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 (IOC) FOR RADAR QUALITY CONTROL AND QUANTITATIVE PRECIPITATION INTERCOMPARISONS

First Session

Exeter, United Kingdom

14 – 15 April 2011

FINAL REPORT

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EXECUTIVE SUMMARY

This report provides a summary of the first session of the International Organizing Committee (IOC) for Radar Quality Control and Quantitative Precipitation Estimation Intercomparison (RQQI).

The IOC reviewed the concept of the intercomparison and the outcomes of a pilot intercomparison and agreed with the proposal. It reviewed the general planning of the intercomparison and made a number of recommendations for its conduction.

The IOC defined general rules and procedures for the conduct of the intercomparison. These included definition of the objectives and possible deliverables, establishment of a project team to conduct the intercomparison, data formats, data exchange procedure, data sets to be used during the intercomparison, data protocols for the intercomparison and for the participants. It also agreed on the principle of the metrics to be used for the evaluation of the results, on the general organization of the intercomparison, rules for participation in the intercomparison, as well as on a tentative schedule for the intercomparison.

GENERAL SUMMARY

1. ORGANIZATION OF THE SESSION

1.1 Opening of the Session

1.1.1 The first session of the International Organizing Committee (IOC) for Radar Quality Control and Quantitative Precipitation Estimation Intercomparison (RQQI) was held in Exeter, United Kingdom, 14-15 April 2011. Dr Paul Joe, Chairperson of the IOC opened the session. The list of participants is given in Annex I.

1.1.2 Dr Wenjian Zhang, Director of the WMO Observing and Information Systems Department, welcomed the participants on behalf of WMO and thanked the host for their generous hospitality. He stressed the success that CIMO instrument intercomparisons had in improving the quality of traditional instruments. He noted that conducting this radar algorithm intercomparison was opening a new field for CIMO. Great benefits can be expected from it as it will help improving weather radar data quality and homogeneity, which are important for numerous applications, but in particular for exchanging weather radar data and for their assimilation in numerical weather predictions (NWP).

1.1.3 Dr Joe indicated that in addition to the focus on quantitative precipitation estimation applications, weather radar data quality control should take into consideration the needs of Nowcasting (non-precipitating or clear air echoes). This has been requested by both the NWP (data assimilation of reflectivity, radial velocity or mean wind profiles as well as error estimates) and climate (regional and global precipitation statistics – intensity and occurrence) communities.

1.2 Adoption of the Agenda

The IOC adopted the Agenda for the meeting, which is reproduced at the beginning of this report.

1.3 Working Arrangements for the Session

The working hours and tentative timetable for the meeting were agreed upon.

2. PROJECT CONCEPT PRESENTATION, CLARIFICATION AND DISCUSSION

2.1 Dr Joe informed the meeting of the strong interest that this project was raising among radar experts, all of them having to do quality control (QC) and quantitative precipitation estimation (QPE). The project appears to be timely because NWP is now starting to use weather radar data, but also because quantitative use of weather radar data and a regional/global exchange of weather radar data are starting. Climate applications are also calling for higher quality weather radar data in view of having more widespread information on precipitation than rain gauges can provide, as well as for the validation of space-based data sets.

2.2 He stressed that the role of the IOC was to agree on the plan for the intercomparison, on the evaluation procedure and on the recommendations that will come out of the intercomparison, ensuring that the intercomparison is carried out in a neutral way and that it represents the WMO-wide community.

2.3 He presented a detailed overview of the project to the participants in the meeting that included a presentation of the manner in which the intercomparison is proposed to be carried out. Annex II presents this proposed concept in details. It will have to be agreed upon and refined by the IOC as described in the following sections of this report.

2.4 The idea of the project is to understand how well radar quality control algorithms perform, independently of the location of the radar on which they are applied but taking into consideration the various factors (scan strategy, data resolution, processing technique, etc). The various processing steps, on from measured radar data to final product, would be decomposed. Several intercomparison projects are envisioned over the coming years. This first intercomparison would only deal with the first few steps of the process. It is proposed to use common data sets, originating from different radars. These data sets would be processed by the “intercomparison participants” using their own algorithms. They would submit the results of their processed data to the intercomparison organizers who would evaluate their results.

2.5 Proposed metrics would quantify the results, based on the idea of having an ideal radar showing a smooth picture in homogeneous weather.

3. PRESENTATION AND DISCUSSION OF PILOT INTER-COMPARISON

3.1 Dr Joe presented the proposed modalities of the intercomparison, illustrated through the presentation of results from a reduced pilot intercomparison, already completed. The objective was to gain practical experience and to illustrate the proposed concepts which follow the principles described in Annex II. This presentation included the detailed description of two of the data sets used in the pilot intercomparison, results obtained with selected algorithms, description of the preliminary inter-comparison metrics and overall results obtained applying the metrics to the results of the algorithms.

3.2 The pilot intercomparison consisted of 10 data sets covering different artifacts, such as sea clutter, anomalous propagation, snow, uniform blockage, etc. These data sets were treated to remove ground clutter, anomalous propagation and sea clutter using seven different algorithms, resulting in the “processed data set”. The algorithms used were based on different techniques, such as CAPPI, zero-notch filtering, fuzzy-logic, etc. The processed data sets should ideally be exempt of any of the artifacts present in the original data and accumulations (of linear reflectivity) of the data should yield “smooth” data fields

3.3 The processed data sets were then evaluated using a metric quantifying the smoothness of the data. The preliminary results showed significant differences. Some techniques performed better than others either generally, or under specific atmospheric conditions.

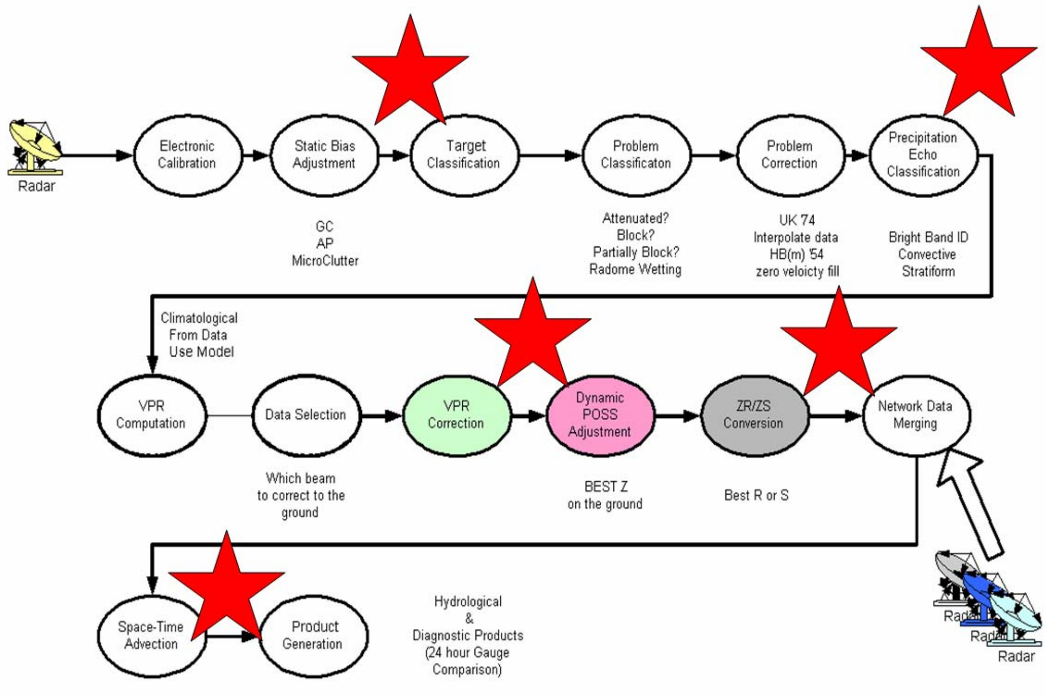
3.4 The meeting agreed that the proposed metric was able to quantify the performance of the various algorithms for each data set individually. Further work/tests on the metric would however still be required so that it could be fully trusted for the evaluation of the full intercomparison.

4. DISCUSSION AND PLANNING OF THE INTER-COMPARISON

4.1 The meeting was invited to review and agree on the modalities of the intercomparion. This included, among others, defining the scope of the intercomparison, agreeing on the type and number of data sets that would be investigated, determining whether short data sets (24 hours) would be suitable to achieve the expected results, defining the data format that should be used and reviewing and agreeing on the metrics that would be used for the evaluation of the results.

4.2 A variety of adjustments are needed to convert radar measurements to precipitation estimates. Various methods are available for each adjustment and are dependent on the radar features. The meeting agreed that a series of inter-comparison workshops should be organized to ascertain the affectiveness of each method for quantitative precipitation estimation globally.

