Methodologies explored to date for assessing catch efficiency and derive adjustments by different teams, including past results

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**In this document, methods used for deriving catch ratio adjustments are collected. Text passages are often copied directly from the references.**

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# 1 WMO Solid Precipitation Measurement Intercomparison – final report by Goodison et al., 1998

In the report a common analysis of all data per gauge is presented as well as the individual country reports are listed at the end, partly providing interesting variations of the chosen common analysis method.

*The detailed analyzing procedure is described in the* ***sixth meeting report of the IOC****. Daqing has found the report in some of Barry’s boxes, ☺ and it will be electronically available soon. Here is the analysis-recipe:*

[…] The final step is to determine the catch ratio for each precipitation gauge as a function of wind speed at gauge 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. The equation may include linear, exponential and power terms. [..]

[…] only events in which the measured precipitation in the DFIR equals or exceeds 3 mm are to be included[…]

[….]blowing snow events are to be eliminated.

It is the duty of the researchers from each nation to develop this catch ratio for the national precipitation gauge of their own country.

***And actually the meeting report (as well as the final report) contained an extended report/paper on site-data analysis from each country****.*

## Average catch ratios per gauge

Goodison et al. , 1998: chapter 4.4.1 (s. 29, example Tretyakov) (more details in WMO/CIMO(1993))



“Investigation of the mean catch ratio of all observations at each site versus mean wind speed at gauge height during precipitation days shows that there is a general dependence of the mean catch ratio (CR,%) on mean wind speed (V) for snow only and snow mixed with rain:

CRsnow=101.9-10.3\*V (n=11, r2=0.79)

CRsnow+rain=100.4-6.7\*V (n=11, r2=0.6)

For rain only and rain mixed with snow, there is no significant correlation between mean catch ratio and mean wind speed for precipitation days.”

“To avoid the over-adjustment or under-adjustment of the wind-induced errors, a constant catch ratio (..) is not recommended for any gauge in any season. Instead the relation of daily or event gauge catch as a function of corresponding daily mean or event mean wind speed should be applied to the gauge measured daily or for an event, since studies show that gauge catch varies by individual precipitation event.”

* Nice for an overview
* Could be done for daily, hourly (operational) and 30min-events (and other time-intervals) to get a feeling for differences caused by different time scales

## Catch ratio versus wind speed – regression analysis per gauge

(Goodison et al., 1998, chapter 4.4.2 (example Tretyakov))

“Regression analysis of all daily gauge catch ratios as a function of the daily wind speed at gauge height and daily air temperature gave best-fit regression equations for the different types of precipitation.

[…]

A similar analysis of data for individual sites […] could result in different equations. It is critical, however, that a representative range of wind speed be sampled so that any derived equation can be applied to a range of sites with differing wind speeds.









**Goodison, et al., 1998, chapter 4.8 (summary):**

“Regression analysis was used to develop relationships of catch ratio versus wind and temperature. Multiple linear regression (MLR) was applied for the initial screening of significant variables.

[..]

Using the MLR results as a guide, non- linear regression analysis was applied to obtain improved fits where appropriate. In some cases, using a second order polynomial or exponential form of the wind variable improved the regression coefficient. The final regression equations […] are given in Table 4.8.1:



### Discussion

(Goodison et al., 1998, chapter 4.9):

#### Applying a DFIR > 3 mm minimum threshold to data sets

This threshold was set in the protocol for analyzing the data, in order to minimize the large variations in catch ratio caused by small absolute differences between the gauges. By applying this threshold, many observations were not included in the analysis. Empirical investigations at Jokioinen showed that this limit is not necessary. The observed catch ratios showed variances of the same magnitude for small precipitation values as for precipitation values satisfying the constraint. Some of the site-analyses were carried out without the threshold (or a much lower one, i.e. 0.2 mm for Jokioinen)

#### Bush/DFIR adjustments

Most of the analyses for the study were performed with an included transfer to the BUSH-gauge, as this provides the most ‘true’ precipitation. The quality of this step does depend on the quality and validity of the DFIR-bush transformation. It is questionable if it can be applied on derived data (with a transfer equation from another gauge) as well as on raw data (directly measured with DFIR). The suggested transformation DFIR to bush is complex in the sense that it is not possible to evaluate statistically, the consequences of implementing the DFIR-Bush transformation prior to analysis of the catch ratios versus e.g. wind speed and temperature. Some of the site-analysis were carried out without applying the bush-transformation and adjusted only to DFIR data.

#### Catch ratio vs correction factor

For the purpose of intercomparing national gauges against the reference DFIR, it is preferable to use catch ratios (CR=Pgauge/PDFIR) since it provides a comparison of the relative catch efficiency of the national gauge against the reference. For the purpose of developing adjusting procedures, it is preferable to use the correction factor (CF=PDFIR/Pgauge) which should be derived independently.

