19
Finnish Prototype Gauge	20

Fischer and Porter Type Gauge with Alter Shield	21
Fischer and Porter Type Gauge with Nipher Shield	22
Fischer and Porter Type Gauge without Shield	23
Geonor Gauge	24
Geonor Gauge in a double fence	25
Hellman Gauge (Danish)	26
Hellman Gauge (Hungarian)	27
Hellman Gauge (Polish)	28
Metra Type 886 with Tretyakov wind shield (500 cm2)	29
Metra Type 886 without wind shield (500 cm2)	30
Norwegian Gauge	31
Pit Gauge	32
Rain gauge with Nipher Shield	33
Snowboard	34
Swedish Gauge (SMHI)	35
Tipping Bucket	36
Tipping Bucket (Danish)	37
Tipping Bucket (Friedrich's)	38
Wild with a Nipher a wind shield	39
Wild without a wind shield	40

Wilska Gauge	41
Aerochem Metrics Gauge	42
U.S. National Weather Service Precipitation Gauge	43
MK2 with a Turf Wall shield	44
MK2 without a wind shield	45
UNDEFINED	88
Atmospheric pressure in millibars	99
MISSING	M

Explanation of Columns 1 through 17

Column	Definition
1	Year
2	Month
3	Day
4	Time UTC
5	Maximum Temperature for Day
6	Minimum Temperature for Day
7	Wind Direction at National Standard Height
8	Wind Speed at National Standard Height
9	Wind Speed at National Gauge Height
10	Wind Speed at DFIR Height
11	Wind Speed at 2 metres
12	Fresh Snowfall Ruler Depth
13	Depth of Snow on Ground
14	Double Fence International Reference Gauge
15	Tretyakov Gauge (0-1 USSR)
16	National Standard Gauge
17	National Standard Gauge without Shield

FORMAT OF THE DATA

File format	Description
Normal	Standard format for a Microsoft Excel worksheet. Use this format if you are using the document with Microsoft Excel or if you plan to link worksheets.
Template	For saving Microsoft Excel templates.
Excel 2.2	For transferring files to Microsoft Excel version 2.2 or later. All graphic objects, including buttons, text boxes, and embedded charts are removed and cell border styles are replaced with single line borders. Although outline formatting is removed, the file still retains cell formats assigned with either outline styles or cell styles.
SYLK	Symbolic Link. For transferring data to another application, such as Microsoft Multiplan or Microsoft Excel for the Macintosh version 1.5 or earlier.
Text	ASCII text. Use this format for transferring data to a word processor. Saves only the text and values as they are displayed in the cells on the worksheet. Columns are separated by tabs, and rows by carriage returns, but all other format information is lost. If a cell contains a comma or a tab, the value from the cell is enclosed in double quotation marks.
CSV	Comma Separated Values (CSV) format is similar to Text format, except that CSV file format uses a comma to separate fields, instead of a tab. If a cell contains a comma, the value from the cell is enclosed in double quotation marks.
WKS	For transferring data to Lotus 1-2-3 Release 1 or Lotus Symphony.
WK1	For transferring data to Lotus 1-2-3 Release 2.
WK3	For transferring data to Lotus 1-2-3 Release 3.
DIF	For transferring data to VisiCalc. DIF stands for Data Interchange format.
DBF 2	For transferring the range named Database to dBASE II.
DBF 3	For transferring the range named Database to dBASE III.
DBF 4	For transferring the range named Database to dBASE IV.
Text (Windows)	For transferring data to a Windows application.
Text (OS/2 or DOS)	For transferring data to an OS/2 or DOS application.
CSV (Windows)	For transferring data to a Windows application.
CSV (OS/2 or DOS)	For transferring data to an OS/2 or DOS application.
Add-In	For saving Microsoft Excel add-in macros. This file format appears only when you're saving a macro sheet.
Int'l Macro	For saving macros so they can be run using any supported language version of Microsoft Excel. This file format appears only when you're saving a macro sheet.
Int'l Add-In	For saving Microsoft Excel add-in macros so they can be run using any supported language version of Microsoft Excel. This file format appears only when you're saving a macro sheet.

METHODS OF CORRECTING DFIR MEASUREMENTS

To correct the DFIR for undercatch, Golubev has proposed the equation:

$$\frac{BUSH}{DFIR}(\%) = 100\left[1 + 0.005*U_3^2\left(\frac{P_a}{1000}*\frac{273}{273+T_a}*\frac{P_a}{P_a+0.4e_a}\right)^2\right] \quad \textbf{(7)}$$

where P_a, T_a, e_a, and U_3 are the station pressure, surface air temperature, vapour pressure, and the wind speed at 3 metres height, respectively, and measured in SI units. Since station pressure and vapour pressure are difficult to obtain, Golubev suggested that a hydrostatic approximation could be substituted; that is,

$$\frac{BUSH}{DFIR}(\%) = 100\left[1 + 0.005*U_3^2\left\{1.013*\frac{273}{273+T_a}*\left(1-\frac{6.5\ H}{288}\right)^{5.255}\right\}^2\right] \quad \textbf{(8)}$$

where H is the station elevation in 1000's of metres. Since air temperature provides only a small correction, Golubev's modified equation becomes

$$\frac{BUSH}{DFIR}(\%) = 100\left[1 + 0.005*U_3^2\left\{1.013*\left(1-\frac{6.5\ H}{288}\right)^{5.255}\right\}^2\right] \quad \textbf{(9)}$$

4.1 Yang, Goodison, and Metcalfe, however, observed that blowing snow conditions erroneously inflate this ratio. Consequently, they removed blowing snow incidents from the database, stratified by precipitation type, and have developed

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

for the DFIR correction for dry snow only conditions. After a discussion, it was recommended that this equation be used to correct the DFIR measurements to be commensurate with the bush gauge for dry snow conditions. They have developed similar equations which were recommended for wet snow, blowing snow, mixed rain and snow, and rain only conditions. These equations are given in the **Annex** to this **Appendix Q.**

EVALUATION OF DFIR ACCURACY AT VALDAI WMO INTERCOMPARISON SITE

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Atmospheric Environmental Service
Environment Canada

INTRODUCTION

It is now widely recognized that, due to systematic errors in measurement by all types of precipitation gauges, correction of precipitation measurements, particularly snowfall measurements, for both hydrological and climate change studies at regional and global scales is critically important. In an attempt to quantify these errors, the World Meteorological Organization Commission on Instruments and Methods of Observation (WMO/CIMO) initiated the Solid Precipitation Measurement Intercomparison in 1985. Fifteen countries are participating in the experiment. After reviewing all possible practical methods of measuring "true" snowfall in a variety of climatic environments the organizing committee designated the octagonal vertical double fence shield (with Tretyakov gauge) as the Intercomparison Reference gauge (DFIR) (Goodison et al.,1988). Golubev (1986) stated that DFIR measurements, compared to Tretyakov gauge measurements in a sheltered bush site at the Valdai station in Russia, are adversely affected by wind speed. His correction equation for the DFIR measurement uses wind speed, atmospheric pressure, mean air temperature and mean air humidity (Golubev, 1989). Analysis of the Golubev equation showed that for the same site, atmospheric pressure and humidity have little effect and the equation could be simplified to consideration of air temperature and wind speed only (Goodison and Metcalfe, 1992). Using the Valdai intercomparison event data from 1970 through 1990, this study investigates the relationship between DFIR and the shielded Tretyakov gauge in the bush (bush gauge) and assesses the factors contributing to any significant differences between the two gauges so as to evaluate the accuracy of the DFIR measurements.

SITE AND INSTRUMENTATION

Valdai station is situated on the flat shore of Valdai lake. There are two DFIR's installed at the station in an open area 200X200m with no nearby obstructions. Approximately 300m from the open site is the bush gauge (Tretyakov gauge with wind shield) placed in 2-4m high shrubs in a three hectare area. Within the 12m diameter working area of the gauge the shrubs are cut routinely to the gauge height of 2m. This gauge has been accepted as the working reference at Valdai station since 1970.

The bush gauge is considered as the most appropriate reference gauge for solid precipitation measurement and is comparable to the pit gauge for measuring rainfall (WMO, 1991). The gauges in both open and bush sites at Valdai are measured twice a day at 0800 and 2000. A weighing method was initially used to determine the precipitation amount and over a period of time a wetting loss correction was determined. Since 1966, a correction for wetting loss of the Tretyakov gauge has been added to every volumetric precipitation measurement and no additional correction for this systematic loss is required.

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Wind speed and direction were measured at 2m height before September 1989 and a linear equation was used to estimate the wind speed at the DFIR height of 3m. Since then, wind speed at 3m has been measured directly. Atmospheric pressure, air temperature and humidity were also measured.

RESULTS

In order to minimize the scatter in the ratio of bush gauge to DFIR due to using small numbers, only event data of DFIR greater than 3.0mm are used in this analysis. From October 1970 through April 1990, 368 precipitation events were recorded. The bush gauge measurements are systematically higher than that of the DFIR in all types of precipitation. The linear relationship between the two gauges is quite significant except during blowing snow events (Fig.1a,1b). On average, the bush gauge catches 6.4, 8.5 and 10.8% more than the DFIR for rain, rain and snow mixed and snow, respectively (Table 1).

Table 1. Summary of event data at Valdai WMO intercomparison site

Type of precip.	# Events	Tmax (c)	Tmin (c)	Ws(3m) (m/s)	BUSH (mm)	DFIR (mm)	BUSH/DFIR (%)
Rain	122	7.7	5.0	4.0	822.8	773.0	106.4
Mixture	88	2.0	-0.9	4.6	606.7	559.2	108.5
Snow	158	-1.7	-4.4	4.7	825.4	744.7	110.8

Golubev (1992) analyzed winter precipitation totals for 35 months from November 1971 through December 1978, without consideration of blowing snow, and found that the DFIR at Valdai station gave 9% lower totals than the bush gauge. According to the report of WMO/CIMO (1985), types of snowfall events should be described as light, moderate or heavy in intensity, wet snow, snow storm (shower), snow grains or pellets and every day with drifting or blowing snow identified. Checking the original Valdai data observation sheets it was found that blowing snow was a serious problem at this site. There were 55 blowing snow cases in the total of 153 events of only snow. Statistical analysis shows that blowing snow generally takes place at a wind speed above 5m/s at this location. For the blowing snow cases (Table 2), the ratio of bush/DFIR is about 10% higher for winds blowing from the two southern quadrants, i.e. from the direction of the lake, than for the northern quadrants. During blowing snow events, the bush gauge at 2m caught, on average, 18% more snow than the DFIR at 3m height, for all wind directions. However, the average ratio of bush to DFIR, over all wind directions, is only 107-108% for both wet snow and dry snow conditions. In dry snow cases, the ratio does not change much with wind direction, except that the lowest ratio does occur with the lowest mean wind speed. The lowest wind speed is from the northwest quadrant which is the location of a forested area. For the wet snow events, the highest ratio is associated with southwest winds and the lowest with northwest winds. It is notable that the average highest winds, from the northeast, do not lead to a corresponding higher catch ratio or conversely a lower snowfall gauge catch, for any of the conditions, i.e. dry snow, wet snow or blowing snow. This fact strongly indicates the important influence of not only wind speed but wind direction to precipitation gauge catch at the Valdai site.

Table 2. Summary of the snow only event data (DFIR > 3.0mm)

a) Dry Snow

Wind Dir. (deg)	Event	Tmax (c)	Tmin (c)	Ws(3m) (m/s)	BUSH (mm)	DFIR (mm)	BUSH/DFIR (%)
1- 90	12	-4.3	-6.7	4.3	65.5	61.1	107.2
91-180	12	-2.9	-6.0	4.0	65.1	59.5	109.4
181-270	16	-1.1	-3.2	4.0	80.4	72.9	110.3
271-360	14	-2.2	-4.3	3.3	68.5	65.7	104.3
All Direction	54	-2.5	-4.9	3.9	279.4	259.1	107.8

b) Wet Snow

Wind Dir. (deg)	Event	Tmax (c)	Tmin (c)	Ws(3m) (m/s)	BUSH (mm)	DFIR (mm)	BUSH/DFIR (%)
1- 90	3	0.8	-0.7	4.9	15.4	14.3	107.7
91-180	8	0.7	-0.5	4.2	37.2	32.8	113.4
181-270	21	0.6	-1.5	4.4	108.5	102.8	105.5
271-360	5	-0.3	-3.7	4.2	26.9	26.0	103.5
All Direction	37	0.5	-1.5	4.4	187.9	175.8	106.9

c) Blowing Snow

Wind Dir. (deg)	Event	Tmax (c)	Tmin (c)	Ws(3m) (m/s)	BUSH (mm)	DFIR (mm)	BUSH/DFIR (%)
1- 90	4	-2.2	-6.0	6.4	19.7	17.6	111.9
91-180	13	-2.8	-5.0	5.7	85.5	71.4	119.8
181-270	25	-2.5	-6.0	5.9	142.9	118.6	120.5
271-360	13	-3.1	-7.7	5.2	78.0	68.8	113.4
All Direction	55	-2.7	-6.1	5.7	326.1	276.4	118.0

Statistical analysis indicates that for dry snow, wet snow and blowing snow events, the bush/DFIR ratio does not relate significantly to surface air temperature, humidity or atmospheric pressure and the only contributing factor is the mean wind speed during the storm. Figures 2a to 2f show the best fitted curves obtained by means of the least square estimation for the various types of precipitation. The regression equations for these are given below:

a) Dry Snow

$$\frac{BUSH}{DFIR}(\%)=100+1.89\times Ws+6.54E\text{-}4\times Ws^{3}+6.54E\text{-}5\times Ws^{5},\quad (N=52, R^{2}=0.37) \quad (1)$$

b) Wet Snow

$$\frac{Bush}{DFIR}\ (\%) = Exp(4.54 + 0.032\times Ws),\quad (N=38, R^{2}=0.56) \quad (2)$$

c)Blowing Snow

$$\frac{BUSH}{DFIR} = 95.40+2.19\times Ws-8.47E\text{-}3\times Ws^{3},\quad (N=54, R^{2}=0.37) \quad (3)$$

d) Rain with Snow

$$\frac{BUSH}{DFIR}(\%) = 101.67 + 0.254 \times Ws^2, \quad (N=39, R^2=0.38) \qquad (4)$$

e)Snow with Rain

$$\frac{BUSH}{DFIR}(\%) = 98.97 + 2.30 \times Ws, \quad (N=43, R^2=0.34) \qquad (5)$$

f) Rain

$$\frac{BUSH}{DFIR}(\%) = 100.35 + 1.667 \times Ws - 2.40E\text{-}3 \times Ws^3, \quad (N=120, R^2=0.22) \qquad (6)$$

Compared to Golubev's catch coefficient versus wind speed for the DFIR, a lower catch efficiency is observed using the formulae derived above for dry snow conditions (Tab.3).

Table 3: Catch efficiency of the DFIR and Canadian Nipher snow gauge versus mean wind speed based on Golubev(1986), Goodison(1978) and proposed method.

Mean Wind Speed	DFIR (Golubev)	DFIR (Proposed)	Nipher (Goodison)
2 m/s	100%	96%	+100%
4 m/s	95%	93%	100%
6 m/s	87%	83%	90%

Dry snow measurements of the DFIR at six Canadian intercomparison sites are corrected by equation 1 (Table 4). Generally the correction ratio increases, as we expect, from 3% to 10% with mean wind speed. Figure 3 shows the ratio of Nipher to corrected DFIR plotted against mean storm wind speed. On the same graph the results from Goodison (1978) of the ratio of the Nipher gauge to snowboard measurements at a sheltered site are plotted for comparison. For wind speed up to 2 m/s, the results are similar. However, at high wind speeds, the current results indicate a catch with a greater scatter and generally lower ratio than that found in earlier field studies. Analysis of the contributing factors to the difference is under investigation in Canadian Climate Centre.

Table 5. Correction of dry snow measurement of the DFIR at six Canadian intercomparison sites

Site	Event	Tmn (c)	Ws(3m) (m/s)	DFIR1 (mm)	DFIR2 (mm)	DFIR2/DFIR1 (%)
Kortright	14	-5.5	2.7	148.4	156.9	105.7
Dease Lake	45	-11.0	1.7	380.7	393.2	103.3
Regina	21	-11.2	3.8	131.1	140.9	107.5
Trent	31	-8.2	2.2	208.1	216.8	104.2
Baie Comeau	48	-8.3	4.2	512.8	562.0	109.6
East Baltic	46	-6.8	4.6	638.4	699.3	109.5

* DFIR1: measured(including wetting loss); DFIR2: corrected

SUMMARY

In terms of measurement accuracy, the bush gauge is the only reference available to check the DFIR in the field. At Valdai, blowing snow, mainly from the lake in the south, occurred during one-third of the snow events greater than 3.0mm. On the average, the bush gauge overmeasures snowfall by 10% during blowing snow conditions. Even after eliminating, as much as possible, the snowfall events during which blowing snow occurred, there remains a systematic difference between the measurements of the two gauges, that is, the bush gauge catches more snow than the DFIR. Therefore, the correction of the DFIR for wind induced loss is necessary in order to best represent true precipitation. The most important factor to the correction is mean wind speed during the storm. Atmospheric pressure, air temperature and humidity have little or no influence. Application of the correction equations to six Canadian intercomparison sites demonstrates the strong dependence of the correction ratio on wind speed.

RECOMMENDATION:

Equation 1, 2, 4, 5, and 6 be used to correct DFIR measurements for the effect of wind speed before comparative analysis with other gauge data.