4.3 Figure 1a (as presented at the meeting) presents a schematic break-down of the radar data-processing algorithms. The meeting agreed principally with this description of the algorithms. Adjustments were made to account for dual-polarization capability. It was recognized that the product requirements from the users were dependent on the applications (e.g. QPE applications require the complete processing depicted in Fig. 1a, while for NWP applications stopping the processing at the end of the first line may be sufficient). In addition, the chain was segmented into different sections (marked by the red stars in Figure 1a) which identify the foci for future inter-comparisons. The figure was altered during the meeting and Fig. 1b represents the updated processing chain. It was noted that there may be loops in this processing chain that are not illustrated in the figures.



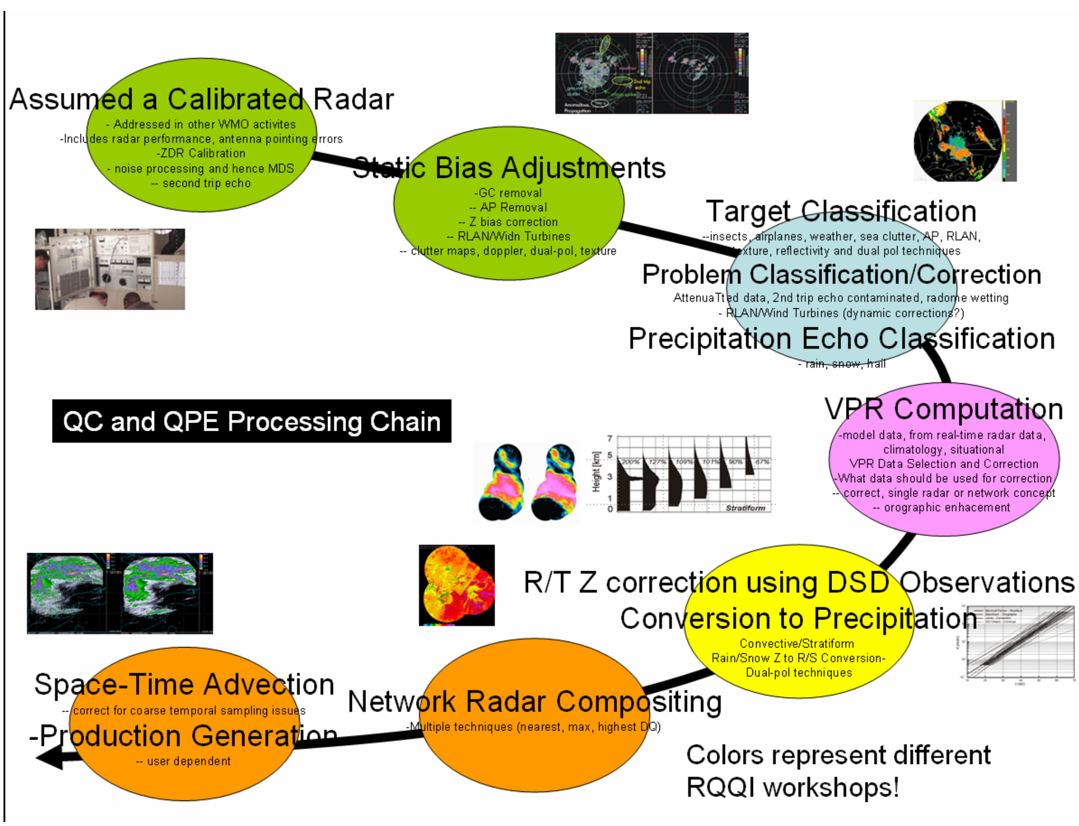


Fig. 1: (a) Segmentation of the data quality adjustment algorithms as initially presented at the meeting (top). The red stars indicate where the chain could be segmented into a succession of inter-comparison project. (b) As revised (bottom).

4.4 The meeting recognized that many operational systems would be able to break up the steps of the data processing algorithms. Consequently, the IOC agreed that this first intercomparison would concentrate on the data processing dealing with the first three bubbles of Fig. 1 (“calibration” or bias adjustment, clutter removal, vertical profile reflectivity correction and target identification) and would not address the complete chain at once. The other steps of the data processing will be handled in later intercomparisons (see red stars in Fig. 1a or colored bubbles in Fig 1b.). The aim being to produce the best estimate of reflectivity, Z, but not yet addressing covariance. Dual polarization data sets should also be considered if they can be made available. These would help in showing the potential of dual polarization for target identification and represent the latest radar technology.

4.5 The meeting recognized the importance of linking the performance of weather radars to ground-based measurements with rain gauges and to satellite observations and recognized such comparison should be considered at a much later stage of the project, once precipitation estimates, rather than radar reflectivities, can be used as the intercomparison data.

4.6 The meeting recognized that some techniques work better with specific types of data (atmospheric conditions, as well as resolution of the data and scanning strategies). Therefore, it was not expected that one technique would work best in all situations and there will be a need to collect data sets obtained with a variety of techniques/conditions, so as to test them all appropriately. An outcome of the project would be to develop recommendations to users about the strengths and weaknesses of the different algorithms in different circumstances and for different types of radar systems.. This should also provide an understanding of why an algorithm is good under those conditions and when it will not be good anymore. Only so will users, like NWP, be able to identify the limitations of the data they use.

4.7 It was noted that a lot of work had already been done on the performance of individual algorithms, but that no real intercomparison of the algorithms, considered together, had taken place yet. While making a list of the available publications on the subject would be useful, the meeting agreed that a real intercomparison was needed to perform an independent evaluation of the relative merits of the different algorithms. The meeting also noted that weather radar researchers had a lot of expertise and insight in the capabilities of the individual algorithms, but recognized that this knowledge was not passed on to the user community. Therefore, the intercomparison should aim at producing a kind of field guide to the algorithms for the users, specifying when they perform well and when not.

4.8 The outcome of the intercomparison should be helpful in working towards intra and inter network operations by providing an understanding of the quality of the data that could be exchanged. In that context the meeting also addressed the weather radar band(s) that should be taken into consideration for the intercomparison. While the inclusion of X-band radars might be feasible, the meeting agreed that this first intercomparison should focus on C- and/or S-band radars because of their widespread operational use, so that the results of the intercomparison could provide a real and prompt benefit to operations.

4.9 In order to properly address the different processing steps of the algorithms, the data sets would have to include a number of different artifacts, such as ground clutter, anomalous propagation, echoes from ships, planes, birds, insects, electro-magnetic interference and wind turbines. Some of the data sets should also include dual polarization moments, though it would not be a requirement for the participants to process them.

4.10 A possible list of data sets (scenarios) that could be collected was presented to the participants in the meeting. Though all of them would be interesting, the meeting recognized that the project would have to concentrate on a limited number of data sets so that the project remains manageable. A revised list of scenarios will be submitted to the IOC for their advice and recommendation.

4.11 The meeting addressed the matter of the electronic calibration of weather radars and whether this aspect should be part of the intercomparison, to test how the algorithms are sensitive to non-perfect radar calibration. The meeting recognized this was a topic in itself, addressed in other CIMO activities, and that this project would use data sets that are assumed to be properly electronically calibrated.

4.12 Short data sets (24 hours) of uniform weather conditions could be used. In situations with less uniform weather longer data sets (3 months to 1 year) would be needed. It was recognized that the exchange of such data sets for the purpose of the intercomparison was feasible using external USB drive. The meeting agreed that such data sets would also be considered for the intercomparison, if available. In addition, insights and understanding can be derived from single instances without resorting to the “smoothing” criteria. A preliminary conclusion of the pilot intercomparison was that smooth accumulated processed data fields could be created by (i) a single instance of data where the data has sufficient coverage (e.g., widespread snow), (ii) short sequences in the case of widespread weather (e.g. a band that persists and moves through the domain) and (iii) seasonal length sequences in the case of convective weather.

4.13 In quantifying the performance of the algorithms through the use of the metrics, it would be critical to have data sets that produce uniform or smooth accumulated fields of reflectivity, as the residues in the processed data sets could originate either from the clutter filtering or from the structure of the precipitation field. In this context the meeting also addressed the possibility to investigate simulated observations from theoretical models or synthetic data created from a combination of measured data, in which the precipitation field would be known. The meeting agreed to consider including such data sets for the intercomparison.

4.14 The meeting recognized that the project could easily become far too big to be handled properly if too many datasets were chosen. It also recognized that the enthusiasm and willingness of experts to participate in the project was critical. Therefore the number of data sets to be treated should remain reasonable to ensure a strong commitment of the community. It should be noted that there was significant interest amongst the IOC members for a viable inter-comparison. It should also be noted that the Baltrad project offered their software infrastructure as a possible vehicle to facilitate the project.

