**Data processing and quality control methodology for the derivation of reference datasets**

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**Version history**

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| Version | Date | Notes |
| 1 | May 7, 2014 | Initial draft prepared by Mike Earle with input from Audrey Reverdin and Craig Smith |

1. **Development of processing and quality control methodology: approach and methods tested**

*Data filtering*

* Initial testing of methods using sample site datasets from Geonor gauges in R2 and R3 configurations, with 6 s and 1 min temporal resolution.
* **Qualitative assessment** of filter performance.
* Identified max/min filter (range check) as an effective method for removing outliers; ‘jump’ filter as an effective method for identifying and removing data spikes, and identifying and flagging potential baseline shifts (e.g. due to ‘dumps’ of accumulated precipitation from the orifice into the bucket, or due to bucket emptying).
* Methods tested for removal of high-frequency noise: moving average, Savitzky-Golay (3rd order polynomial fit), Gaussian filter in time domain (moving window), Gaussian filter in frequency domain (employing fast Fourier-transforms to generate periodogram, allowing for identification and removal of high-frequency noise).
* Gaussian filter in time domain shown to be effective; decision to test further alongside moving average filter, which was both effective and widely-applied, historically.
* Artificial datasets generated for known precipitation rates to allow for **quantitative assessment** of filter performance using moving average and Gaussian methods; true precipitation signal known for artificial events.
* Tested moving average and Gaussian approaches with various parameters (filter width, standard deviation of Gaussian distribution) using artificial datasets for rates covering range of expected conditions, between 0.6 mm/hr (light precipitation) to 30 mm/hr (heavy precipitation).
* Used root-mean-square error (RMSE) to assess filter performance and make recommendations for processing approach.
* Current recommendations for filtering approach based on this assessment are outlined in Section 2.

*Compensating for temperature effects*

* Diurnal solar radiation/temperature variations impact precipitation amounts reported by Geonor and Pluvio2 gauges.
* Influence for Geonor gauges generally characterized by a decrease of 0.1 mm for every 10 degree increase in temperature. Adjustment functions can be derived from daily accumulation-temperature relationships in non-precipitating conditions; however, variation of relationship with specific transducer, bucket amount, incident solar radiation (cloud cover, solar elevation and azimuth), and the fact that temperature is not recorded at the sensing element complicate the adoption of these functions for continuous temperature compensation in the processing of Geonor reference datasets.
* Hysteresis has been observed in the accumulation-temperature relationship for Pluvio2 gauges, precluding the determination of adjustment functions as described above.
* Given the difficulty in compensating for temperature effects, it was decided that this would not be part of the processing methodology for reference datasets; rather, the emphasis was placed on characterizing the temperature during precipitation events (allowing for sorting of events by temperature behavior in subsequent analysis).
* It should be noted that the Pluvio2 firmware applies static temperature compensation to processed outputs from these gauges, which will be considered as part of the intercomparison.

*Averaging Geonor data*

* To facilitate subsequent analysis, the accumulated precipitation measurements from the three transducers in a given Geonor gauge must be averaged to generate a single, ‘representative,’ gauge output.
* Averaging methods considered: simple arithmetic averaging; weighted averaging based on noise, in which noisy wires are weighted less when computing averages; and majority voting, in which pairs of transducers with consistent outputs are considered to be ‘correct’ (majority rules), and used to justify the exclusion of data from a third wire with output differing beyond a set threshold.
* Key consideration: the load (weight of bucket and accumulated precipitation) is shared among the three transducers; hence, giving less weight to, or excluding, a given wire may bias the averaged output from the ‘true’ value.
* For this reason, arithmetic averaging is currently recommended, with a flag to identify potential transducer performance issues (e.g. noise, offsets in magnitude, differences in response to precipitation).
* In cases of severe transducer performance issues, the other averaging methods, or manual intervention, may be required. Additional testing on site data is required to establish guidelines for implementing procedures beyond the simple arithmetic approach.
1. **Processing of reference datasets from Geonor and Pluvio2 gauges**