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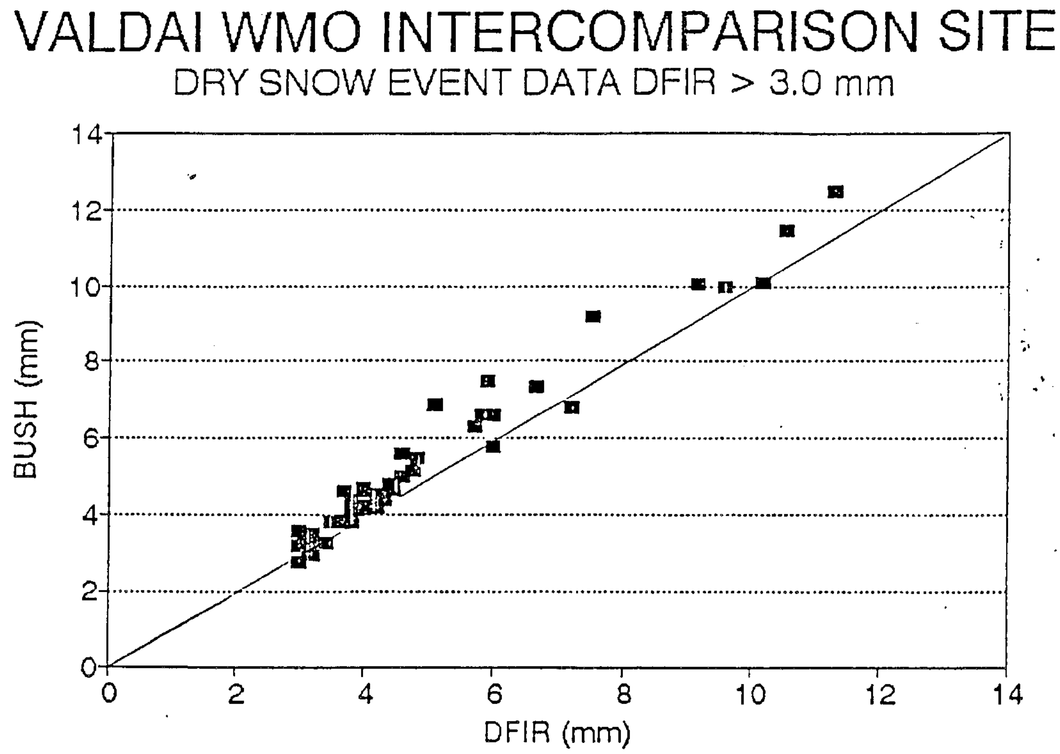
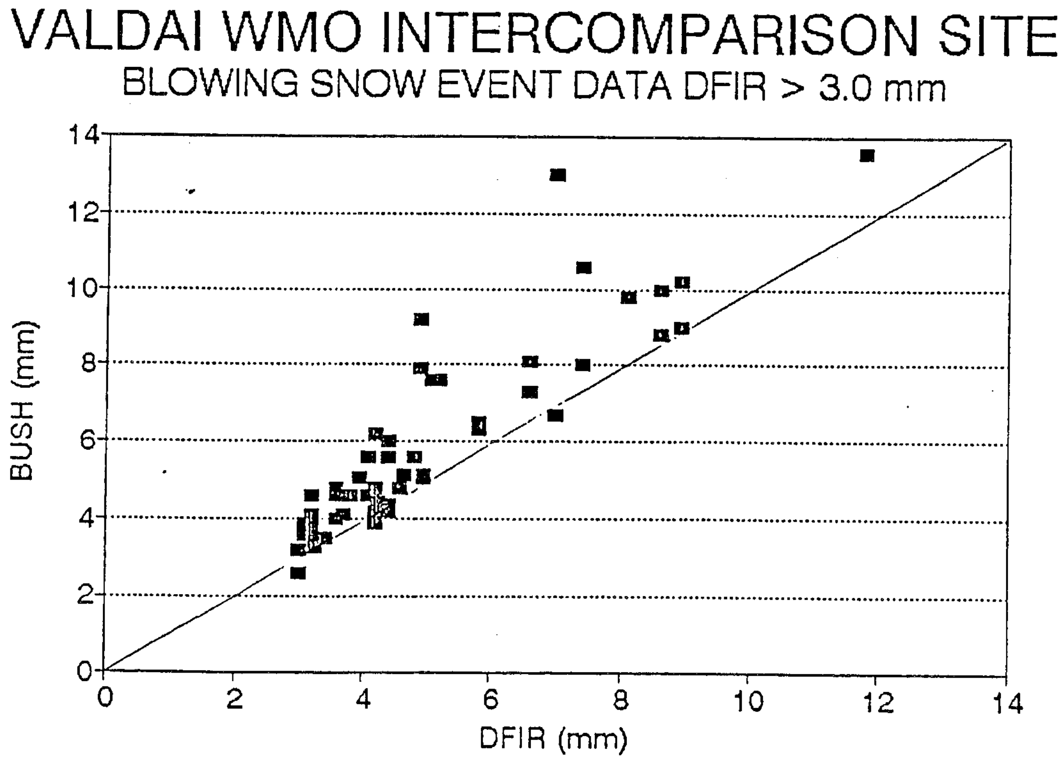
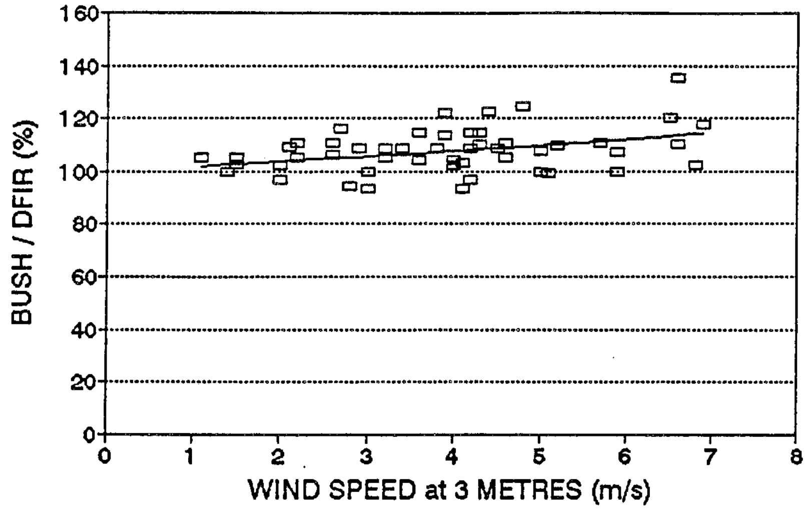
1a


VALDAI WMO INTERCOMPARISON SITE
DRY SNOW EVENT DATA DFIR > 3.0 mm
BUSH (mm)
DFIR (mm)
0
2
4
6
8
10
12
14

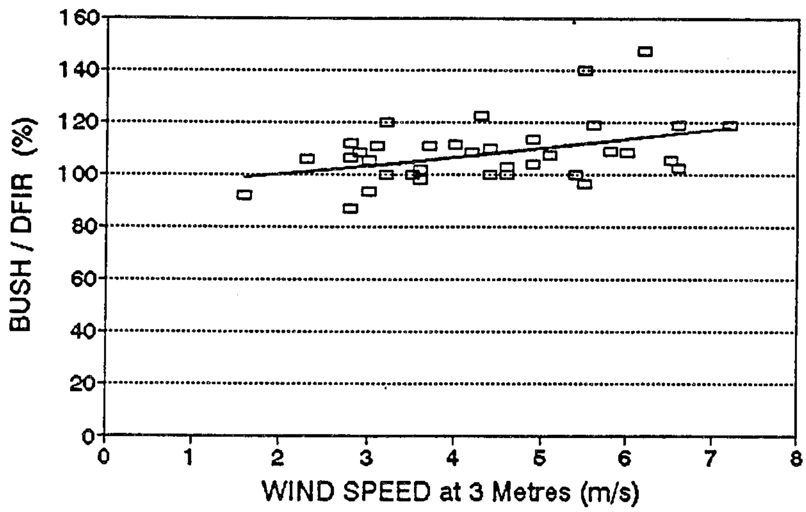
1b


VALDAI WMO INTERCOMPARISON SITE
BLOWING SNOW EVENT DATA DFIR > 3.0 mm
BUSH (mm)
DFIR (mm)
0
2
4
6
8
10
12
14

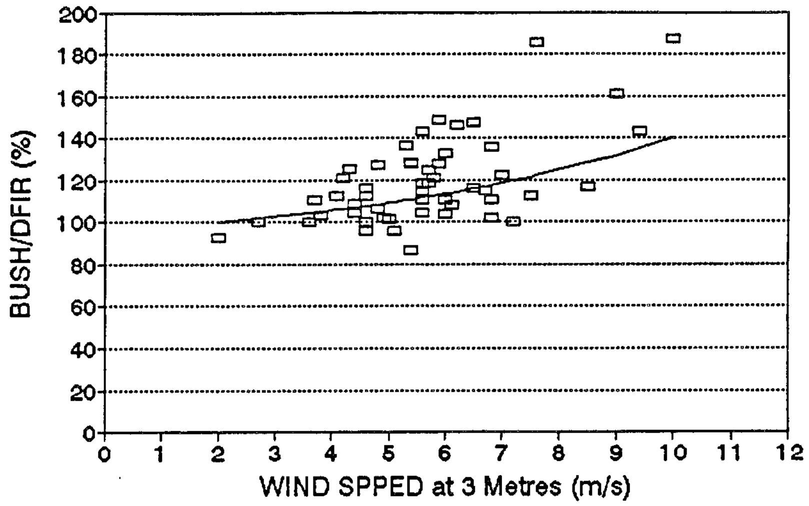
2a) VALDAI WMO INTERCOMPARISON SITE DRY SNOW, DFIR > 3.0 mm



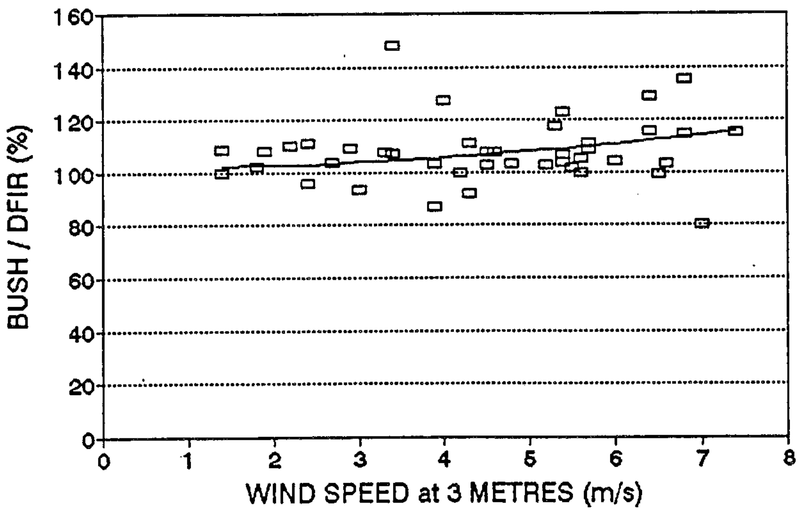
2b) VALDAI WMO INTERCOMPARISON SITE WET SNOW, DFIR > 3.0 mm



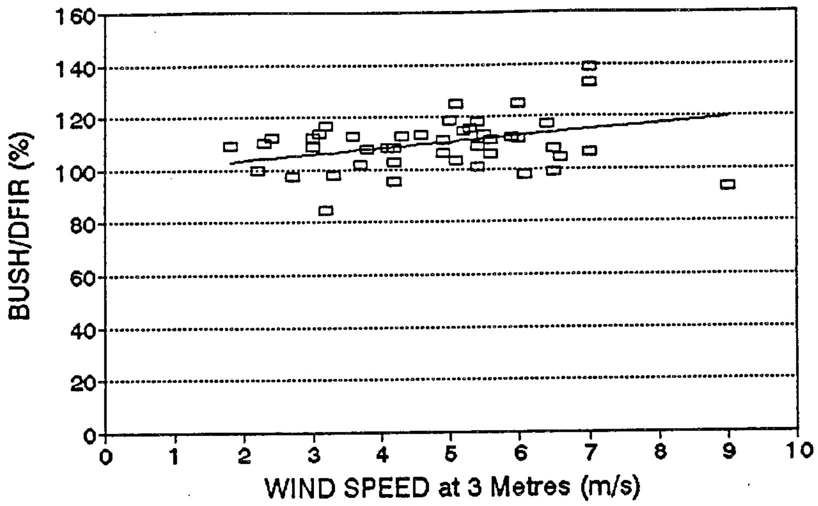
2c) VALDAI WMO INTERCOMPARISON SITE
BLOWING SNOW, DFIR > 3.0 mm



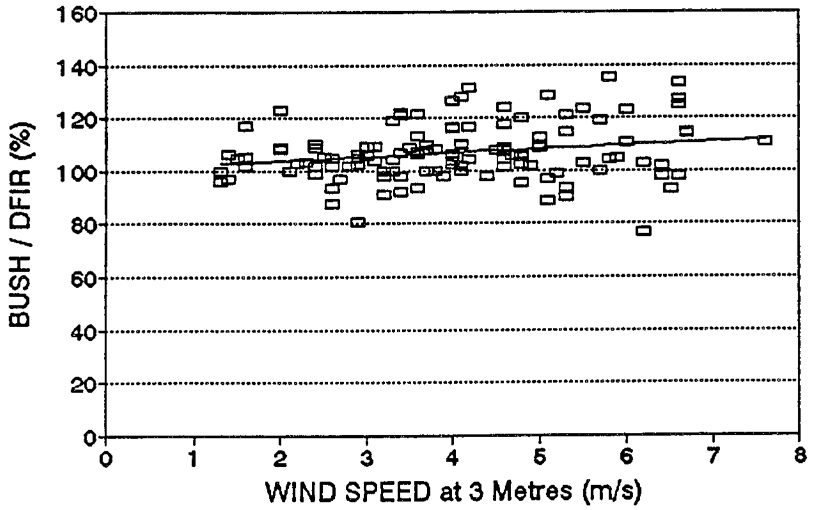
2d) VALDAI WMO INTERCOMPARISON SITE
RAIN with SNOW, DFIR > 3.0 mm

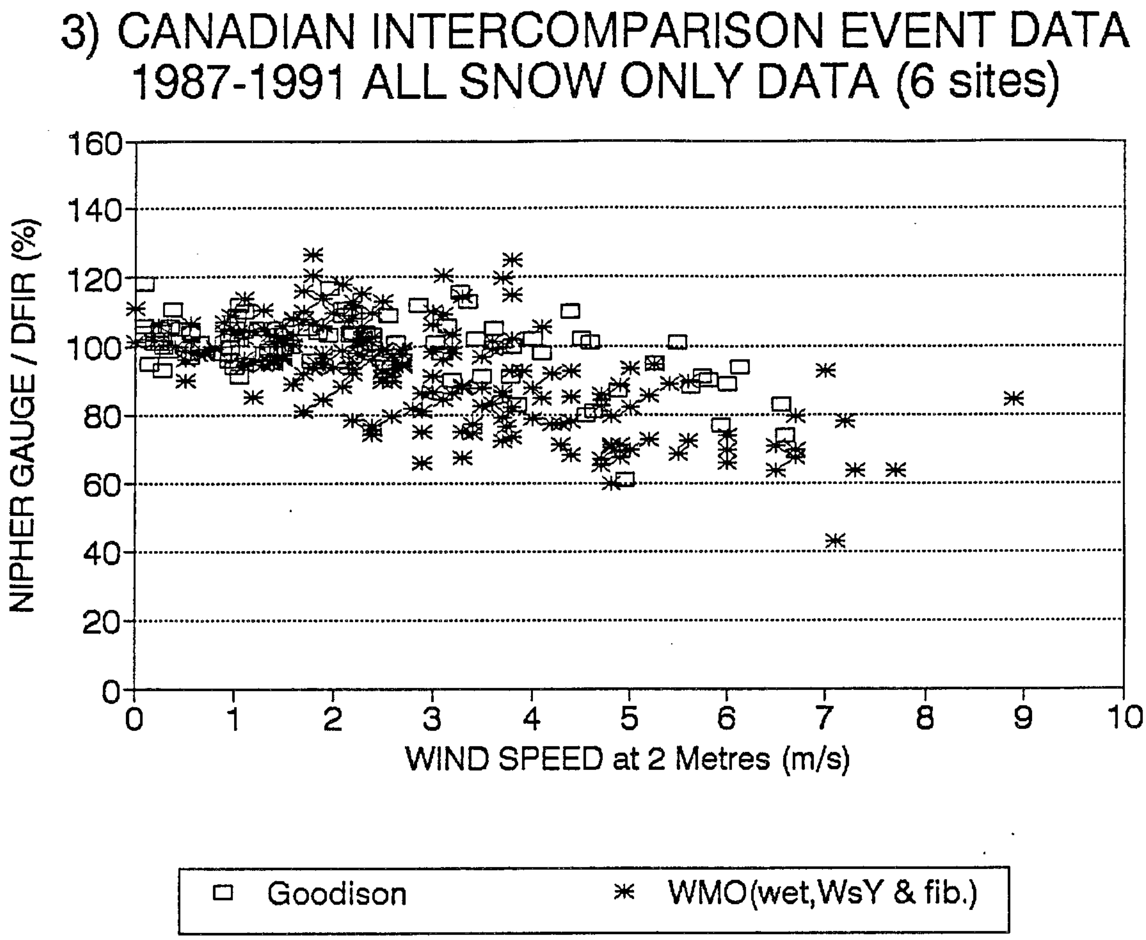


2e) VALDAI WMO INTERCOMPARISON SITE SNOW with RAIN, DFIR > 3.0 mm



2f) VALDAI WMO INTERCOMPARISON SITE RAIN, DFIR > 3.0 mm




3) CANADIAN INTERCOMPARISON EVENT DATA
1987-1991 ALL SNOW ONLY DATA (6 sites)
NIPHER GAUGE / DFIR (%)
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
WIND SPEED at 2 Metres (m/s)
Goodison
WMO(wet,WsY & fib.)