4.15 The IOC decided that the intercomparison should not be by invitation only, but that manufacturers should be allowed and encouraged to participate since many members rely on them for their operational data quality processing. Therefore, a general invitation to potentially interested groups and manufacturers will have to be issued by the Secretariat through a circular letter sent to all Permanent Representative of WMO Members and to the Association for Hydro-meteorological Equipment Industry (HMEI).

4.16 The IOC reserved the right to limit the participation so that the project remains manageable. In such a case, the participants would be selected based on the diversity of the approach of their algorithms.

4.17 The meeting recognized that the algorithms should not be tuned specifically for each situation, but that normal algorithms that are used 24/7 should be tested though ancillary data (e.g. radar location for purposes of development of land-water masks or use of a digital elevation model) would be acceptable. Part of the objectives of the intercomparison being to understand why specific algorithms work well or not in specific situations in view of improving data quality generally, it would be necessary to understand the general concepts used in the different algorithms being tested. These algorithms would consequently have to be appropriately described in the application to participate in the intercomparison. This will in turn enable the project team to develop guidance on best practices and recommended procedures to be used in processing algorithms.

4.18 The meeting was informed that Alan Seed had offered to host the data and had already developed a website to that effect. The meeting welcomed this initiative but requested that this website be password protected and that no data be shared with potential participants before their selection, confirmation of their intent to participate and to comply with the data protocols of the intercomparison.

5. ORGANIZATION OF THE RADAR QUALITY CONTROL AND QUANTITATIVE PRECIPITATION ESTIMATION

5.1 The meeting was invited to review and agree on the plans for the organization of the intercomparison itself.

5.2 In addition to the general rules and procedures for WMO Intercomparisons as defined in the Guide to Instruments and Methods of Observation (WMO-No. 8), Part III, Chapter 4, Annex 4.A and 4.B, the IOC agreed on the following rules and procedures for the Radar Quality Control and Quantitative Precipitation Estimation Intercomparison (RQQI):

Objectives and deliverables:

5.3 The main objectives of the intercomparison are to:

- Inter-compare radar quality control algorithms for QPE, Nowcasting, Climate and NWP applications,
- Identify best practices and recommendations for operation for WMO Members, specifying in which conditions specific algorithms perform well/don't perform well and why,
- Quantify the quality of QPE radar products globally.

5.4 Possible deliverables of the intercomparison are:

- A better and documented understanding of the performance of an algorithm (signal and data processing) for a particular radar setup, weather and environment ,
- A better and documented understanding of the optimal volume scanning strategy to mitigate the effects of clutter in a QPE system,
- A legacy of well documented algorithms (and possibly code),
- Quality metrics description,
- Best practices / recommendations of the "state of the art".

Project Team

5.5 The IOC decided to establish a project team to lead the intercomparison and agreed on the composition and duties of the Project Team (PT). The PT will be responsible for preparing the intercomparison in liaison with the WMO Secretariat. The PT will organise the conduct of the intercomparison, finalize the metrics to be used for the evaluation of the intercomparison, carry out the evaluation of the results, and prepare the Executive Summary, Draft Final Report, and Final Report of the intercomparison.

5.6 The Project Team will consist of:

- Paul Joe, as Project Leader,
- Norman Donaldson,
- John Hubbert,
- Lipping Liu, and
- Daniel Michelson.

Data, Data Format and Data Exchange

5.7 Two different types of data are considered:

- **Original data**: Data collected on a variety of radars and atmospheric conditions, as well as possibly synthetic data sets produced by models, that will be provided to the participants and that they will have to process with their algorithms
- **Processed data**: Output data from the participants algorithms.

5.8 The IOC agreed that the data format that would be used for the intercomparison be ODIM_H5. A review of the ODIM-H5 information model will be conducted and requests for changes may be made.

5.9 The participants would download the original data from a password protected server, process them and then put their processed data on the server for evaluation by the Project Team.

In case the amount of data would be too large, they would be exchanged through external USB drive.

Data Sets

5.10 Original data sets will be solicited by invitation only by the Project Leader. He will ensure that they come from a diversity of geographic regions and that they cover a number of artifacts (such as ground clutter, anomalous propagation, echoes from ships, planes, birds, insects, electro-magnetic interference and wind turbines). Some data sets will also include dual-polarization moments.

5.11 The original data sets could include short data sets (approx. one day), season-long datasets, as well as simulated and/or synthetic data sets (if available).

5.12 The datasets will be kept to a reasonable number: of the order of a dozen.

Data Protocols

5.13 The IOC agreed with the data protocols provided in Annex III and requested the Secretariat to formalize them with the participants and data providers as needed, taking into consideration the expertise gained in organizing previous intercomparisons.

5.14 Postscript: All participants will be required to agree, in writing, to abide by the terms of the agreed data protocols for RQQI, prior to their participation in the intercomparison.

Metrics

5.15 The objective of the metrics is to describe the smoothness of the processed data. The project team will refine the preliminary metrics that were developed for the pilot intercomparison.

5.16 Human inspection of the data will still be needed and the final meeting of the IOC after compilation of the Draft Final Report will have to verify the results.

Organization, Data Processing and Rules for Participation

5.17 There will be an open call for participation in the intercomparison that will be sent from the WMO Secretariat to Permanent Representatives of all WMO Members (who should circulate the announcement not only within NMHSs, but also to third party groups that could be interested in it) and HMEI.

5.18 The potential participants will have to describe their algorithms, explaining what is unique in them and why they should be selected for the intercomparison. The description should be detailed enough to enable the Project Team to understand why specific algorithms work/don’t work in given situations. The length of the description should be succinct and of the order of one page.

5.19 The algorithms proposed for participation should ideally be used operationally 24/7 and should not require manual tuning.

5.20 The Project Team will review the proposals and make a recommendation to the IOC on the participants to be selected to participate in the intercomparison. Should the number of participants be limited for practical reasons, the IOC will select them based on the diversity of the approaches of their algorithms.

5.21 The list of data sets will be communicated to the selected participants who will then have to confirm their commitment to participate and to formally agree with the data protocols of the intercomparison. Only then, would the data sets be shared with them. They will run their algorithms on the provided data sets and return their processed data for evaluation by the project team. In the event they would not provide the processed data, it is planned that they would still be listed in the list of participants, mentioning they did not provide the results of their evaluation.

5.22 No dataset would be provided to potential participants before the selection of the participants.

Tentative Schedule of the Intercomparison

5.23 The tentative schedule of the intercomparison will be as described below, but may need to be shifted in case of problems with any of the steps:

- July 2011: Letter to PRs and HMEI calling for interest to participate in intercomparison;
- September 2011:
  - o Data sets collected by the Project Leader,
  - o Deadline for application for participation to be received by the WMO Secretariat;
- October 2011: Selection of participants. Participants will be informed about their selection and about the datasets that will be part of the intercomparison. They will be requested to confirm their interest to participate;
- November 2011: Datasets will be provided to the confirmed participants;
- Winter 2011-2012 (Northern Hemisphere): possible interim meeting of project team
- March 2012: Deadline to provide processed datasets by the participants;
- April 2012: Possible meeting of project team or teleconferences;
- July 2012: Draft report to be shared with participants for review and comments;
- September 2012: Workshop of the IOC and participants to approve the final report that will be published in the WMO IOM Report Series.

6. OTHER BUSINESS

None.

7. DRAFT REPORT OF THE SESSION

The meeting decided to adopt the report of the session by correspondence.

8. CLOSURE OF THE SESSION

The session was closed on 15 April 2011 at 16h15.

ANNEX 1

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ANNEX 2

The WMO Radar QC QPE Inter-comparison Project RQQI[1]

(As presented at the first IOC meeting)

Project Statement

Inter-comparison workshops will be conducted to identify, document and exchange the best techniques for quality control and quantitative precipitation estimation from weather radar in a variety of radar scenarios and in different weather and environment regimes and to develop data quality metrics for global and regional applications.

Goals

1. Undertake systematic inter-comparison and validation of radar QC/QPE algorithms evaluated under a variety of environmental conditions
2. Assess the impact and provide guidance on quality control processes employed in radar-based QPE
3. Characterize errors involved in radar-based QPE
4. Report and provide a source of applications employed in QC/QPE

Objectives

1. Development of a framework for radar QC/QPE algorithms inter-comparison.
2. Development of inter-comparison and validation data sets. Collect data sets in a variety of radar types, collection modes, weather and site conditions
3. Development of radar data quality metrics.
4. Inter-comparison and evaluation of algorithms at focused workshops and develop a data quality framework
5. Development of data and product exchange formats that include data quality.
6. Report on results with recommendations approved by a International Committee of Experts

The Need

Advances in severe weather nowcasting, data assimilation, weather and climate model validation, satellite rainfall verification, and hydrological applications have led to new and enhanced requirements for high quality regional and global radar data and radar precipitation products. Also, recent advances in radar technology, signal and data processing have brought the field to the brink of operational readiness for these products for its quantitative use. In the past, radars were perceived to address only local and qualitative applications, such as severe weather diagnosis and warning, but this view is rapidly changing as telecommunication networks and storage capacity allow vast amounts of data to be transferred and archived, as National Meteorological and Hydrological Services consolidate weather offices and automated data processing into fewer locations.

