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# Integration of observations from different rainfall observation systems

### SUMMARY

This document provides information on issues related to the integration of observations from different rainfall observation systems.

### ISSUES TO BE DISCUSSED: The IPET is invited to discuss the content of the document and agree on further and future activities related to the subject.

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**1. Introduction and definitions**

Precipitations can be observed through various systems :

1. Raingauges
2. Weather radars
3. Satellites

Each of these systems alone provides only an incomplete picture of the precipitation field. Some typical characteristics of these systems are given below.

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|  | *Measured parameter and accuracy* | *Temporal resolution and integration* | *Spatial resolution and coverage* | *Remarks* |
| Raingauges | Measure the accumulated precipitation over some time interval T. Typically 0.1 mm resolution. | T can be down to 1 minute for raingauges in AWS ; low cost raingauges can have T as high as 6 hours | Size of the collection area (typically 400 cm2) | Solid precipitation need to melt before measurement is possible ; there is often a bias by strong wind |
| Weather radars | Indirect mesurements through reflectivity. Resolution is roughly 10% of the precipitations intensity | Typically 5 minutes revisit time for each cell in the covered area | On average, around 1km2 (better close to the radar, lower far away). Coverage for QPE can reach 100km away from the radar. | As an active teledetection method, radar suffer from artefacts measurements which cannot be fully eliminated |
| Low orbiting satellites | Some can measure both reflectivity (active detection) and water content (passive detection) | Revisit time of several days at medium latitudes | Around 100 km² Global coverage, even over the oceans. | Multi-frequency technology |
| Stationnary satellites | Don't really measure precipitations | Around 30 minutes revisit time | As low as 1km² at nadir, with a continental size coverage | Useful to assess « no cloud so no rain » |

So the idea is to blend all those sources of information to obtain a more complete and accurate description of the precipitation field. Information from weather radars was early on merged to obtain « **radar composites** ». Projects like GPM plan to use a satellite constellation to overcome the low revisit time of a single satellite.

The above blending process is generally called « **data fusion** » when it involves different observing systems (see [Data\_fusion](https://en.wikipedia.org/wiki/Data_fusion)).

A special case sometimes put under the general data fusion umbrella is when one of the information source is the discretized atmospĥeric state in a numerical weather prediction model. The goal of the blending in that case is to reduce the incertainty in that discretized atmospĥeric state to start a new numerical forecast from it. It is called « **data assimilation** », and is not what we will be discussing in the following, because that peculiar information source is not a physically measured quantity.

The practice of correcting radar data with reference raingauges is called **calibration** (even if it a different process than electronic calibration of the radar), but is indeed data fusion.

In the following, we will refer to the integration of precipitation observations of various origin as data fusion.

**2. Theoretical issues**

Due to the differences in characteristics of the above systems, there is no possible straightforward blending of all the available information.

If we assume the expected end result is a precipitation field, and if we already have such a field as values on a gridded array originating from either radar or satellite, a standard approach would be to correct that field with the more pointwise raingauges measurements.

Perhaps the simplest method here is Mean Field Bias correction (MFB). In MFB, the radar or satellite precipitation field is corrected globally by the ratio sum of the raingauges mesurements over sum of the precipitation field values colocated at these raingauges. The interval of precipitation accumulation, the maximum range at which raingauges are used and the update frequency of the ratio are tuned empirically. The method has natural extensions : local instead of global correction, ratio dependent on range...

Inverse distance weighting (IDW) corrects each pixel of the precipitation field with the weighted mean of the differences between gauge value and colocated precipitation field value. It is also known in data assimilation as the Cressman method (see [Data assimilation concepts and methods](http://www.ecmwf.int/sites/default/files/Data%20assimilation%20concepts%20and%20methods.pdf)).

If a more elaborate theoretical and statistical framework is requested for the correction method, regression kriging can be used (see [Regression-kriging](https://en.wikipedia.org/wiki/Regression-kriging)).

The pratical application of such a method involves the knowledge of the measured precipitation field statistics, which cannot be obtained reliably from the too few observations available.