Finland and Scandinavia

Statistical analysis of data from the international experimental field at Jokioinen, Finland

Observations of solid precipitation collected during the five winters 1987/88 - 1991/92 in the experimental field at Jokioinen, Finland have submitted to statistical analysis. These studies concern results from comparing the national precipitation gauges from the Nordic countries of Denmark, Finland, Norway and Sweden to a Tretyakov gauge with wind shield placed in a Valdai double fence.

Data from the analysis include about 200 semidaily values using storms with a measured DFIR amount ≥ 0.5 mm and temperature below 0°C (dry snow).
The wind error of the precipitation gauge can be expressed in terms of the precipitation deficit (M_r-M_n), where M_r and M_n are amount of precipitation measured at the reference gauge (DFIR) No. r and the considered gauge No. n respectively.

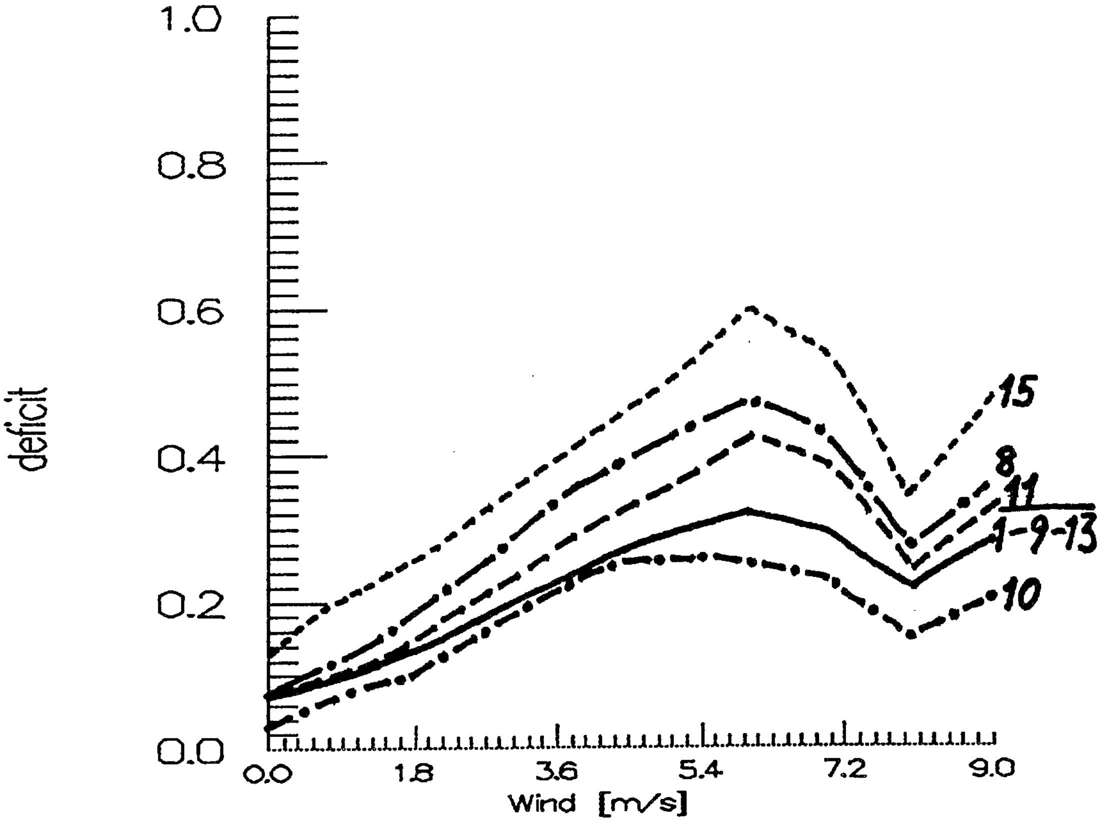


Fig. 1. *Precipitation deficit for gauges No. 8, 10, 11, 15 and average of No. 1, 9 and 13. Solid precipitation.*

No. 8:	*Norwegian standard gauge (shielded)*
No. 10:	*Finnish prototype (shielded)*
No. 11:	*Swedish standard gauge (shielded)*
No. 15:	*Danish standard gauge Hellmann (unshielded)*
No. 1.9 and 13:	*Tretyakov (shielded)*

Deficit is calculated for the 4 nordic national gauges and 3 Tretyakov gauges. The results (see fig. 1) show an increasing deficit for all gauges up to a wind speed of 6 m/sec. (wind measured at 2 m level). The unshielded danish gauge catches a relatively small part of the snow, whereas the other shielded gauges catch more of the snow.
For wind speed higher than 6 m/sec. the deficit are not increasing, but decreasing. The reason for that may be due to only a few cases with wind speed higher than 6 m/sec. Another reason may be due to some wind speed around the reference gauge in the Valdai double fence as reported by Dr. Golubev.

However the deficit also depends on the temperature or rather the interaction between wind speed and temperature as demonstrated below.
Following model will be tested in Denmark for correction of solid precipitation:

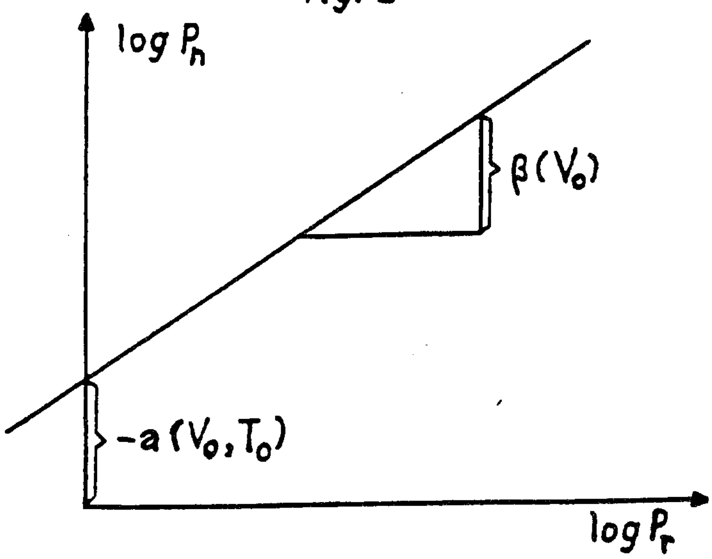
$$(1) \qquad P_n = e^{-a(V,T)} \cdot [P_r]^{\beta(V)}$$

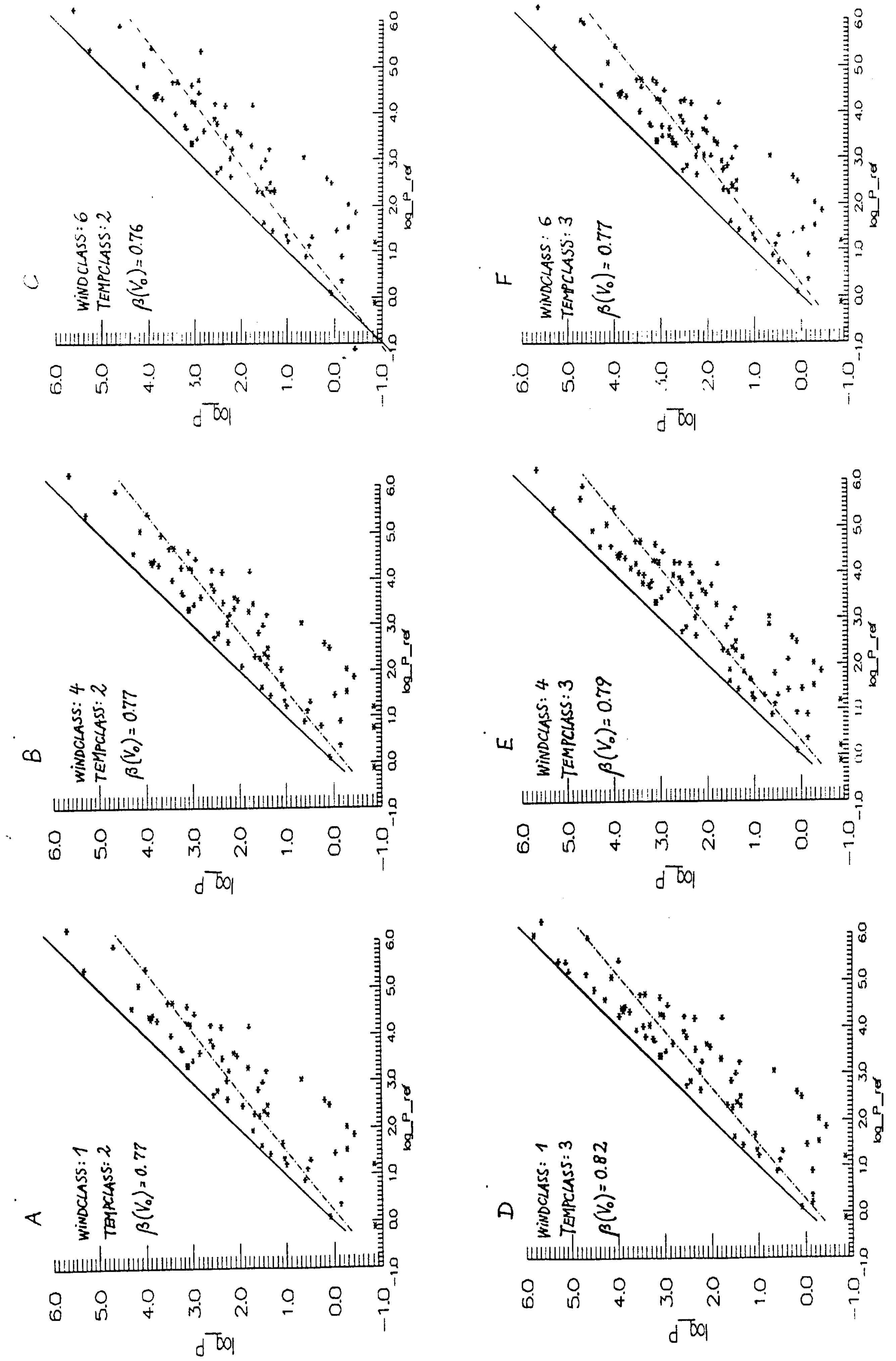
where P_n is national gauge, P_r reference gauge, V wind speed, T temperature, -a(V,T) and $\beta(V)$ are functions of wind speed and temperature, and wind speed respectively.
Verification of the model (1) is done by the following procedure:
From (1) it is easily obtained by taking logarithms that

$$(2) \qquad \log P_n = -a(V,T) + \beta(V) \cdot \log P_r$$

Hence, if (1) is true (2) shows that a linear relationship between log P_n and log P_r must exist! $\beta(V)$ is the slope and a(V,T) the intercept values.
For each $(V,T)=(V_0,T_0)$ combinations ($V_0=1,2,....,10$ m/sec, $T_0=0,-1,....,-10$°C) a plot of log P_n versus log P_r will be a <u>test</u> of the linear structure ~~(1)~~ (2) and at the same time provide estimates ~~on~~ of a (V_0,T_0) and $\beta(V_0)$ (see fig. 2).

Fig. 2




A
WINDCLASS: 1
TEMPCLASS: 2
β(V₀) = 0.77
B
WINDCLASS: 4
TEMPCLASS: 2
β(V₀) = 0.77
C
WINDCLASS: 6
TEMPCLASS: 2
β(V₀) = 0.76
D
WINDCLASS: 1
TEMPCLASS: 3
β(V₀) = 0.82
E
WINDCLASS: 4
TEMPCLASS: 3
β(V₀) = 0.79
F
WINDCLASS: 6
TEMPCLASS: 3
β(V₀) = 0.77
log_P
log_P_ref

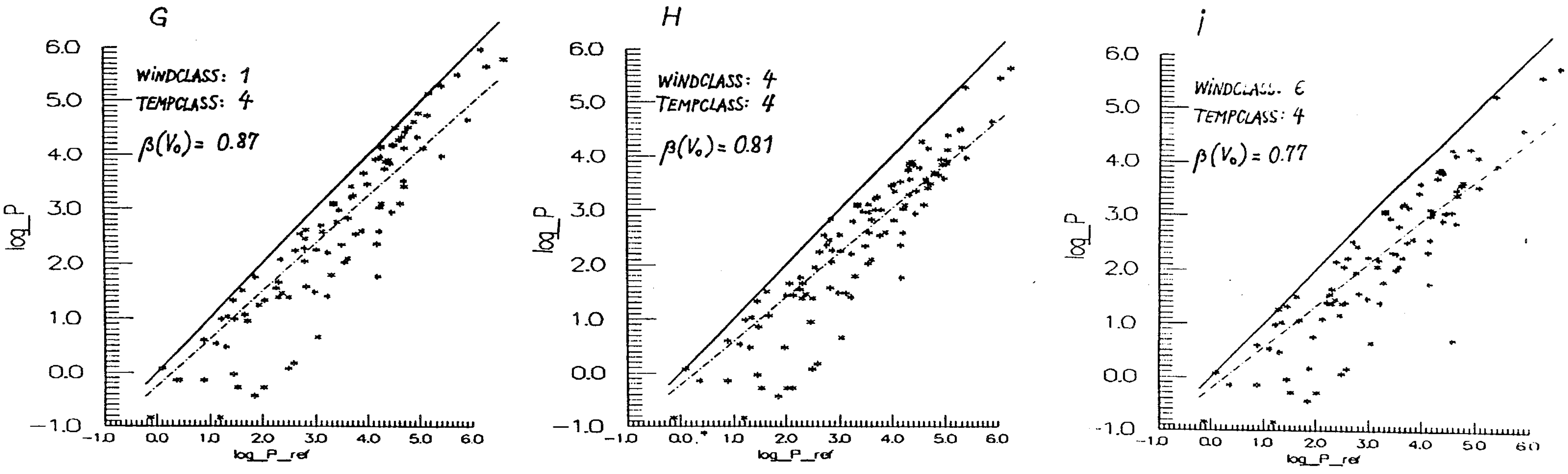


Fig. 3A-I. Slope values ($\beta(V_0)$) in log-log (observation) relation. The danish gauge No. 15 compared to the DFIR gauge.

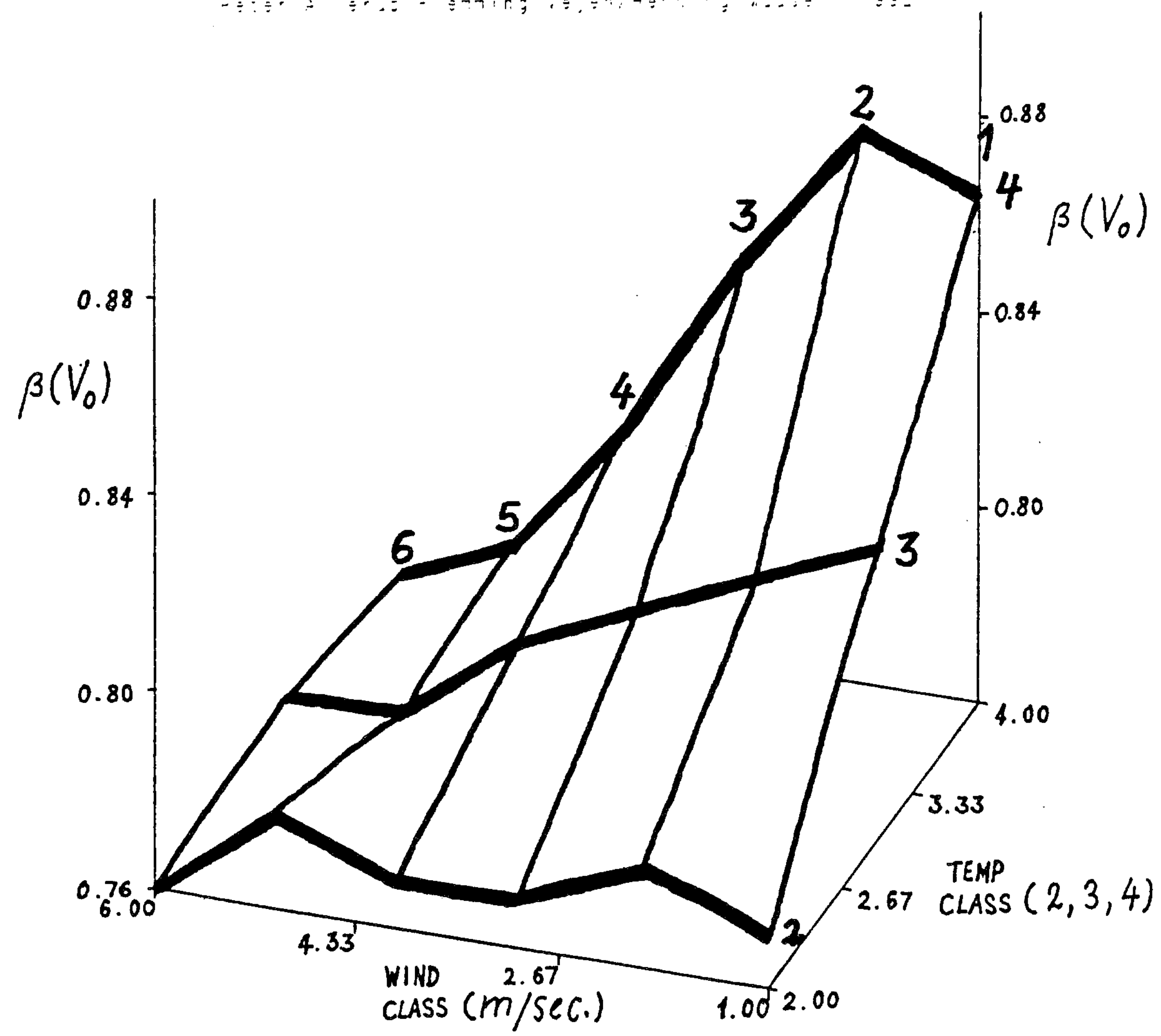
Fig. 3A-I illustrate $\beta(V_0)$'s dependence on wind speed and temperature with respect to the danish gauge No. 15 compared to the DFIR gauge. Following (V_0,T_0) combinations are used: V_0=1, 4 and 6 m/sec., and T_0=0°C-÷3°C (class 4), ÷3°C-÷7°C (class 3), and ÷7°C-÷10°C (class 2). The observation of precipitation, wind speed and temperature are 10 min's values, (see below).