While the progress in the radar QPE has been impressive, it is also recent and there are many differing approaches and solutions. It is therefore necessary to harmonize, consolidate, validate, verify, identify the best algorithms and under what conditions to specify the quality of the products.

Radar QC-QPE processing is a common problem for all NMHS' and a collaborative and sharing approach of the techniques and results will have mutual benefits. Otherwise, diverse and difficult to reverse programs will emerge that will confound the integrated use of radar QPE products in the future. Many global issues arise that need consensus, resolution and quality assessment.

Processing differences include techniques or algorithms to mitigate ground clutter,, vertical profile of reflectivity, attenuation effects, bias correction and consistency , etc. Product differences include temporal and spatial scales of the data, accuracy and precise, data format exchange standards.

Radar Technology

The Radar Technology: Radars are complex instruments and there can be many technical differences related to the radar hardware technology (reflectivity-only, Doppler, dual-polarization, data resolution), equipment location (ground echoes) and purpose (scan strategy).

The radar technology and signal processing options have significant impact on the range of approaches available for one of the primary issues for rainfall measurement – ground clutter and anomalous propagation removal and the potential errors. Conventional radars still form the bulk of the operational radar technology globally though this is rapidly changing. Reflectivity statistical techniques, ground clutter maps, texture of the data and high altitude CAPPI maps to mitigate ground clutter are still used to mitigate ground clutter. Doppler radars afford the possibility of using velocity signal processing to remove stationary targets. This has been a significant improvement but there are some drawbacks (see Fig. 2). Polarimetric radars are now being deployed operationally and offer significant potential through differential phase measurements to identify and separate clutter targets, mitigate the impact of drop size distribution effects, attenuation in precipitation, and a number of non-meteorological error sources.

Performance, Calibration and Maintenance: A number of engineering, system design and related sources impact the accuracy of measurement and may dominate without careful treatment. These are loosely lumped into "radar calibration" but can be separated to performance, electronic calibration and system maintenance. Performance refers to the sources of uncertainty related to the radar specifications such as the antenna pattern, gain and sidelobe structure, receiver and filter losses, pulse shape, frequency drifts, noise and even antenna tilt. For the radar engineer, calibration refers to the accuracy and precision of the received power only. In the past, this was a major source of uncertainty and some research radar receivers were calibrated on a daily basis. The receivers are much more stable now. Maintenance refers to monitoring for component failures and drift. Changes in these factors over time is requires a systematic approach to metadata definition and reporting. Considerable experience has been gained over a number of years with a range of radars and the application of various techniques for analysis and treatment of this problem.[1] While it is initially assumed that the radar is calibrated and maintained, this will be addressed in specialty workshops such as RADCAL[2] and RADMON.[3]

Figure 1: Radar calibration course conducted by the Turkish Meteorological Service on behalf of WMO. Figure courtesy from Oguzhen Sireci.

Processing Radar for Precipitation Estimation

The following figure describes the steps required to process radar data for quantitative precipitation estimation. The purpose of this figure is to illustrate the complexity of the data processing steps that are required to convert radar measurements to precipitation estimates. While the details and

[1] The issue of network calibration, important to many agencies employing different radar hardware has been investigated extensively within the Nordic Weather Radar Network and within the U.S. Nexrad radar network. Polarimetric techniques also offer ways forward for self-consistent reflectivity bias calibration.
[2] RADCAL was a workshop sponsored by the AMS in 2001.
[3] RADMON was a workshop sponsored by WMO in conjunction with ERAD2010.

sequence may be debated, it serves to illustrate the problems that need to be solved. The steps are briefly described. Radar QPE application is the focus of this inter-comparison. Nowcasting and NWP applications, where clear air echo and convergence lines are important are not covered here.

Radar hardware changes over time (component failure, mis-adjustments, etc) and in order to make use of radar data archives, calibration-related meta data on each radar is needed in order to perform re-analysis of the data.

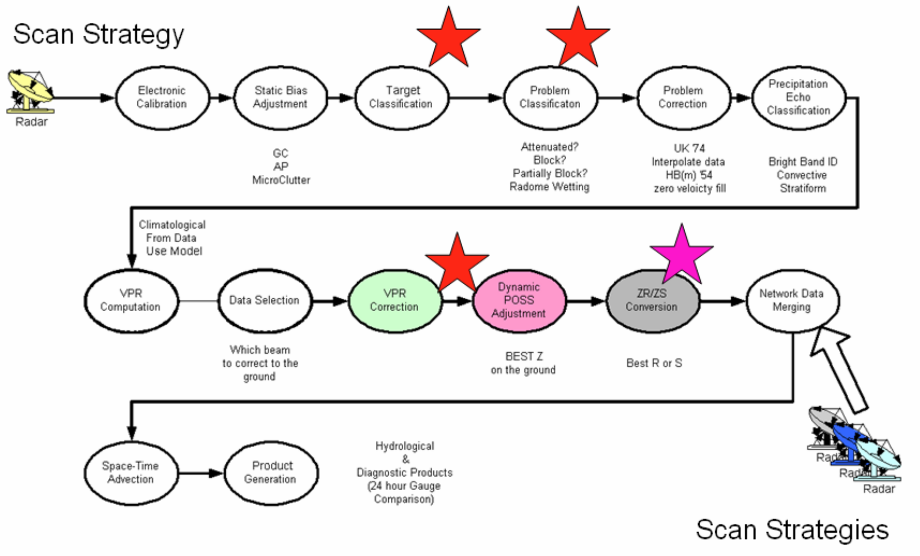

Figure 2: A representation of the processing chain for radar QPE. Currently, only electronic calibration and Z to R conversion is universally done. Impact of other adjustments (red stars) can be substantially larger depending on the environment and application.

1. The processing chain begins with radar data (moment data). It is assumed that calibration (as described in the text) has been done.
2. The static bias adjustment step (second bubble) refers to ground clutter and anomalous propagation removal step. With Doppler technology, the zero notch filter and second trip echo removal techniques can be applied in signal processing. Recently, a combination of signal and data processing techniques have been developed to address these issues.
3. The next step is to classify the echo and determine if it is due to precipitation or due to non-meteorological targets. For the QPE application, that data must be flagged or eliminated.
4. Areas of partial or complete blockage, attenuation or wet radome need to be identified.
5. Then corrected using various techniques (for example, using vertical profile of reflectivity or dual polarization).
6. Then, the weather echo needs to be classified as stratiform, convective, bright band, rain or snow or hail.
7. Then an appropriate VPR needs to be computed (in real-time, statistically or climatologically).
8. Then appropriate base data value is needed to be determined. (The lowest beam may be corrupted and a higher elevation scan may need to be identified and used.)
9. The VPR and/or horizontal spatial data can then be used to compute the best reflectivity at the surface.
10. Then if there is a DSD device, the Z value may be adjusted.
11. Once the best Z is determined, a conversion from Z to precipitation is done using a ZS, ZR, ZA relationship.
12. If there are sufficient rain gauges available, the precipitation values may be adjusted.
13. Then the radar data may be merged on a network basis. The merging of rainfall estimates from overlapping and non-overlapping radars into one product can overcome the sudden attenuation due to a wet radome or heavy rainfall.

14. Ideally, another adjustment at the radar boundaries (i.e., inter-radar power calibration) should not be necessary but could be included at this point.
15. Hourly (or other) accumulated products from each radar cycle, with an advection accumulation technique applied, is required.

Currently, only electronic calibration and Z-R are widely implemented[4]. The effect of the other adjustment factors can be substantially greater particularly at long ranges from the radar.

Major QPE Issues

Weather and Radar Environment Variation: Identification of applicability and quantitative assessment of these techniques in a wide variety of conditions is needed to under their impact on quantitative precipitation estimations. Fig. 3 shows some of the environmental impacts on the weather radar and includes biological and clear air targets useful for other purposes than QPE.