To overcome that difficulty, one can simulate numerically such fields with a random generator to obtain a result close to the requested statistics ; this is the so called « radar ensemble » technique (see for instance [MeteoSchweiz\_ScientificReport - sr95vogel](http://www.meteoswiss.admin.ch/content/dam/meteoswiss/en/Ungebundene-Seiten/Publikationen/Scientific-Reports/doc/sr95vogel.pdf)). It also allows to obtain an estimate of the measurement error of the final data fusion field, which can be a valuable input to end users applications (like hydrological numerical models).

**3. Practical sensor issues**

**Geometry and physics of radar measurements**

In the previous section, we have assumed that remote sensing observations used in data fusion have already been corrected from some errors. In particular for radar data, ground clutter, beam blocage, bright band and beam height at large distance are supposed to have been taken into account (see below « Algorithmic issues »). The assessment of these corrections may have used long term statistics comparing raingauges measurements with radar data, leading to the elimination of some raingauges as not usable to correct data from a given radar.

In particular, corrections for bright band and beam height at large distance need the freezing level estimate, which can be obtained most conveniently through a numerical model output.

During the lifetime of a radar, it's clutter map can change for the worse, if buildings or wind farms are erected, or if trees are growing in the vicinity. So the choice of the radar siting should take into account these risks.

**Raingauges limitations**

Raingauges are not the reference measurement tool for precipitations (see below section « Psychological issues »). The error in case of strong wind can be substantial. Raingauges models which are not heated cannot handle real time snowfall accumulation. In addition, siting and servicing must be good to take advantage of a well designed device.

Even if all the above drawbacks are avoided, the variability of rainfall accumulation between raingauges in flat land at a distance below 1 km from each other can be important (see for instance [pedersen\_2010](http://www.dhigroup.com/upload/publications/mike11/pedersen_2010.pdf)

or [JAMC-D-13-0210.1](http://journals.ametsoc.org/doi/pdf/10.1175/JAMC-D-13-0210.1)).

So a variability of around 30 % can be expected when comparing perfect measurements with instruments of so wildly different spatial scale of measurements (radar/satellite 1km2 and raingauge 400cm2 collecting area).

**Satellite measurements**

Frequency of low orbit satellite measurements above a given point is poor, and the spatial resolution of stationnary satellites is low.

**4. Organizational issues for real time processing**

The production line of of raingauges data in most NMS has a long history, going back to transmission of data through teletypewriter. So up to now, there is no real time concentration of that data for a lot of raingauges not part of an AWS, and the 6 hours accumulation period of these raingauges helps more climatology than nowcasting.

On the contrary, the primary use of radars as a warning system for severe weather events has helped its production line to allow fast data availability.

As long as there will not be enough real time raingauges able to calibrate radar, the potential of precipitation systems integration cannot be fullfilled.

Among the curb on the upgrading of all remaining « simple » 6 hours raingauges to higher frequency AWS is the financial cost involved for an NMS.

Even when that upgrade will be realized, NMS will still have the task to improve compatibility of the 2 production lines (radar and raingauges), to ensure that algorithms can be applied to both sets of data.

In the case of low orbiting satellites data merged with other type of observations, their low revisit time can only be overcome by the use of a very costly constellation of similar satellites operating in collaboration. This can only be achieved by international agreements and cost sharing between the involved countries.

**5. Algorithmic issues**

The following radar processings are unavoidable before calibration to obtain quality QPE:

1. need to determine radar beam blocking areas; only partial blocking can be corrected
2. need to determine height where radar QPE was measured; this allows, with knowledge of the freezing level, to perform a climatological correction of the variation of rainfall intensity between surface and altitude of measurement
3. need to take into account rain cells movements to avoid the « stroboscopic effect » of fast moving rain cells

If QPE is computed far away from the radar and during heavy precipitation events, beam attenuation correction must be implemented. This can only be done efficiently with a dual polarization radar.

Dual polarization technology allows also for better classification of type of precipitation, which in turn will improve QPE.

**6. "Psychological" issues**

As raingauges have been in the past the main precipitations measurement tool, there have become the de facto reference toward which other instruments are compared. As shown above, this has no scientific justification.