It appears from the figures, that $\beta(V_0)$ in general decreases with increasing wind speed and decreasing temperature. This means that the precipitation deficit for the danish gauge also decreases like the $\beta(V_0)$ value. It is difficult however, to see any destinct structure for wind speed >4 m/sec. when inspecting the temperature classes, which too is the case for temperature class 2 (÷7°C-÷10°C) when examining the wind classes. In the last case it may be due to relatively few observations.

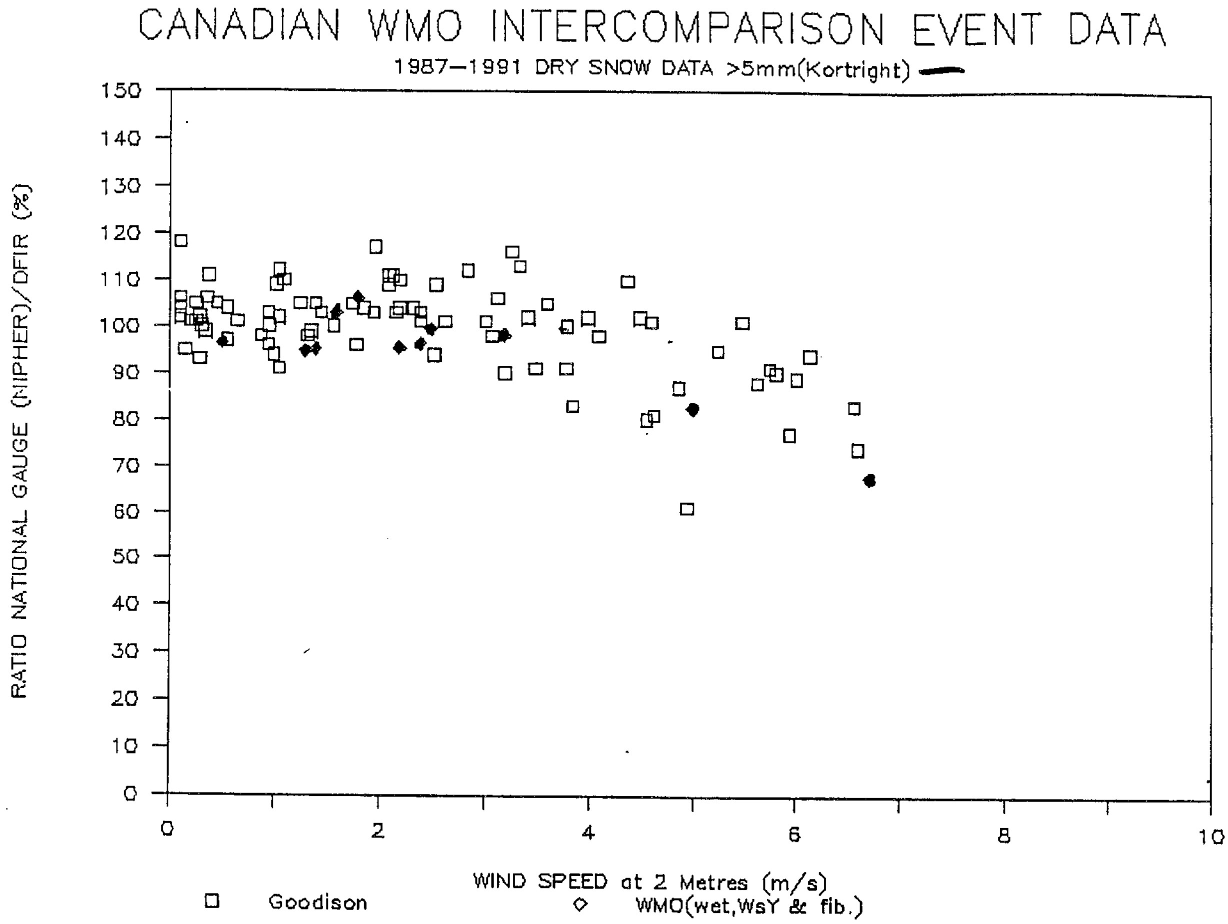
All combinations (V_0,T_0) are included in fig. 4, which illustrates simultaneous influence of wind speed and temperature on $\beta(V_0)$.

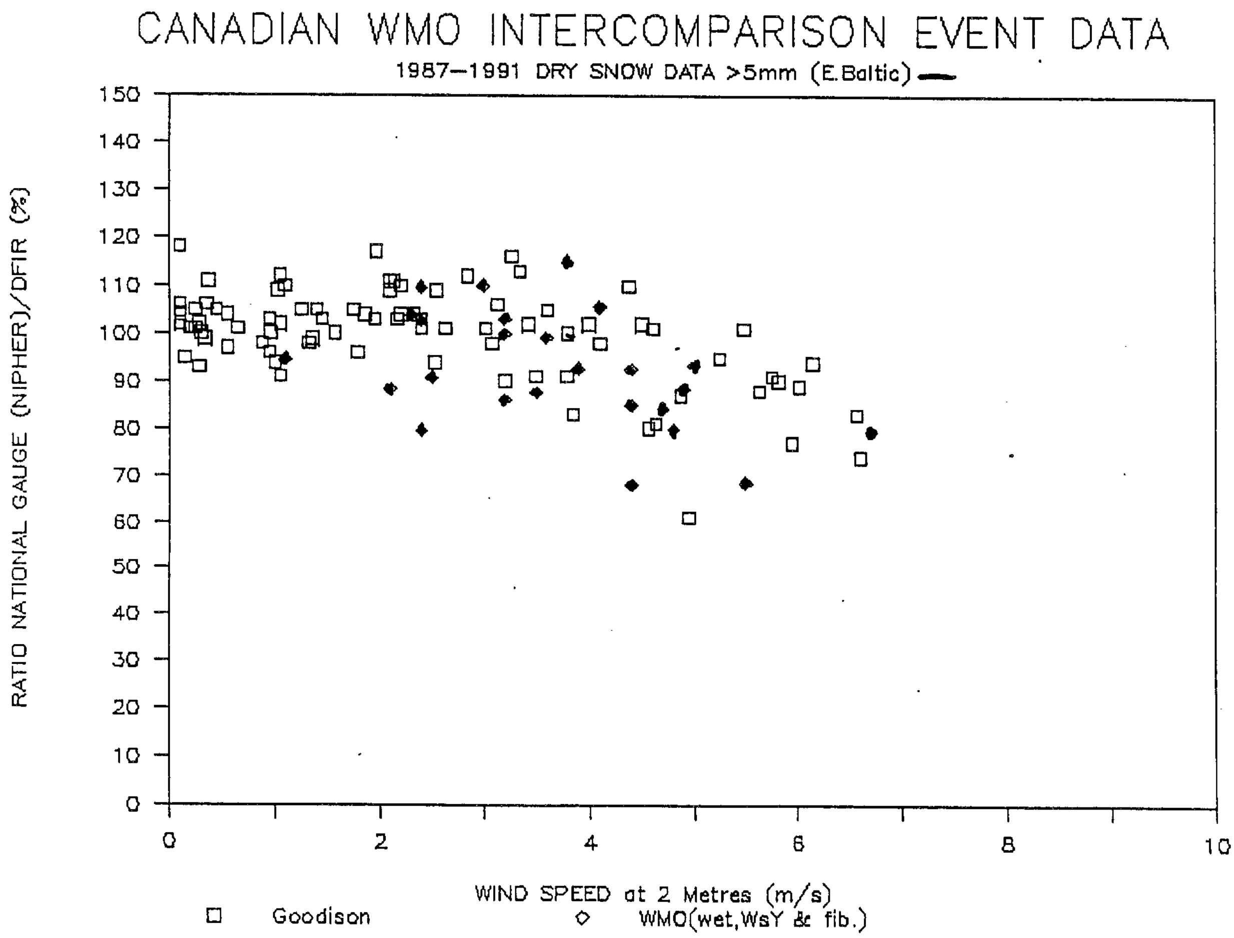
Fig.4 Measurements gauges: 15

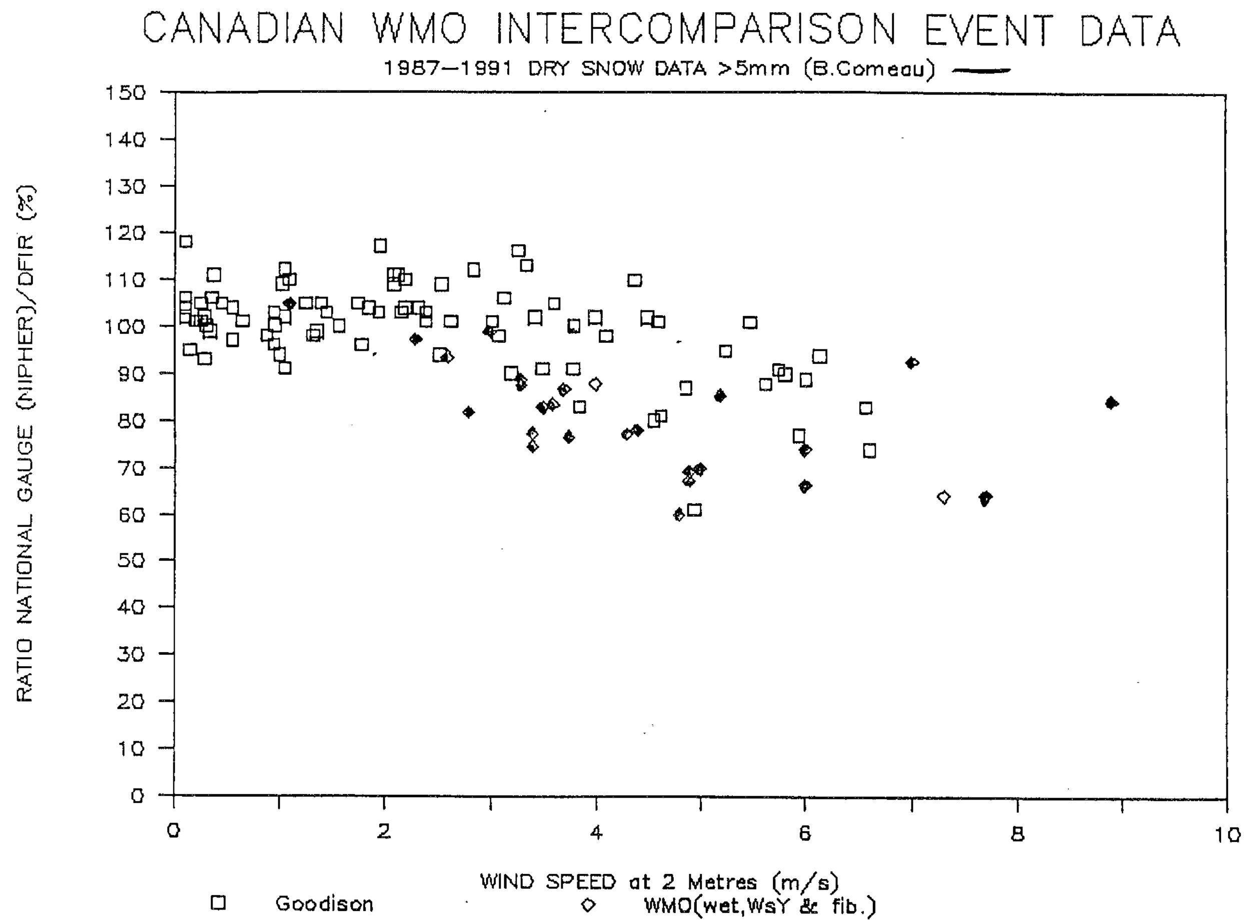
slope values in log–log (obs) relations

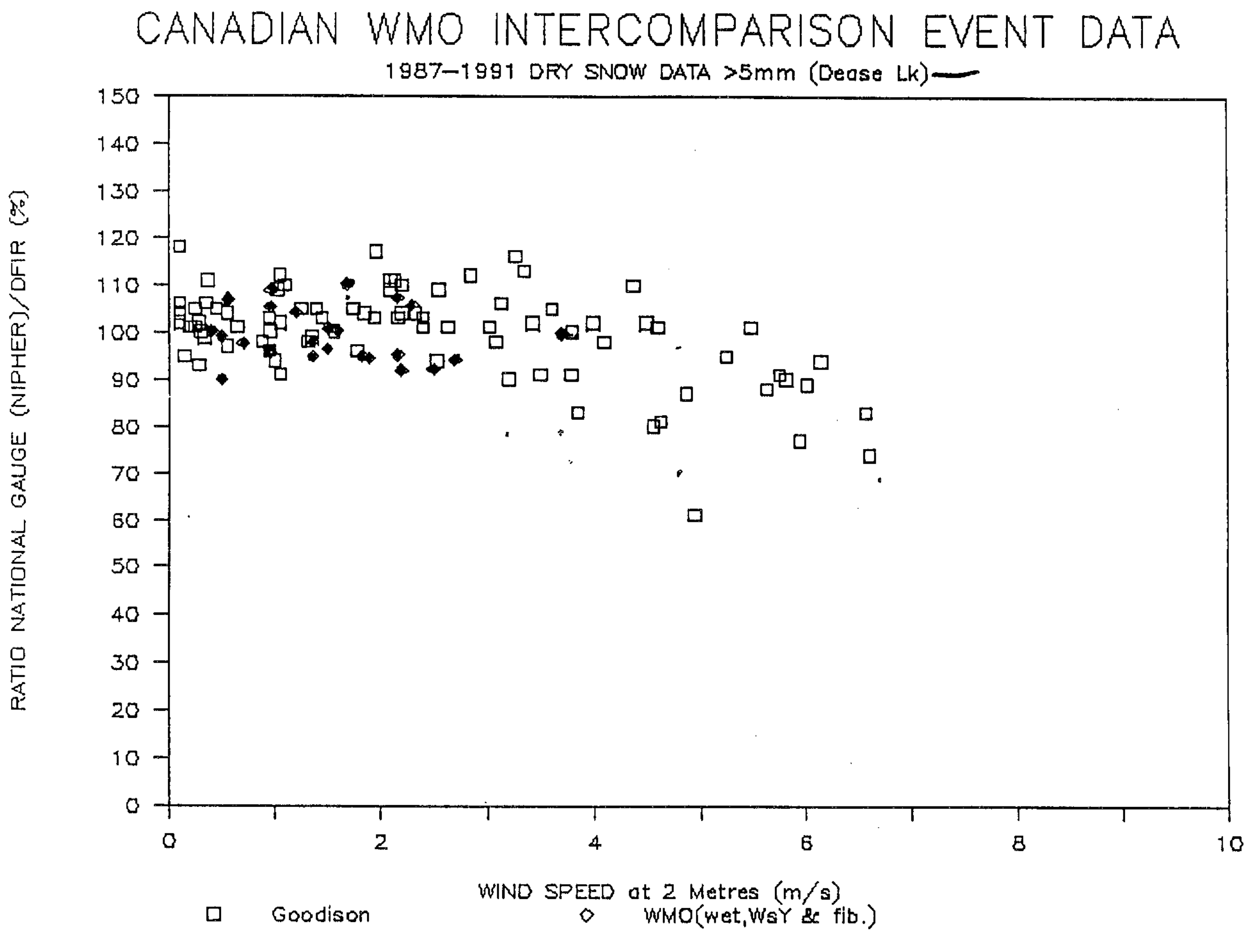


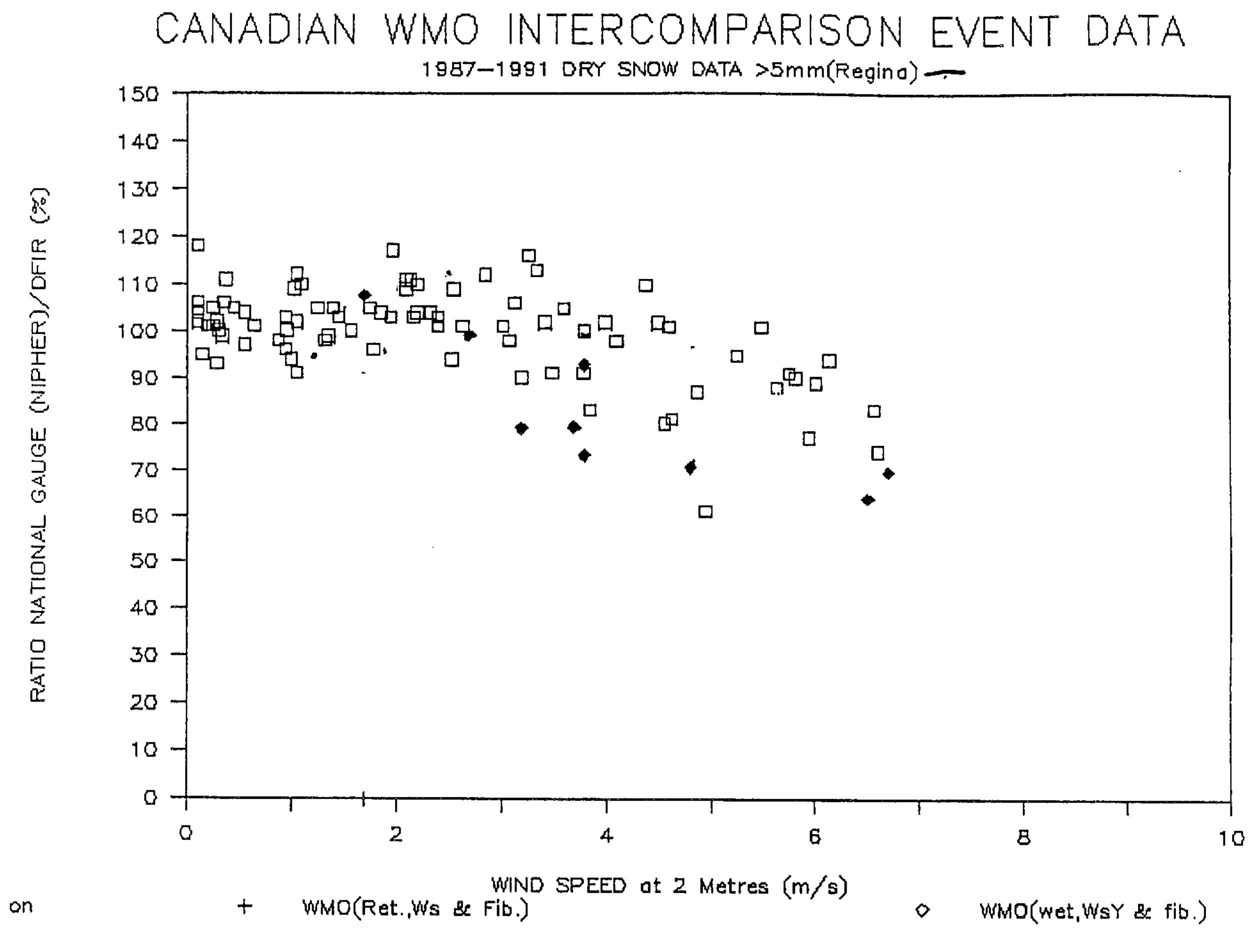
Due to the extreme mild winters the last five years, we have been compelled to use 10 min's value of precipitation in order to analyse the data. We are now however, due to the many data we have got, able to make an anlysis on the basis of semidaily values of precipitation. Semidaily values, unlike 10 min's values, makes it possible to perform a better test of the model (1), since the semidaily events show no interdependence compared to 10 min's events.