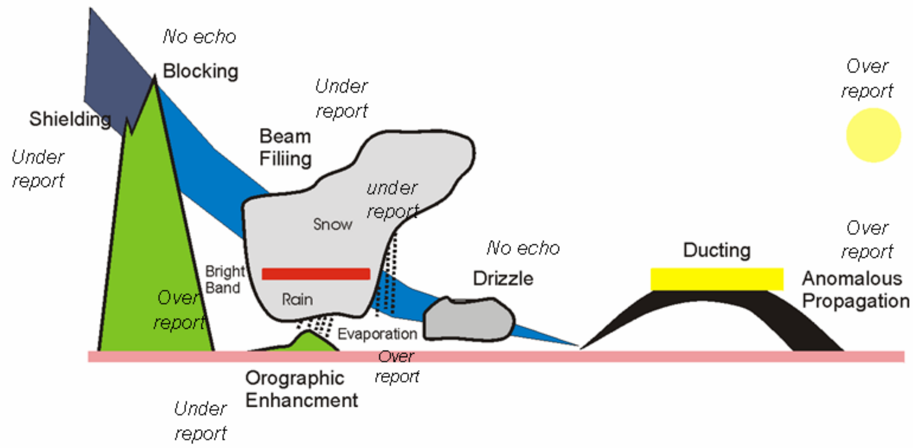

Figure 3: A cartoon depicting some of the physical effects that impact on radar QPE. Even if a radar is perfectly calibrated, these physical effects due to the environment dominate the use of radar data for QPE. Substantial progress has been made in this area in the past few years and operational systems correcting and adjusting the radar data for these factors are now just emerging. Bold text indicates the physical effect and the italics indicate the impact on QPE.

Ground Clutter Mitigation: All radars have ground clutter, particularly around the radar due to the side of the main lobe and side lobes. A major improvement has been the deployment of Doppler technology where the narrow power spectra due to ground clutter can be separated from the broader weather spectra. See Fig. 4. However, when the weather spectra is narrow (as in the case of light snowfall) and the radial velocity is near zero, the technique can fail. Newer techniques involve a fuzzy logic decision system to identify whether a ground echo is predominant and whether to apply a Doppler filter in order to minimize the damage to the data. Without Doppler radar, a common technique was to use a CAPPI product so the data used for display is above the height where the ground echoes are observed.

[4] A recent WMO survey of weather radar practices indicated that some countries do not do electronic calibration.

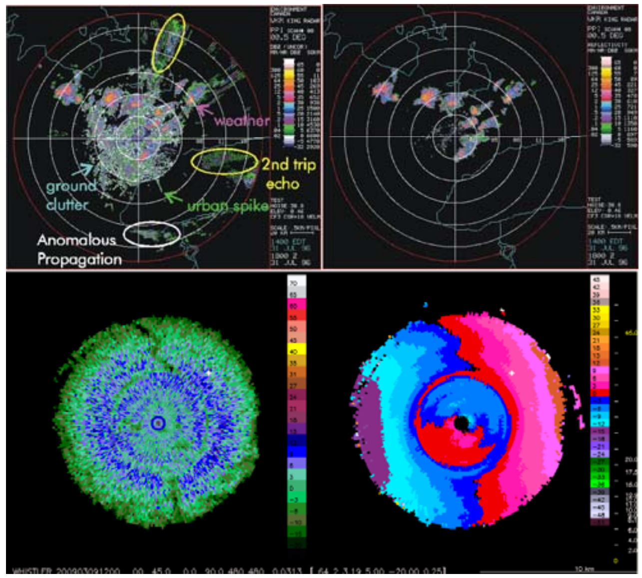

Figure 4: An example of the ability of Doppler signal processing to adaptively remove ground clutter and anomalous propagation echoes. Image on left is a reflectivity image without filtering and image on the right is with filtering. The technique can at times remove too much weather echo and not enough in other situations on a data point basis for local QPE applications but may be perfectly fine for larger scale applications.

Vertical Profile Effects: Other physical processes can also dominate the estimation process in a practical sense including the contamination of rain by melting hydrometeors e.g., hail and the bright band effect. These effects are particularly important in stratiform rain for non-tropical winter time situations and have regional, seasonal and local variations that impact the estimation process. See Fig. 3 for a cartoon of the source of the various factors.

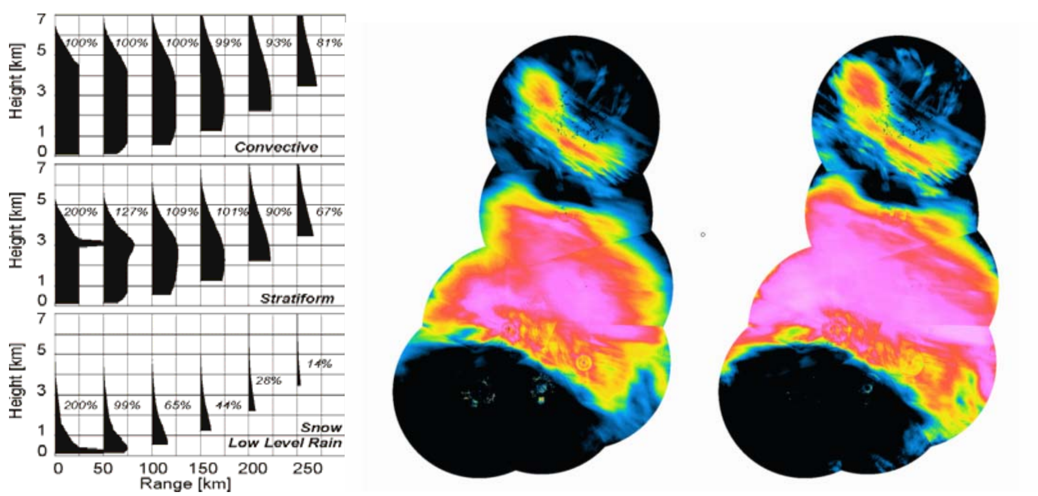

Figure 5: An example of a precipitation accumulation product from the Finnish radar network where the vertical profile of reflectivity corrections have been applied to a case of a quasi-stationary front where precipitation accumulations are expected to be uniform. On the left is an uncorrected image and it shows a drop off of accumulation with range from the radar. This is due to beam filling (beam not filled and hence precipitation is under-reported) and vertical profile decrease of reflectivity (VPR) with height leading to underestimate of surface precipitation. The figure on the right shows an accumulation after VPR correction (Left figure after Joss and Waldvogel, 1990; right figure courtesy of Jarmo Koistinen).

In the following example, the precipitation is accumulated over a winter season from Finland. The fall off with range in the accumulation on the left most figure is due to the VPR effect. The near circular and uniform fall off is indicative of a very high quality radar site free of artifacts. On the right of the figure, is a comparison with the range gauge data. The falloff is evident and the scatter is relatively small. This is a key image upon which the proposed metrics are based on. The uniformity in azimuth and drop off with range is considered ideal. Ideally, ground clutter and anomalous propagation correction should attempt to achieve this performance.

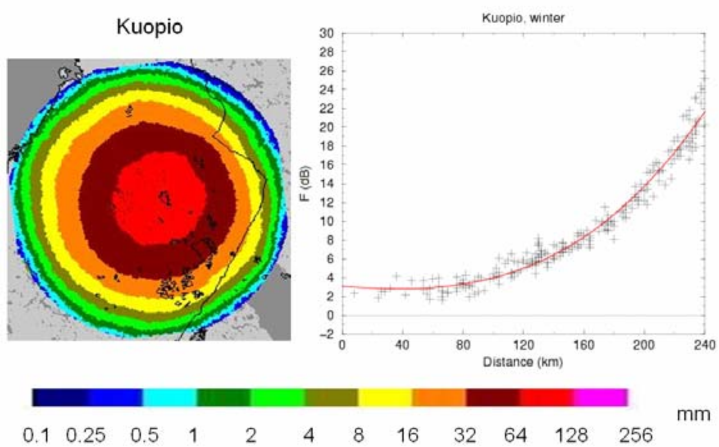

Figure 6: Precipitation accumulation over a winter season from the Kuopio radar in Finland. The right figure shows the gauge-radar ratio. At 200km, a bias of 20dB (factor of 100) is applied to the radar data. Figure courtesy of Daniel Michelson.

The following figure shows a similar plot but this site has terrain blockage and it is for summer. The increased scatter is due to the greater variability of the Z-R relationship in convective situations but also due to the data in the partially blocked area. Corrections for partial blockage and precipitation type should result in reduction in the scatter. This forms the concept for another quality metric.