#### Log transformation of ratios

A logarithmic transformation of the CR or CF’s is likely to produce homogeneous variances (homoscedasticity) which is preferable for most of the statistical analysis undertaken. In fact, direct modeling of the CR’s in relation to wind speed and temperature runs the risk of biased results and inaccurate confidence limits. A range of regression analyses has been used in the country reports, some of which have applied the logarithmic transformation to the ratios before further analysis.

#### The effect of how averages of wind speed and temperature are estimated

With data from Jokioinen the effect of different averaging periods were assessed. Wind speed and temperature averages for snow events were estimated (based on 10 min temperature and wind speed measurements) as:

* Storm averages
* 12-h averages
* Averages using 3-hourly observations only
* Average of the period maximum and minimum temperature

The figure shows that the storm averages perform best, but this is not surprising because the chosen adjustment model is based on storm data. 12-hour and 3-hourly data result in a slight underestimation of the total sum of snowfall (in accordance with that they underestimate the storm-temperatures), but the differences are in fact small over the 7-year period

#### Different statistical models

The intercomparison study extends over very different geographical and climatological fields, which gives rise to ‘errors’ of very different nature. Furthermore, a series of statistical models have been used which cannot be compared directly even within a common statistical framework.

# 2 Yang, D., 2014: DFIR vs Bush Gauge

The statistical tools used, such as regression and correlation analyses of gauge catch ratios as a function of wind speed, have been recommended and tested in the previous WMO gauge intercomparisons.

The regression analysis derives a best-fit curve by means of the least square estimation, i.e. the relationship between catch ratio and wind speed, which is statistically 95% significant.

# 3 Førland, E., 1996

Using adaptions of earlier used equations for the correction factors of different gauges and calculated the best fitting coefficients based on the data set from Jokioinen, Finland. Correction factors are calculated separately for liquid and solid precipitation. The mixed phase correction factors are a combination of liquid and solid correction factors.

For stations without explicit windspeed measurements, a simple correction method is introduced, using a correction factor based on the exposure of the site.

The study includes very concrete recipes and calculation examples. Often cited

# 4 Methodology for correction of solid precipitation data at col de Port by Y. Lejeune, S. Morin, (Météo-France – CNRS, CNRM-GAME, Centre d’Etudes de la Neige, Grenoble, France)

Correcting raw solid precipitation data for gauge undercatch is critical for a proper evaluation of mass fluxes at the snowpack/atmosphere boundary. At Col de Porte, France, a GEONOR T200-1B – 600 mm with a single alter shield has been operating since the summer 1993 and provides hourly measurements of the mass of the collection bucket. Additional precipitation gauges include two so-called PG2000 gauges developed and operated by EDF (tipping bucket, 2000 cm catch surface area, no wind shield – see below for details).

A description of the environmental setting of the site can be found in Morin et al. (2012), which provied an overview of meteorological and snow conditions at the site for the period from 1993 to 2011. The information in this document remains appropriate for the following snow seasons.

The description of snow precipitation correction provided in this document is reprinted below :

« The master precipitation gauge at CDP is the GEONOR gauge. Complementary precipitation data are provided by the two PG2000, only one of both is heated as soon as the collector temperature drops below 5°C. Note that the heat rate is adjusted so that the temperature of the precipitation collector remains lower than 5°C to avoid evaporation as much as possible.

Precipitation data are manually partitioned between rain and snow using all possible ancillary information, primarily air temperature but also the information from the heated/nonheated rain gauge, snow depth and albedo measurements. Relative humidity data are used to rule out spurious precipitation events, i.e. small but non-zero hourly recordings of the GEONOR gauge occurring while RH is lower than 70 %. The GEONOR gauge is corrected for windspeed and temperature following Forland et al. (1996), using a heated cup anemometer placed a short distance from the gauge (1m horizontally, same height above ground), since the 1999–2000 snow season. For completeness, we provide here the equations used for the correction factor (multiplying the raw precipitation rate). In the case of solid precipitation, the following equation is used as long as the windspeed is between 1.0 and 7.0ms−1:

k = exp(β0 + β1 ug + β2 T + β3 ug T) (1)

where β0 = −0.12159, β1 = 0.18546, β2 = 0.006918, β3 =−0.005254, ug is the windspeed at gauge height (in ms−1) and T is air temperature (in °C). For windspeed values below 1.0 ms−1, no correction is applied, and above 7.0 ms−1 the correction for a windspeed of 7.0ms−1 is used. Similarly, the equation is used only when the temperature is above −12 °C ; below this value, the correction factor at T = −12°C is used.