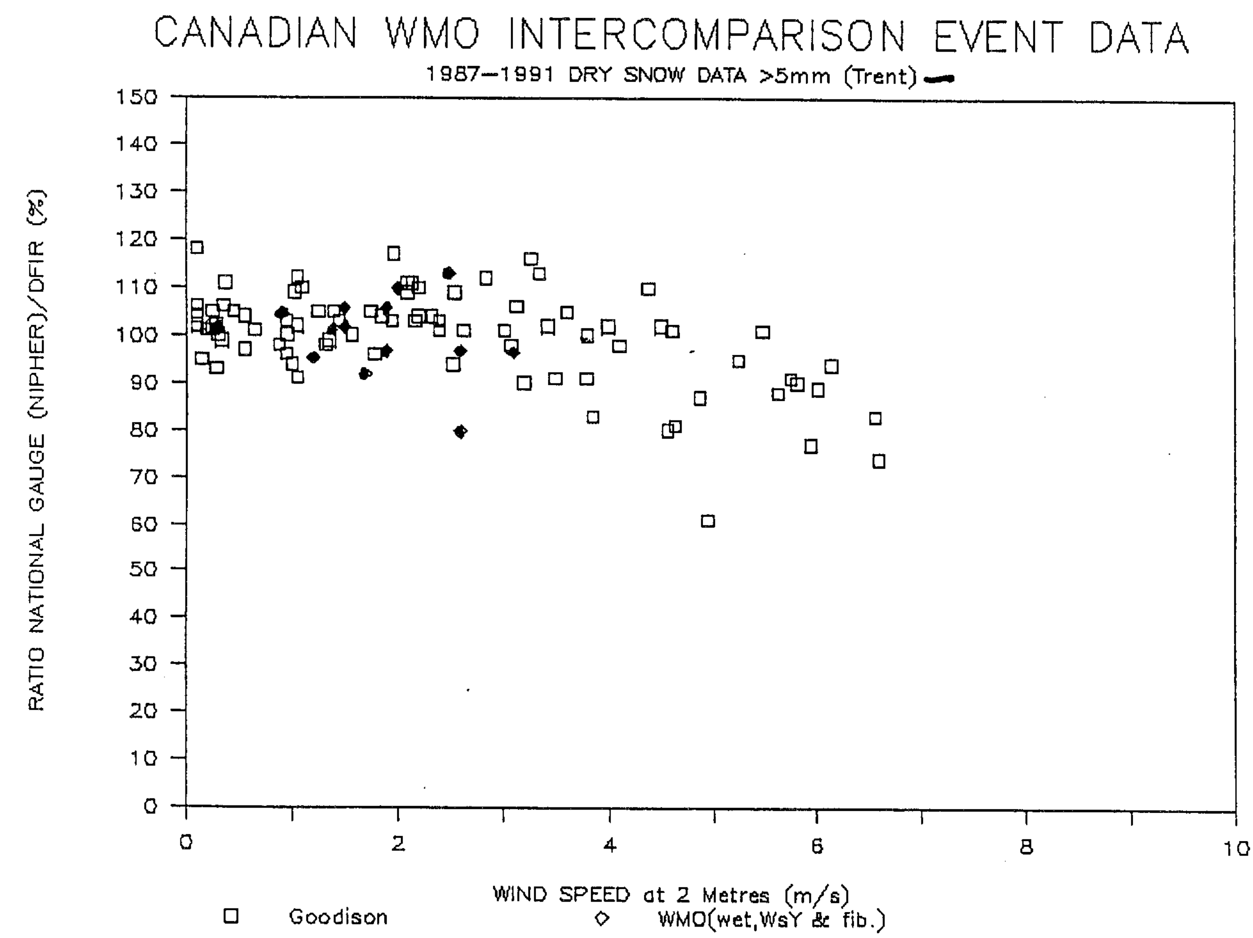

CANADIAN WMO INTERCOMPARISON EVENT DATA
1987—1991 DRY SNOW DATA >5mm(Kortright)
RATIO NATIONAL GAUGE (NIPHER)/DFIR (%)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
WIND SPEED at 2 Metres (m/s)
Goodison
WMO(wet,WsY & fib.)


CANADIAN WMO INTERCOMPARISON EVENT DATA
1987—1991 DRY SNOW DATA >5mm (E.Baltic)
RATIO NATIONAL GAUGE (NIPHER)/DFIR (%)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
WIND SPEED at 2 Metres (m/s)
Goodison
WMO(wet,WsY & fib.)


CANADIAN WMO INTERCOMPARISON EVENT DATA
1987–1991 DRY SNOW DATA >5mm (B.Comeau)
RATIO NATIONAL GAUGE (NIPHER)/DFIR (%)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
2
4
6
8
10
WIND SPEED at 2 Metres (m/s)
Goodison
WMO(wet,WsY & fib.)

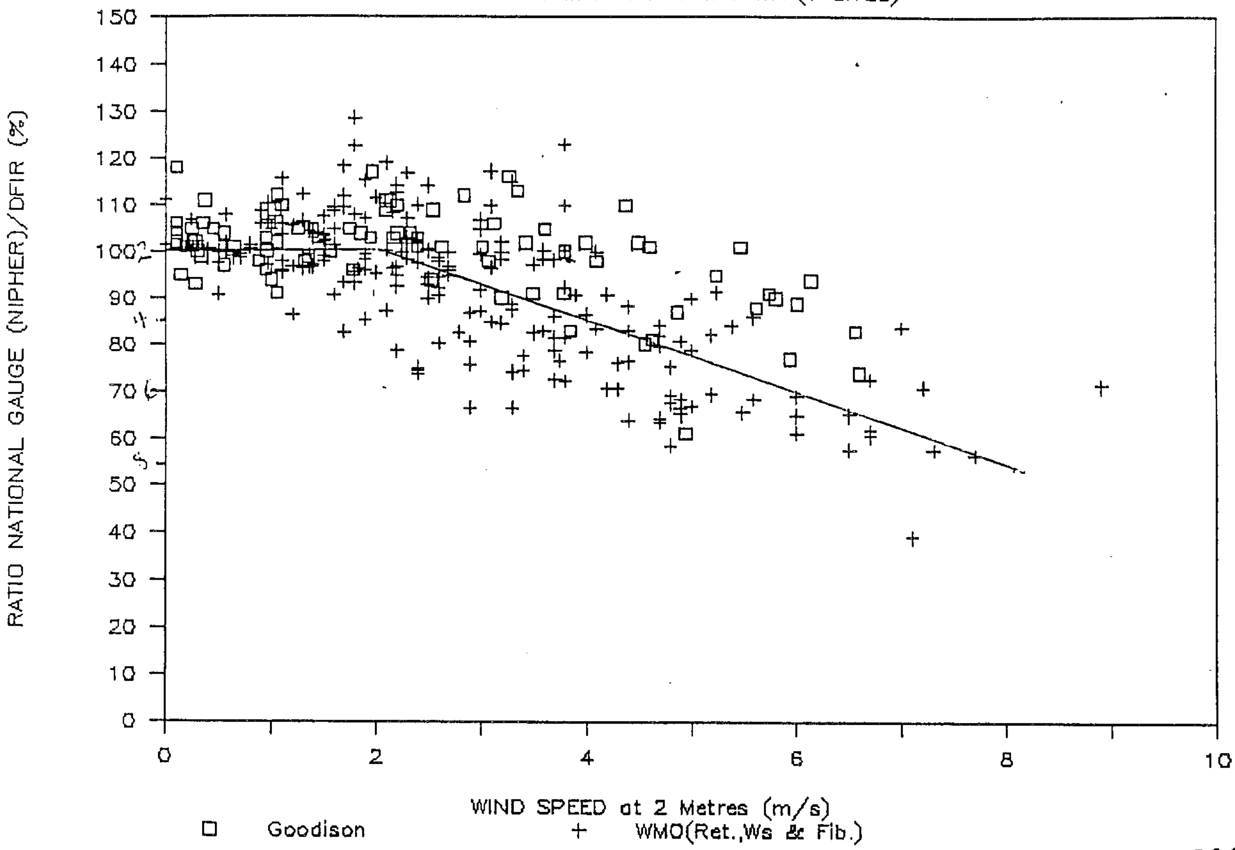

CANADIAN WMO INTERCOMPARISON EVENT DATA
1987–1991 DRY SNOW DATA >5mm (Dease Lk)
RATIO NATIONAL GAUGE (NIPHER)/DFIR (%)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
2
4
6
8
10
WIND SPEED at 2 Metres (m/s)
Goodison
WMO(wet,WsY & fib.)


CANADIAN WMO INTERCOMPARISON EVENT DATA
1987–1991 DRY SNOW DATA >5mm(Regina)
RATIO NATIONAL GAUGE (NIPHER)/DFIR (%)
WIND SPEED at 2 Metres (m/s)
on
+ WMO(Ret.,Ws & Fib.)
◇ WMO(wet,WsY & fib.)


CANADIAN WMO INTERCOMPARISON EVENT DATA
1987–1991 DRY SNOW DATA >5mm (Trent)
RATIO NATIONAL GAUGE (NIPHER)/DFIR (%)
WIND SPEED at 2 Metres (m/s)
□ Goodison
◇ WMO(wet,WsY & fib.)

CANADA & FRG INTERCOMPARISON EVENT DATA

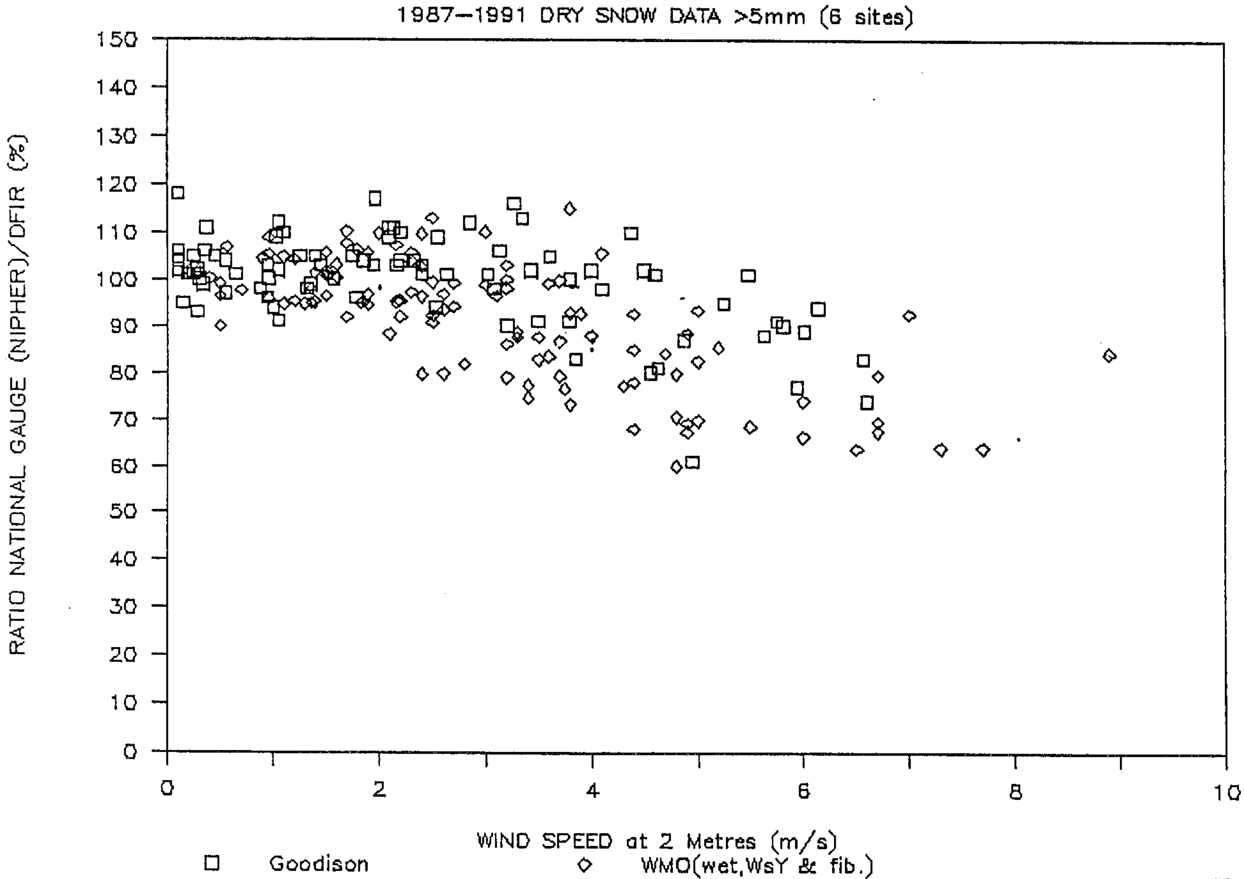
1987—1991 ALL SNOW ONLY DATA (7 SITES)