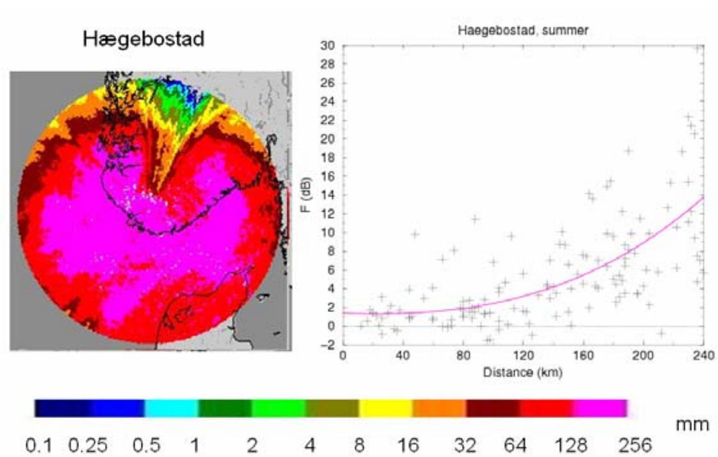

Figure 7: Similar to the previous figure, except an area of partial blockage is included and for summer where there is greater variation in the Z-R relationship (stratiform-convection). Figure courtesy of Daniel Michelson.

Radar Scanning Geometry: The limitations imposed by the above physical process are further confounded by issues related to the scan strategy, geometry and data/signal of the radar viewing of precipitation. Potential non-uniform filling of the radar beam with increased range, the height of the radar beam above the ground, blockage of the beam by obstacles especially in mountainous terrain, ground clutter are examples of non-meteorological factors that can further limit the accuracy and bias precipitation measurements. Fig. 5 shows an example of a corrected precipitation map. These factors vary significantly from site to site and under various conditions.

Drop Size Distribution Factor: Precipitation is inferred most frequently through the reflectivity factor Z, which is well known to suffer significant limitations imposed by the microphysical changes impacting drop size distribution. With a climatological Z-R the limit of measurement accuracy is approximately 30-40%. With adaptive methods based on precipitation type this can be improved as it can be through the adoption of polarimetric approaches (combinations of Z_{DR} and K_{DP}). The physical limits to accuracy are then somewhere near 10-15% with systematic variations in dropsize characteristics. Such systematic variations occur in orographic situations with low concentrations of large drops, convective maritime with high concentrations of smaller size drops, convective subtropical/continental modes with lower concentrations of large drops and of course within different stratiform precipitation processes e.g., melting of large dry snow and cases with small rimed ice. The accuracy of QPE is strongly situation dependent and therefore it is necessary to sample a wide range of weather, locations, and radar configurations when characterizing QPE errors.

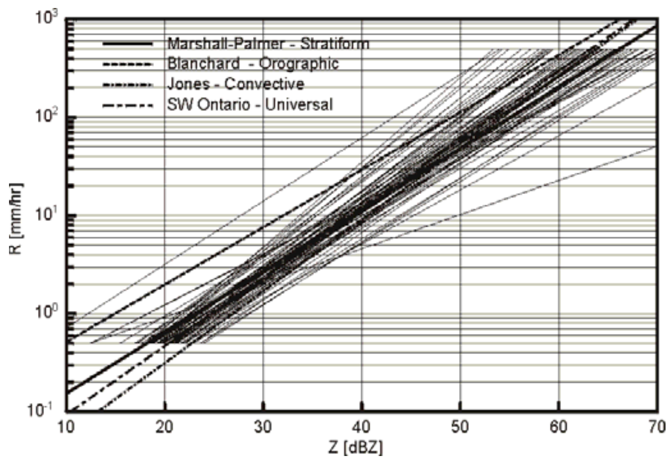

Figure 8: A plot of various Z-R relationships found in the literature. Note that the original and classic Z=200R^1.6 relationship is drawn in a thick line.

Advanced Techniques: Polarimetric radars using differential phase shift can be helpful in overcoming a number of limitations including beam blocking situations. The practical treatment of these issues certainly impacts the overall accuracy of the rainfall measurement and varied approaches to mitigation have been adopted. A particular contribution that polarization can make is in the classification of the radar echo. The following figure shows the results of a particular scheme on a C-band radar.

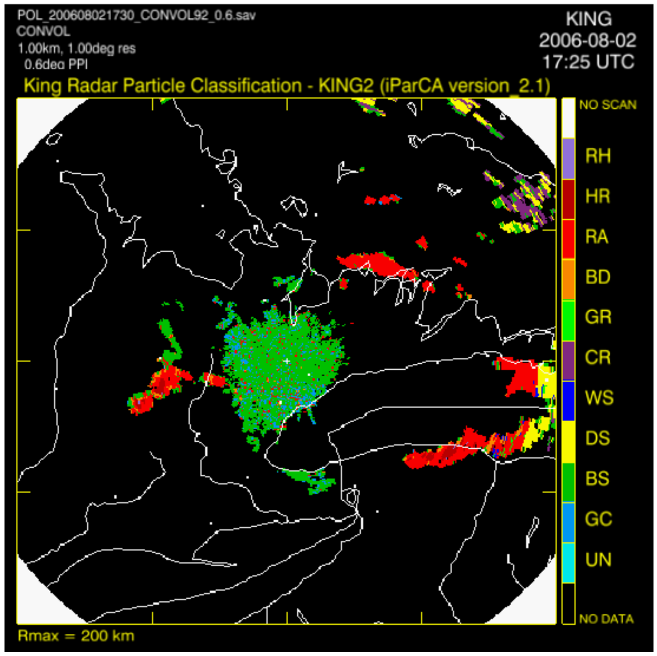

Figure 9: Particle classifiction from the King City Radar in Canada. The symbols are as follows: RH = rain/hail; HR = heavy rain; RA = rain; BD = big drops; GR = graupel; CR = crystals; WS = wet snow; DS = dry snow; BS = biological scatterers (includes birds, bugs, chaff); GC = ground clutter; UN = unclassified. Figure courtesy from Dave Hudak.

Prioritized List of QPE Issues

The following is a prioritized list of QPE:

- Ground Clutter and Anomalous Propagation
- Vertical Profile of Reflectivity
- Partial Occultation
- Reflectivity Bias Calibration (Monitoring)
- Attenuation Correction/Handling
- Minimize Impact of DSD Variability
- Gauge Adjustment (function of density)
- Consistent verification and Data Quality Metrics
- Uncertainty/Scale/Probability Concepts

QPE Validation Issues

The validation of the radar estimates of rainfall, typically undertaken by inter-comparison with gauges raises a number of serious issues. Radars and gauges measure rainfall on different scales and both are affected by individual sampling and instrument errors. Dense gauge networks are crucially important with attention to calibration just as required with the radar measurements. Quality control of gauge data is also an important consideration. Utilization of independent, systematic and consistent validation processes and techniques are certainly desirable. This is also true for NWP and satellite validation and climate change applications. As this is application dependent, it will be addressed at later stages of the project.

Data Quality Metrics

Driven by a variety of applications, including data assimilation, NWP and satellite validation, hydrological applications, uncertainty in radar precipitation estimates have been a hot topic of discussion and research. Given the differences in radars, radar networks, a consistent framework for describing the quality of the final QPE products is needed. An outcome of this project will be recommendations on the metadata and procedures required to describe the quality of the radar data and of the products.

Fig. 6 shows what a near-perfect radar under the correct uniformly distributed precipitation conditions would look like. It is smooth indicating that it is free from ground clutter. It is symmetric indicating that there are no spatial biases in the area. There is tight scatter between the radar and the precipitation estimates. The difference in range is due to the physical vertical profile effect of the weather for that area.

There appears to be a bias of 2 dB at zero range. One would expect the curve to be very flat within the effective range of the radar for QPE. The effective range is defined by the flat part of the curve which is about 80 km.

While the figure shows that the shape of the curve is computed from a radar – gauge comparison, the curve should be computable from the data within the effective range of the radar.

This premise for data quality metric is therefore that perfectly corrected reflectivity accumulations should be smooth and are available spatial correlations or variograms could be used to quantify the smoothness of the resulting ground clutter and AP corrected fields. That is, there are no lumps or holes. Given the weather, the shape of the curve may be steeper or shallower. Once the curve is computed, the scatter of the data around the curve should be small.

Metrics could be developed at the pixel level or summarized for the entire radar space. We leave radar network issues till later.

Inter-comparison Modality

Two modalities are identified for the inter-comparisons. Comparing algorithms against a common dataset and comparing an algorithm on diverse radar datasets both in terms of hardware and technology configuration but also in different weather and beam propagation regimes (mountains, coastal, flat).

The target QPE product needs agreement. It is proposed that totals at 4 km ^{2} spatial resolution with an hourly time granule within approximately 150 km of the radar be the base product for consideration. This would fulfill many requirements including significant hydrological applications. This is not meant to preclude other products and with other user requirements but sets a base product for evaluation.