The use of weather radar has developped quite separately in various countries. So most NMSes operating a radar network have long entrenched practices, and they can be very different from country to country. This hinders exchange of radar data, with difficulties ranging from the format of the data to their very definition (e.g., is « raw reflectivity » with clutter removal applied or not ? ; or is the nominal time stamp of a radar scan the beginning or the end of that scan ?).

There are programs, at the continental level at least, to overcome these differences (see e.g. the OPERA program in Europe).

**7. Delayed data fusion**

Data fusion target was initially weather forecasters. Today, its use has expanded towards an input for automated systems, like numerical models for hydrology or meteorology. In all these cases, data fusion is performed in real time as soon as the data is available.

Nevertheless, delayed data fusion computations unfit for nowcasting make sense. In the case of raingauge calibration, a delay as long as a few weeks may be necessary to collect and control data from the climatological raingauge network. Running a data fusion process using that expanded network after that delay fullfills climatological needs, and is sometimes performed at the NMS level over their domain of responsability.

If such an NMS is archiving raw radar data, a reanalysis after a few years by data fusion of the precipitation field has the advantage that it can take into account progress in radar data processing algorithms.

The current interest in climate change has raised the question of performing such work at a more global scale, to help monitor it's evolution. GCOS/AOPC has started studying that subject.

**8. Examples of existing integration methods**

1. **Satellite decontamination**

Odyssey (OPERA/Eumetnet)

Radar artefacts like anomalous propagation and residual clutter are removed when satellite cloud classification indicates there is clear sky.

1. **Calibrated radar QPE**

Panthere (France)

Radar rainfall accumulation is calibrated by raingauges, so it is a method of the MFB type. A selection of « good » raingauges is performed by climatological analysis. The calibration factor is a weighted mean of the individual ratios hourly raingauges accumulation over corresponding radar data, down to several hours before the current time ; oldest individual hourly ratios have less weight than recent ones.

Antilope (France)

The product is an hourly precipitation accumulation field over France. It uses both IDW and kriging.

Input data for the Antilope product are :

1. The 12 last radar Panthere composites (produced every 5 minutes)
2. Raingauges
3. The 4 last satellite cloud classification images from MSG

Satellite data is used to remove artefacts, like for the Odyssey product.

Convective cells are identified by image processing tools and extracted from the radar composites. The corresponding hourly accumulation becomes the small scale field for radar and small scale values for raingauges (the difference from the original measurements becomes the large scale parts).

IDW is applied to that small scale radar field using the small scale raingauges accumulation to become the « small scale accumulation field ».

Kriging is applied to the large scale field for radar using the large scale accumulation for raingauges to produce the « large scale accumulation field ».

The final product is the sum of the small and large accumulation fields.

Bibliography for Panthere and Antilope : [INF.3.3.2\_Report\_METEOFRANCE\_QPE](https://www.wmo.int/pages/prog/www/OSY/Meetings/ET-SBRSO_ET-RSO-2011/DocPlan/INF.3.3.2_Report_METEOFRANCE_QPE.pdf)

1. **Off line QPE reanalysis**

Comephore (France)

It is an hourly rainfall accumulation reanalysis by raingauge calibration and satellite decontamination of radar data. The product covers France metropolitan territory and is currently available from year 1997 to 2007. Work is underway to perform the analysis for years after 2007.

Input data are:

1. Radar data: 5 minutes frequency reflectivity in cartesian up to year 2006, and all polar scans of reflectivity for 2007 and beyond
2. Raingauges (AWS, climatological stations and some private networks)
3. MSG 15 minutes frequency satellite cloud classification for 2007 and beyond

Corrections applied to radar data up to 2006: beam blocage, clutter, advection, clear sky artefacts.

A full rerun of the radar computer production line to obtain a Panthere-like QPE started from year 2007, with the addition of satellite decontamination. The data fusion process with raingauges is similar to the Antilope method.

Bibliography :

Tabary, P. et al. (2012): A 10-year (1997–2006) reanalysis of Quantitative Precipitation Estimation over France: methodology and first results. Weather Radar and Hydrology. *IAHS Publ. 351, 255-260*

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