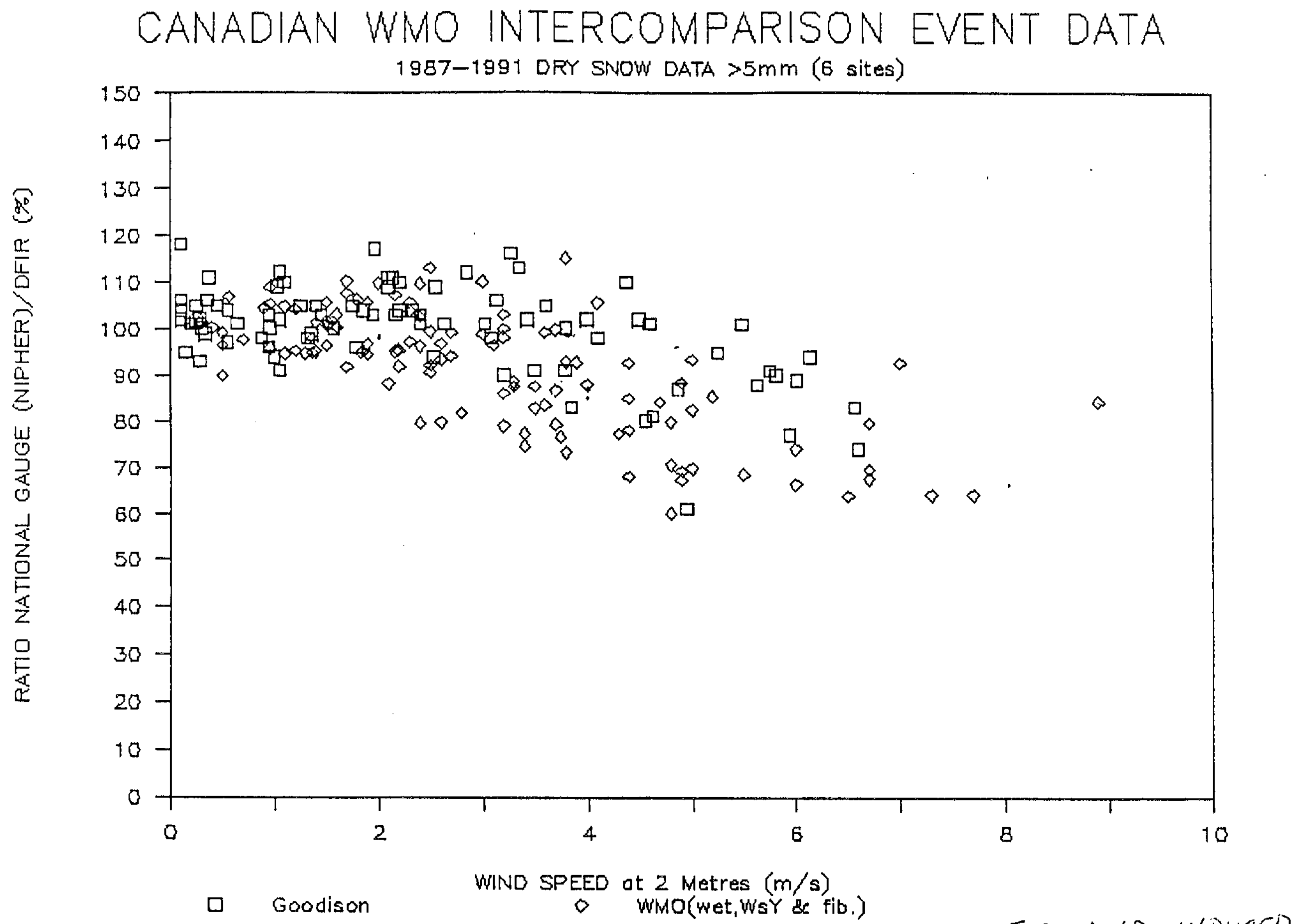
DFIR CORRECTED FOR WIND INDUCED ERRORS USING GOLUBEV METHOD

CANADIAN WMO INTERCOMPARISON EVENT DATA

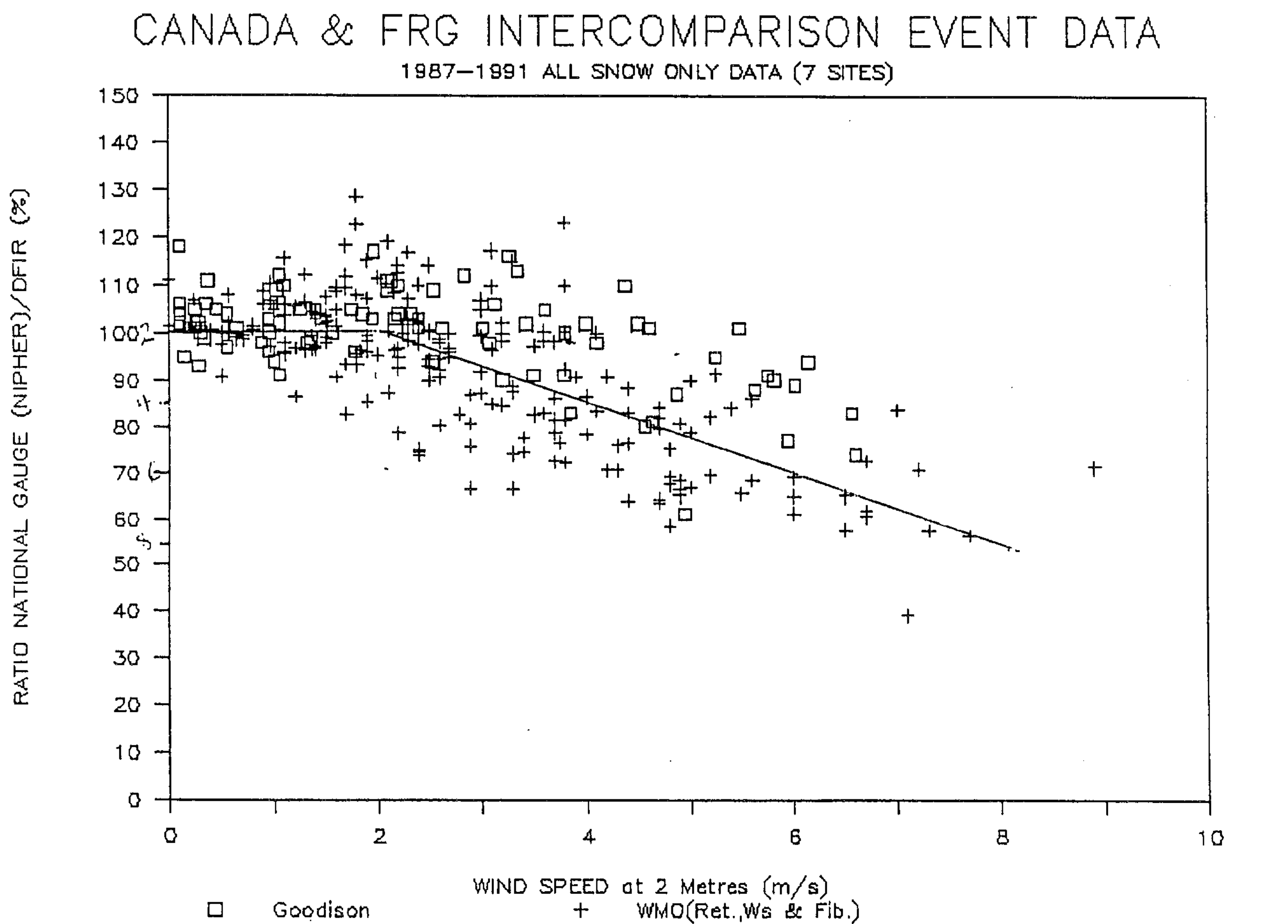
1987—1991 DRY SNOW DATA >5mm (6 sites)



DFIR CORRECTED FOR WIND INDUCED ERRORS USING YANG METHOD



DFIR CORRECTED FOR WIND INDUCED ERRORS USING YANG METHOD



DFIR CORRECTED FOR WIND INDUCED ERRORS USING GOLUBEV METHOD

CORRECTION OF CANADIAN WINTER PRECIPITATION DATA

J.R. Metcalfe and B.E. Goodison

Canadian Climate Centre
Environment Canada
Downsview, Ontario, Canada

1. BACKGROUND

Many of the assessments of future global change are intrinsic to climate and hydrology. Monitoring of the climate system through systematic observation and analysis of climate related variables on a global, national and regional scale is an important contribution to improving our ability to assess variability and change. In northern latitudes snow is a critical element in the determination of global and regional storage and fluxes of water. Accurate and compatible precipitation measurements are crucial if the storage and fluxes of water are to be determined accurately.

The inherent nature of snowcover (eg. highly variable temporal and spatial structure related to land cover and terrain and redistribution by wind) and of snowfall (varying density, significant errors in gauge measurements due to wind, wetting and evaporative losses) make snow much more difficult to measure accurately than rainfall. In northern regions, snowfall can occur during all months of the year; for most of Canada, snow comprises over 30% of the annual precipitation. In addition to its importance in the climate system, snow serves as the critical source of water supply for soil moisture recharge, reservoir filling for hydro-electric and irrigation purposes, and is a major contributor to winter or spring flooding. Consequently, the Canadian Climate Centre (CCC) of the Atmospheric Environment Service (AES) has expended considerable effort on quantifying precipitation measurement errors and developing improved methods for snow measurement and analysis (e.g. Goodison 1978, 1981; Goodison and Louie, 1986; Goodison and Metcalfe, 1989, 1992).

The problems of measuring snowfall were recognized by the World Meteorological Organization (WMO) and in 1985 it initiated an international intercomparison aimed at assessing national methods of measuring solid precipitation. Past and current procedures as well as new methods suitable for use at automatic weather stations were to be assessed against a standard method whose accuracy and reliability were known (Goodison et al., 1989). Figure 1 demonstrates the magnitude of the potential measurement errors for selected gauges compared to "true precipitation" which in this case was the double fence shield (DFIR) (Golubev, 1986). The DFIR was selected as the reference gauge for the WMO Intercomparison. Notable is that the correction factors to estimate true winter precipitation (over 3.0 for unshielded gauges) are much greater than those for correcting summer rainfall (about 1.1 for the gauges tested). Canada recognized this experiment as an opportunity to provide solutions to some of the challenges of winter precipitation measurement and operated seven intercomparison stations located in different climatic and physiographic regions across the country.

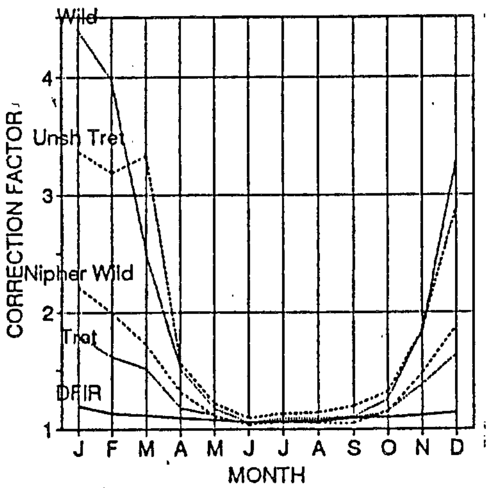


Fig.1 Monthly correction factors (adopted from Golubev, 1986) for different gauges, Valdai, Russia (1970-78, mean wind speed 3ms^{-1} at 2m): Double Fence Intercomparison Reference (DFIR), Tretyakov with wind shield (Tret), Wild gauge (Wild), Wild gauge with Nipher shield (Nipher Wild), unshielded Tretyakov (unsh Tret).

2. CANADIAN STANDARD WINTER PRECIPITATION MEASUREMENT METHODS

Currently in Canada, solid precipitation amount is measured at more than 2,400 AES co-operative climate stations, resulting in an average precipitation station density of 2.5 stations per

10,000km². Most stations still use non-recording or manual methods of measurement, with an observer making the measurements. The Canadian Nipher Shielded Snow Gauge System is the standard AES instrument for measuring snowfall water equivalent at about 350 of these stations. The remaining 85% of the stations estimate snowfall precipitation from ruler measurements of the depth of freshly fallen snow and by assuming the density of fresh snow to be $100 kgm^{-3}$.

The AES also operates or accepts data from approximately 200 automatic meteorological stations. These auto-stations either log data on site for extended periods or transmit data in real time via land line or satellite. Precipitation sensors on these auto-stations vary from the unheated tipping-bucket, providing rainfall measurements only, to the more sophisticated mechanical weighing gauge fitted with an electronic interface allowing measurement of all forms of precipitation. More recently, an inexpensive ultrasonic ranging device has been added to some auto-stations to provide reliable snow depth measurements (Goodison et al., 1988), complementing the precipitation measurements. A more complete discussion on the Canadian network and on methods of precipitation measurement is given in Goodison et al. (1981), Goodison and Louie (1986) and Goodison and Metcalfe (1989a, 1989b).

3. ERRORS IN CANADIAN METHODS

3.1 Snow Ruler Measurements

Prior to 1960, all AES stations used this method of measurement. Goodison et al.(1981) and Goodison and Metcalfe (1981) showed that the snowfall water equivalent estimated using the mean fresh snowfall depth measurement and a mean density of $100 kgm^{-3}$ can be subject to substantial error. The error depends on the magnitude of the deviation of the true density from $100 kgm^{-3}$, on the representativeness of both the site and the depth measurements and the time of the observation during the storm. Goodison and Metcalfe (1981) reported on an experiment to measure fresh snowfall water equivalent at selected Canadian stations over a three year period. Seasonal average fresh snowfall densities ranged from $70 kgm^{-3}$ to $165 kgm^{-3}$.

Dease Lake in northern British Columbia is an AES synoptic station, an evaluation station in the WMO Intercomparison and was a study site in the earlier fresh snowfall experiment. Seasonal average densities for freshly fallen snow at the station for the duration of the study varied from 71 to $84 kgm^{-3}$. Recent results from the WMO Intercomparison confirm this range of seasonal average density for Dease Lake. Figure 2 compares measured snow water equivalent from the WMO reference standard (DFIR) and estimated snow water equivalent from fresh snowfall ruler measurements using a mean density of $81 kgm^{-3}$, which was calculated from comparative DFIR/ruler ratios for six hourly snowfall observations greater than 2.0cm at the station from 1987-1990. Storm densities actually varied from 30 to $155 kgm^{-3}$. Use of the standard $100 kgm^{-3}$ mean density (Fig.3) resulted in a 20% overestimation of winter precipitation.

These two independent studies show a consistent bias in winter precipitation measurement using ruler data in this region. In this case, winter snowfall precipitation is overestimated, quite the opposite from most gauge measurements and from the common perception of hydrologists. Since the seasonal average fresh snowfall density varies across the country (Goodison and Metcalfe, 1981), correction of ruler measurements will not be a simple task.

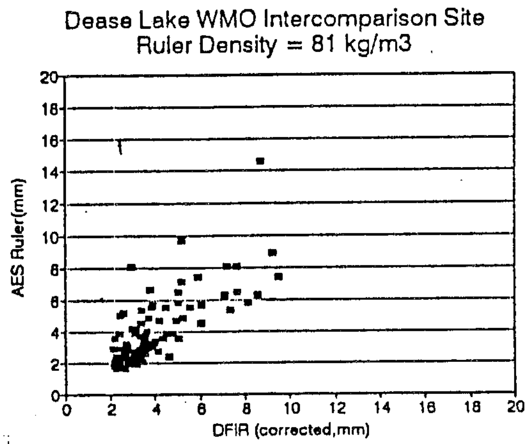


Fig.2 Snowfall water equivalent from ruler measurements using mean density of $81 kgm^{-3}$ compared to measured water equivalent from DFIR.

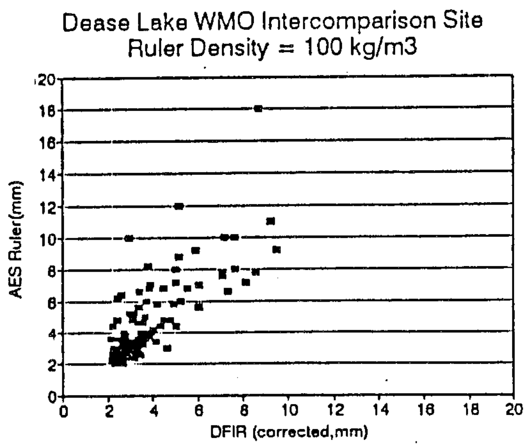


Fig.3 Snowfall water equivalent from ruler measurements using national standard mean density of $100 kgm^{-3}$ compared to measured water equivalent from DFIR.

Table 1

Effects of applying corrections for wetting loss and trace amounts to Nipher gauge measurements of winter precipitation at Regina, Saskatchewan for three winter seasons.

Winter Season	Normal Precip. (mm)	Accumulated Precip. (mm)	Nipher Emptied (#times)	Trace Recorded (#times)	Corrected Precip. (mm)	Increase (%)
1986/87	123	89	89	156	113	27
1987/88	123	64	62	173	85	33
1988/89	123	78	90	180	104	33
Average	123	77	80	170	101	31

3.2 Snow Gauge Measurements

The Canadian Nipher Shielded Snow Gauge System has been designated as the standard AES instrument for measuring snowfall amount in terms of water equivalent. The accuracy of this snow gauge and others used in Canada was first defined by Goodison (1978). Preliminary results from the WMO Intercomparison show results similar to those found previously and indicate the catch of the national standard Nipher shielded gauge to be almost the same as the WMO reference standard (DFIR) (Goodison and Metcalfe, 1992).

The Canadian Nipher gauge and the Russian Tretyakov gauge (the collector used in the DFIR) are non-recording systems requiring the melted contents to be poured out into a measuring graduate. Both gauges retain a certain amount of water which cannot be poured out; this is known as the retention or wetting loss. Previous field experimentation (Goodison, 1978) determined an average wetting loss for the Nipher gauge collector of 0.15mm +/- 0.02mm. Recent studies (Goodison and Metcalfe, 1989b), as part of the WMO Intercomparison experiment confirm these findings, with older collectors showing even greater wetting loss. The Tretyakov gauge wetting loss averaged 0.20mm per observation. Although this is a systematic loss every time the contents are melted and poured out of the gauge, no correction for this error has been applied to the Canadian network data.

The measurement of "trace amounts" of precipitation (<0.2mm) using the Nipher gauge is also a concern. Some Arctic stations have reported over 80% of all precipitation observations as trace amounts. Officially, a trace is given a value of zero in the AES digital archive. Using techniques similar to those described above for resolving wetting loss, it was determined that a trace could be an actual measurable amount, the value of which lies between 0.0mm and 0.15mm.For experimental purposes a trace reported in any 6-hour period was assigned a value of 0.07mm.

Regina, Saskatchewan, located in the south central Canadian prairies, is another AES synoptic station participating in the WMO Intercomparison. For winter seasons 1986-87 through 1988-89, which were considered abnormally dry years, the Nipher gauge was emptied an average of 80 times per season when there was a measurable amount of solid precipitation (wetting loss equals 80 X 0.15mm). In addition, the Nipher gauge amount was reported as "trace" on average 170 times each season (trace equals 170 X 0.07mm). Without even considering the effect of wind on gauge catch, these two "errors" in measurement resulted in an average underestimate of winter snowfall precipitation at Regina of 24.0mm. Table 1 shows the effect of correcting measured winter precipitation for these two systematic errors for three below normal snow years. The magnitude of this correction could be even larger for normal or above normal years.

Many investigators have indicated that wind is the major cause of error in precipitation gauge measurements (Goodison et al., 1981). The effect of wind on gauge catch can be reduced by proper gauge siting, in naturally sheltered locations, or by using artificial shielding. Goodison (1978) showed that for most gauges, the mean ratio of gauge catch to "true precipitation" as a function of wind speed decreases exponentially with increasing wind speed. The Canadian Nipher gauge was an exception. The unique design of the Canadian Nipher shield minimizes disturbance of the airflow over the gauge and eliminates updrafts over the orifice. This results in an improved catch by the gauge, for gauge height wind speeds up to 7ms^{-1}, relative to other shielded and unshielded gauges (Goodison et al., 1983).

Figure 4 shows the ratio of the Nipher gauge (corrected for wetting loss) to the DFIR as a function of wind speed for all intercomparison stations along with the results from Goodison (1978). The DFIR measurements were corrected for wetting loss and for its wind induced catch deficiency according to Golubev (1986). For wind speeds higher than 3.5 ms^{-1} the results from the current WMO Intercomparison show the catch efficiency of the Nipher to be generally lower than that reported previously by Goodison (1978). Considering that two quite different methods of determining "true precipitation" were used and that the current intercomparison involves sites in different climatic regions, the results from these two studies are quite compatible.