The proposed inter-comparison process is summarized as follows:

- Existing quality control and rainfall estimation applications developed by various groups are applied to a set of radar datasets.
- These datasets are collected from a set of representative locations.
- In this model the individual groups with existing quality control and rainfall estimation algorithms will agree to run their estimation applications on these new independent datasets. This will mean an agreed radar data format and radar operating process for the collection of the respective radar datasets.
- In the fullness of the project, availability of ancillary information will also be required e.g., numerical weather prediction fields, soundings, clutter maps, dependent radar data for algorithm optimization and learning, spatial, uncorrected reflectivity and geographical datasets etc.
- The estimation algorithms will have to provide output in agreed product form e.g., an hourly granule of rainfall accumulation for verification.
- Initially the focus of the QC/QPE goals will be single radar approaches are envisaged but will not preclude network approaches.

Verification and inter-comparison of the results would then be undertaken using agreed metrics with techniques and applications available to all contributors

Based on the initial verification and inter-comparison, an iterative process to optimize and improve the estimates is likely to be required. This is could potentially involve collective use of “best” algorithms that are shown to improve the estimation process.

Potential issues relate to radar calibration and sub-optimal performance of the estimation algorithms\quality control processes for both the radar and gauge data. The incorporation of improved QC applications may require hardware intervention on the radars. This possibility should be considered.

Linkages and Stake Holders

This project addresses a core issue that contributes to other WMO mandates and initiatives. Core links are evident with the CIMO ET on Upper and Remote Sensing , WWRP nowcasting group, the THORPEX DAOS group and WMO WCRP GEWEX RGP (WGPRN), amongst others.

The best approaches need to be identified, documented and shared with all member countries. Commonality of approach, when possible, is needed to promote collaboration and efficiencies. Data quality metrics and standards need to be identified and developed so that these data and products can be integrated as part of the Global Observing System and as part of Global Earth Observation System of Systems (GEOSS)[5]. Processes for maintaining, monitoring and meta-data reporting radars need to be established to support a long term archive.

Many new radars are being established in developing nations where societal impact is high. An example is Africa and this proposed project will help them attain the Millennium Development Goals through improvements in the use of their radars for climate purposes. Other related WMO programs will also benefit from this project and include: WMO Information Systems, Quality Management Framework, Natural Disaster Prevention and Mitigation, Flash Flood Initiative, contribute to foster closer collaborations between NHS and NMS's and International Exchange of Data and Products and enhance the social and economic benefits of NHMS'.

A Climate Perspective

The extremes in the hydrological cycle manifest in changing extremes of precipitation. Precipitation rate is so highly variable in time and space that it is one of the most difficult of the essential climate variables to measure and monitor precisely, particularly the more extreme (rarer) events. Current surface precipitation gauge arrays are much too sparse in spatial coverage and (usually) report too infrequently to resolve precipitation variations and can easily miss extreme events. Although indirect satellite precipitation products do exists at relatively high space and time resolution, the indirect nature of these methods may not be able to properly capture the extreme events that represent non-average conditions by their very nature. Spaceborne radars have good spatial resolution but have very low time sampling frequencies compared with the variations of precipitation.

Weather radars, specifically designed to observe precipitation at high temporal and spatial resolutions, are becoming ubiquitous in many nations around the world and are currently the only precipitation-measuring system with the requisite space-time sampling. However, until now these systems have also been generally sparsely distributed and operated and analyzed separately in a case-study approach. The recent significant growth in the number of radars being operated, now makes possible high-resolution determinations of precipitation over extensive land areas and over long time periods. Such datasets, when merged with very stable spaceborne radar reflectivities would provide the observational basis for learning how the small-scale extreme events are connected with the large-scale atmospheric circulation and how this may be changing in time. To provide this type of data requires systematic collection and analysis of data from these radar networks in as many different climate regimes as possible on a retrospective basis to produce appropriate "climate-scale" statistics. The potential of these radar networks for climate studies is high but has not been realized.

The detailed corrections and adjustments are a pre-requisite for the generation of appropriate products to study climate variations and extremes. A consistent global measure of radar data quality applicable for a variety of radar networks in different climate regimes and recording of quality meta-data are needed to make use of the radar data for these types of studies.

[5] The GEOSS goal is to establish a global, coordinated and sustained observing system to meet societal needs particularly in respect of severe weather warning and disaster management.

Inter-comparison Datasets/Testbeds

The above process implies that data will be required from representative locations. Some sample regimes and potential locations/groups that could be considered include:

i. High Latitude Regime Including Mixed Phase Precipitation (Winter rain)–
   1. Baltic Sea Region – BALTRAD – nework (SMHI and others)
   2. UK MetOffice
   3. Polarimetric Radar Montreal (McGill University)

ii. Tropical Maritime (Tropical convection)
   1. Darwin, (CPOL, Polarimetric), Australia (BMRC)
   2. Melbourne, Florida or Kwajalein (NASA TRMM)

iii. Sub Tropical Regime (Moist severe weather regime)
   1. Brisbane (Polarimetric -CP2), Australia (BMRC)
   2. Beijing, PRC (CMA/BMB, B08 FDP)
   3. Japan (JMA)
   4. Korea (KMA)
   5. Hong Kong (HKO)

iv. Continental Regime (Arid regimes with severe weather)
   1. KOUN Oklahoma, USA (NNSL)
   2. CHILL, Colorado, USA (CSU)

v. Mountainous (Orographic enhancement process and blocking)
   1. Meteoswiss, Switzerland
   2. Catalunya, GRAHI-UPC, Spain
   3. Germany (DWD)
   4. France (Meteofrance)
   5. Canada (Vancouver 2010 project)

vi. Signal processing QC
   1. NCAR
   2. Environment Canada
   3. NSSL

Project Deliverables

- Intercomparison data sets
- Standard data quality metrics.
- Intercomparison Workshops
- Workshop summary reports.
- Reports/publications on best techniques and best practices for radar QC and QPE.
- Recommendations for global implementations
- Training workshops

International Organizing Committee

WMO has guidelines for organizing inter-comparison projects and has a requirement for a Science Committee to review plans, results and sign off on the recommendations resulting from the workshops.

Kick-off/Pilot Workshop

A pilot workshop is proposed to be held in 14-15 April 2011. There are many variables with perhaps some controversial elements. In preparation for a full inter-comparison, a kick-off meeting of the IOC and invited experts is planned. The following are the objectives of this kick-off meeting:

- Discuss and refine the project concept - inter-comparison modality, data set selection, ancillary data, inter-comparison processes, metrics and metric interpretation) leading to an implementation plan for the full inter-comparison.

- As part of the kick-off meeting, a limited number of data sets will be chosen and only a few algorithms highlighted.

- The focus will be the removal of ground clutter and anomalous propagation echo to generate the best low level (i.e. surface) reflectivity and radial velocity field from a single radar.
- The data sets will be chosen from a few locations (to test the scan strategy and format issues) from selected situations (to test different ground clutter and anomalous propagation) and will focus on one or two steps of the adjustment chain (removal of ground clutter and anomalous propagation, infilling perhaps by vertical profile extrapolation). It is envisioned that 4 cases, each of 24 hours or so duration will be prepared (see table below).
- A limited number of groups will be asked to process the data to generate “best” surface reflectivity product. At this stage, bias correction is not considered.
- There results of each data cycle will be accumulated and the spatial variogram metrics will be computed.
- The results will form a core element of the kick-off meeting. The key questions will be whether carefully “short” data sets are adequate, whether the metrics are adequate and can be interpreted qualitatively or quantitatively leading to viable recommendations to WMO members.

Table 1: **Four *Initial Test Data Sets***

It is envisioned to prepare volume scan data sets with total reflectivity, zero notch corrected reflectivity (option) and Doppler velocity. These parameters are commonly available in Doppler systems. While reflectivity metrics are the primary focus, radial velocity metrics are relatively novel and adjusted Doppler velocity fields will be evaluated, if available.

	Case	Notes
1	Ground Clutter with uniform precipitation	A “common” standard test case with moderate ground clutter with no weather and uniform weather. Ground clutter and Anomalous Propagation echo has zero Doppler velocity.
2	Sea Clutter with uniform precipitation	Similar to previous, sea clutter is very low level, uniform in reflectivity but has non-zero Doppler velocity.
3	Strong Anomalous Propagation with convective weather	AP echoes have a vertical structure that can be used to detect and remove. The issue is whether two dimensional detection and correction algorithms will also remove convective weather.
4	Partial Blockage and uniform precipitation	There are detection and correction algorithms that work on a two or three dimensions and this examines issues

Glossary

Signal Processing – processing of the time series, or IQ data
Data Processing – processing of the moment data.
Raw Data – generally refers to the moment data
Time Series Data – this is the voltages or the in-phase or quadrature data
Products – refers to highly processed raw data into relevant end-user units such as mm/h.