*Recommended approach*

* Max/min filter (range check), with maximum thresholds corresponding to bucket capacity for each gauge.
* Jump filter to remove spikes exceeding threshold value (TBD); data flagged if number of consecutive jumps exceeds another threshold value (also TBD), indicating a potential shift in baseline.
* For Geonor and Pluvio2 precipitation data with 6 s temporal resolution, a moving average or Gaussian filter with a width of 2 minutes is recommended to mitigate the influence of high-frequency noise; for the latter, the standard deviation of the Gaussian distribution is recommended to be either equal to, or one half of, the filter width.
* For Geonor and Pluvio2 precipitation data with 1 minute temporal resolution, a moving average or Gaussian filter with a width of 8 minutes is recommended to mitigate the influence of high-frequency noise; for the latter, the standard deviation of the Gaussian distribution is recommended to be either equal to, or one half of, the filter width.
* Arithmetic averaging of precipitation data from three transducers of a given Geonor gauge, with flag(s) to indicate potential performance issues.

*Caveats*

* Filter methodology has been tested and developed primarily using 6 s Geonor datasets. Subsequent testing on 6 s Pluvio2 datasets has indicated that the recommended filter width may not be optimal, given the lower frequency of noise observed; however, the 2 minute filter width was still recommended for these data to maintain the same time response as the Geonor approach.
* Limited testing has been conducted using 1 minute datasets for both reference gauges; current recommended filter width not well-established, and should be used with caution.
* No methods are currently employed to mitigate/compensate for the effects of temperature or evaporation.
1. **Applicability of processing and quality control methods to other gauge data**
* Max/min filter (range check) can be broadly applied to data from all gauges, and requires only the maximum and minimum value thresholds for implementation.
* Similarly, the jump filter can be broadly applied to other gauge data, provided threshold values for the maximum increase in a given parameter per data point (jump threshold) and number of subsequent ‘jumps’ indicating a baseline shift (if applicable; for example, due to system resets) are defined.
* For any gauge data subject to high-frequency noise, moving average or Gaussian filters can be applied. Prior to implementation, tests should be conducted on site datasets to establish a rough guideline for the filter parameters (filter width, standard deviation of Gaussian distribution).
* For gauges with multiple sensing elements/transducers, similar averaging methods can be used. Arithmetic averaging is the most straightforward approach, but majority voting is an established method of averaging/quality control for systems with independent, redundant, sensing elements.
1. **Additional data processing and quality control procedures for consideration**
* Characterization of missing data and values removed by filtering to facilitate diagnosis of gauge and/or site issues.
* Application of gauge-specific corrections and offsets for processing of snow on the ground (SoG) data. The SoG analysis plan indicates that offsets are to be applied for temperature and gauge geometry, as well as offsets for zero snow depth and zero snow water equivalent (SWE). The offsets can be applied on an ongoing basis, while the offsets are determined at the end of a measurement season, and so can only be applied retroactively.
* Temperature artefact compensation in weighing gauge data by matching increases in bucket weight with corresponding decreases in bucket weight. This method has been shown to be effective in situations without appreciable evaporation, in which decreases in bucket weight can predominate. As decreases in temperature are not necessarily balanced by corresponding increases within a given dataset, this method should be viewed as a means of mitigating the influence of temperature-induced variations, rather than fully compensating for, or correcting, these variations.
* Ideally, all quality control methods and processing could be standardized and automated to ensure that all gauge data are processed in the same way, using the same set of rules; however, given the variability of the natural phenomena being measured, and the limitations of the measuring devices and site installations involved, it is difficult to define rules for processing data in all potential scenarios. For this reason, manual intervention may be required in some cases. To the extent possible, manual processing should be governed by well-defined criteria in order to ensure consistent application across datasets. These criteria will necessarily need to be defined at a later stage of analysis; if the rules for when and how to intervene were clear at this stage, they could be coded and automated. Development of these rules/criteria would help to inform future iterations of data processing and quality control methods.