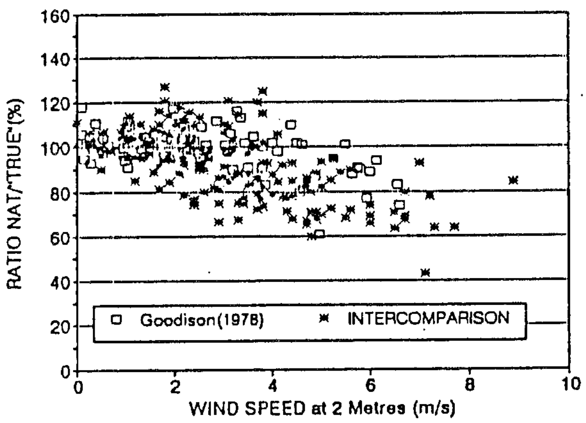


Fig.4 Comparison of catch ratios, Canadian Nipher to "true precipitation" for WMO Intercomparison event data >3.0mm and previous results by Goodison (1978). Both gauges corrected for wetting loss and DFIR corrected for wind induced errors.

4.PRECIPITATION CORRECTIONS

Like agencies in all countries, except Russia, AES does not yet correct its precipitation data for systematic errors due to wind, wetting loss, evaporation or trace amounts. The users of Canadian precipitation data, and especially winter precipitation data, must be aware of the conditions and limitations that exist with these measurements. An archive of consistent and compatible precipitation data must be available before reliable analyses of climate variability and detection of change can be made. To this end, the CCC has begun developing a set of standard procedures for correcting its historical precipitation archive based on the precipitation intercomparison studies conducted over recent years.

For climatological applications, including homogeneity testing and trend analysis of precipitation time series, users must consider the method of observation and the type and shielding of the gauges from which they are using data. Snowfall water equivalent and total precipitation data time series will be affected by the introduction of the Nipher gauge into the AES network (approx. 1960); this has nothing to do with natural or anthropogenic changes in climate. Correcting Nipher gauge measurements using the procedures outlined above would permit calculation of corrected snowfall water equivalent which could then be used with double mass curves (Goodison et al., 1981) to adjust the annual snowfall water equivalent previously estimated from ruler measurements. In addition, in areas where no such relationship is available, a better determination of seasonal snowfall water equivalent from ruler measurements may be obtained by using estimated densities which are more representative of the climatic regime (Groisman, 1992). Using these procedures, a consistent and compatible data record could be assembled which would be suitable for the assessment of station homogeneity and ultimately climatic variability. These adjustments to precipitation data are even more critical to hydrologists who are attempting to calculate basin or large scale water balances.

Figure 5 shows the result of correcting Dease Lake synoptic station annual snowfall precipitation for the reference gauge (DFIR) and the AES standard methods of snowfall measurement, ruler and Nipher gauge, for four consecutive winter periods during the WMO Intercomparison. The Nipher gauge at this station, where average winds are less than 3.0 ms^{-1}, showed only a 5-10% undercatch compared to the DFIR. Ruler measurements, however, overmeasured by as much as 20%. After correction, both the ruler and Nipher gauge measurements were within a few percent of "true precipitation" (C/DFIR).

The ability to implement accurate correction procedures for the Canadian precipitation archive, however, presented several unexpected challenges. Information within the AES archive is stored as separate elements. For precipitation, the elements archived include each 6 hour precipitation measurement, 24 hour rainfall, 24 hour snowfall (centimetres of fresh snowfall, i.e. ruler measurement) and 24 hour precipitation (millimetres of water equivalent, i.e. gauge measurement). As mentioned previously 6 hour trace amounts are given a value of zero. Also, during months when mixed precipitation occurs, i.e. rain and snow, it will be difficult to determine with any degree of accuracy the type of precipitation and Nipher gauge wetting loss on a six hourly basis. A consistent and reliable method of estimating these must be developed.

For wind speed, the element archived is

hourly average speed. From these, the mean wind speed for the 6 hour period corresponding to the precipitation observation times were determined. The station wind speed and direction sensor at Dease Lake is mounted at 15.24m which is non-standard. It is also poorly sited in a stand of trees. Often the 2m wind speed, measured as part of the intercomparison, was higher than the station wind speed. This inverse relationship made the task of determining wind speed at gauge height difficult. The ability to reduce wind speed from the standard height (generally 10m) for a range of site conditions will be important. Good site descriptions and assessment of gauge exposure are necessary to do this with any degree of accuracy. For most Nipher gauge sites, wind is measured, but where it is not, a regional estimate of wind speed will have to be made, or only correction for trace and wetting loss can be implemented.

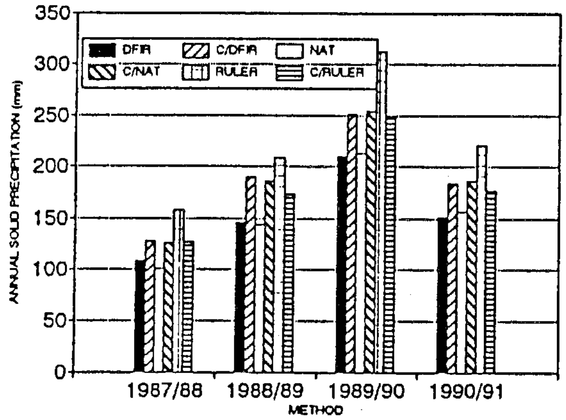


Fig.5 Annual measured and corrected snowfall precipitation for three different measurement methods at Dease Lake for 1987/88 to 1990/91 winter periods: Double Fence Intercomparison Reference (DFIR); corrected DFIR or "true precipitation" (C/DFIR); Nipher gauge (NAT); corrected Nipher gauge (C/NAT); fresh snowfall ruler using 100 kgm^{-3} (RULER), corrected ruler using 80 kgm^{-3} (C/RULER).

With the trend toward increased automation additional changes in measurement method are being introduced into the AES observation network. In order to provide not only more accurate precipitation measurements, but also to provide data which would be compatible with measurements made with current national gauge, AES has developed and tested a large Nipher-type shield suitable for use on recording precipitation gauges (Goodison et al., 1983, Goodison and Metcalfe, 1989a). The error associated with this method of measurement has been quantified as part of the WMO Intercomparison and methods of correcting the measurements are being tested. Again the need for wind speed measurements is critical.

These initial correction procedures will be tested on selected data from Arctic and Mackenzie Basin stations, which are particularly important for GEWEX, ACSYS and other climate system studies. The impact of correction is expected to be significant, with winter precipitation measurements possibly being doubled in some years. This will be significant in the study of climate variability and change and in determining accurate fluxes and storage of water in these northern regions.

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WMO SOLID PRECIPITATION MEASUREMENT INTERCOMPARISON

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BACKGROUND

Members of the World Meteorological Organization (WMO) recognize that it is of prime importance to provide high quality and compatible meteorological and hydrological data. International and regional intercomparisons are one important method to evaluate and compare the accuracy and performance of meteorological instruments and new methods of observation. The WMO Solid Precipitation Measurement Intercomparison, initiated in 1985, was one such international intercomparison. Its goal was to assess national methods of measuring solid precipitation against methods whose accuracy and reliability were known, including past and current procedures, automated systems and new methods of observation. Countries which have participated in the experiment, and submitted data for analysis for at least one winter season, include: Bulgaria, Canada, China, Croatia, Czechoslovakia, Denmark, Finland, Germany, India, Norway, Russia, Sweden, United Kingdom, USA, and recently, Romania.

The Intercomparison was designed to: determine the wind related errors in national methods of solid precipitation measurement, including consideration of wetting and evaporation losses; derive standard methods for correcting solid precipitation measurements; and, introduce a reference method of solid precipitation measurement for general use to calibrate any type of precipitation gauge. Unlike some WMO intercomparisons, this experiment is being conducted by Members at sites selected in their own country or region. Field studies were started by some countries during the 1986/87 winter. The last official field season was to have been 1991/92. However, warm winters in several countries have resulted in a reduced number of snow events; thus, the organizing committee agreed to extend the intercomparison to 1992/93 to have a larger data base of solid precipitation measurements. The committee aims to complete the final report for WMO during 1993. It is expected that some countries will continue the intercomparison to meet their own needs.

Determination of the reference standard for the snowfall intercomparison was critical. After reviewing all possible methods (bush shield, double fence shield, forest clearing, snow board measurement, dual-gauge approach) the organizing committee designated the octagonal vertical double-fence shield (with Tretyakov gauge) as the Intercomparison Reference (DFIR). Specifications are given in (2,11). An artificial shield was selected, since natural bush sheltering could not be found in all climatic regions which should be studied. Continuing assessment of the DFIR as a reference standard is required, particularly if results of this intercomparison are to be used to correct winter precipitation measurements to create spatially and temporally compatible data sets.

REVIEW OF THE INTERCOMPARISON

A summary of the progress by each reporting country is given in (12). Initial research results are also available in (3,4,6,8,10). A brief summary of significant results is given here to provide the scientific community with an idea of the magnitude of differences in measurements between precipitation gauges.

One evaluation station has been operated in Germany at Harzgerode since December 1, 1986. Initial results for the first four winter seasons show the percentage catch of the Hellmann gauge (German National Standard) to be between 46% (snow only) and 96% (rain) compared to the DFIR (Table 1). For snow only events, the unshielded Hellmann gauge measured 23%-67% of the DFIR. Table 2 summarizes the mean catch by wind speed class for snow only events. For the study period 21% of the precipitation was snow only; 49% occurred as mixed snow and rain. The need to assess the performance of gauges during mixed precipitation events is recognized as an important challenge for all participants.

Table 1: Percentage catch compared to DFIR for selected precipitation gauges at Harzgerode, Germany (December-March 1986-1990) (12).

Precipitation Type	Number of cases	TRET %	HELLM unsh. %	HELLM sh. %	AUTOM. gauge %	METRA %
Snow	67	62.9	46.0	65.1	42.9	39.0
Snow with rain	45	69.7	64.0	76.7	58.5	52.3
Rain with snow	69	91.8	92.4	96.8	89.4	83.5
Rain	139	92.4	96.1	99.0	93.6	90.2

Note: TRET-Tretyakov;HELLM unsh.-Hellmann unshielded;HELLM sh. - Hellmann shielded; AUTOM. gauge-Automatic gauge; METRA-automatic gauge.

Table 2: Percentage Catch of Comparison Gauges Relative to DFIR (%) as a Function of Wind Speed for Snow Only Events, Harzgerode Germany,December-March 1986-1990 (12).

Mean Wind Speed (m/s)	Number of cases	Mean Air Temp (°C)	TRET %	HELLM unsh %	HELLM sh. %	AUTOM. gauge %	METRA %
0.0-1.0	2	-12.9	85.7	57.1	85.7	0.0	57.1
1.1-2.0	17	-6.3	85.7	67.2	88.5	57.0	60.2
2.1-3.0	17	-4.3	82.8	64.6	73.7	55.5	59.2
3.1-4.0	21	-3.2	49.3	40.9	63.6	30.7	30.5
4.1-5.0	8	-2.5	54.3	29.5	48.2	-41.7	24.2
>5.1	2	.6	32.6	22.8	47.8	26.1	19.6

Finland has operated the test site at Jokioinen for the intercomparison of the national gauges from the Nordic countries of Denmark, Finland, Norway and Sweden. Twenty-one gauges are being tested at this site (12). Sums of solid precipitation over 12 winter months (1988-1991) showed differences up to 39% compared to the DFIR. The results show that for the unshielded Hellmann gauge used in Denmark, the deficit is higher than the deficit for the other countries' shielded gauges. This is similar to the results for Germany. Wetting loss and evaporation from the gauges were also assessed. Wetting losses for different types of gauges varied from 1.8% to 9.5% in the twelve monthly sums for all cases and from 0.0% to 4.0% for precipitation intensities >5.0mm/12h (12). Mean daily evaporation from the gauges during rainless days was in general less than 1mm/12 h. In April, however, it could exceed 1mm/12h (5).

Table 3: Ratio of gauge catch compared to DFIR (%) for sums of precipitation for 12 winter months (1988-1991) for selected gauges at Jokioinen Finland (12).a:all events(370);b:events>5.0mm/12h(37).

TRET		TRET unsh		NOR		WILD unsh		WILD sh.		TRETSF		SMHI		DAN	
a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
83	84	65	68	76	78	61	64	71	73	88	90	81	83	66	70

Note: TRET - Tretyakov; NOR - Norwegian gauge with wind shield; TRETSF - Finnish prototype with wind shield; SMHI - Swedish gauge with wind shield; DAN-Hellmann without wind shield; WILD-Wild gauge.

Much of the historical research on the accuracy of precipitation measurements was conducted in Russia at the Valdai experimental station by the State Hydrological Institute. The design and experimental results supporting the use of the DFIR as a reference standard came from research at this station. To check the measurements of the DFIR, precipitation is also being measured by a Tretyakov gauge installed in a protected plot in nearby bushes which are cut periodically at the height of the orifice. These values are the closest measurement of true at this site. Monthly precipitation totals for rain and snow for the winter months for 1988 to 1990 are given in Table 4. The DFIR measured 3.5% less than the Tretyakov in the protected plot. The Canadian Nipher gauge measured 87% of the DFIR; the Tretyakov recorded 82%. Future analysis will separate storms by precipitation type and wind speed.

Table 4. Monthly precipitation (rain and snow) totals (mm) measured by different gauges at Valdai Russia, 1988-1990 (12).

Gauge Type	Nov	Dec	Jan	Feb	Mar	Apr
Tretyakov in bushes	110.9	125.6	180.7	131.1	134.7	40.4
Tretyakov in DFIR	104.7	121.6	174.0	127.3	130.0	40.1
Tretyakov gauge	76.6	98.2	140.3	105.8	113.9	36.0
Canadian Nipher	90.7	108.5	151.8	110.3	111.5	34.1
Hellmann (Poland)	53.4	70.1	101.9	96.9	100.0	34.0

Canada has operated six evaluation stations in different climatic regions. Initial results are reported in (1,3,9). Special consideration has been given to assessment of the accuracy and performance of automatic gauges. In Canada, the use of weighing recording gauges is presently the most practical method of measuring annual precipitation at auto-stations. Heated tipping bucket gauges were not a feasible alternative for winter precipitation measurement in areas where the temperatures fell below 0°C for prolonged periods. The use of an acoustic snow depth sensor, in conjunction with a precipitation gauge, was found to be effective in providing additional information on type and timing of precipitation.

FUTURE EFFORT

Future efforts of the Committee and considerations for WMO Members are given in (12). A digital archive of all of the measurements has been compiled for use by all participants. Initial analytical efforts by participants have been with their own data. Data from the same type of instrument at different sites will be combined for subsequent analyses. Events of rain, snow and mixed precipitation will be analyzed separately to derive systematic wind-related errors. The minimum DFIR measured value for an event to be included in the comparative statistical analysis is 2.0 mm. Time steps to be assessed are 12 h, daily, storm or event, and monthly. Wind speed and temperature (at gauge height) will be regressed against the ratio of gauge/DFIR. Initial results should be compiled by late 1992 for review.

The committee also discussed the implementation of proposed correction procedures, including their application to global data sets. Russia is the only country to implement some type of correction procedure for systematic errors in the precipitation observations. Corrections are made for wetting losses and monthly adjustment coefficients have been developed to adjust for changes in gauge type. This is an important first step in preparing homogeneous time series. Correction for undercatch due to wind for individual observations remains a challenge for everyone. On a global basis, future precipitation research will require correction of monthly totals in addition to long-term averages. To remove gauge induced biases, efforts like those of Legates (7) must be made. This Intercomparison should provide the climatological community with correction procedures to minimize the systematic errors. Procedures must take into account the type of gauge and shield (if any) used, the measurement technique, precipitation type and variation in wind speed. Estimates of the accuracy of a particular gauge correction procedure must be provided and a sequence of correction procedures, including simplified ones in case data are missing, should be available. Procedures for correcting daily and monthly accumulations, as well as storm totals, must be developed. Results of this Intercomparison, together with the necessary metadata, should provide the scientific community with the capability to derive more accurate and representative spatial and temporal time series.

Implementation of correction procedures should be done by Member countries. Each country should plan a demonstration project to test how the procedures might be implemented in their country for historical and current data sets. In order to understand future changes in methods of observation, the Organizing Committee feels that it would be very useful to establish National and Regional Precipitation Centres. Such Centres would have the task to compare national or regional methods of precipitation measurement against standardized reference instrumentation. The reference station should be equipped with a pit gauge for rain and a DFIR for snow. Suggested terms of reference for such Centres are given in (12). If homogeneous precipitation time series are to be developed, not only are corrections for systematic errors necessary, but on-going intercomparison of methods of observation by Members will also be critical. WMO Members should consider the benefits of such Centres.

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PREPARATION OF THE FINAL ANALYSIS
(Some ideas how to proceed)

1 Definitions (necessary at least for the following terms)
(Some draft definitions are contained in the following pages)
- a. Catch ratio
- b. Deficit
- c. Wetting loss
- d. Retention loss
- e. Accuracy/uncertainty
- f. Precipitation gauge
- g. Rain gauge
- h. Snow gauge
- i. Dry snow (drifting/blowing snow)
- j. Solid precipitation
- k. Wet snow
- l. Undercatch
- m. Mixed snow
- n. Systematic/random error
- o. Exposure
- p. ......to be continued.....

2 Recommendations
- a. Need for correction of systematic errors
- b. Wetting loss correction
- c. Need for shielding
- d. Trace amount
- e. Need for wind correction
- f. DFIR as (secondary?) reference
- g. Need for national/regional precipitation centres
- h. Need for wind measurement at the measuring site (problem of transmission - FM 12!)
- i. Heated/unheated gauge
- j. Blowing (drifting) snow
- k. Correction: event, daily, monthly, seasonal (correction for an event is the best but not the easiest)
- l. Gauge exposure, size of the orifice
- m. Reporting and archiving of the measured/corrected data
- n. Engineering application of corrections
- o. Evaporation and further case studies
- p. Distinction of rain, snow and mixed precipitation
- q. need for regular calibration in lab. and field

3 Analysis procedures

0. PRECONDITION:
   - Check and correction for deviation of orifice area from true
   - Calibration and installation according the specification

1. Correction of the measured value with the wetting loss
2. Correction of DFIR for wind speed (formula "Yang")
3. Calculation of the catch ratio
   Catch ratio R in dependence on:
   u = wind speed (primarily)
   t = temperature (secondary)
   starting with a minimum of 3mm water equivalent
   -First: Select time step (6h/ 12h/ 24h/ event)
   -Second: Separate type (snow/ rain/ mixed)

GLOSSARY OF TERMS USED IN THIS REPORT

Precipitation Gauge:
An instrument designed to measure the amount of all forms of hydrometeors, solid and liquid, that fall from the sky or through the atmosphere.