ANNEX 3

DATA PROTOCOLS FOR RQQI

1. Introduction

1.1 The Radar Quality Control and Quantitative Precipitation Intercomparison (RQQI) is an international intercomparison project being conducted as part of the work programme of the Commission for Instruments and Methods of Observation (CIMO) of the World Meteorological Organization (WMO).

1.2 RQQI aims to quantify the similarities and differences in effectiveness of various automated techniques in use around the globe for improving the quality of output weather radar data used for quantitative precipitation analysis, data assimilation and nowcasting, using different radar signal and data processing systems, under different weather scenarios, climate regimes, geographical and topographical features and in the presence of different data-degrading phenomena, such as radiofrequency interference and clutter. It focuses on C and S band radars operated in conventional mode (relectivity only), Doppler mode, and dual polarization mode.

2. Project Governance and Execution

2.1 RQQI is being conducted under the leadership of its **Project Leader**, Dr Paul Joe, who was selected by CIMO's Management Group to fulfil this role.

2.2 Overall project governance is the responsibility of an **International Organizing Committee (IOC)**, which is chaired by the RQQI **Project Leader**. The IOC is responsible for project governance, broad organization and planning, including setting of project terms of reference, goals and objectives, for ensuring the scientific integrity of the project, for taking pragmatic steps to promote the project, for approval of the project conclusions and output recommendations for WMO Members, for reviewing the draft Final Report and for approving the Final Report. The IOC reports, through its Chair, to WMO through the CIMO Secretariat.

2.3 Membership of the **IOC** was proposed by the **Project Leader** in consultation with the CIMO Secretariat and has been approved by the Secretary General of WMO. The **IOC** for RQQI comprises:

Paul JOE	Env. Canada	Canada (Chair)
Yoshihisa KIMATA	JMA	Japan
Liping LIU	CAMS/CMA	China
Alan W. SEED	BOM	Australia
Daniel B. MICHELSON	SMHI	Sweden, Representing BALTRAD
Timothy D. CRUM	NOAA/NWS/ROC	USA
Roberto CALHIEROS	IPMET/UNESP	Brazil
Estelle de CONING	SAWS	South Africa
John C. HUBBERT	NCAR	USA
Nicolas GAUSSIAT	Met Office	UK, Representing OPERA
Vincenzo LEVIZZANI	ISAC-CNR	Italy, Representing WCRP/IPWG

Daniel SEMPERE-TORRES	Univ. Barcelona	Spain

2.4 The main work of RQQI is being performed by its **Project Team**, a small group of experts selected by the **IOC** for this purpose. The **Project Team** is responsible for the selection of **Test Datasets** for the project, for organizing the processing and analysis of those datasets by participants, for analysis and review of all results, for preparation of draft conclusions and recommendations, and for drafting the Final Report. The **Project Team** reports, through its Chair, the **Project Leader**, to the **IOC**. The **Project Team** comprises:

Paul JOE	Env. Canada	Canada (Chair and Project Leader)
Norman DONALDSON	Env. Canada	Canada
Liping LIU	CAMS/CMA	China
Alan W. SEED	BOM	Australia
Daniel B. MICHELSON	SMHI	Sweden
John HUBBERT	NCAR	U.S.A.

3. Selection of Test Datasets and Project Participants

3.1 WMO will call for expressions of interest in participation in RQQI from CIMO Members and from weather radar manufacturers (via HMEI) as prospective **Project Participants**: either **Test Dataset Providers**, and/or **Test Dataset Processors** (processors of **Test Datasets**, using their automated radar data processing software).

3.2 Prospective **Test Dataset Providers**, will be requested to submit to the CIMO Secretariat their proposed **Test Dataset(s),** and **Input Documentation** that describes it, including the respective weather radar system(s), the data processing steps already applied to the data, and the features of each submitted dataset that are likely to make it suitable for use as a **Test Dataset**.

3.3 Prospective **Test Dataset Processors** will be requested to submit to the CIMO Secretariat **Input Documentation** that describes the relevant algorithms used within their automated radar data processing software.

3.4 All proposed **Test Datasets** and/or **Input Documentation** that are/is received from prospective **Project Participants** will be provided to the **Project Team**, which will then select the RQQI **Project Participants,** based on the perceived value to RQQI of the participation of that proposed **Test Dataset** and/or prospective **Project Participant's** automated radar data processing algorithms.

4. The Intercomparison Process

4.1 Once the **Project Team** has selected **Project Participants** and **Test Datasets**, **Test Dataset Processors** will be requested to process each of the **Test Datasets** using their automated radar data processing algorithms, to produce **Processed Datasets**.

4.2 The resulting **Processed Datasets** are to be submitted by each **Test Dataset Processor** to the **Project Team** for:

a) Individual Analysis and Assessment (analysis and assessment of the **Processed Dataset(s)** from a single **Test Dataset Processor,** which resulted from the application of one or more of their algorithms), and

b) **Comparative Analysis and Assessment** (i.e. comparative analysis and assessment of the **Processed Dataset(s)** from some or all **Test Dataset Processors,** which resulted from the application of one or more of their respective algorithms). This analysis and assessment will be performed using **Analysis and Assessment Algorithms and/or Software** (hereafter **AAAS**) developed for this purpose by the Project Team. The resulting **Analysis and Assessment Data and Information** (hereafter **AADI**) will then be used by the **Project Team** in drafting the **Final Report**.

5. Protocols

5.1 Test Datasets and Input Documentation

5.1.1 All proposed **Test Datasets** and/or **Input Documentation** provided by prospective **Project Participants** shall remain the intellectual property of the respective provider.

5.1.2 WMO will destroy copies of proposed **Test Datasets** and **Input Documentation** which are not selected for participation.

5.1.3 **Test Dataset Providers** agree to WMO retaining, using and publishing part or all of the selected **Test Datasets** and accompanying **Input Documentation,** as part of this and any similar future intercomparison project(s) that WMO may conduct. WMO will acknowledge the source of the data and/or information used in any resulting publication(s).

5.1.4 **Test Dataset Processors** agree to WMO retaining, using and publishing part or all of their **Input Documentation** as part of this intercomparison project, and for any repeat or follow-on analysis using the same or improved **AAAS.** WMO will acknowledge the source of the information in any resulting publication(s).

5.2 Processed Datasets

5.2.1 No manual intervention or software tuning is permitted in the production of **Processed Datasets**, and **Test Dataset Processors** agree to abide by this requirement.

5.2.2 **Processed Datasets** shall be the intellectual property of the **Test Dataset Processor** who produced them. **Test Dataset Processors** may independently publish their own **Processed Dataset(s)**, but not that of others, prior to the publication of the **Final Report**. Should they do so, they shall obtain prior permission of the **Test Dataset Processor** who produced the **Processed Dataset**.

5.2.3 **Test Dataset Processors** agree to WMO retaining, using and publishing part or all of their **Processed Datasets** in this intercomparison project and for possible future reanalysis using the same or improved **AAAS**. WMO will acknowledge the source of the data used in any resulting publication(s).

5.3 Analysis and Assessment Algorithms and/or Software (AAAS)

5.3.1 Pre-existing **AAAS** provided to RQQI by members of the **Project Team** will remain the intellectual property of the provider.

5.3.2 **AAAS** developed and published as part of RQQI by the **Project Team** will be in the public domain.

5.4 **Analysis and Assessment Data and Information (AADI)**

5.4.1 WMO shall be entitled to publish in the **Final Report** part or all of the **AADI** produced from the **Processed Datasets** using **AAAS** as part of RQQI, irrespective of the source of the **AAAS** WMO shall also be entitled to publish some or all **AADI** on its website after the publication of the **Final Report**.

5.4.2 The **Project Team** will provide to each **Test Dataset Processor** a copy of the **Individual AADI** corresponding to their **Processed Dataset(s)**. This **Individual AADI** will not be provided to other **Test Dataset Processors** or **Test Dataset Providers** before the publication of the **Final Report**.

5.4.3 Notwithstanding the foregoing, **Test Dataset Processors** may independently publish the **Individual AADI** corresponding to their **Processed Dataset(s),** prior to the publication of the **Final Report**, on condition that WMO is acknowledged as the source of the **AADI**. However, in so doing, they agree to make neither statement(s) either directly or indirectly comparing the performance of their automated radar data processing algorithms to those of any other **Test Dataset Processor(s),** nor statement(s) comparing the relative value of any of the various **Test Datasets**.

5.4.4 After publication of the Final Report, WMO will make all **AADI** available to whoever may request it, on condition that it is used solely for the purposes of scientific research and not in order to gain commercial advantage.