In the case of liquid precipitation, the following equation is used:

k = exp(α0 + c + α1 ug + α2 ln(I) + α3 ug ln(I)) (2)

where α0 = 0.007697, α1 = 0.034331, α2 = −0.00101, α3 = −0.012177, c = −0.05, ug is the windspeed at gauge height (in ms−1) and I is the precipitation rate (in kgm−2h−1). In the case of mixed-phase precipitation, a mixed correction factor is obtained by averaging the two correction factors with a weighting coefficient according to the relative snow- and rainfall rate. Before the 1999–2000 snow season, the precipitation data were multiplied using a scaling factor adjusted for each year by minimizing the difference between the precipitation record and the observed amount of fresh snow recorded using a snow board; this factor remained on the order of 10 %, with year-to-year variations. »

Below we provide additional information on the preliminary spurious data removal and how the partitioning between solid and liquid precipitation is carried out. What is dealt with in the following is hour-to-hour variations of bucket weight, corresponding to raw precipitation rate. First of all, bucket purges and antifreeze refills are removed from the record. An additional treatment is required to handle hourly precipitation data consistently. Indeed, weight accumulation data (reported with a precision of 0.1 kgm-2h-1) from the Geonor frequently exhibit spurious slightly negative/positive values (from -0.1 to -0.5, large values mostly related to wind-speed), which is related to uncertainties in the measurement technique (vibrating wires perturbed by structure vibrations induced by the wind) and the data acquisition precision. While the cumulative sum of weight differences would remain correct, it is not appropriate to report negative precipitation values, as well as potentially erroneous (even small) positive precipitation values. A dedicated algorithm is applied on hourly weight increments to remove spurious negative values. Starting from the first record of the series and moving forward in time, once a negative precipitation value is identified, a search (forward and backward in time) is carried out on neighboring time steps to identify positive values which are reduced correspondingly. Note that this algorithm can thus only be applied a posteriori, given that the number of hours forward and backward in time to mitigate a negative precipitation data can range from 1 to ca. 100 hours and more (in the case of the 2013-2014 season). Large numbers correspond to long (several days) periods without precipitation with a negative precipitation record around its middle. As also stated by Morin et al. (2012), “relative humidity data are used to rule out potentially spurious precipitation events, i.e. small isolated non-zero hourly recordings of the GEONOR gauge occurring while RH is lower than 70 %” (actually rather 90% in practice). In case they are spurious, the corresponding precipitation value at the time step is set to 0, but the value is affected to the nearest precipitation event.

Once this step is carried out, what remains to be achieved is to partition the precipitation rate between solid and liquid precipitation, and apply gauge undercatch corrections.

As indicated in Morin et al. (2012), the partitioning between solid and liquid precipitation is carried out “using all possible ancillary information, primarily air temperature but also the information from the heated/nonheated rain gauges, snow depth and albedo measurements.” In short, if air temperature lies below 0°C, precipitation is considered snow. If air temperature exceeds 2°C, it is considered rain. This simple set of threshold is applied to the whole time series, and intermediate cases are then handled on a case-by-case basis. In such cases, not only temperature data but their time evolution (increasing or decreasing during the event) are taken into account. Variations of snow surface temperature are considered (a decrease of snow surface temperature may indicate fresh snow precipitation, while an increase or stagnation at the melt point may indicate rain precipitation). During the day, the measured snow albedo is used: albedo increase indicate fresh snow precipitation, while albedo stagnation or decrease can be linked to rain precipitation. Snow height variations, and measurements of snowboard measurements are also indicative of whether solid or liquid precipitation occurred, but they need to be considered together with the measurements referred to above, as settling for instance, renders the interpretation of snow height measurements difficult in terms of snow accumulation. All of the above leads to inform decisions regarding precipitation phase during intermediate air temperature cases.

However, practical experience indicates that assigning a 50% partitioning between solid and liquid precipitation regarding such intermediate cases is better than crudely attributing the phase to either liquid or solid (this needs to be quantified, however – to be done). One good way to test such impacts is to use a detailed snowpack model (Crocus in our case) to compare model output, driven by precipitation data explicitly separating liquid and solid precipitation but also other drivers of the surface energy and mass balance, with measurements of snow height and snow water equivalent. This check is regularly carried out as a consistency check of the whole correction procedure (i.e., not only precipitation). Compensations may occur, but precipitation remains the main driver of positive snowpack mass variations.

# 5 Norway, Haukeliseter

The main difference here is the use of Bayesian statistic to analyse the data instead of a more traditional regression analysis. In Wolff et al. (2014) the used method is explained more detailed.