Rain Gauge:
An instrument designed to measure the amount of liquid precipitation only that falls from the sky or through the atmosphere.

Snow Gauge:
An instrument designed to measure the amount of solid precipitation that falls from the sky or through the atmosphere.

Solid Precipitation:
The solid products of the condensation of water vapour falling from clouds or deposited from air on the ground. For the purposes of this experiment solid precipitation includes snow, snow pellets, snow grains, ice pellets, hoar-frost and rime but excludes hail.

Snow is precipitation composed mainly of hexagonal ice crystals, mostly star shaped and usually clustered together to form snowflakes.

Snow Pellets are white, opaque balls of snow. They range from 2 to 5 mm in diameter and usually bounce when landing on a hard surface.

Snow grains are very small white and opaque grains of snow-like structure. The grains are somewhat flat or elongated. Their diameter is generally less than 1 mm. When they land on a hard surface they do not bounce or shatter. They usually fall in small quantities.

Ice Pellets are pellets of ice which form when raindrops freeze before reaching the ground. Ice pellets may also form when pellets of snow are covered by a thin layer of ice before reaching the ground. Ice pellets are 5 mm or less in diameter. They usually bounce and make a noise when landing on a hard surface.

Hoar-frost is a deposit of ice having a crystalline appearance generally assuming the form of scales, needles, feathers or fans, produced in a manner similar to dew, but at a temperature below 0°C.

Rime is a deposit of ice composed of grains more or less separated by trapped air, sometimes adorned by crystalline branches.

Dry snow:
Solid precipitation in the form of snow that normally fallsin the absence of liquid precipitation at shelter-height air temperatures less than -3°C.

Wet snow:
Solid precipitation in the form of snow that normally falls in the absence of liquid precipitation at shelter-height air temperatures greater than or equal to -3°C.

Mixed Precipitation:
Any combination of liquid (rain, drizzle), freezing (freezing rain, freezing drizzle) or solid precipitation falling during the observational period.

Blowing Snow:
Snow particles raised and stirred violently by the wind to moderate or great heights.-- Visibility is poor (6 miles or less), and the sky may become obscured when the particles are raised to great heights.

Systematic Error:
An error in precipitation gauge measurement that introduces a preferred bias into the observations. Systematic underestimation biases include the wind-induced effect, wetting and evaporative losses, out-splashing effects, friction of the recording pen, high intensity rainfall with tipping bucket gauges, and the treatment of traces as no precipitation. Overestimation biases can be introduced by blowing snow and gauge design (e.g., the Canadian Nipher shield).

Random Error:
An error in precipitation gauge measurement that introduces no preferred bias into the observations. These biases include both observer and recording errors.

Accuracy/Reliability:
Since the gauge correction procedure will not result in an exact value but will introduce some degree of uncertainty into the corrected estimates, it is imperative that the reported values include not just the corrected estimate, but an interval in which the "real" value is expected to lie. It is proposed that 95% confidence limits be used since they are widely understood and recognized. This requires that some estimate of the goodness of fit of the correction factor be reported. It is also required that this "goodness-of-fit" be computed from an independent data set and not from the data which were used to specify the model parameters. Cross-validation can be used to obtain this independent data set.

Automatic recording techniques:
Precipitation measurement techniques that involve mechanical (moving pens), electrical, or chemical procedures. (?)

Gauge site exposure:
The exposure of the gauge site as to wind. To express the degree of protection of gauge site from the wind objectively and quantitatively, the average vertical angle of obstacles, α, can be applied. On the basis of assessments of α, a classification of gauge site exposure is possible (e.g., a distinction into open or exposed sites, partly open sites, partly protected sites, and protected sites).

Wetting loss:

Water subject to evaporation from the surface of the inner walls of the precipitation gauge after a precipitation event and from the gauge after its emptying.

Catch Ratio (R_c):

Ratio of the amount of precipitation caught by any gauge including the recorded amount and wetting loss (P_m) to the true precipitation (P_t). Mathematically,

$$R_c = \frac{P_m}{P_t}$$

Deficit (D):

Ratio of the difference between the true precipitation (P_t) and the gauge measured precipitation (P_m) to the true precipitation. Mathematically,

$$D = \frac{(P_t - P_m)}{P_t} = 1 - R_c$$

Gauge Undercatch: See deficit.

Correction factor (k):

Ratio of the true precipitation (P_t) to the gauge measured precipitation corrected for wetting losses (P_m). Mathematically,

$$k = \frac{P_t}{P_m} = \frac{1}{R_c} \Rightarrow P_t = k * P_m$$

Gauge Correction (ΔP_m):

Ratio of the true precipitation (P_t) to the gauge measured precipitation corrected for wetting losses (P_m) expressed as a percent. Mathematically,

$$\Delta P_m = (\frac{P_t}{P_m} - 1) * 100 = (k - 1) * 100$$

DRAFT RECOMMENDATIONS FOR CIMO-XI

Draft Recommendation X1 [CIMO-XI]

NEED FOR THE CORRECTION OF SYSTEMATIC ERRORS IN PRECIPITATION OBSERVATIONS

NOTING that these errors can have a considerable influence on accurate precipitation totals.

CONSIDERING that all types of precipitation gauges are subject to systematic error including wind-induced losses, wetting losses, and trace amounts. The results of the WMO Solid Precipitation Measurement Intercomparison showed that these errors are especially large for solid precipitation measurement. The use of uncorrected precipitation data introduces significant errors into climatological and hydrological studies which can yield false conclusions. There is a need for accurate precipitation estimates in a wide variety of applications.

RECOMMENDS:

a. the methods of correcting for systematic errors in precipitation measurement that are available for different types of precipitation and for various time intervals as reported in the Instruments and Observing Methods Report No. ??, WMO-TD. ?? "WMO Solid Precipitation Measurement Intercomparison" should be adopted and applied to current and archived data;

b. both measured and corrected precipitation data should be reported and archived;

c. metadata, including detailed site description of gauge exposure, gauge configuration, and changes in methods of observation, must be compiled, archived and made available digitally;

d. trace precipitation shell be treated as a non-zero event; and

e. blowing snow should be treated separately because it is not precipitation.

Draft Recommendation X2 [CIMO-XI]

INSTRUMENTATION FOR MEASUREMENT OF PRECIPITATION INCLUDING AUTOMATIC METHODS

NOTING Recommendation 17 [CIMO-IX] "Measurement of Solid Precipitation", a WMO Intercomparison of Solid Precipitation Measurements was conducted by 13 countries from 1986 to 1993.

CONSIDERING the results of this comparison, an International Organizing Committee set up by the president of CIMO concluded that there is a need for more accurate precipitation measurements, especially for solid precipitation, for use in global water balance and climate change analyses.

RECOGNISING that the increased use of automatic gauges for precipitation measurement by member countries offer advantages including capabilities for increased temporal sampling, on-site computation and real-time access. The Intercomparison has identified challenges in the interpretation of the data, including errors such as evaporation from heated gauges, the accurate timing of the occurrence of precipitation events and the identification of precipitation type.

RECOMMENDS that the precondition for reliable precipitation measurements requires the following:

a. acceptance of the DFIR as the standard for the measurement of solid precipitation and the pit gauge as the standard for the measurement of liquid precipitation (see Instruments and Observing Methods Reports No.17, WMO-TD. No. 38 "International Comparison of National Precipitation Gauges with a Standard Pit Gauge" and Report No.??, WMO-TD.No. ?? "Final results of the WMO Intercomparison of Solid Precipitation Measurements")

b. use of a proven gauge design and construction;

c. regular calibration and maintenance;

d. gauges be installed with proper exposure which, in the case of solid precipitation measurements, requires shielding (natural and/or man-made) to minimise the adverse effects of winds;

e. additional wind speed measurements be taken at the level of the gauge orifice in order to correct for wind-induced errors; and

f. heated tipping-bucket gauges are not a feasible alternative for winter precipitation measurements where temperatures fall below 0°C for prolonged periods of time.

Draft Recommendation X3 [CIMO-XI]

NEED FOR ESTABLISHING NATIONAL PRECIPITATION CENTRES

NOTING recommendation 17 [CIMO-IX] "Measurement of Solid Precipitation", a WMO Intercomparison of Solid Precipitation Measurements was conducted by 13 countries from 1986 to 1993.

CONSIDERING the following:

a. the WMO Instruments and Observing Methods Reports No. 17, WMO-TD. No. 38 "International Comparison of National Precipitation Gauges with a Standard Pit Gauge" and the DFIR and No.??, WMO-TD.No.?? "WMO Intercomparison of Solid Precipitation Measurements";

b. the conclusions of the "Workshop on the Correction of Precipitation Measurement" (Zurich, 1985), WMO Instruments and Observing Methods Reports No. 25, WMO-TD.No. 104;

c. the need to know the compatibility and homogeneity of precipitation time-series for hydrological and climatological research and applications including evaluation of **GCM(??)** outputs and the study of climate variability and change detection; and

d. the need for more accurate solid precipitation data to allow a better planning of water use and also as an important input for hydrological models, water balances, and the estimation of evaporation.

RECOMMENDS that National Precipitation Centres be established with the terms of reference given below.

National Precipitation Centres should:

a. operate the WMO standard gauge configurations for rain (pit gauge) and snow (DFIR). Installation and operation will follow specifications of the WMO precipitation intercomparisons. A DFIR installation is not required when only rain is observed.

b. operate past, current, and new types of operational precipitation gauges or other methods of observation according to standard operating procedures and evaluate the accuracy and performance against WMO reference standards,

c. make auxiliary meteorological measurements which will allow development and application of precipitation correction procedures,

d. record, abstract, provide quality control and archive in a readily acceptable format, preferably digital, all precipitation intercomparison data, including the description of the gauge surroundings collected at this centre,

e. agree to operate the evaluation station continuously for a minimum of ten years,

f. facilitate the conduct of research studies on precipitation measurement. These centres will not be expected to provide calibration or verification of instruments. Rather, they would make recommendations on national observation standards and would assess the impact of changes in observational methods on the homogeneity of precipitation time series in the region. The site would provide a reference standard for calibrating and validating radar or remote sensing observations of precipitation.

Draft Recommendation X4 [CIMO-XI]

NEED FOR ESTABLISHING REGIONAL PRECIPITATION CENTRES

NOTING recommendation 17 [CIMO-IX] "Measurement of Solid Precipitation", a WMO Intercomparison of Solid Precipitation Measurements was conducted by 13 countries from 1986 to 1993.

CONSIDERING the following:

a. the WMO Instruments and Observing Methods Reports No.17, WMO-TD. No.38 "International Comparison of National Precipitation Gauges with a Standard Pit Gauge" and the DFIR and No.??, WMO-TD.No.?? "WMO Intercomparison of Solid Precipitation Measurements";

b. the conclusions of the "Workshop on the Correction of Precipitation Measurement" (Zurich, 1985), WMO Instruments and Observing Methods Reports No.25, WMO-TD. No.104;

c. the need to know the compatibility and homogeneity of precipitation time-series for hydrological and climatological research and applications including evaluation of GCM outputs and the study of climate variability and change detection; and

d. the need for more accurate solid precipitation data to allow a better planning of water use and also as an important input for hydrological models, water balances, and the estimation of evaporation.

RECOMMENDS that Regional Precipitation Centres be established with the terms of reference given below.

Regional Precipitation Centres should:

a. operate the WMO standard gauge configurations for rain (pit gauge) and snow (DFIR). Installation and operation will follow specifications of the WMO precipitation intercomparisons. A DFIR installation is not required when only rain is observed.

b. operate past, current, and new types of operational precipitation gauges or other methods of observation according to standard operating procedures and evaluate the accuracy and performance against WMO reference standards,

c. make auxiliary meteorological measurements which will allow development and application of precipitation correction procedures,

d. record, abstract, provide quality control and archive in a readily acceptable format, preferably digital, all precipitation intercomparison data, including the description of the gauge surroundings collected at this centre and at all evaluation stations operated within the region for which the Centre is responsible,

e. test all precipitation correction procedures available (especially those outlined in the final reports of the WMO intercomparisons) on the measurement of rain and solid precipitation,

f. advise national precipitation centres on methods of measurement and organize the exchange of data and results between national and regional centres,

g. agree to operate the evaluation station continuously for a minimum of ten years,

h. facilitate the conduct of research studies on precipitation measurement. These centres will not be expected to provide calibration or verification of instruments. Rather, they would make recommendations on regional observation standards and would assess the impact of changes in observational methods on the homogeneity of precipitation time series in the region. The site would provide a reference standard for calibrating and validating radar or remote sensing observations of precipitation.

WMO file

The University of Oklahoma

DEPARTMENT OF GEOGRAPHY
COLLEGE OF GEOSCIENCES
455 West Lindsey, Room 804
Norman, Oklahoma 73019
(405) 325-5325

May 28, 1991

Dr. Joe Friday
Assistant Administrator for Weather Services
National Weather Service/NOAA
1325 East-West Highway
Room 18130
Silver Spring, Maryland 20910

Dear Dr. Friday,

I have recently returned from the Fifth Session of the International Organizing Committee of the WMO Solid Precipitation Measurement Intercomparison (CIMO) held in Valdai, USSR from March 11 to 15. Thank you for your help in allowing me to attend this meeting. A copy of the final report of the fifth session should be forthcoming shortly.

At the meeting, several questions were raised regarding the National Weather Service's ASOS program. As I am not affiliated with NWS and am not completely informed about the proposed changes in instrumentation and observational practices with the new ASOS program, I could not respond directly to their questions. However, I indicated that I would contact you and try to alleviate some of their concerns.

The committee recognizes that many countries are automating their observing networks, including precipitation measurement. However, for the United States this raises the concern about the use of only a tipping bucket gage, the discontinuation of the use of the present standard 8" gage, and the compatibility of the data. This concern stems from climate change and land-use change studies where long time-series of homogeneous precipitation records are required. In the past, other countries have changed their standard precipitation gages and/or observational practices which has introduced an inhomogeneity into the precipitation time-series. This has, in the past, posed a serious problem for climate change research and the concern now is that automation will again introduce inhomogeneities into the global precipitation record. The committee was concerned about the potential impact on the data record and was asking about what, if any, studies were being done to assess the impact and to implement corrections, if necessary.

A second concern focussed on the use of tipping bucket gages and their ability to accurately measure snowfall. It was argued that tipping bucket gages (even with heating units) are inappropriate for measuring snowfall and there was concern about how the ASOS network would accurately measure winter precipitation, including snowfall. Since significant snowfall is observed over much of the United States, it was commented that the data compiled by the NWS raingage network might be useless for climatological as well as hydrological studies.

I have been asked by the Senior Scientific Officer of the WMO/WWW Secretariat, Mr. Klaus Shultze, to obtain information for the committee from the NWS regarding their position on these concerns. I would be pleased if you could provide me with information about ASOS and how you feel I might address a response to alleviate these specific concerns.

Thank you again for your assistance. I shall look forward to hearing from you.

Sincerely,

David R. Legates

Dr. David R. Legates

cc: Dr. Barry Goodison, committee chair

National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

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Dr. David R. Legates
The University of Oklahoma
Department of Geography
College of Geosciences
455 West Lindsey, Room 804
Norman, Oklahoma 73019

Dear Dr. Legates:

Thank you for your letter regarding the National Weather Service's (NWS) Automated Surface Observing System (ASOS) program. I assure you the NWS is sensitive to the issues you have raised regarding automation and its impact on precipitation measurements, data continuity, and the continuation of support to climate research.

In order to ensure sound data continuity, the NWS is planning to provide overlapping observations to support an independent comparative study of temperature and accumulated liquid precipitation. The purpose of the study is to determine if systematic differences exist between the historical observing methods and ASOS, and to document any biases that may occur. The results of the comparative study should ensure the transition to automated observations without significant discontinuities.

Initially, NWS-staffed locations will provide these comparative observations at approximately ten of the ASOS units to be deployed in the central United States beginning in 1991. These comparative observations may be expanded to include other locations as well. This study will consist of at least 1 year of comparative manual observations and ASOS observations. The comparative observations will consist of daily liquid precipitation accumulation using the NWS's standard weighing rain gages, daily maximum and minimum temperatures, and six hourly temperature and dewpoint temperature observations.

As the modernization of the NWS proceeds, some future NWS offices will be collocated with the ASOS, but many will not. However, supplemental observations will be taken at all of these NWS-staffed offices. The supplemental information will consist of six hourly observations of sky condition, dust and aerosols, snowfall and snow depth, and daily observations of the water equivalent of snow on the ground. Hail, ice pellets, and volcanic ash will be reported on occurrence.

We share many of your expressed concerns regarding the tipping bucket gage for snowfall measurements. In fact, no gage in use today has been demonstrated to be fully effective for this purpose. It is for this reason that traditional snowfall, snow depth, and water equivalent of snow measurements will be continued at the 100 plus NWS-staffed locations. Additionally, information on snowfall amounts and water equivalent of snow on the ground will be obtained from existing and new cooperative observing networks, from Airborne Gamma Radiation Snow Surveys, the snowpack telemetry (SNOTEL) network operated by the Soil Conservation Service in the western United States, and satellite imagery.

Enclosed is the ASOS Operational Implementation Plan which will give details on the implementation and transition to our operational ASOS network. Please do not hesitate to contact me again, or Harold Bogin of the ASOS Program Office (301-427-7975), should further information be required.

Sincerely,

Elbert W. Friday, Jr.
Assistant Administrator
for Weather Services

Enclosure