Three winters with precipitation data were collected at Haukeliseter test site and analysed during the study. Precipitation events were identified and afterwards filtered in order to pick only those events which were not disturbed by not-controllable parameters, as for example affected wind measurements. The classification of the dataset after key parameters which possibly influence precipitation loss gave a good idea of the shape of possible adjustment functions**.**

The following attributes for an adjustment function, for a given temperature are proposed:

1. The ratio between true and observed precipitation is a function of only wind speed.
2. The ratio is monotonically decreasing from unity when V = 0 to a limit greater or equal to zero when the wind speed V approaches infinity.
3. The ratio decreases exponentially as a function of wind speed.
4. The rate of change of ratio varies significantly as a function of wind speed, and can take the value of zero in parts of the domain.

Bayesian statistics were then used to (objectively) choose the model describing the data set best. Only wind speed and air temperature are input variables for the derived adjustment. It calculates the catchment efficiency of a Geonor with Alter windshield compared to Geonor inside a double fence construction. Two equations were derived, one for the use of 10-m wind measurements, the other for the use of gauge-height wind measurements.

How well the derived function and associated covariates describes the actual catch ratio was evaluated by analysing the residual plots.

No signs of model misspecification could be seen for the covariates wind speed and temperature. Plotting the residuals against the true precipitation, measured in the DFIR, yields a trumpet shape, which may indicate that the noise variance is dependent of the amount of true precipitation. Furthermore, the residuals seem to have a heavier tail than a normal distribution, which also indicates a non-sufficient description of the noise or uncertainty of the adjusted values.

# 6 Thériault, J.M. et al., 2012: Dependence of Snow Gauge Collection Efficiency on Snowflake Characteristics

Intercomparison of the theoretical collection efficiency retrieved from the results of fluid dynamic modelling (Lagrangian model for trajectories) and measured collection efficiency.

Collection efficiency is defined as the ratio of the precipitation rate averaged over 10 min measured by the Alter-shielded gauge to that of the Geonor in the DFIR. The wind speed value used to correlate with the collection efficiency is also averaged over the 10-min period (at gauge height). The following figure shows measurements from one snow storm, 20th February 2010. The mean diameter of the snowflakes falling in the gauge has been calculated and the collection efficiency is also plotted versus the mean diameter of each sample. In general, the snowflake size increases with decreasing collection efficiency. This is consistent with the theory that larger snowflakes will fall in the gauge cause larger snowflakes are less affected by the wind than smaller ones. It also depends on the type of snowflake, however. For example, a large dendrite will still fall slower than small graupel.



From observations, each sample has been numbered and classified as “wet/rimed” or “dry” snow, there are eight samples each. The dry snowflakes are generally larger than the wet/rimed snowflakes. Dry-snow samples 4 and 8 are anomalies. Sample 4 exhibits lightly rimed dendrites, and sample 8 exhibits radiating assemblage of plates, whereas the other samples depict moderately to heavily rimed dendrites.

Using the mean diameter of the snowflakes falling inside the gauge, the mean terminal velocity of each sample was computed using equation and parameters from Rasmussen et al. (1999). They were divided into dry and wet/rimed snow categories. Results are shown in the following figure. The dry snowflakes fall at a terminal velocity that is close to 0.65 m/s, whereas the wet/rimed snowflakes have a terminal velocity that is close to 1.3 m/s, independent of diameter. As expected, the faster-falling snow crystals are associated with a higher catch efficiency. The slower-falling snowflakes (dry) are associated with a lower catch efficiency. For example, the larger dry-snow samples 4 and 5 have a lower collection efficiencies than does wet-snow sample 7 for the same wind speed



# 7 WMO Field Intercomparison of Rain intensity gauges (Italia)

Interesting retrieval of the field reference data set, not presented here.

## Comparison of measuring performance

In order to compare the measurement results of several installed gauges with respect to the calculated reference a series of scatter plots is used. The one-minute rainfall intensity measured by each rain gauge was plotted with linear scales versus the one-minute reference intensity, for the three best events available. Rain gauges were categorized in groups according to the measurement principle or data output averaging time. Dashed lines indicate the ±15% interval around the one-to-one fit in all graphs, see figure below. Some tests were done (not reported), if the observed differences are depending on wind speed or temperature. No dependency could be seen. That was expected, as only high intensity events with comparable large dropsizes were studied.



# 8 A few remarks/explanations on inverse model theory (something very related to the Bayesian Model likelihood) from a non-professional, ;-)

I think the book from Tarantola, 2005, gives a good (but unfortunately not simple for a non-mathematician) theoretical background on inverse model theory or how to estimate models and model parameters. I personally like figure 1.12 from the book:



I think inverse model theory offers an (objective) tool to choose the best-fitting model from a large amount of possible curves including a comparable evaluation of the uncertainty and likelihood of the fit.

Classic regression analysis is often limited to evaluate only a few possible models. Least-square-methods assume Gaussian uncertainty distributions, which performs badly if outliers are present.

Another book, explaining explicitly Bayesian statistics is Gelman, A., et al. , 2013.

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